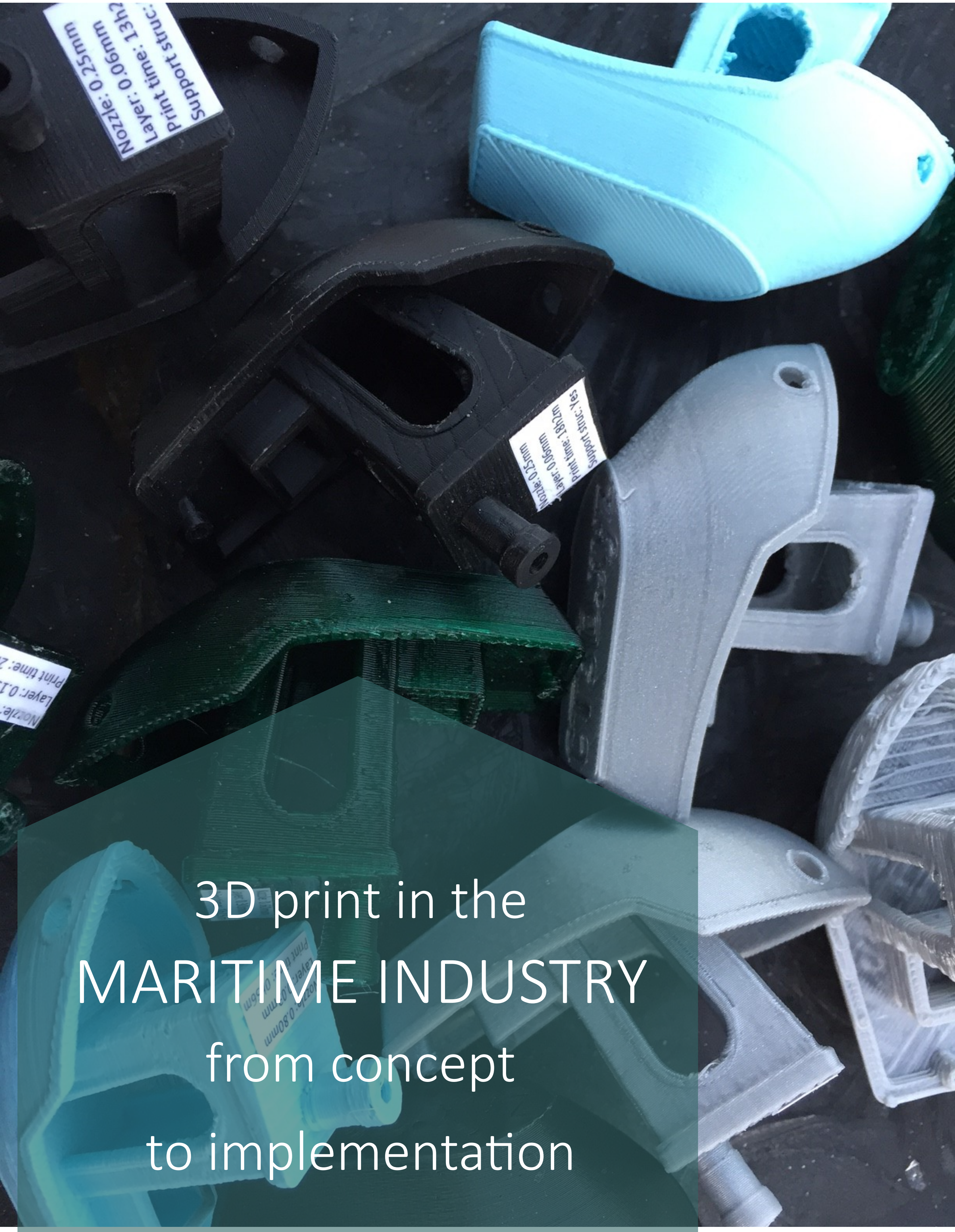

3D print in the MARITIME INDUSTRY from concept to implementation

GREEN SHIP
OF THE FUTURE

This project is sponsored by

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CONTENT

INTRODUCTION

Copenhagen 2018

3D print in the Maritime Industry: from concept to implementation in the maritime industry

This project constituted part III of a process exploring the maritime opportunity space of 3D print and additive manufacturing (AM). While the objective of part I and II was to understand the technology and the complexity of exploring digital technologies, the purpose of part III was to inspire adoption of 3DP, AM and related digital technology in the maritime industry by testing real applications. And, to challenge some of the current technical and sector specific limitations that exists such as size and material.

With this project, we explored how different stakeholders in the maritime industry can use 3D Print and AM technology to develop and improve a product and/or service ahead of competitors. The partners deep dived into four specific cases of relevance to their core business, but there are undoubtedly many other out there, waiting to be explored. While a common learning from the process is that academia, in general, is more optimistic about additive manufacturing than what commercial availability suggests possible, the applications change as technology evolves: in a fast pace. What seemed impossible yesterday, may be commercially feasible tomorrow. For that reason, we encourage anyone who considers exploring 3D print and additive manufacturing more in depth to do so in their own context with the latest available technology.

The results are likely to be very different from ours. In addition, the partners have also searched for indications on how the 3D print and AM technology will affect our industry when other industries increasingly adopt the technology and how the supply chain may have to adapt.

Throughout the project, we sought inspiration in the pains and ideas voiced by the participating companies and the technology insights shared by experts. We explored individual maritime cases, but shared and evaluated collectively, as our aim was (and still is with this report) to motivate and inspire more maritime companies to consider how 3D printing, AM and other digital technologies can be a tool or even an enabler in their future product, service and/or business development.

On behalf of the project partners Alfa Laval, Clorius Controlos, Copenhagen Business School, Create, Create it Real, DNV GL, Force Technology, J. Lauritzen, Maersk Drilling, Maersk Tankers, MAN Energy Solutions, OSK ShipTech, PJ Diesel Engineering and Thürmer Tools:

A very special thanks to the Danish Maritime Fund for making this journey possible, but also to the many participating companies, industry partners and 3DP experts for playing a long!

CASE 1 ON-BOARD PRINT

The idea of applying on-board 3D print to bring down lead times and costs or to reduce spare part inventory is widely discussed. The purpose of this project was to investigate the possibilities of using 3D print on board merchant vessels. From a shipowner and technical managers perspective the vision was twofold:

- Limit the requirements for on-board storage and free capital tied up in expensive units
- Print on demand with minimal lead time, possibility to tailor units for special needs and/or be sure always to get "latest version" from maker

By placing 9 table top printers on board 6 vessels and 3 rigs, the partners tested the minimum viable solution of on-board printing in order to explore the hypothesis above and identify challenges as well as needed actions for on board printing to be commercially feasible.

Key findings

Successful on-board adoption of the 3D print technology proved to rely more heavily than anticipated on buy-in from the crew. The 3D printers used in the project was plug-n-play and the software likewise user friendly. However, there was an underlying assumption that some of the (particularly younger) crew members would be genuinely interested in exploring a new technology and print parts that could fix simple onboard issues. Unfortunately, this was, generally speaking, not the case. The "digital-readiness" may have been overestimated based on the popularity of other onboard digital services, e.g. availability of social medias. In addition, the professional - and technical interest and curiosity was overestimated as a what's-in-it-for-me driver. Having said that, there were crew members that engaged and explored the possibilities. Yet, the general feedback indicates that too few crew members understood the possibilities of the project, and rather saw it as a hazzle. One partner has evaluated the options of printing smaller non critical items such as ventilation fans for electrical equipment, but moving forward in the operational environment, requires designated persons to dedicate their time on the development.

Conclusions

Short term, only few parts makes sense to print onboard. The cost for a sufficiant printer is, at this point, too high to install onboard all vessels in a fleet. However, as the quality and flexibility of affordable 3D printers and materials increase, the technology already is, or soon will be, ready to adopt onboard. The human element, however, is not to be underestimated and must be addressed ahead of implementaion in order to be succesful. One key learning is, that it must as simple to 3D print a spare part on board, as it currently is to order it. This is not yet the case.

In additon, on-board 3D printers will need to integrate with existing parts ordering system. Such an integration would allow the crew to start a print job as soon as the part has been identified within the system. Currently, the process includes searching on onboard servers or the web, downloading files to an USB key, selection of material, temperature and density for the print and many other things. It can not be assumed that the average on-board crew has, or is interested in adopting, the skills required to design parts for 3D printing onboard. Accordingly, a shore based support function must be available. A natural next step, could thus be to explore the local 3D printing infrastructure of printing onboard in terms of the procurement/ vessel crew /technical department interaction, further. Furthermore, the total cost of 3D printed parts is not yet competitive with conventionally produced spare parts.

Finally, the question of IP rights also needs further exploration. The printers used in this project supported an encryption technique that allows a manufacture to target a 3D print file for a specific printer on a specific vessel and further apply limitations on the number of prints per file and/or specify a time span where-in the file could be printed. Tests with this technology was initiated, but not completed. While the partners will not invest further in 3D printing at this point, they will stay informed and assess both technology and costs ongoingly. A final, but unexpcted, learning was that the project emphazised the difference between office staff and onboard crew and the need for turnkey solutions with very limited, or preferably no, need for training when introducing new technologies on-board.

TESTING PRINTERS AND CREATIVITY

9 printers were placed on board 6 vessels and 2 rigs. The crew were asked to print non-critical parts, such as parts that would often break, had a long lead time or in other ways constituted an annoyance if not replaced. Below are examples of the first prints from Maersk Tankers.

Left

Nozzle body for Dry Powder fire extinguisher

Maersk star for first print, DIN rail for relays, Flexible couplings for IGG DO pump (orange is original)

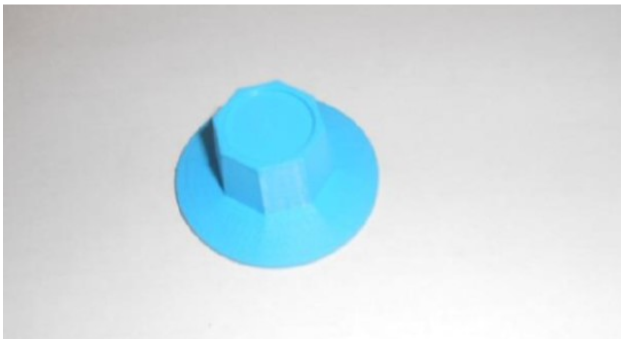
Rail bracket replacement

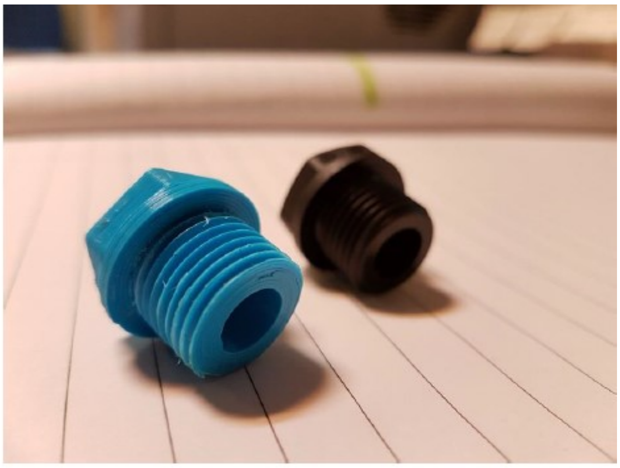
Right

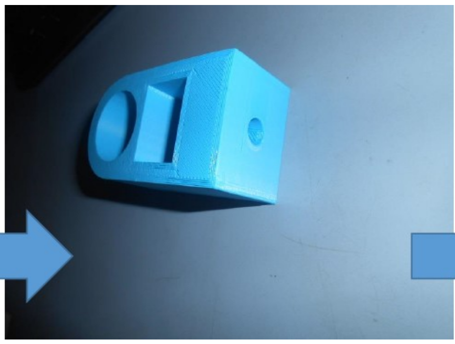
AE electric heater thermostat knob

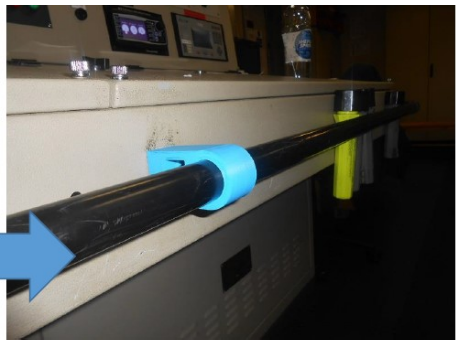
Nozzle body for Dry Powder fire extinguisher

Replacement handles for turning machine









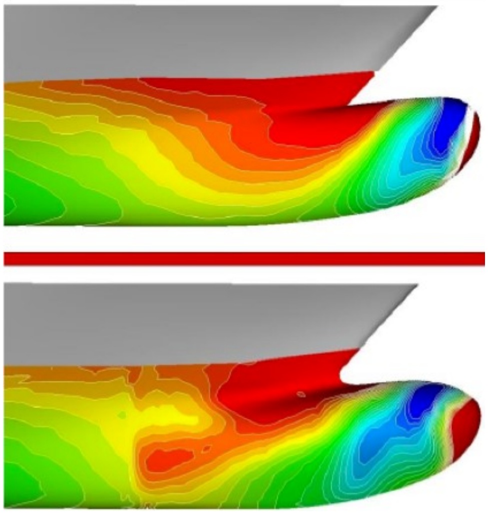
CASE 2 UPSCALING 3D PRINT FOR LARGE SCHIP STRUCTURES

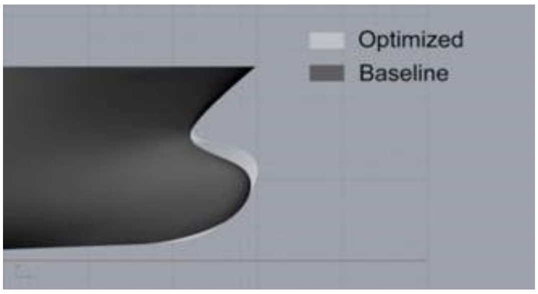
OSK-ShipTech A/S create.dk DTU

3D print is highly refined when it comes to small scale prints, while the maritime industry, in general, is characterized by the appliance of very big components. Yet, complex structures and need of light weight materials, suggests that the production benefits of 3D print also apply for large scale structures.

With this case, the partners wanted to explore the limitations of size. It is envisaged that steel vessels can be constructed at a lower cost by utilizing 3D-printing. Certain parts of a hull are carefully rounded to obtain the optimal hydrodynamic performance. This shaping of the hull is particular expensive to produce in steel when double-curvature render the shell plating non-developable. Merchant vessels are usually built in small series and highly customised, so 3D-printing complex parts seems an obvious opportunity space, though size, to this point, is a limiting factor.

The objective of this case was to identify Big Area Additive Manufacturing (BAAM) experts and explore relevant large scale 3D-printing technologies in order to test rapid manufacturing of an interchangeable bulbous bow, a concept owned and patented by OSK ShipTech.





Key findings

Together with DTU Mechanical Engineering, the partners, OSK-ShipTech and Create identified a number of relevant BAAM experts and technologies.

With conventional shipyard technique as the reference case, the relevant technology experts represented both printing by arc welding, thermoplastic materials, concrete casting, fibre reinforced thermosetting materials and automated glass fiber lay-up.

As the interchangeable bulbous bow by OSK-ShipTech is based on a flange connection, it was concluded that by proper design all included technologies could mate with such a flange. It was further noted that all technologies, some with proper post treatment, could obtain a suitable surface.

There are considerable benefits in terms of costs and lead-time. Cost of thermoplastic printing is similar to conventional steel shipbuilding, but once a reasonable number of printers are available, the lead-time is halved For concrete printing or casting lead time is similar to conventional ship building, but here cost is only about a fifth. The glass fibre lay-up is interesting both for lead-time and cost, but only if a number of similar bulbous bows are to be manufactured. Automated fibre layup does not seem sufficiently mature, in the near future, to alter this impression.

Conclusion

The low cost of concrete, and the possibility to both print and cast the shaped parts of the interchangeable bulbous bow makes this option relevant for further investigation as OSK continue to develop the concept of an interchangable bulbous bow.

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CASE 3 4D PRINT

Conventional 3D printing (or AM) turns digital blueprints into physical objects by building them layer by layer. Add shape memory to this technology and you have 4D print. With sophisticated materials and designs, shape memory materials can change shape post production. They will return to original shape when prompted by external triggers such as water, heat or wind or other types of energy.

The purpose of this project was to explore and asses the maturity and commercial availability of 4D print technology and relevant materials. If found satisfactory, the vision was to create a 'one component' pipe and valve with no actuators by applying 4D print technology.

Key findings

The partners explored a number of geometries and common valves to identify a candidate with potential for real improvement by applying 4D print production technology.

In this research, the partners found that the Zahroof compressor valve could be a prime candidate for this production technology.

Also, a number of concepts for new matrix multiple valve components would be significantly easier to produce with additive manufacturing

And finally, check valves, with their floating sphere inside a pipe, are relevant for further exploration. The floating sphere could be printed within the pipe to make it a one piece component**.**

Conclusions

The partners made a working prototype using 4D Nitinol to function as the shape memory part of a valve, while the valve housing was 3D printed. Yet, concluding the project, it is clear that 4D print technology, at this point, has its limitations. Throughout the process, science has been optimistic about the usage of 4D print, however, commercial availability suggests otherwise.

While there are numerous scientific articles, the partners found only one commercial supplier who was able to deliver a 4D printed object.

Shape memory materials like Nitionol only remembers one geometry. You can have two shape memory positions but one of them has to be 'forced' into position with a suspension.

4D print is still to be considered cutting edge. Except from medical stents, 4D materials are only used for compression rings in the automotive industry due to the shape memory and elastic properties of Nitinol. Accordingly, it is likely that the first use case of 4D print in Clorius control is high temperature, elastic and super strong compression ring.

General Electric has introduced a 1m3 3D metal printer. With that, valves for ships are technically within range. Clorius Controls is an early adopter, also compared to innovators like GE, yet with very few commercial actors, the technology and materials are, at this point, very costly.

Will 4D print impact the maritime industry? The very potential for production of industrial products from one component only is challenging the way we think of, design and manufacture products. We have yet to see the full impact of 3D print and additive manufacturing and even more so of 4D print.

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CASE 4 REPAIR AND RECONDITIONING WITH AM/3D PRINT

The overall aim of the case was to investigate the potential benefits and possibilities of applying 3D Print and Additive Manufacturing methods to repair and reconditioning in the maritime sector, hoping to create more environmentally friendly repair procedures.

As in the previous cases, theory presented the technology as versatile and easy to use. Some material show case considerable savings (both financial and environmental) as well as improved products. Accordingly, pre-project expectations mirrored this optimism. The partners expected immediate reduced environmental impact and underestimated the number of trials necessary before operational testing accordingly.

To test their hypothesis, the partners chose to print blades for two turbine wheels using laser cladding technology. Results where inspected with both non-destructive testing (NDT) and destructive testing (DT)

Key findings

Parameter optimization is difficult, time consuming and requires substantial testing. In the course of the project, two turbine wheels had blades printed by laser cladding. Even though process and laser parameters were changed several times, the final result was not adequate for operational testing.

In addition, the partners found that trials did improve each time, which indicates that, with further testing, it is not out of reach. The challenges with quality are most likely due to grain structure of the cast turbine wheel.

A comparison of the two repair scenarios showed that the laser cladding repair technology shows substantial potential as a more sustainable type of repair. But whether repair has a lower impact than replacement depends entirely on mode of transportation as this is by far the largest impacting factor.

Furthermore, collaboration across the supply chain is key, especially in the maritime industry. AM is disruptive and will have a large impact across stakeholders in the maritime industry. While threatening some stakeholders, it offers opportunities for others.

Finally, for a product or repair with AM process to be accepted in the industry, classification needs to be involved. Today most classification societies have developed rules and guidance for AM, but it is strongly advised to have classification involved in R&D projects.

Conclusions

A large share of the AM market in 2017 was in production which suggests that certain technologies and scenarios within AM are commercially viable.

In certain scenarios, AM creates tremendous value as demonstrated by other industries such as aviation. In maritime, the situation is slightly different. The application of AM is not as wide-spread and research is still in its early phases, especially for repair and reconditioning. To become commercially viable, more research is required. For application of AM for repair to provide value, the correct value scenario needs to be identified and recognized. I.e. repairs that are expensive, with long lead time for replacement components, or for components critical for operation. AM may be “good enough” until the new component arrives, but a major challenge here is the classification societies and their reluctance to recognize and approve repairs. Furthermore, printers are still costly and purchase should only be considered when the demand for printed parts can be aggregated. Also, the presence of distinctive competences within AM is key for succesful adoptation.

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CONCLUSION

With this project, we explored the minimum viable solution to test 3D print technology, get fast results and commercial experience. Our budget was (deliberately) limited, but the willingness to test and explore was not. We identified challenges of specific relevance to maritime, invited the partners we felt necessary to solve consequences across the supply chain and worked agile throughout the process.

Based on the learnings from our cases, we expect a short term impact mainly within prototyping and product development. On the longer term, additive manufacturing may become the solution of choice for small volume and high value components. AM is still considered a key enabler of a more efficient supply chain and it will make financial sense once we transition into a customization-mentality rather than a mass production-mentality. For adoption to increase, however, end customers need to become more flexible about part availability and part suppliers need to adapt by either operating their own 3D printers or advice blue prints to end customers or 3rd party market entrants. It may even become an integrated part of on-board order systems allowing for direct on-board- or port hub prints, once we see the right combination of quality, price and availability. While *that* will decrease the customers dependency on suppliers, it raises the question of IP rights and quality assurance and need for this to be solved. Collaboration across the supply chain is the key in solving this: Successful adoption of the technology requires willingness to change and adapt across all stakeholders in the supply chain.

For that reason, the collaborative part of the project has been a core component. The partners have shared ideas, experience and challenges during the project, but they have also shared enthusiasm and curiosity. Their reasons for engaging were various, but they all shared the need to understand what opportunities and consequences 3D print constituted for them and their position in the supply chain. On a general level, working with additive manufacturing changes your mindset. It adds perspective on the development of your core business, as does other digital- and disruptive technologies. It is not just another machine at the factory floor, it is in fact an enabler of change in design, efficiency, production, systems and the supply chain in general. In accordance, for many of the participating partners, the exploration of 3D print has kickstarted or been part of the process towards creating a digital strategy – with or without 3D print.

Will 3D print impact the maritime industry? Yes. But. We have yet to see the full impact of 3D print and additive manufacturing and even more so of 4D print. The very potential for production of industrial products from e.g. one component is challenging the way we think of, design and manufacture, sell and buy products. But that is the nature of disruptive technologies.

ABOUT THIS PUBLICATION

This report marks the conclusion of the project 3D PRINTING IN THE MARITIME INDUSTRY part 3. It was part of the project portfolio of Green Ship of the Future in 2017 & 2018.

The purpose of this project was to inspire adoption of 3DP, AM and related digital technology in the maritime industry by testing real applications and use cases.

The original partners include: Alfa Laval, Clorius Controlos, Copenhagen Business School, Create, Create it Real, DNV GL, Force Technology, J. Lauritzen, Maersk Drilling, Maersk Tankers, MAN Energy Solutions, OSK ShipTech, PJ Diesel Engineering and Thürmer Tools.

A very special thanks to the Danish Maritime Fund for supporting the project financially

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