Transdisciplinary Engineering: Crossing Boundaries
M. Borsato et al. (Eds.)

doi:10.3233/978-1-61499-703-0-77

Template for Supporting Welding Design on Aluminum Vessels

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Abstract. The use of aluminium hulls has advantages such as versatility in achieving complex shapes, lightness, strength, durability and it doesn't present corrosion issues nor embrittlement by temperature. When designing aluminium hulls the designer prioritizes welding as a major joining method. However, the aluminium welding process is complex, therefore the requirements involved in the manufacturing are critical. Furthermore, it is noted that when the design is performed on small and medium-sized vessels, these requirements are not adequately considered early in the design process. This fact is made worse when considering the product life cycle, generating problems such as redesign of the product, increasing manufacturing time and material waste. This paper proposes a design Template to assist obtaining the design specifications of aluminium vessels in the early stages of product development. The Template is based on the product life cycle and takes into account the general and specific attributes in order to generate a list of design rules, recommendations, best practices and solution-solving principles, which were established based on the literature and on professional experience. The outcome of the Template is a set of information which are available throughout the matrix. In order to improve the result, surveys and interviews were conducted with experts in the field. The main advantages of the use of this tool in designing a vessel are: i) to enhance knowledge management since new information (knowledge) can be added in the matrix cells, as the shipyard acquires knowledge; ii) to facilitate the integration of designers with different technical areas of a shipyard; iii) to reduce the design and manufacturing time of the vessel; and iv) to reduce product development costs, since waste is reduced.

Keywords. Design, Template, Welding, Aluminium

Introduction

The aluminum applied to shipbuilding has numerous advantages and its use is widespread all over the world, especially in countries with a strong market for recreational boats like the USA and the Netherlands, where aluminum is widely used in the construction of motorboats and sailing yachts of all sizes [1].

The main advantage of aluminum compared to steel is resistance to corrosiom. Available in a large number of blade's thicknesses obtained by rolling and extrusion, besides automated cuts for mounting boats and CNC machining (Computer Numeric Control), the application of aluminum in the shipbuilding industry is promising because it minimizes the difficulties in manufacturing complex hull geometry. This trend can be

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observed in the growing market of aluminum. According to data published by the Brazilian Aluminum Association (Abal), there was an increase of 5% aluminum use in 2013, with a large participation in the transport sector with 7.4% growth between 2012 and 2013 [2].

In Brazil, the market is potentially favorable, especially in the northern region. Besides the sustainability due to easy recycling of aluminum (which does not occur in composites), the material is distinguished by its durability and a good reason between cost and benefits. The immense river basin in the northern region is essential for the transport of the local population in everyday life. According to Antonio Teles, these sectors evolve driven by the development of the free trade area of Manaus, which consumes metal in increasing doses, particularly in construction and shipbuilding [3].

In addition, at least 60% of small and medium-sized vessels are produced using aluminum. The result is 450,000 vessels currently anchored in yacht clubs, fishing clubs, garages and marinas throughout Brazil. Every year, over 10,000 aluminum vessels are produced thanks to an average growth of 10% per year, from recreational boats to sports [4]. Much of the growth of aluminum vessels occurs by public preference for tougher boats, which do not break with impacts and have increased durability. These boats can reach a percentage up to 95% of aluminum in its structure, as some fishing boats currently found on the market, which can reduce the final weight of the vessel in approximately 30% [5].

In the construction of these vessels, welding is a fundamental and critical union process. According to Stump and Vatavuk [1], the welding can be applied to shipbuilding industry nowadays only because the development of new methods and modern welding equipment of inert gas welding, applied to plates with thickness from 2mm. The aluminum alloy welding usually use argon gas to prevent the formation of alumina, which would hamper the penetration of the alloying metal, therefore, decrease the welding quality. For thicknesses above 12 mm, it is recommended to enrich the gas with helium, taking care with cleaning and preheating up to 75 degrees Celsius [7].

For the shipbuilding industry, two welding techniques are used and are known as TIG (Tungsten Inert Gas) and MIG (Metal Inert Gas). TIG welding is used for thin blades and some other fine weldings. The welder uses a rod of alloy metal manually, this rod reach its melting point by an electrical arc from a tungsten electrode. On the other hand, MIG welding is the most widely used technique because it is faster for large constructions. The melted metal is automatically deposited by a gun that also diffuses the argon (with or without added helium) in the zone to be welded.

According to Nasseh [6], the construction of aluminum boats is still a procedure recommended only for experts because extensive knowledge of techniques of welding and fabrication is required. The most common defects arising from errors of operation can be the lack of penetration, lack of fusion, inclusions, porosity, etc. [1]. Furthermore, the operations employed in welding should be defined and respected in order to limit distortions, whether local or general. Depending on the thickness of the aluminum and the length of welding, the difference of temperature can cause distortion of several centimeters along the hull.

From the above, it is clear that the growing use of aluminum and its alloys in the shipbuilding industry requires a larger study of the methods and welding recommendations. The lack of technical knowledge can cause enormous damage to shipyards and damage the positive reputation that aluminum has in the market. Given this situation, this paper seeks to define a methodology for creating recommendations for the design and construction of aluminum vessels in the welding process.

1. Background to the Proposal of the Template

In view of the increasing production of aluminum vessels, the more necessary is technical knowledge, enabling sustainable growth of this sector in the shipping industry. The literature, in general, still lacks clear recommendations for the design and execution of welding aluminum alloys applied to manufacture hulls.

There is currently on the market a wide range of vessel types using aluminum in its structure. The main examples are fishing boats, sailboats, yachts and sports boats. Because the high exigency of those users, a high quality product is essential, not only because customer demand, but also because the performance required of the vessel is higher. The applied aluminum percentage varies according to the type and purpose of the vessel, reaching 95% for some fishing boats.

The shipyards performing that sort of process have usually harmful environments that are exposed to weather conditions such as wind, humidity and salinity. In contrast, the quality level required in the process is high. The workforce has become more specialized with the increasing number of trained professional available to work in the shipbuiling field, however, there is still some shortage in the sector.

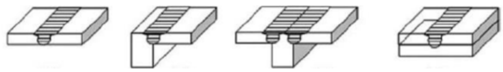
A key point in the development of aluminum vessels is that many design requirements show dependency on each other, resulting from the multidisciplinary and interdisciplinary approach of the information from the knowledge of vessels experts. In practical terms, this dependence results in trade-off solutions for product design, which do not always produce the desired result, since the design requirements are not covered in their fullness simultaneously. In other words, because of the difficulty of interpreting design requirements in a integrated manner, experts end up using their knowledge in isolation, setting solutions that do not end up the most appropriate for designing aluminum boats.

When dealing with the product development process, two types of knowledge can be used. Explicit knowledge and tacit knowledge. According to Nonaka and Takeuchi (1997) [14], explicit knowledge are those structured and capable of being verbalized. It corresponds to part of the knowledge that can be expressed, stored and shared in documents, books, worksheets, systems, etc. Tacit knowledge are those inherent in the people, such as the skills they possess. They constitute the knowledge that is not structured and can not be registered and/or easily transmitted to others.

In this context, it is observed that:

- The rules, strategies and solution principles used for aluminum boats projects, the explicit knowledge, are quite generic and do not provide project specific situations.
    - Design rules indicate the proper way to perform an action in order to achieve a specific goal, being established through proven knowledge by experts in the field. These rules are the explicit knowledge of these experts;
    - The design strategies indicate the best conditions or favorable paths in order to achieve a specific goal, being established by the expert, through the observation of manufacturing practices. These strategies are the tacit knowledge of these experts;
    - The solution principles are graphical representation of explicit and tacit knowledge of experts.

Table 1. Example of rule, strategy and solution principle.

Design Rule for Welding	Ensure that it is used compatible adition material, preferable used MIG process.
Welding Strategy	To reduce plate distortions plan the joining ahead, weld small segmented portions within a good distance from one another. Deposit less heat by depositing less material.
Solution Principle	

- Incorrect use of this knowledge may result in negative effects on the quality, cost and functionality of the product. Yet, the failure to fulfill a design rule, in some cases, can mean a better solution for product design;
- Project specifications involve assigning values to design requirements, which is performed subjectively as usually occurs based only on the experience of the product development team (tacit knowledge). As the design tools do not support these features, specifications have been formulated without considering systematically the knowledge of aluminum boats development area, which may cause problems in the stages of conceptual design, preliminary and detailed product.

As stated the welding process of aluminum vessels is complex and the knowledge of experts is fundamental. In this regard, the definition of recommendations and best practices for the design and manufacture of aluminum vessels is important to:

- Consider and evaluate the knowledge of experts in an integrated and systematic manner;
- Assist the development of concept (shape) of the product, which is determined considering restrictions associated with the use of the product, the manufacturing process, the rules, the recommendations and principles of typical aluminum product design solution;
- Facilitate the evaluation of the technical and economic feasibility of design alternatives, considering as an integrated manner the parameters associated with the project, processes, mold and injection material and simultaneously possible approaches costs and the level of abstraction of information.

In short, considering the above, there is the necessity to have the means to apply this knowledge effectively and consider the particular circumstances of the project.

2. Proposal of Design Template for Aluminum Hull Welding

The Template proposed is based on the approaches by: i) Ferreira [15], which seeks to integrate QFD tools - Quality Function Deployment - and TRIZ - Theory of Inventive Problem Solving - to assist the definition of project specifications of injected components; and ii) Fonseca [8], which presents a system for assisting the setting of industrial products.

The proposed model is shown in Figure 1.

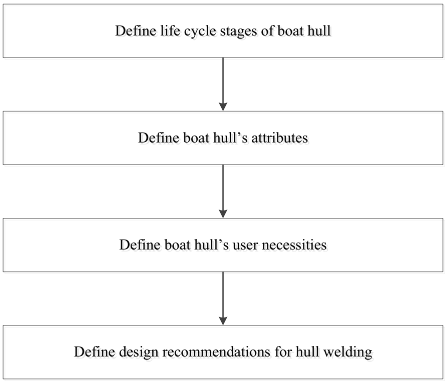


Figure 1. Proposed model to define the design recommendations.

Next, each of the steps proposed will be carried out.

2.1. Definition of life cycle stages

The identification of a product's life cycle is important, particularly to define the ones involved in each stage of product development. As shown by Back et al. [15], based on the work of Fonseca [8], and exposed in Figure 2.19, the product life cycle includes the stages of planning, manufacturing, assembly and packaging, transport and distribution, sale, purchase, use and maintenance, decommissioning, disposal and recycling.

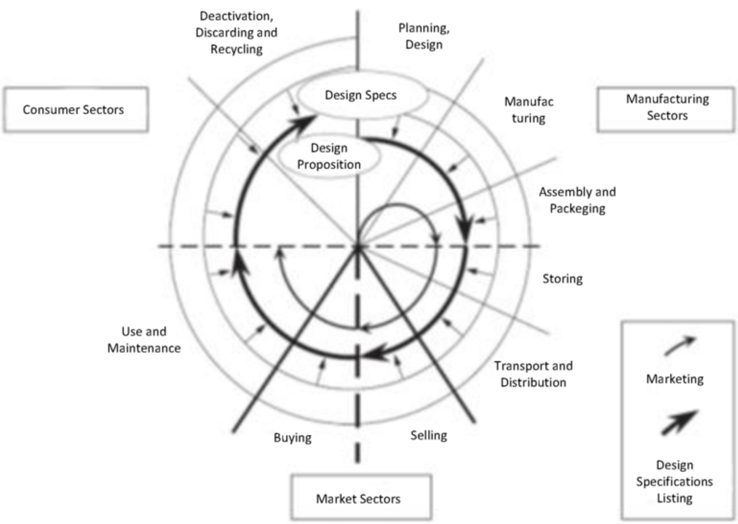


Figure 2. Stages of life cycle of a product (Back et al. [15] adapted from Fonseca [8]).

In the case of the shipping industry, those involved are users, shareholders, company departments (design, product engineering, manufacturing, assembly, sale, distribution), suppliers, after-sales team, among others.

2.2. Definition of product attributes

To define the design requirements, Fonseca methodology [8] was used. The product basic attributes represent competitive factors defined by the product properties that will be evaluated by the market and the customer, while the life cycle attributes are those corresponding the product phases throughout its life. Considering the properties of an aluminum shell, the most relevant attributes are shown in Table 1. They are: function, ergonomics, safety, normalization, aesthetics and reliability. And, the life cycle phases are: design, manufacturing, mounting, use, function, maintenance and deactivation. This matrix received the name of User Needs Support Matrix.

2.3. Users needs definition based on expert consultation

Related to the product needs matrix, a questionnaire was developed and applied to four experts from the welding area. The answers provided by the experts were able to generate the specific needs of the product throughout its life cycle. These needs will be used, later, to elaborate a matrix to support the conversion of user requirements in design requirements. The main requirements raised by experts are represented in Table 2.

Table 2. Raising support of users' needs Matrix, adapted from Fonseca [8].

LIFE CICLE PHASES	**PRODUCT ATTRIBUTES**				
	Function	**Ergonomic**	**Economic**	**…**	**Reliability**
Project	Guarantee the parts performance.		Reduce cost.		
Manufacture	Prioritise modular mounting structures to be used in different constructions.				
Mounting		Focusing on the mounting facilities.	Choosing commercial components.		Minimizing the components number. / Limiting components with high dimensional accuracy.
Use					
Function	Ensure balance between the parts and the use of compatible materials.	Ensure access to parts.			
Maintenance	Minimizing maintenance.				
Deactivation			Use of easily recyclable materials.		

2.4. Elaboration of design recommendations' Matrix

The design recommendations' Matrix intend to guide the project team in the selection and determination of metrics and indexes of target quality for the unions design specifications welded in aluminum hulls. This matrix being grounded in this life cycle has brought the users needs of each phase, the specific attributes and design requirements to achieve the desired quality. The design recommendations, given by the crossing of the project requirement and columns of the matrix, reflect the attributes of the product life cycle in order to guide and facilitate their contribution during project execution (Table 3).

Table 3. Design Recommendation for Life Cicle Matrix.

			Basic Attributes				
User Require-ments	**Specific Attributes**	**Design Requirements**	**Manufac-turability**	**Market-ability**	**Usability**	**. . .**	**Reliability**
RU_1	Geometry	RP_1	RC_{11k}				
RU_2		RP_2	RC_{21k}				
…	…	…			…		
RU_i		…					RC_{ijk}

The first column brings the users needs from the User Needs Support Matrix from Fonseca [8]. Each set should be categorized to attend their respective specific attribute as noted in user requirements conversion matrix in design requirements, also Fonseca authoring [8]. This division and organization tries to instill in the project team the need to be measured these requirements for the quality to which they are attached, since that, during the project implementation is extremely important to have in mind its origin, thus avoiding unnecessary questions and revisions of previous phases.

The columns guide and lead the project team throughout the life cycle. In it are willing attributes of the life cycle: manufacturability, condition, technologies and features that the object to be manufactured must possess to be capable of manufacturing according to the existing processes and methods on the factory floor to which the project is intended; rideability, the characteristics, conditions and technologies required to mount the component in space, which was designed to occupy; transportability, to be possible the shipping, while maintaining its integrity and quality; functionality, integrity and quality aspects that would give conditions for the elements bearing the load and environments that should be designed; maintainability, conditions, characteristics and technologies used to provide adequate maintenance, thus ensuring its reliability; recyclability and disposability, holds the relevant information for the product to be dismantled and for the best possible way to its disposal and recycling.

The design recommendations are derived from the specialized literature and the best practices of the company's knowledge management to the intended design. They are allocated at the lines intersection with the matrix columns above and are organized in the vector form, acting as a file drawer. Eventually the company will specialize in solving that hall of user requirements, providing its products with the desired quality by users as the main activity.

It is noteworthy that the project team should focus its efforts together with the users hull at all phases of the life cycle, attempting to mount this matrix in project meetings. Besides being also important that the other entities involved in the project also keep their processes history and best practices to feed the matrix. In this way the project team can select the design recommendations that best suit their design issue.

3. Proposed Template Application Example

The construction of the matrix provides some thoughts for its use. The first concern is with the importance of each inserted recommendation. The reported information will be used by the designer several times, so any bad reference should be discarded in order to prevent a very costly errors chain to the yard (Table 4). The same goes for its use in day-to-day. One of the main intentions of this tool is that it is used in design management information, continuously enriching it with more information extracted from errors and trial of shipyard everyday. Shallow or dubious conclusions should be avoided so this tool can bring security throughout the design and construction of vessels. Therefore, discussions about any change should be encouraged by all involved.

Table 4. Design Recommendation Matrix Example for Welded Joints in Aluminium Hulls

Users Requirements	**Specific Attributes**	**Design Requirements**	**Basic Attributes**			
			Manufacturability	**Marketability**	**Usability**	**....**
Guarantee the performance of the parts	Geometry	Welding position	Torch Conduction: attack angle, tilt, performing weaving 9			
		Weld Bead Aspect	Standards AWS D1.1/DNV	Use MIG welding or pulsed or goticular to obtain weld beads with better look [9]		
	Signals	Weld beads aspects	Non-destructive testing: Ultrasounds Welding through pass aft technique			
	Quality	Number of defects	Use suitable filler material to the base material according aluminum class. Using pure argon		Eliminate the presence of hydrogen / oxygen during welding [9]	
Reduce cost	Geometry	Welding position	Always try to use the flat position for welding			
	Material	Cost of adding material	Prioritize rods / most common wires commercially: AWS 5.10 ER4043/ AWS 5.10 ER5356 [11]		Reduce time in stock of the electrodes and the material used [9]	
	Signals	Welding Process	Prefer goticular welding using simpler equipment	Use friction welding to reduce welding costs in large platings [12]		

		Number of passes	For joining sheet from 1.2 to 50mm in a single pass use friction welding [12]			
Ensure crew safety	Material	Reliability of the filler material	Use suitable filler material to the base material according to the class aluminuio			
	Estability	Cord continuity	Use friction welding to minimize distortion [12]. Perform the welding in a single pass. Be careful with external air currents [11]			
	Quality	Number of defects			To minimize lower penetration than adequate, increases the supply of energy	
		Deformation of the welded joint	Use the tab. 5-3 "Permissible Alignment of Butt Welds (ABS)" to find alignment tolerance. Use friction welding to minimize distortion [12]	Use MIL-STD 1689 Tolerance to minimize distortions union [12]		

4. Conclusions

Some conclusions can be drawn from the generated matrix by responses from experts. First, there were not raised needs for the aesthetics of the weld bead generated, as the phase of "use" in the life cycle has no necessary recommendations. In addition, there is the suggestion of the use of modular structures, capable of being used in more than one operation. The difficulty of this process is found in yards that has poor reproducibility of its products, requiring even greater flexibility for these structures. Another factor is the security that the user demand for himself and the crew, this requirement is not only important, but also a result of standardization requirements and, also, function. As for the economic aspect, it is noteworthy that unlike other recommendations, *e.g.* respect standards, it is an optional feature, varying according to the product offered to the customer. Finally, note that there are considerable number of recommendations that encourage a care in maintaining a simple design, facilitating welding and reducing the number of components.

Looking at the matrix as a whole, other observations can be made. It should be noted immediately that not all spaces are filled, however, this is not a factor that invalidates the construction of the matrix, because only the most important requirements should be cited. In all, 14 mentioned requirements, despite the diversity of each cell of the matrix, none of the requirements excludes any of the others. This fact allows the unrestricted use for the matrix construction of the project recommendations.

It does not escape the attention the fact that this is an innovative tool to organize and support the process systematization of getting design specifications proposed by Fonseca [8], since the exploration in the literature on project management and product development does not point systematic in the same form and content. However the population of these crossings becomes a harvest of few and for few holders of knowledge. It is an iterative and knowledge management task that the project team and the institution to which they belong must keep your organism processes, with the target point the record of valuable "lessons learned".

In short, with the Template, it is expected to:

- provide a wider range of design information to minimize the high level of abstraction and maximize the number of available data considering the multidisciplinary and interdisciplinary knowledge of experts;
- generate information to guide the phases implementation of conceptual design;
- consider the dependence of the design requirements in an integrated manner and seeking, mainly, solutions that address these requirements in their entirety, therefore, thus avoiding whenever possible, the call compromise;
- help define design constraints;
- provide means to employ the tacit and explicit knowledge of experts in a systematic and integrated way, and considering the particular circumstances of the project;
- identify areas in which greater efforts (time, technical resources, financial resources) should be concentrated.

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