TAMPEREEN TEKNILLINEN YLIOPISTO
TAMPERE UNIVERSITY OF TECHNOLOGY

RIINA PIHL

IMPROVEMENT OF EFFICIENCY AND QUALITY OF ALUMINIUM HULL WELDING

Master of Science Thesis

Examiner: professor Seppo Virtanen
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Diplomityön tavoitteena oli kehittää ja parantaa rungon hitsauksen tehokkuutta sekä laatua Baltic Workboats -telakalla. Kehitys- ja tutkimustyö toteutettiin useiden vuosien aikana ja se sisälsi useita strategiamuutoksia sekä merkittäviä muutoksia rungon tuotantoketjussa.

Alumiinia käytetään meriteollisuudessa laajasti, koska sillä on useita hyödyllisiä ominaisuuksia. Alumiinin käsittely on erittäin haastavaa ja vaativaa, minkä vuoksi on tärkeää kouluttaa alumiinia hitsaavaa henkilöstöä. Tutkimuksen aikana sertifioitujen hitsaajien määrä telakalla kasvoi 25% ja rungon hitsauskustannukset laskivat uusien menetelmien seurauksena 35%.

Tuotekehityksessä ja tekniikassa on nykyään erittäin kova kilpailu, mikä tekee jatkuvan kehityksen tärkeäksi. Meriteollisuudessa menestyäkseen on oltava askeleen edellä muita kilpailijoita niin kustannusten, tehokkuuden kuin laadunkin näkökulmasta.

Tämän tutkimuksen tulokset vahvistavat, että muutokset tuotannossa ovat olleet merkittäviä. Muutosten johdosta tuotannon lisääntynyt tehokkuus ja henkilökunnan parantunut osaaminen ovat nostaneet hitsaustyön laadun korkeimmalle eurooppalaiselle tasolle.

ABSTRACT

TAMPERE UNIVERSITY OF TECHNOLOGY
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The aim of the thesis was to develop and raise hull welding efficiency as well as quality in Baltic Workboats Shipyard. The development and research was carried out during several years and it included several significant changes in strategy and in the whole hull production.

Aluminium with its beneficial metallurgical properties is widely used in marine applications. Handling aluminium is very challenging and demanding. Due to this fact it is quite relevant to develop the aluminium handling process and educate personnel. During the development process the number of high quality certified welders in the shipyard rose 25% and the costs of hull welding due to implementation of new methods decreased up to 35%.

There is a tight competition in modern product development and engineering in marine industry which makes sustainable development essential. In the industry it is crucial to be one step ahead of the other competitors in costs but also in the efficiency and quality.

The results of the current research confirm that the drastic and bold changes implemented in the aluminium hull production have been significantly successful and in addition the welding personnel have achieved the highest quality level of the European aluminium welding.

PREFACE

The current thesis was written at the Baltic Workboats shipyard in Saaremaa island in Estonia. The research, data collection, educating personnel and developments have been implemented on several years starting from 2009. The actual laboratory research, analyses and conclusions were carried out mainly from March 2011 to May 2012.

I would like to render thanks to my supervisor, Professor Seppo Virtanen, for his positive mind, courtesy and patience during the long research. I obliged also for Mr. Dragan Jerčić from Croatian Register of Shipping for his advices on methodology. Also I acknowledge getting supportive ideas on different development stages from experienced shipbuilders in Latvia, Sweden and Finland.

Secondly I would like to thank my family and friends for supporting me during my studies in Finland and injecting me confidence and courage while taking challenging decisions.

Last, but clearly not least, I would like to show my gratitude to the personnel of Baltic Workboats Shipyard for their co-operative mind and motivative thinking.

Contents

ABBREVIATIONS

Al	Aluminium
Al_2O_3	Aluminium oxide
Ar	Argon
B	Vessel's breadth
BWB	Baltic Workboats Shipyard
CAM	Computer added machining
CNC	Computer numerical control
C_{cb}	Ceramic backing costs
C_{en}	Energy costs
C_{eq}	Machinery and equipment usage costs
C_{mat}	Material costs
C_{sg}	Shielding gas costs
C_w	Welding wire costs
C_{work}	Workers costs
E_i	Production efficiency index
FCC	Face centered cubic crystal structure
F_f	Fillet material consumption
HAZ	Heat affected zone
He	Helium
HVAC	Heating, ventilation and air conditioner system

kn	Knot
LOA	Vessel’s length over all
LSA	Life saving appliances
M	Weld material
MIG	Manual inert gas welding
MPa	Mega Pascal
SAR	Search and rescue vessel
T	Vessel’s draught
t_a	Welding assistance time
t_c	Welding completion time
TIG	Tungsten inert gas welding
t_{op}	Welding operation time
t_p	Welding processing time
t_{prep}	Welding preparation time
t_{su}	Welding supplement time
t_w	Welding time
ϱ	Material density
σ_y	Yield strength
Δ	Vessel’s displacement

1. Introduction

Peter Drucker has said "If you can't measure it, you can't manage it”. Therefore it is essential for successful production management to be able to evaluate and survey the actual limits of the costs as well as develop and educate the staff.

Modern product development and production engineering are growingly focusing on minimizing costs as well as maximising profit and efficiency. Due to intense pressure of competition scientists and producers are continuously searching for new materials and methods to be one step ahead from their competitors.

Aluminium with the weight of 1/3 of steel’s weight is widely used in maritime and shipbuilding. The most important advantages of using aluminium in naval architecture are clearly its light weight and corrosion resistance. Among others these properties allow new-built vessels to be with high speed and resistant at different circumstances.

Irrespective of the major advantages aluminium welding procedures compared to steel are much more complex and demanding, requiring skilful and precise personnel. While building of aluminium, material specific properties have to be considered and the welding significance must be implemented in a distinctive way.

Due to aluminium properties, its welding significance and demanding application the vessels built of aluminium often come across welding deformations and distortions. And clearly these issues show high impact also for welding matters in Baltic Workboats shipyard. Subject to that currently the biggest problematic issues connected with the quality of the new-building are generated by aluminium welding; more precisely distortions and deformations of aluminium welding.

For solving the most critical matters of the production it is advisable to start the improvements from the critical areas. Subject to the matters pointed out previously it has appeared that the shipyard welding procedures need development, higher efficiency and speeding up the processes. And from that fact follows the requirement to start from the beginning: educating welders. One of the pre-requirements of high quality welding is to assure that the staff has as an addition to their practical knowledge also a high theoretical knowledge package.

The aim of the thesis is to rise the efficiency and lower the costs of hull welding in Baltic Workboats shipyard. Subject to that the research investigates possibilities to resolve and reduce welding deformations and distortions as well as improving the efficiency and quality of the whole production. Having a bigger efficiency, higher quality and faster welding procedures bring the company produce vessels with very high quality and accordingly also more satisfied customers and subject to that bigger profit.

The current research has been carried out during long period developing different vessels, educating the staff and during the time several changes to improve welding have been implemented. Before the current study there was nevertheless no clear proof of whether the developments and changes have been beneficial and to what limits the welding works could now with the possibilities of modern world market still be developed.

The master thesis comprise of introduction, 5 body chapters, conclusion, references and appendixes. Chapter 2 clarifies the theoretical background of using aluminium materials, importance and significance of material properties to welding, aluminium boatbuilding and describes and overview of the Baltic Workboats shipyard where the research was carried out. The chapter mainly focuses on aluminium handling and welding specific theory package which shall be added to the shipyard's Quality Manual. Chapter 3 explains the research methodology and calculation background. Chapter 4 describes the research results comprising of mainly mathematical calculations. Chapter 5 discusses the research results and tries to find out clear reasons of the results and compares them to what was expected. The aim of chapter 6 is to explain and gather most significant data of carrying out hull welding in BWB in future. Chapter 6 also clarifies keywords and general chapters of the hull production chapters of the Quality Manual.

Overall it must be mentioned that the research and development work was expected to be challenging. That mainly because the experience of producing aluminium hulls in Europe is poor and it is hard to find supervision or advice of high level were aluminium handling and shipbuilding is combined. The actual results or the study and development areas were not predictable as similar research had not been carried out in any shipyard producing aluminium hulls.

2. Theoretical Background

2.1. Properties of Aluminium

Aluminium is the third most common element in the earth's crust, coming after oxygen and silicon. It makes up approximately 8% of the crust's total mass and is the most abundant metal [1].

Aluminium with its density of around 2,7 kg/m^3 is the most common and widest used light metal. Aluminium cells have a face centered cubic (FCC) crystal structure which makes it possible to alloy other elements and means that the material does not suffer from a loss of notch toughness as the temperature is reduced. Due to that some alloys even show an improvement in tensile strength and ductility as the temperature drops. According to Gene Mathers [2] widely in marine applications used alloy EN AW 5083 shows a 60 % increase in elongation after being in service at -200 ºC for a period of time. The crystal structure also means that formability is very good, enabling products to be produced by extrusion, deep drawing and high energy rate forming.

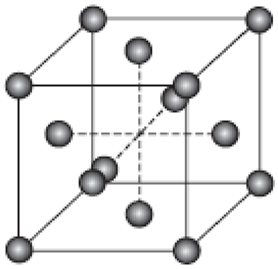

***Fig 1.** Face centered cubic (FCC) crystal structure*

The production of primary aluminium currently amounts approximately 34 million tons worldwide, where approximately 9 million tons are attributed to Europe [3]. The aluminium industry achieves a turnover of approximately 100 billion euros worldwide with about 1,2 million employees. There is a turnover in Europe of 25 billion euros with 237 000 employees.

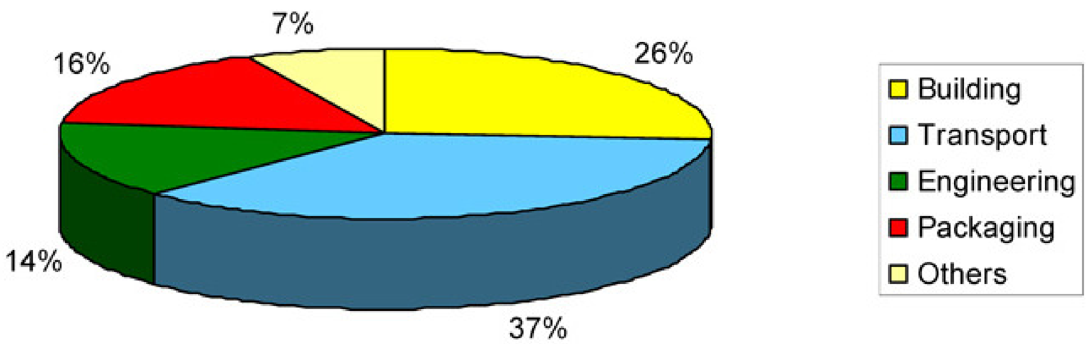

***Fig 2.** Main end-use markets for aluminium products in Europe in 2010 [4]*

Pure aluminium is a soft material with very good heat and electrical resistivity properties and resistance to corrosion. To achieve even better strength, corrosion and processing properties other alloying elements are used; copper for rising strength, silicon to rise melting temperature and stiffness, manganese for rising strength without losing its good stiffness properties, magnesium for rising strength without losing its good corrosion resistance properties, zinc (with magnesium and copper) for rising strength. [5]

2.1.1. Aluminium Alloys

In mechanical engineering and marine applications very few materials are used in the pure state. To increase strength the metal is alloyed. Many elements alloy with aluminium but only a relatively small number of these give an improvement in strength or weldability. The most important elements are silicon, which increases strength and fluidity; copper, which can give very high strength; magnesium, which gives both strength and corrosion resistance; manganese, which gives both strength and ductility improvements; and zinc, which in combination with magnesium and/or copper, will give improvements in strength and will assist in regarding some of the strength lost when welding.

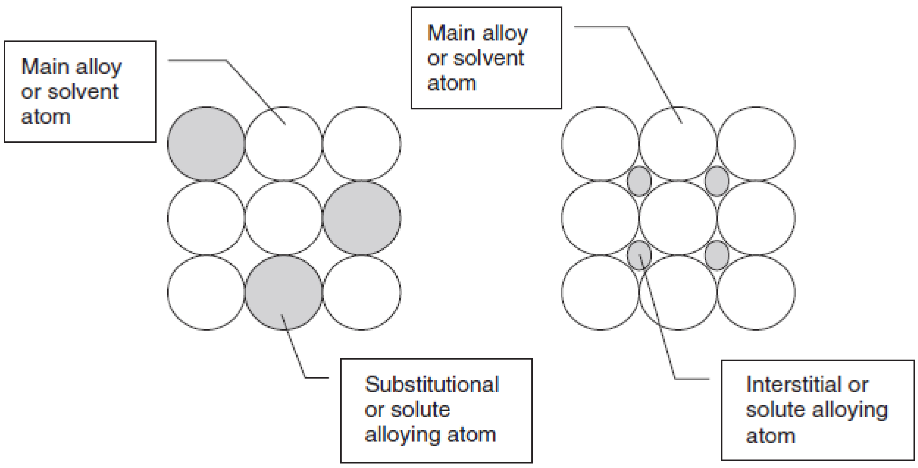

Fig 3. *Substitutional and interstitial alloying [2]*

Aluminium is used in various shapes and forms (described on figure 4). As an addition like mentioned in the previous chapter aluminium is alloyed with several components in order to achieve better properties. Based on the composition and tempering method aluminium alloys are divided into two main groups cast and wrought aluminium, both of them have additional subgroups based on the alloying elements. The marking of aluminium is basic principle is shown on figure 5 below.

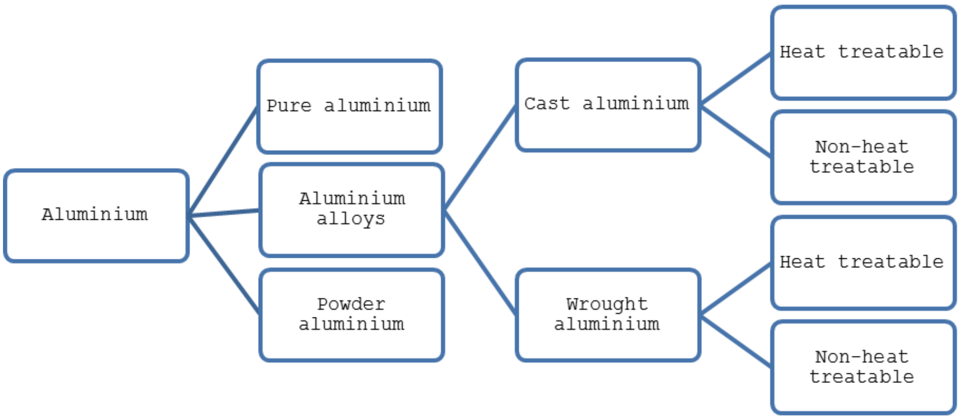

Fig 4. *Aluminium alloys [6]*

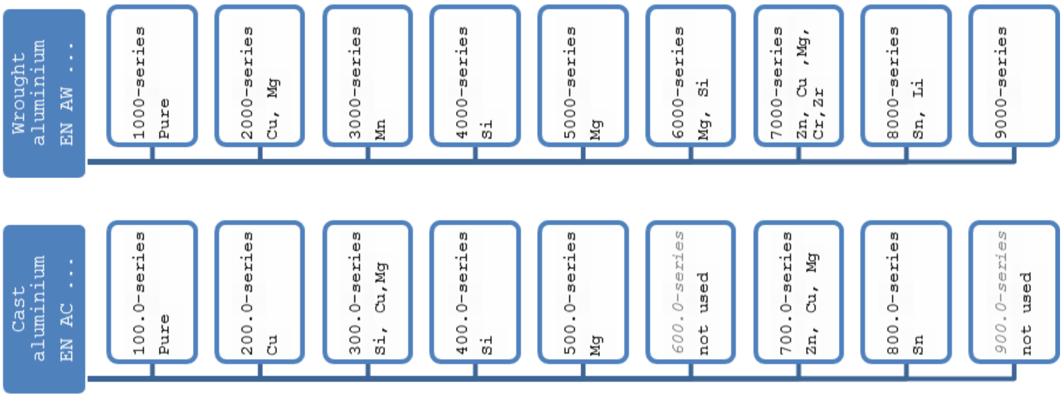

Fig 5. *Aluminium alloys [6]*

Aluminium does not change its crystal structure on heating and cooling, unlike steel which undergoes phase changes and crystal transformations at specific temperatures. This makes it possible to harden steel by rapid cooling whereas changes in cooling rate have little or no effect on aluminium alloys. For achieving even better properties as an addition to using alloying elements aluminium is strengthened with several other methods.

In general terms grain size increase reduces yield and ultimate tensile strength. Different from steels grain size is not generally used to control strength in the aluminium alloys, although it is used extensively in reducing the risk of hot cracking. The yield strength σ_y, is related to the grain size by the Hall-Petch equation:

$$\sigma_y = \sigma_1 + k_y \cdot d^{-\frac{1}{2}}$$

where *d* is the average grain diameter and σ_1 and k_y are constraints for the metal.

In the aluminium alloys the strength loss due to grain growth is a marginal effect, with other effects predominating. Grain size has a marked effect on the risk of hot cracking, a small grain size being more resistant than a large grain size.

Cold work, work hardening or strain hardening is used to increase strength and/or hardness of metals and alloys that cannot be strengthened by heat treatment. These involve a change of shape brought about by the input of mechanical energy. As the deformation proceeds the metal becomes stronger but harder and less ductile requiring more and more energy to continue deforming the metal; see figure 6.

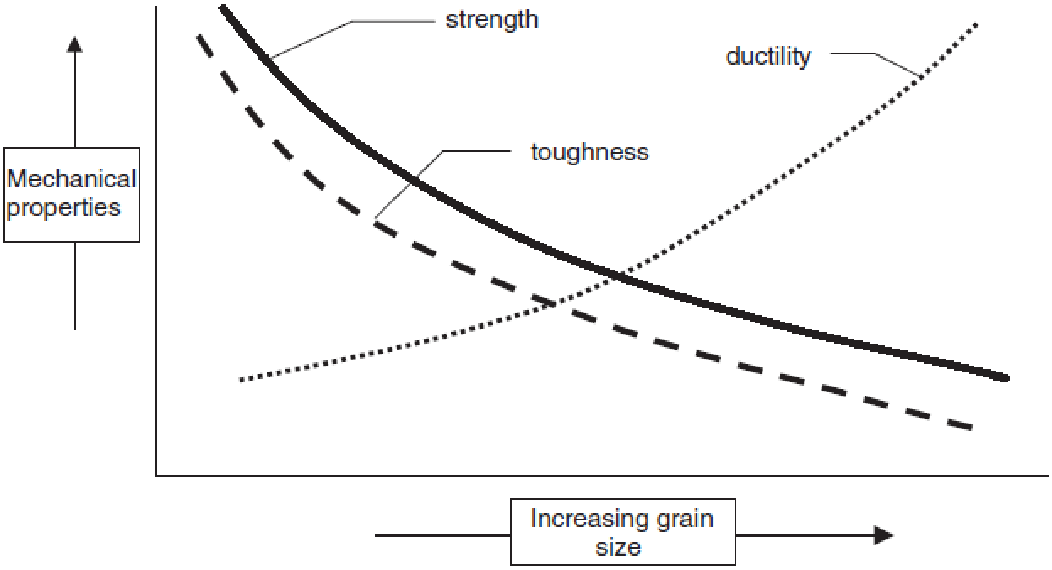

Fig 6. *Relationship of grain size with strength, ductility and toughness [2]*

Aluminium alloys are controlled also by precipitation hardening, which in principle means that strengthening process is controlled by time and temperature.

With different heat treatment methods the alloys will receive better mechanical, physical and chemical properties. Table 1 below explains the marking of temper designations of aluminium marking.

Table 1. *Aluminium alloys [6]*

Temper Group	**Explanation**
F	As fabricated
O	Fully annealed (dead soft)
T	Heat treated
H	Strain hardened

Some aluminium alloys are more suited for marine purposes and some are not suitable in any circumstances. The table below lists aluminium alloys suitable and used for marine environment and boat building.

Table 2. *Aluminium alloys used in boat building [7].*

Alloy	Hardening	Tensile strength	Yield strength	Elongation
Sheets (2 mm < t < 40 mm)				
EN AW 5052	H111	170	65	16
	H32	210	160	10
	H34	235	180	9
EN AW 5154	H111	215	85	16
EN AW 5754	H111	190	80	17
	H24	240	165	10
EN AW 5454	H111	215	85	16
	H32	250	180	10
	H34	270	200	9
EN AW 5086	H111	240	95	14
	H116	275	195	9
	H32	275	195	10
	H34	300	235	9
EN AW 5083	H111 (<6mm)	275	125	15
	H111 (>6mm)	270	115	14
	H116	305	215	10
	H321	305	215	10
EN AW 5383	H111	290	145	17
	H116-H321	305	220	10
Profiles (2 mm < t < 25 mm)				
EN AW 6060	T5/T6	190	150	12
EN AW 6061	T4	180	110	24
	T5/T6	260	240	8
EN AW 6063	T5	150	110	7
	T6	205	170	9
EN AW 6005 A	T5/T6	260	215	8
EN AW 6082	T4	205	110	14
	T5/T6	310	260	10

2.1.2. Thermal Expansion and Conductivity

Aluminium has relatively high thermal conductivity staying in the limits from 76 to 236 W/mºC [8].

High thermal conductivity properties rise risks for joint defects, forming of pores and can mean unacceptable buckling and distortion during welding. Due to that the areas around the weld cool down fast an there may be insufficient amount of heat for melting the metal during welding.

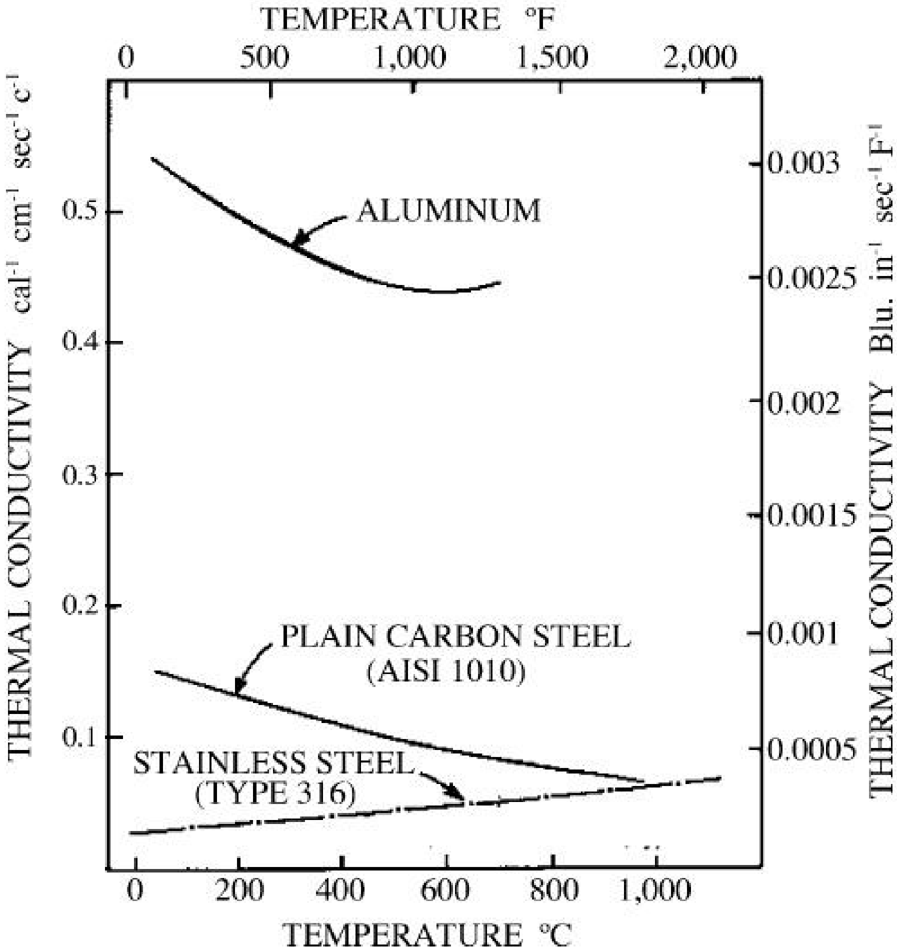

Fig 7. *Thermal conductivity of aluminium and steel [9]*

The coefficient of thermal conductivity of aluminium is approximately six times that of steel (figure 7). The result of this is that the heat source for welding aluminium needs to be far more intense and concentrated than for steel. Particularly this is significant for thick sections, where the fusion welding processes can produce lack of fusion defects if heat is lost too rapidly.

2.1.3. Solidification Shrinkage

Steels generally have welding shrinkage of up to 2,8 % whereas aluminium can have up to 6,5 % during cooling to solid and additional 2 % during cooling to room temperature. Shrinkage and shrinkage stresses cause cracking and deformations which are all unwanted issues.

2.1.4. Oxide Layer

Aluminium oxidizes easily in contact with air and as a result a thin oxide layer (Al_2O_3) forms to the material surface. The oxide layer has several influences welding in several ways:

- oxide layer is hard and tough;
- oxide layer is heavier than the aluminium (ϱ_{Al}=2,7 g/m^3, ϱ_{Al2O3}=3,9 g/m^3) and that due to sinking into weld causes joint failures;
- oxide layer has significantly higher melting temperature (Al=660 ºC and Al_2O_3=2050 ºC) due to what it does not melt in weld;
- oxide layer has hygroscopic properties and due to that during welding unwanted hydrogen particles segregate;
- oxide layer functions as insulator and that has negative effects to welding.

Even though the oxide layer is very thin, it's wide enough to protect the surface from the corrosion in various ways. The oxide layer is generally transparent and typically 2-5 nm thick.

2.2. Aluminium Welding

Alloyed aluminium is used in versatile engineering applications. Main developments connected to aluminium welding are derived from car industry, plane industry and clearly marine industry. Different aluminium alloys are fast gaining popularity as choice of material for structural applications because of the high strength to weight ratio and it can be readily welded with inert gas shielding process [10].

Welding is the most common joining method of aluminium. Compared to steel the diffusion coefficient (factor that shows the spreading of thermal field) of aluminium is approximately 10 times bigger than for steels and also the melting temperature is much lower. Due to the properties mentioned above and its good heat conductivity properties the heat impact required for welding aluminium is on the general basis from the same level as for steel. High heat conductivity properties on the other hand rise risks for joint failures and pores. As an addition compared to steel about twice as large thermal expansion of aluminium generally causes problems like deformations and distortions.

The most significant properties if aluminium influencing aluminium welds are:

- high thermal conductivity;
- high solidification shrinkage;
- oxide formation at the surface;
- high coefficient of thermal expansion;
- high solubility of hydrogen when in molten state;
- relatively wide solidification-temperature ranges

2.2.1. Common Defects of Aluminium Welding

The figure below illustrates the common defects of welding joint.

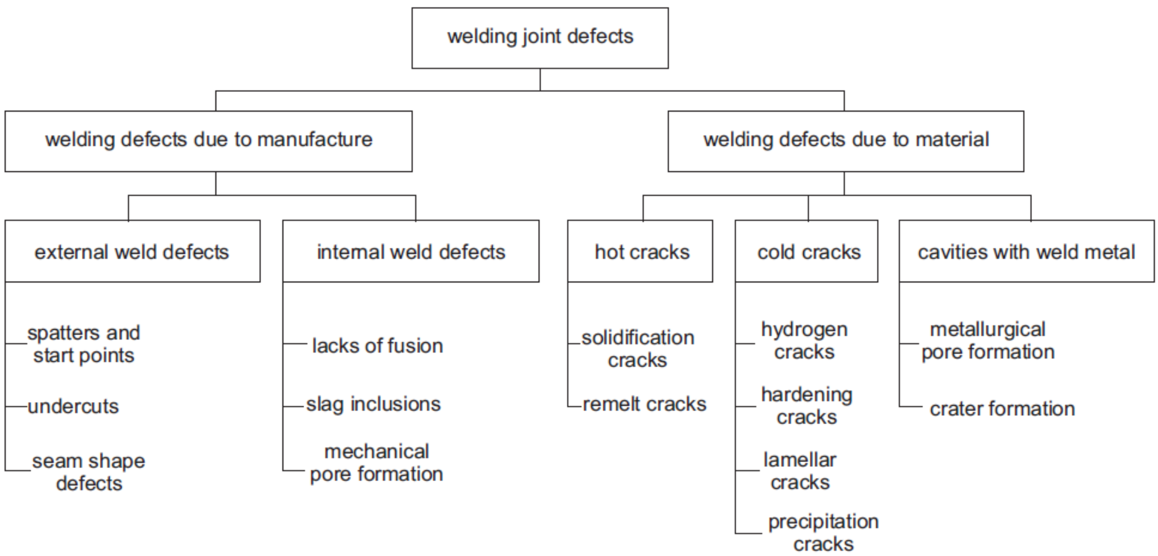

Fig 8. *Welding joint defects [11]*

2.2.1.1. Porosity

One of the most severe problems in welding of aluminium alloys is the development of hydrogen gas porosity. Porosity in aluminium can range from being extremely fine micro-porosity to coarse pores with 3 - 4 mm in diameter. Generally the origin of pores derives from the solidification of the weld or formed by gases (figure 9).

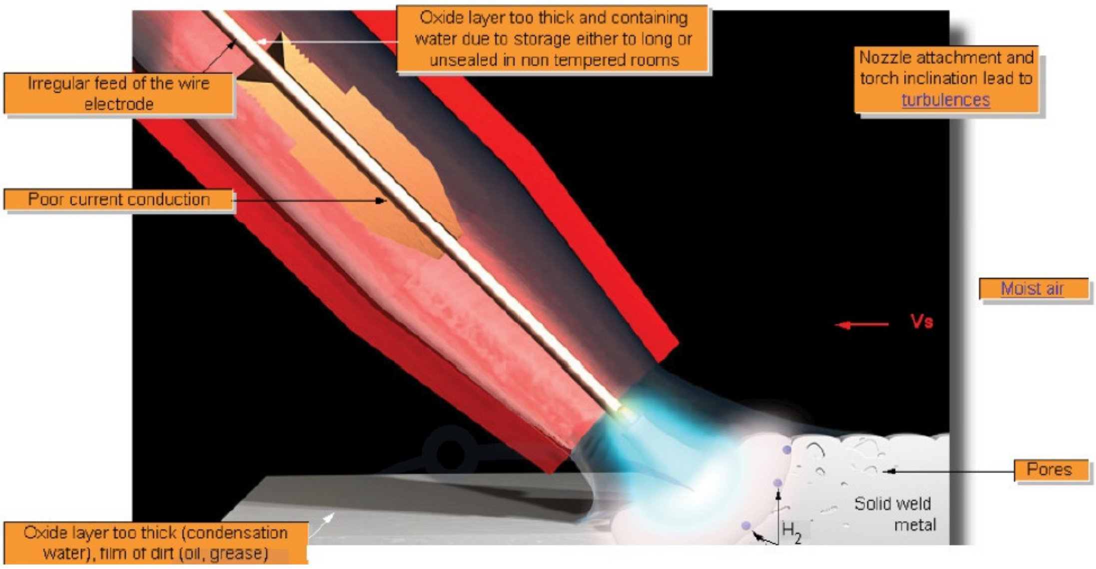

Fig 9. Resources of pores in welds [3].

Metallurgical pores predominantly occur at pure aluminium, where the transition liquid-solid is so fast that the shrinkage cavities formed during solidification cannot be filled again by re-flowing of liquid metal. On alloys with a solidification interval this phenomenon can also occur if the flowing of the residual melt is impeded by dendrite arms.

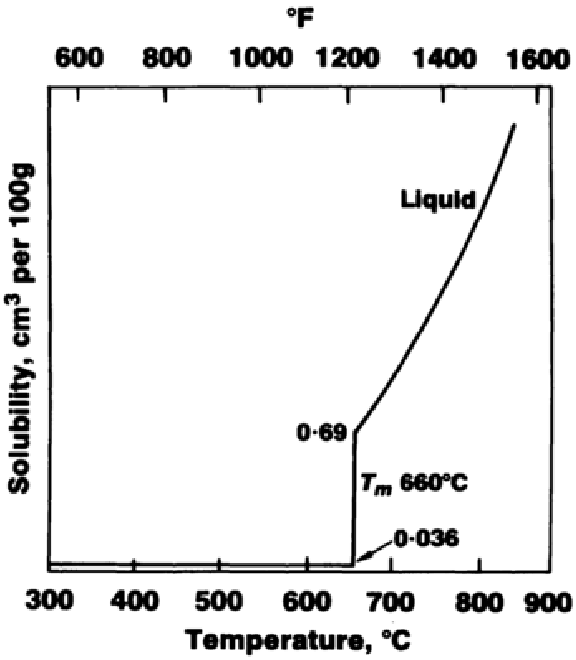

Fig 10. Hydrogen solubility in pure aluminium [12]

Gaseous pores on aluminium are caused generally by hydrogen dissolved the melt. Due to the fact that the solubility of the hydrogen decreases with temperature and during solidification is considerably reduced uniformly distributed pores can be generated (figure 10). Therefore is essential that the base material and the filler metal would not introduce hydrogen and the shielding gas should be extremely pure. As an addition possibly present oil or grease and the oxide layer are to be removed prior to welding as well as moisture is to be kept away.

2.2.1.2. Cracking

Pure metals solidify at one temperature, whereas alloys generally transform from liquid to solid over a broader temperature range. The temperature range over which this gradual transition occurs is known as solidification range. This thermo-mechanical behaviour of the semisolid body depends very much on its mechanical properties. Hence, the materials show varied tendencies towards cracking. Welding cracks are conformed mainly due to 3 main reasons:

1) Due to shrinkages and distortions appearing from the cooling after the welding due to large thermal coefficient of aluminium.
2) Due to structural stresses in the solidifying metal.
3) Due to partly melted metal in the heat affected zone (HAZ).

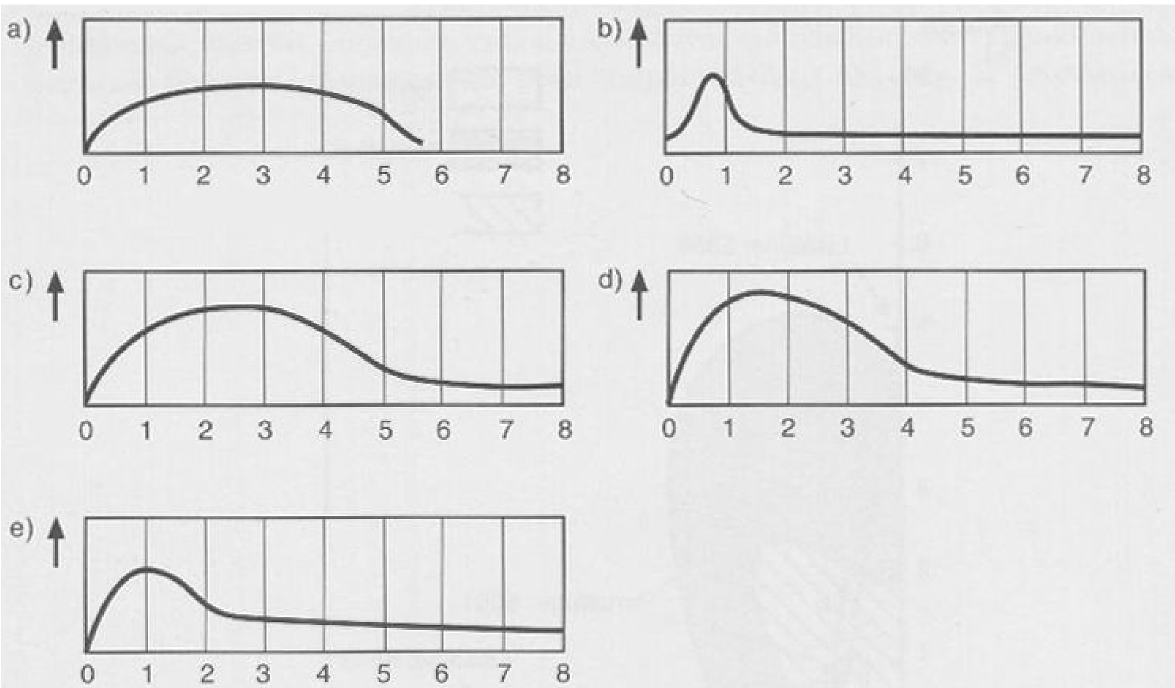

Fig 11. *Crack sensitivity [7]. Arrow on y-axis shows the relative cracking sensitivity direction and the numbers on x-axis show the content % of alloying elements. a) Al-Li alloys b) Al-Si alloys c) Al-Cu alloys d) Al-Mg alloys e) Al-Mg_2-Si alloys*

There are several types and reason of cracking in welding:

- Hot cracks are generated at relatively low temperatures due to joint material being partly liquid while the rest of the material is already solidified.
- Solidification cracks are generated during the solidification process.
- Liquation cracks are generated at low temperatures while the components are solidifying on the grain boundaries.
- Cold cracks are generated due to stresses at low temperatures after the compounds have been solidified and cooled.
- Hydrogen cracks are generated due to hydrogen existence in the solid state of the material.
- Shrinkage cracks are generated due to progress of shrinkage during cooling of the material in the solid state or due to distortions as the cross-sectional area are not sufficient enough for the deformations.

Almost all of the cracks of aluminium welding are considered hot cracks, which is also the most severe problem of aluminium welding.

2.2.1.3. Deformations and Distortions

Compared to steel aluminium has lower elastic modulus of approximately 1/3 and coefficient of thermal expansion is about twice as much. Due to that the material is heating and cooling unequally. The factor that the heated areas tend to expand and cooler areas try to prevent deformations in the material occurs. Aluminium has also larger danger of buckling and distortions are larger than for steel. Due to the mechanical properties it is with very high significance to have the aluminium welding hot and fast otherwise the sample is extremely sensitive to deformations.

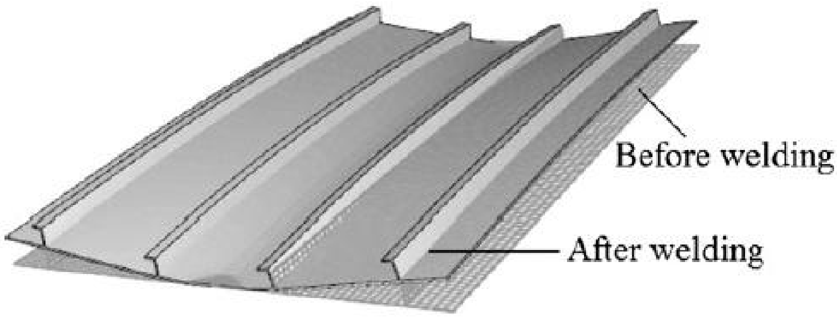

Fig 12. *Distortions of aluminium extruded panel [13]*

	Reference section position					
	$x = 20$	$x = 360$	$x = 580$	$y = 0$	$y = -116$	$y = -310$
Computed deflection	4.08	4.26	4.17	4.38	4.38	4.24
Experimental deflection	5.00	4.42	4.80	3.36	4.19	3.59

Fig 13. *Research results [13]. Deformation values of sheet from measurement and simulation results in mm*

2.2.2. Common Challenges of Aluminium Welding

On the assumption of the material properties aluminium welding has lead and encountered new significant challenges, of which the most severe are:

- joining of different grades of aluminium alloys;
- joining of reinforced and unreinforced aluminium alloys;
- reduction of cracks in weld;
- reduction of deformations and distortions.

2.2.2.1. Joining of Different Grades of Aluminium Alloys

Based on the research and experiences aluminium is grouped into 3 main clusters:

- Alloys with good weldability; can be used in structural constructions.
- Alloys with restricted weldability; use in structural constructions is not advisable.
- Alloys with poor weldability; cannot be used in structural constructions.

The most significant matter to evaluate the weldability of aluminium alloys is the predisposition of hot cracking. Generally wrought aluminium has rather good weldability properties (table 3), these are clearly subject to the composition and alloying elements. Cast aluminium is generally more difficult to weld and with tendency to have more welding defects caused by welding gas, pores and shrinkage. That in turn causes low quality of weld. Cast aluminium can nevertheless be joined and welded with wrought aluminium (in forms of sheets, profiles, extruded materials).

Table 3. *Weldability of wrought aluminium. A – good weldability; B – welding may require specific methods and sampling; C – restricted weldability; X – welding not recommendable*

Alloy	**Weldability**			
	Gas arc welding	**Manual metal arc welding**	**Gas welding**	**Resistance welding**
Non heat treatable alloys				
EN AW 1060	A	A	A	B
EN AW 1100	A	A	A	A
EN AW 1350	A	A	A	B
EN AW 3003	A	A	A	A
EN AW 3004	A	A	B	A
EN AW 5005	A	A	A	A
EN AW 5050	A	A	A	A
EN AW 5052	A	A	A	A

EN AW 5083	A	C	C	A
EN AW 5086	A	C	C	A
EN AW 5154	A	B	B	A
EN AW 5454	A	B	B	A
EN AW 5456	A	C	C	A
Heat treatable alloys				
EN AW 2014	C	C	X	B
EN AW 2017	C	C	X	B
EN AW 2024	C	C	X	B
EN AW 2036	B	C	X	B
EN AW 2090	B	X	X	B
EN AW 2218	C	C	X	B
EN AW 2219	A	C	X	B
EN AW 2519	B	C	X	B
EN AW 2618	C	C	X	B
EN AW 6005	A	A	A	A
EN AW 6009	B	C	C	B
EN AW 6010	B	C	C	B
EN AW 6013	B	C	C	A
EN AW 6061	A	A	A	A
EN AW 6063	A	A	A	A
EN AW 6070	B	C	C	B
EN AW 6101	A	A	A	A
EN AW 6262	B	C	C	A
EN AW 7004	A	X	X	A
EN AW 7005	A	X	X	A
EN AW 7039	A	X	X	A
EN AW 7075	C	X	X	B
EN AW 7079	C	X	X	B
EN AW 7178	C	X	X	B

2.2.2.2. Reduction of Cracks in Weld

Welding of light metal alloys has gained popularity over the last decade especially in transportation industry (lately even more specifically in automotive industry). The reason for popularity is weight saving because of reduction in fuel consumption. However, welded aluminium alloys possess lower strength in the weld zone as compared to base material. The effect of welding in the microstructure of the materials on the two main weld zones are as follows [9]:

- Fusion zone
  - Solidification cracking occurs;
  - Porosity due to hydrogen entrapment.
- Heat affected zone (HAZ)
  - Recrystallization of grain due to heat input liquation cracking;
  - Poor corrosion properties;
  - Brittle fracture initiation.

Solidification cracking occurs when the thermal stresses that build up during freezing exceed the strength of the solidifying weld metal. The most common methods to reduce the tendency for solidification cracking include:

- Altering the weld composition through the addition of a filler wire;
- Close process control;
- Control of grain structure within the fusion zone.

The tendency for liquation cracking without heat affected is function of heat input that causes local melting and presence of specific phases of grain boundaries.

2.2.2.3. Reduction of Deformations and Distortions

As mentioned above comparing aluminium to steel has several differences. Most significant properties connected to deformations and distortions are:

- Elastic modulus of aluminium is approx. 1/3 that of steel;
- Coefficient of thermal expansion is about twice as much as that of steel; due to that strains from cooling of welds and surrounding areas produce lower residual stresses;
- Reduced elastic modulus; due to that tend to produce greater distortion than in steel structure; due to the same reason buckling of plates occur.

There are several common methods that can be considered in order to minimize distortions during welding:

- The plate should not be free to rotate about the axis of the weld during welding;
- Design of the joint should be symmetrical;

- Welding procedures should be symmetrical;
- Minimum welding heat should be used;
- Excessive filler material should be avoided;
- Fillet welds should be made with aluminium heat input;
- Fillets should not be greater than required for strength;
- Fit-up should be made as accurate as possible to minimize weld size (root gaps and irregularities are to be minimized);
- Welding sequence has high significance
    - Butts and seams in plating should progress outward from the center;
    - Butts in strakes of plating welded before the longitudinal seams;
    - Beneficial is to weld only small portions at a time (welding short intermittent beads; returning to weld seam after structure farther away has been welded).

2.3. Aluminium Boat Building

The start of using aluminium at sea environments began in the 1930s in USA when the US Navy began hull corrosion studies. Extensive research was carried out from 1960s to early 1980. As a result some new marine environment suitable alloys were developed and from the 1980s aluminium is growingly used as construction material for several applications.

Over the past several years there has been a dramatic increase in ferry industry, mostly high speed passenger catamarans manufactured of aluminium. The studies have become on the basis for the initial regulatory and classification society rules concerning the design and construction of high speed marine vessels [14]. Globally Austal Limited is the leading company of design and manufacturing of high performance aluminium vessels. As an addition the company has developed a significant portfolio of aluminium shipbuilding expertise.

Aluminium boatbuilding has a variety of advantages and benefits [10]. The primary advantage of aluminium is its high strength-to-weight ratio, which is a comparison of the dead weight of the material to its mechanical properties. In other words the higher the strength-to-weight ratio of the hull material, the lighter the boat can be constructed while maintaining a given level of strength.

In addition to light weight and high strength aluminium is also durable with high degree of elasticity and very ductile. Due to that it is able to be bent or drawn out without breaking and has a high resistance to impact damage.

Fig 14. *Construction of hull upside down. Baltic Workboats project 90080, LOA 25,8 m fishing protection vessel to Northern Ireland built in 2010.*

Another major advantage of aluminium hulls is low maintenance. It is considered that aluminium hulls last indefinitely with a minimum care. Marine grade aluminium alloys of 5000-series and structural alloys of-6000 series are almost impervious to atmospheric and seawater corrosion. From surface treatment for an example in Northern America the hulls are not coated with any methods (even paint is not used), that also reduces costs and maintenance requirements.

In Northern Europe the largest and most developed aluminium vessel producers are Uudenkaupunkin Työvene (Finland), Docksta Varvet (Sweden), Baltic Workboats (Estonia) and Damen (The Netherlands).

Fig 15. *Construction of hull in jig. Baltic Workboats project 90087, LOA 24 m Swedish Coast Guard patrol vessel built in 2011.*

There are different methods of building the hulls. Even the very basic structural design can vary significantly in different shipyards; example the hull can be constructed upside down and then flipped around like it is done in ASK Enterprises (Latvia) and Kewatec Aluboat (Finland). Or then the hull can be built in a jig like it is mainly done in Baltic Workboats Shipyard (Estonia) and Uudenkaupungin Työvene (Finland). There is specific internal research carried out in each yard considering all local and financial perspectives and clearly the results are often classified and due to development and rivalry perspectives mainly not shared. All those reasons generate necessities for rising development and research also in the Baltic Workboats Shipyard.

2.4. Baltic Workboats

2.4.1. The Shipyard

Baltic Workboats is a shipyard in western Estonia on the island of Saaremaa. The company is based fully on Estonian capital. Since 1998 the yard has been producing mainly aluminium workboats such as pilot boats, patrol boats, research vessels, tug boats, diving boats, ferries, SARs and other special purpose small crafts. At the beginning the shipyard was also producing ice capable steel vessels; these hulls are nowadays subcontracted. For several reasons nowadays the yard is focusing on aluminium hull high speed crafts.

During its short history the shipyard has produced more than 120 different vessels with the LOA of up to 27 m. The boats have been delivered to various countries such as Azerbaijan, Belgium, Bulgaria, Croatia, Finland, Northern Ireland, Latvia, Lithuania, Poland, Sweden, Ukraine, and of course Estonia.

With the production area of around 4400 m^2 the yard is capable to build vessels up to 45 m LOA. In the management department there are around 20 employees, design department around 10 employees and on the production site there are around 150 employees; welders, outfitters, mechanics, electricians, carpenters and finishers as an addition to that there are daily around 20 subcontractors. Since 2011 the company also has an affiliated company in Croatia (Adriatic Workboats).

Fig 16. *Baltic Workboats project 90063, LOA 17 m. Customer Swedish Maritime Agency, built in 2008.*

Fig 17. *Baltic Workboats projects 90076 and 90077, LOA 23,9 m. Customer Polish Border Guard, built in 2009*

Fig 18. *Baltic Workboats project 90105, LOA 24 m. Customer Väinamere Liinid, passenger catamaran built in 2012*

Baltic Workboats is certified with ISO 9001 and ISO 14001, work is in progress to receive also ISO 3834. As an addition the shipyard has been approved and recognized by different shipping agencies around Europe, among other Swedish Transportation Agency, Russian Maritime Register of Shipping, Polish Register of Shipping, Croatian Register of Shipping, Maritime and Coastguard Agency of the United Kingdom, Finnish Maritime Administration and Estonian Maritime Administration. In the latest years the shipyard has been awarded several times to the top enterprises of Estonia and also several local production awards.

2.4.2. Production Overview

The production is divided into 7 sections according to the area and scope of work. There is a CNC section, welding section, carpeting section, mechanics section, electrical works section, outfitting and finishing section.

CNC section is dealing with prefabricating phases mainly cutting the raw material (both for metalwork and carpeting). There is a unique Homag CNC unit in the hall. The unit is a CNC-controlled processing centre in gantry construction, for trimming and drilling panels of wood, aluminium or similar materials. The machine prepared for 2 main spindles for synchronous processing or for the independent processing of 2 panels on independent axis. The Homag unit can process large panels with the limits of up to 6 m in length, 3 m in width and 0,3 m of thickness. The CAM data is programmed internally by the department according to the production requirements and element specifics.

The welding section is working with all the welding and material joining works in the shipyard. The welding section is located in a separate hall, which is currently the largest of the production area. The welding works of the shipyard are carried out with a high quality of welding- low amount of pores, X-ray passes and no warranty items connected to the welding quality are explicit proofs of it.

Fig 19. *Pantry of BWB project 90080.*

Carpeting section is producing all the interior and furnishings for the vessels. Generally all the furniture and interior is built of wooden or wood based composite materials. The interior design is made by the design department of the shipyard and is generally custom made, clearly the design also considers the customer's wishes and requirements. The section has all the relevant tools and equipment for constructing and decorating the interiors of the vessels and no production phase requires sub-contracting. With the latest developments in the material science fields the shipyard is widely taking advantage of composite panels and several items are produced of those in order to gain even more weight reductions.

Fig 20. *Cabin of BWB project 90066.*

Mechanics section is working on all mechanical works and installations required to build up the systems on the vessels.

The mechanical works include building up and installing the power, gear and transmission systems and machinery. Vessels produced by the shipyard have regularly one to three main inboard marine diesel engines, the main engine units are subcontracted from global producers like MTU, Scania, Volvo Penta and Sisu. Other specific purpose equipment like rudders, bow thrusters, boilers, pumps, filters etc. are also subcontracted. The mechanical systems and schemes are designed by the internal design department. Based on the standards and requirements mechanical systems like grey water, fresh water, HVAC, bilge, sullage, hydraulic, seawater cooling, anchoring and fire fighting are build up by the mechanics section.

Electrical works section is building up and installing the whole electrical system. This includes lighting system, cabling, electrical switchboards but also communication and navigation systems.

Outfitting section is building up and mainly dealing with works on deck. Outfitters works include installing fenders, hull surface protections, life saving appliances (LSA) and rescue equipment. Finishing section comprises mainly of surface coating areas, painting and markings. Though aluminium hulls do not in all circumstances require coatings, all vessel hulls in BWB are coated and surface protected to ensure the quality of hulls and exterior areas (especially seawater contact areas).

2.4.3. Aluminium Welding in the Shipyard

For several years all welding works for building ship hulls was done by using aluminium sheet materials of EN AW 5083 H111 and profiles of EN AW 6082 T6. With the development of extruded panels since 2010 the shipyard started using extruded panels with the main aim of reducing welding works hours. Until 2011 there has not been any actual research or financial studies about the real benefits of using the extruded panels.

Due to the specifics of aluminium all the welding works are carried out in a distinct production hall. The raw material (aluminium sheets and profiles) is cut in the yard by the CNC department and delivered to the welding section.

The shipyard has a wide selection of welding equipment. Welding facilities in the shipyard include the following:

- Welding machinery
  - Fronius TPS 2700, 17 pcs
  - Fronius TPS 4000, 5 pcs
  - Fronius TIG MagicWave 2200, 1 pcs
  - Fronius TIG MagicWave 3000, 2 pcs
  - Fronius TIG MagicWave 4000, 1 pcs
- Filler material
  - Fidat Filo AlMg4,5Mn Ø1,2 mm σ_u 320 MPa
- Shielding gas
  - Centralized gas system Airoc Ar 99,99 % (copper piping)
  - Bottled gas Ar 99,95 %
  - Bottled gas Ar 50 % He 50%

The welding personnel are highly skilled and certified to carry out the welding works, personal quality and qualification controls are carried out in every 6 months for each welder. On the general basis it is considered that the aluminium welding productivity is on the research measured basis approximately 1,5 kg/h.


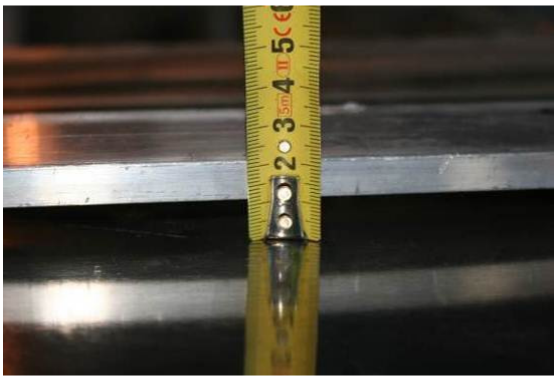

Fig 21 and 22*. Distortion on BWB project 90087 (engine room ventilation box on the aft deck)*

Fig 23. *Distortion on BWB project 90099 (bottom plating between frames)*

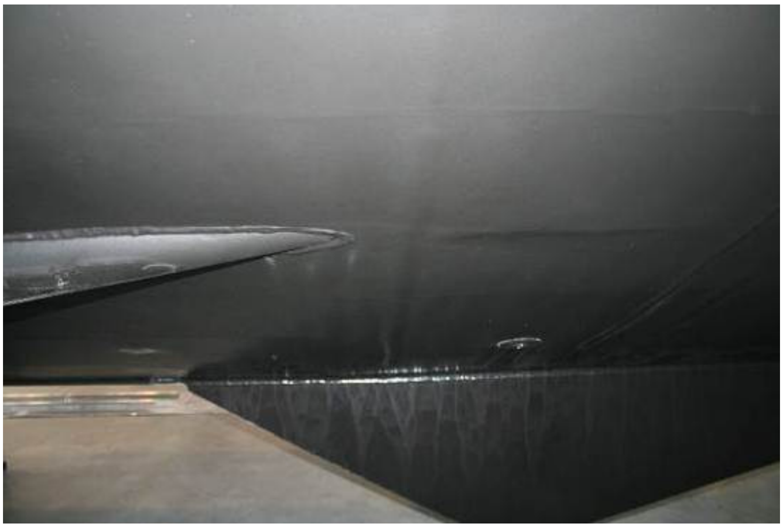

Fig 24. *Deformations on BWB project 90095 (shaftline and hull joining)*

Nevertheless, due to the peculiarity of aluminium material the welding works encounter several problematic issues; mainly deformation and distortion problems that lower the welding quality highly. Examples of deformation and distortions of the vessel production can be followed from the figures 21 - 24. Aluminium hull welding is the main area of the shipyard, this is where the whole vessel production starts from and clearly failures there have the biggest risks. Therefore it magnifies and emphasis the need of making the hull welding more productive in every matter.

3. Research Methods and Material

To be able to reduce production costs and raise efficiency it is significant to know exactly what the actual costs are, which processes can still be optimized and with which methods. Knowing which factors affect welding costs can enable the production to focus its energy on changes that will reduce costs, enabling the company improve its competitiveness and profitability. An accurate cost model can permit comparisons of manufacturing options, therefore every operation being directly or indirectly connected to welding can be charged to weld fabrication. The greater the number of factors considered when calculating welding costs, the more accurate the results of the model will be. As an addition considering all relevant factors increases the opportunities for cost reduction.

The current research is done using 3 different possible methods of combining aluminium materials while producing aluminium hulls. Each of the methods has pros and cons and each of them is used in some of the shipyards in the world. One of the main goals of the present research is to verify taking into account all areas of the methods and finding the most suitable one for the Baltic Workboats Shipyard. The principles of the three methods used in the research are explained in the following chapters.

There are two approaches to determine the welding costs: complex and simple. The complex computer-based models attempt to capture every contributing factor. Unfortunately the shipyard does not have any standard programmed complex model available and due to that it is impossible to assess the exact costs for so large scale production. Therefore a simplified model shall be created and used. The simplified model of the welding costs is estimated comprising from two principle factors: firstly of labour and overhead and secondly of welding consumables and shielding materials.

Welding costs can be estimated using one of the three basic approaches:

- Cost per unit
- Cost per length
- Cost per weight.

Cost per unit is the most effective when the application involves pieces that move through the key cost variable directly and there is no need to use the operating factor variable. For the present research the approach is not suitable because the joints in the vessels vary. As an addition estimating welding costs per unit in the shipyard production is not beneficial as all of the projects are not produced in series.

Cost per length is appropriate for estimating the costs of long welds. Also this method is not suitable for the research because the values determined by it will differ for welds for different sizes. Even though the hull welding includes also large amount of long welds there is also a large amount of short and complex welds.

Cost per weight is the most suitable method for the research as the volumes are big and the variable of time can be evaluated by measuring the deposition rate. The approach is though not accurate when applied to single pass, small and short welds. For general model estimation the approach is suitable and due to that applied.

Calculating welding economy and productivity in its details can be measured with several methods depending on the terms relevant to the specific production method. Nils Stenbacka has published several guidelines of evaluating welding production productivity that are suitable and comparable to research the quality and efficiency of welding works in the Baltic Workboats shipyard [15]. Consequently the calculation approach in the research is on large bases application of modified equations from N. Stenbacka.

3.1. Description of Research Methods

The development research was carried out mainly on 8 sister vessels built from 2008 to 2012. All 8 vessels have similar basic dimensions but due to the customer requirements and specific purpose of the ship, specifications and equipment have many modifications and developments (Table 4). In principle the research was mainly carried out on BWB standard type Baltic Patrol 24 (see data in Appendix 1-4).

Table 4. *Patrol 24 General Data*

Project 90052 "Rānda"		
Vessel Data	Customer	Latvian Coast Guard
	Length o.a.	25 m
	Breath	5,65 m
	Draught	1,35 m
	Displacement	42 t
	Speed	< 35 kn
	Crew capacity	12
	Main engine	2 pcs MTU 10V
Project 90066 "Valve"		
Vessel Data	Customer	Estonian Police and Border Guard
	Length o.a.	23,9 m
	Breath	5,3 m
	Draught	1,3 m
	Displacement	44 t
	Speed	< 40 kn
	Crew capacity	9
	Main engine	2 pcs MTU 12V
Project 90076 "SG -112 Patrol 2"		
Vessel Data	Customer	Polish Border Guard
	Length o.a.	23,9 m
	Breath	5,3 m
	Draught	1,3 m
	Displacement	42 t
	Speed	< 35 kn
	Crew capacity	9
	Main engine	2 pcs Scania D16 M43
Project 90077 "SG -111 Patrol 1"		
Vessel Data	Customer	Polish Border Guard
	Length o.a.	23,9 m
	Breath	5,3 m
	Draught	1,3 m
	Displacement	42 t
	Speed	< 35 kn
	Crew capacity	9
	Main engine	2 pcs Scania D16 M43

Project 90080 "Banríon Uladh"		
Vessel Data	Customer	Northern Ireland DARD
	Length o.a.	25,9 m
	Breath	5,9 m
	Draught	1,47 m
	Displacement	51 t
	Speed	< 26 kn
	Crew capacity	7
	Main engine	2 pcs MTU 10V 2000
Project 90087 "KBV 312"		
Vessel Data	Customer	Swedish Coast Guard
	Length o.a.	26,5 m
	Breath	6,2 m
	Draught	1,5 m
	Displacement	50 t
	Speed	< 31 kn
	Crew capacity	5
	Main engine	3 pcs Volvo Penta IPS 1050
Project 90088 "KBV 313"		
Vessel Data	Customer	Swedish Coast Guard
	Length o.a.	26,5 m
	Breath	6,2 m
	Draught	1,5 m
	Displacement	50 t
	Speed	< 31 kn
	Crew capacity	5
	Main engine	3 pcs Volvo Penta IPS 1050
Project 90089 "KBV 314"		
Vessel Data	Customer	Swedish Coast Guard
	Length o.a.	26,5 m
	Breath	6,2 m
	Draught	1,5 m
	Displacement	50 t
	Speed	< 31 kn
	Crew capacity	5
	Main engine	3 pcs Volvo Penta IPS 1050

To carry out the research models of part of a watertight bulkhead in 3 different methods were made (descriptions of the methods follow in chapters below). The specimens were with basic dimensions of length 300 mm, width 300 mm and thickness 8 mm. All joints were butt welds. Sheet material was made of material EN AW 5083 H321, profiles EN AW 6082 T6 and extruded panels also of EN AW 6082 T6 (material certificates in Appendix 5-7).

3.1.1. Method 1

Method 1 in the research and testing carried out is the traditional way of producing hulls. In principle this means that traditional aluminium materials are used; uniform thickness plates combined with the required profiles (T, L or I).

Model test material certificates follow in Appendix 5 and 6 (sheet material EN AW 5083 H321, profiles EN AW 6082 T6).

Hulls are produced with placing the keel, welding frames, added longitudinals and stiffeners and then shell and deck plating. This method was used in the production efficiently from the start of producing aluminium vessels until summer 2010. The principle method is used in steel hull productions. From aluminium hull productions for example in ASK Enterprises (Latvia) and Docksta Varvet (Sweden) the same method is still being used.

Fig 25. *Hull built using method 1, project 066*

3.1.2. Method 2

Method 2 is more innovative way of hull production. This is enabled due to the word's developments in aluminium material fabrication. Technically nowadays aluminium may be extruded to the desired shapes and sections; this is widely used especially in car industry and in electrical components.

In principle the bulkheads and frames made of the panels are in one piece and cut with CNC to the desired shape. The panels are significantly more expensive than normal sheet and profile materials but due to the fact that there is no need to weld stiffeners or longitudinals to the panels the price of the whole hull production is balanced. Due to using extruded panels production is much faster due to smaller amount of welded joints and the expenditures for workers also drop down.

Model test material certificates follow in Appendix 7 (extruded panels material EN AW 6082 T6).

Method 2 was developed and since 2010 all aluminium hulls and wheelhouses in the shipyard are produced with that method. The pioneering project of using method 2 was a 17,6 m LOA Estonian pilot boat *Ahto 29*. The project was an extreme success for the end user and for the production costs. The production time was 12% smaller than predicted and due to that the production techniques were changed. Actual effectiveness and benefits of the changes are carried out in this research.

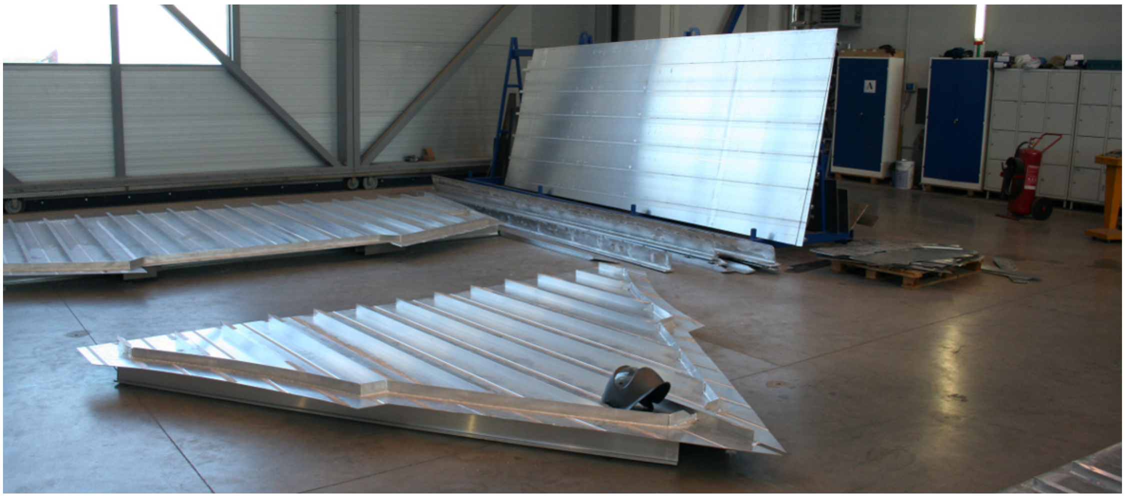

Fig 26. *Watertight bulkhead using method 2, project 088*

3.1.3. Method 3

Method 3 is included to the research but it in the production it is currently not applied. In case the research outcomes are with beneficial results the method will be developed and shall be implemented in the production.

In principle method 3 has aluminium of extruded panels and uses ceramic backing material for welds. Using ceramic backing material enables the joints to be only one sided which reduces welding time even more.

CERAMIC BACKING MATERIAL / LCR-SB01

Ceramic backing material or welding backing on aluminum tape.Flat type with round groove 12mm, groove depth 1,2mm. Overall length 600 and 1000mm.

Description	Dimensions	Lenght	Art. code
On aluminium tape	27 x 8 / 12 x 1,2mm	600/1000mm	LCR-SB01

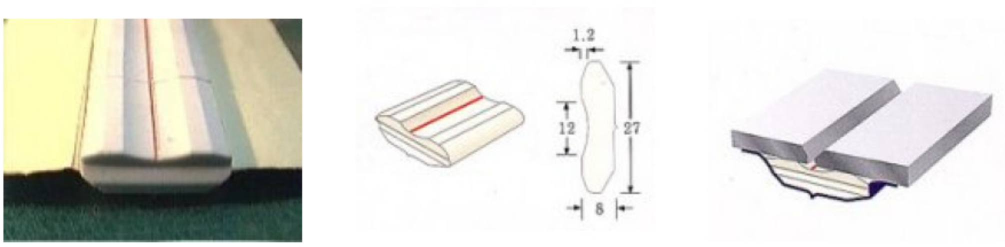

Fig 27. *Ceramic-backing material datasheet.*

In theory the weld back up strips save of welding costs of 50 – 60 % whereas welding time is saved by 50 %. The joining results are to be 100 % radiographic welding. It is claimed that in practice using ceramic backing should have the following pros:

- Back side grinding is not required
- Purging is not required
- Eliminates defects and reworks and improves quality
- Deposit more weld metal for full penetration
- Can be used for different types of weld joints; i.e. single and double V butt joints, dished ends, tube plates to shells etc.
- The ceramic backing are available in several different profiles.

Ceramic weld backings used in the research are suitable for V-butt welds and the profile dimensions and data can be followed from the data-table in figure 27.

Model test material certificates follow in Appendix 7 (extruded panels material EN AW 6082 T6, ceramic backing data figure 27).

3.2. Description of Research Calculations

3.2.1. Welding Time

Before the actual and direct welding can be started there is necessary to prepare for the process. Preparation time (t_{prep}) is the term generally used for the time that is consumed to set and adjust the machinery but also to prepare and prefabricate the product.

Direct welding time (welding time in further text) is considered as the period while the arc burns. This term is used only for the period while the actual process is on-going and progressed. Welding time (t_w) can be calculated in the following way:

$$t_w = \frac{M}{P_w} \tag{1}$$

where M is weld material in kg and P_w is welding material productivity in kg/h.

Welding supplement time (t_{su}) is the period that is used for executing works relevant to welding. Welding supplement time can be for example time used for changing electrodes or welding wire, changing shielding gas containers, cleaning the torch or shielding gas outlets, etc.

Processing time (t_p) covers the period spent for processing and handling the specimen or work piece. Example fixing the work piece to brackets and dimensioning the work piece are considered as processing time.

Assistance time (t_a) is generally included into welding operation time for events that cannot directly be related to welding processes. In a way it can be used as a safety factor and it is designated as a certain percentage of the whole process.

Operation time (t_{op}) is the time consumed to accomplish the welding works. Operation time is the sum time spent for the welding sub-processes and can be generalized in the following way:

$$t_{op} = t_w + t_{su} + t_p + t_a \tag{2}$$

Completion time (t_c) is the overall time spent to complete the whole welding process:

$$t_c = \frac{t_{prep}}{n} + t_{op} \tag{3}$$

where t_{prep} is the time consumed to start to operate the process, n is the amount of work pieces or specimens. As the production in Baltic Workboats shipyard is not a series production the equation has no significant effect, completion time and completion time are the same.

3.2.2. Production Efficiency Index

The production efficiency index (E_i) prescribed in percentages is on general basis the duty cycle rate and it can be calculated in the following way:

$$E_i = \frac{t_w}{t_{op}} \tag{4}$$

where t_w is the welding time and t_{op} is the operation time and described in welding time section above.

3.2.3. Filler Material Consumption

Filler material consumption (F_f) is a measure that describes and depends on the joint geometry. Based on the cross section area of the joint and the weld length, the consumption of the filler material can be calculated:

$$F_f = A \cdot L \cdot \varsigma \tag{5}$$

where L is the joint length in metres [m] and ς is the relative density [kg/m^2]; $\varsigma = \frac{\rho_{substance}}{\rho_{reference}}$; ς for pure aluminium is approximately 2710 kg/m^2 and A is the cross section are of joint [m^2]. Theoretically the cross section area of the joint (single V-butt weld) can be calculated with the following formula:

$$A = t^2 \cdot \tan(\alpha) + t \cdot b \tag{6}$$

where t is plate thickness [mm], α is V angle [º] and b is the gap between plates [mm].

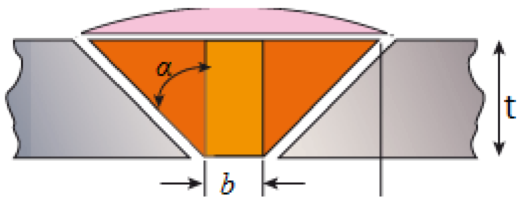

Fig 28. *V-butt weld parameters.*

3.2.4. Welding Costs

Total welding costs comprise roughly of labour and overhead costs and cost of welding consumables and shielding materials. More specifically total costs for welding depend on various factors like direct costs for workers *(*C_{work}*)*, including example salaries and social services; material costs (C_{mat}) including the raw material, welding wire and shielding gas costs; equipment costs (C_{eq}) including machinery; energy costs

(C_{en}); maintenance costs (C_{ma}) including example spare parts, equipment maintenance, calibration etc. Subject to that the total welding costs (C_{tot}) are determined as follows:

$$C_{tot}=C_{work}+C_{mat}+C_{eq}+C_{en}+C_{ma} \tag{7}$$

3.2.4.1. Workers Costs

Costs for workers *(C_{work}[€])* are determined in the following way:

$$C_{work}=(M\cdot P_w)\cdot(\frac{100}{E_i})\cdot C_{os} \tag{8}$$

where M is weld material in kg, P_w is welding material productivity in kg/h, E_i is the production efficiency index (E_i) in percentages and C_{os} is the operator's salary [€/h].

3.2.4.2. Material Costs

Material costs (C_{mat} [€]) are determined based on the actual costs of materials used for the welding processes.

$$C_{mat}=C_{sg}+C_w+C_{cb} \tag{9}$$

where C_{sg} is the shielding gas costs, C_w filler material costs and C_{cb} is the costs of welding brackets if they are used.

3.2.4.3. Shielding Gas Costs

Costs for the shielding gas are determined as follows:

$$C_{sg}=\frac{M\cdot K_g\cdot P_{gas}}{N} \tag{10}$$

where M is the weld material [kg], K_g is the shielding gas specific consumption [m^3/wire kg]; typically used 0,4 m^3/kg, P_{gas} is the shielding gas cost [€/m^3] and N is the benefit reading [%].

3.2.4.4. Welding Wire Costs

Welding wire costs are determined as follows:

$$C_w=\cdot F_f\cdot P_{wire} \tag{11}$$

where F_f welding wire consumption [kg], typically used 1kg/1wire kg and P_{wire} is welding wire price [€/kg].

3.2.4.5. Ceramic Backing Costs

The costs for the ceramic material are relevant only to method 3. Ceramic backing costs depend linearly on the weld length and are described:

$$C_{cb} = L \cdot P_{cb} \tag{12}$$

where L is weld length [m] and P_{cb} is the price of ceramic backing [€/m].

3.2.4.6. Equipment Costs

Machinery and equipment costs are determined as follows:

$$C_{eq} = \frac{M}{P_w} \cdot \frac{1}{E_i} \cdot P_{eq} \tag{13}$$

where M is the weld material [kg], P_w welding material productivity [kg/h], E_i efficiency index [%] and P_{eq} is the price of equipment working hour [€/h].

3.2.4.7. Energy Costs

Welding process consumes energy of which costs are:

$$C_{en} = K_e \cdot M \cdot P_{en} \tag{14}$$

where K_e is specific consumption of energy [kWh/weld kg]; typically used 3kWh/weld kg, M is weld material [kg] and P_{en} price of energy [€/kWh].

4. Research Results

4.1. Costs for Method 1

Calculations based on the equations in chapter 3.2.

Welding time based on Eq. (1)

$$t_w = \begin{pmatrix} 0.856 \\ 0.864 \\ 0.889 \end{pmatrix} h$$

Operation time based on Eq. (2)

$$t_{op} = \begin{pmatrix} 1.089 \\ 1.047 \\ 1.156 \end{pmatrix} h$$

Production efficiency index based on Eq. (4)

$$E_i = \begin{pmatrix} 0.786 \\ 0.825 \\ 0.769 \end{pmatrix}$$

Workers costs based on Eq. (8)

$$C_{work} = \begin{pmatrix} 10.41 \\ 10.011 \\ 11.047 \end{pmatrix} \cdot €$$

Shielding gas costs based on Eq. (10)

$$C_{sg} = \begin{pmatrix} 0.555 \\ 0.561 \\ 0.577 \end{pmatrix} \cdot €$$

Welding wire costs based on Eq. (11)

$$C_w = 1.477€$$

Material costs based on Eq.(9)

$$C_{mat} = \begin{pmatrix} 2.032 \\ 2.037 \\ 2.054 \end{pmatrix} \cdot €$$

Equipment costs based on Eq. (13)

$$C_{eq} = 0.658€$$

Energy costs based on Eq. (14)

$$C_{en} = \begin{pmatrix} 0.924 \\ 0.933 \\ 0.96 \end{pmatrix} \cdot €$$

Raw material costs from the supplier of sheet and profile aluminium

$$C_{ma} = 3.698€$$

Total welding costs based on Eq. (7)

$$C_{tot} = \begin{pmatrix} 17.722 \\ 17.339 \\ 18.417 \end{pmatrix} \cdot €$$

4.2. Costs for Method 2 (Extruded Panels)

Welding time based on Eq. (1)

$$t_w = \begin{pmatrix} 0.327 \\ 0.331 \\ 0.325 \end{pmatrix} h$$

Operation time based on Eq. (2)

$$t_{op} = \begin{pmatrix} 0.427 \\ 0.448 \\ 0.475 \end{pmatrix} h$$

Production efficiency index based on Eq. (4)

$$E_i = \begin{pmatrix} 0.766 \\ 0.739 \\ 0.684 \end{pmatrix}$$

Workers costs based on Eq. (8)

$$C_{work} = \begin{pmatrix} 4.081 \\ 4.281 \\ 4.538 \end{pmatrix} \cdot €$$

Shielding gas costs based on Eq. (10)

$$C_{sg} = \begin{pmatrix} 0.548 \\ 0.555 \\ 0.544 \end{pmatrix} \cdot €$$

Welding wire costs based on Eq. (11)

$$C_w = 1.477€$$

Material costs based on Eq.(9)

$$C_{mat} = \begin{pmatrix} 1.286 \\ 1.294 \\ 1.283 \end{pmatrix} \cdot €$$

Equipment costs based on Eq. (13)

$$C_{eq} = 0.27 \cdot €$$

Energy costs based on Eq. (14)

$$C_{en} = \begin{pmatrix} 0.912 \\ 0.924 \\ 0.906 \end{pmatrix} \cdot €$$

Raw material costs from the supplier of extruded aluminium

$$C_{ma} = 7.481€$$

Total welding costs based on Eq. (7)

$$C_{tot} = \begin{pmatrix} 14.031 \\ 14.25 \\ 14.478 \end{pmatrix} \cdot €$$

4.3. Costs for Method 3 (Using Ceramic Backing)

Welding time based on Eq. (115)

$$t_w = \begin{pmatrix} 0.553 \\ 0.547 \\ 0.549 \end{pmatrix} h$$

Operation time based on Eq. (2)

$$t_{op} = \begin{pmatrix} 0.886 \\ 0.874 \\ 0.899 \end{pmatrix} h$$

Production efficiency index based on Eq. (4)

$$E_i = \begin{pmatrix} 0.624 \\ 0.626 \\ 0.611 \end{pmatrix}$$

Workers costs based on Eq. (8)

$$C_{work} = \begin{pmatrix} 8.471 \\ 8.355 \\ 8.595 \end{pmatrix} \cdot €$$

Shielding gas costs based on Eq. (10)

$$C_{sg} = \begin{pmatrix} 0.548 \\ 0.543 \\ 0.544 \end{pmatrix} \cdot €$$

Welding wire costs based on Eq. (11)

$$C_w = 0.369€$$

Ceramic backing costs based on Eq. (12)

$$C_{cb} = 0.63€$$

Material costs based on Eq.(9)

$$C_{mat} = \begin{pmatrix} 1.547 \\ 1.542 \\ 1.544 \end{pmatrix} \cdot €$$

Equipment costs based on Eq. (13)

$$C_{eq} = 0.532€$$

Energy costs based on Eq. (14)

$$C_{en} = \begin{pmatrix} 0.912 \\ 0.903 \\ 0.906 \end{pmatrix} \cdot €$$

Raw material costs from the supplier of extruded aluminium

$$C_{ma} = 7.481€$$

Total welding costs based on Eq. (7)

$$C_{tot} = \begin{pmatrix} 18.943 \\ 18.813 \\ 19.058 \end{pmatrix} \cdot €$$

4.4. Differences of Hull Welding Methods in Production

Methods 1 and 2 have been used in production and the hull welding hours were analysed and gathered during the current study. Hull welding working hours are summarised and listed in figure 29 below.

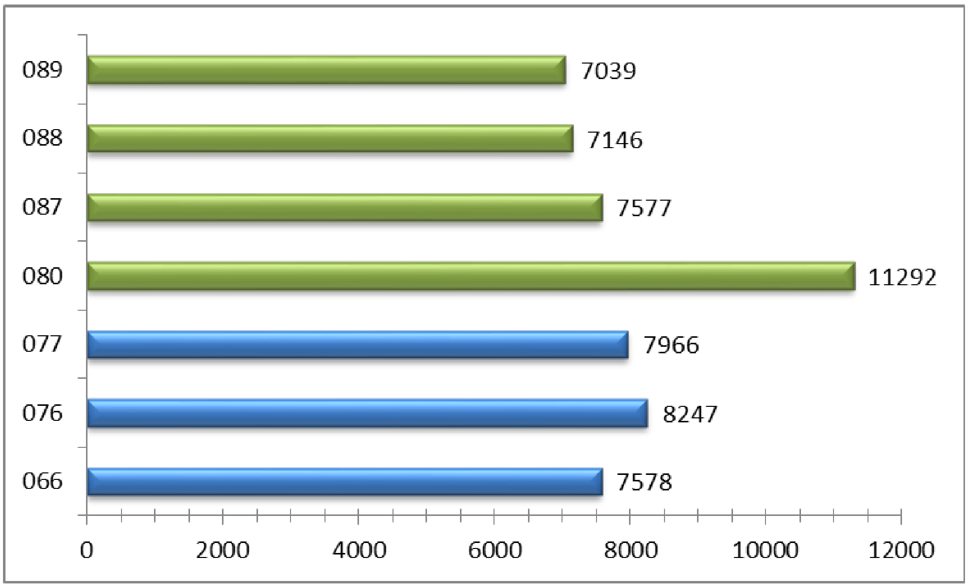

Fig 29. *Working hours of hull welding with method 1 (green bars) and method 2 (blue bars) of BWB projects 066, 076, 077, 080, 087, 088 and 089*

The change to start using method 2 instead of method 1 had in reality no scientific success assurance and the Estonian Pilot *Ahto* 29 (BWB project 094) was a test project and the predicted benefits were all analytical and spontaneous. The current study and the working hours spend on the vessels produced after project 094 have confirmed and justified the welding method change.

The collected and processed data of actual production results show that welding hulls with method 2 is in general basis 17 % faster from the working hour perspective. There is no simple equation of general costs of the whole hull production benefits and it is not possible to analyse specific costs of the hull welding of the projects that have ended. Therefore the costs and production benefits are based on the research made by models and working hours.

4.4.1. Quality Assurance of Method 3

Due to the fact that method 3 is not commonly used in the shipyard additional laboratory tests an analysis were carried out. (Detailed results in Appendix 8 - 10)

The analyses show that using ceramic backing would not cause quality issues in welding. There occurred no failures in material microstructure and bend tests.

To assure the quality also tensile strengths were measured and in general basis the reduction of tensile strength after welding was approximately 25 %. In theory, as mentioned above, the tensile strength after welding reduces up to 35 % of the preliminary tensile strength. Therefore also the tensile strength causes no low quality issues.

The laboratory research confirms that using method 3 in hull welding would cause no material quality issues for the shipyard and from that perspective method 3 would be beneficial to implement.

5. Discussion of Results

The long development and research carried out in Baltic Workboats shipyard has shown that the change from the traditional plates and profiles combination (method 1) to extruded materials (method 2) was cost efficient and beneficial for the production. The main perspectives for the overall production are financial benefits and faster hull production.

During the long study developments and variety of trainings for the welding staff have been essential but time consuming and therefore the research was extended to longer period than planned preliminarily. The outcomes both from the welding personnel and hull production efficiency context are positive and advantageous.

Based on the model research method 2 is the most cost efficient way to weld aluminium hulls. Already the small scale simple specimens have verified that method 1 is 25 % and method 3 33 % more expensive than method 2. Due to the fact the study confirms that the recent years development have been successful and no significant kickbacks have risen.

During the research it was verified that at the current stage producing with the method 3 would not be the most beneficial for the production and due to that the shipyard will not be producing hulls using ceramic backing at this stage. Nevertheless using ceramic backing is a perspective welding method when the hulls are produced in jig.

The research showed that when the hull is produced with the upside down and flipping method (as explained in chapter 2.3) using ceramic backing is not beneficial due to the following disadvantages:

- Welding positions are difficult or not possible
- Unfavourable welding environment; welding gases and heat form below the hull
- Several connections of ceramic backing are required and these cause the undesired scallops
- Fitting and cleaning after removal is time consuming

When the hull is produced in jig using ceramic backing could be an alternative due to the following most significant factors:

- Comfortable welding positions
- Easy access for welding
- Welding shall be carried out from the interior of the hull leaving the sheet material properties from the exterior side resistant
- Deformations that arise from the cooling of welding are hull curvature directional.

To conclude it may be generalized that the development carried out by the long research has been beneficial and cost efficient but the new welding methods are not developed in the world enough to implement new methods just yet (though it has prospect).

6. Recommendations to Production

6.1. Welding Method

Currently there are two basic principles to produce hulls in the shipyard: in jig and on deck. Both methods have pros and cons and according to the study both methods depending on the severity of the project could be used also in the future.

The research shows that in the future the hull welding from the material profile selection should be carried out with method 2 – using extruded profiles.

Method 2 on deck principle welding works should be carried out in the following order:

- Mounting of frames and bulkheads of extruded profiles
- Fixing fixtures and joining frames and bulkheads starting from the midship section to the fore and aft
- Spot welding of shell plating and mounting stiffeners
- Removal of oxide layer and welding of shell plating
- Welding of frames and bulkheads to stiffeners and shell plating
- Flipping the hull to upright position
- Finalizing the hull welding and quality control

Method 2 in jig principle welding works should be carried out in the following order:

- Welding and setting up jig
- Setting bottom plating on jig and welding from the interior
- Fixing watertight bulkheads starting from the midship section to the fore and aft
- Mounting of stiffeners, frames and interior bulkeads
- Welding the shell plating and deck to hull construction
    - As an alternative and for deck and shell plating ceramic backing from the exterior side could be used
- Finalizing the hull welding, removal from jig and quality control

During the research it was verified that it is essential to train and develop the welding personnel continuously and not only due to the certification requirements. Sustainable theoretical and practical lessons about the developments of aluminium welding are recommended to rise and keep the high quality of welding works to the level that the development has achieved.

6.2. Aluminium and Consumables

Proper precautions are to be taken to ensure that all welding is done under conditions where the welding site is protected against deleterious effects of moisture, wind and severe cold. Paint or oil mist and other contaminants which tend to cause weld porosity are to be excluded from the vicinity where welding is in progress. Due to the location of the shipyard the storing and working environment must be focused at all times.

Aluminium must be stored in clean and dry area. The material must be protected against contamination during storage by preventing airbone contaminants such as oil, grease fume and solid metal particles. Also welding consumables must be stored in a closed package at room temperature; welding wires should be used within 24 hours. An oxide film maybe formed on the welding wire resulting in extensive porosity in the weld metal if the wire is allowed to absorb moisture. All the welding works has to be carried out in an enclosed area (temporary shelters or permanent buildings), as an addition the manufacturing must be totally separated from all other metal works (especially steel). Moisture and high humidity has serious effect on the quality of aluminium welds. While using ceramic backing it is extremely important to notice that all humidity must be removed and the ceramic materials may not be moist as aluminium is sensitive to hydrogen and ceramic materials absorb hydrogen.

Prior to welding cleaning the surfaces has significant importance. The surfaces must be cleaned from all greases, additional particles and for most important the oxide layer. The welding should be carried out as soon as possible after the cleaning but at no circumstances more than 6 h later.

Preheating before carrying out the welding is generally not required for aluminium and may even have negative affect therefore it should not be used in Baltic Workboats.

6.3. Minimizing Deformations and Distortions

During the welding process there are specific measures that should be used to avoid and minimize deformations, distortions and other welding defects.

Due to high conductivity properties it is important to use an intense, localised heat sources. All the complicated matters of aluminium require a high degree of skills and experiences when welding aluminium.

While welding large structures it should be noted that starting the centre of a seam and welding outward with a backstep sequence will reduce distortion.

In case the distortions occur they must be corrected using a suitable hydraulic or mechanic presses or inducting correcting through heating. Though it is used, it is nevertheless generally not recommended at any circumstances to add extra weld or heat with TIG as that may reduce fatigue properties significantly.

Welding quality is also affected by cracks. Therefore an important measure to take for reducing hot cracks is to select the correct welding wire for the specific material.

Second recommendable measure is reducing stresses by selecting suitable toughness and supports for the structure.

6.4. Welding Sequence

Hulls in Baltic Workboats are welded depending on the project with two different methods: in jig or on deck. In both methods the welding works are to be started from the main structural elements (from keel when welded in jig) and setting up the watertight bulkheads, the rest of the frames are to be welded starting from the central section to the aft and fore. After all the frames and bulkheads are positioned the deck and shell plating welding can be started.

The aim of the correct welding sequence is to reduce possible deformations and distortions. In case significant deformations occur it is to be noticed that additional heat is to be decreased to absolute minimum as it affects significantly the material strength properties. In case deformations and distortions are vast the whole section is to be replaced.

6.5. Aluminium Handling Health Risk

Several researches in European Union health organizations have been carried out to find out the possible hazards of aluminium welding. Welding fume exposure in the workplace is a serious occupational hazard and due that all workers engaged with welding works must be acquainted with the possible risks of the work.

Though there are no clear and firm proofs deriving from welding in the shipyard the possible health risk hazard must be considered and apprized to welding personnel.

7. Conclusion

The goal of the current thesis was to develop and rise the efficiency and quality of aluminium hull production in Baltic Workboats shipyard.

The development work started from the assessment of the welding personnel and the essential educating of them. Due to the demanding application of aluminium, poor knowledge and experience in the world of producing vessels and handling aluminium this became rather challenging episode of the research.

Parallel the efficiency of the production method was assessed and a study to implement new production method was carried out. Due to successful research the new method of hull production with extruded aluminium profiles was implemented.

The research was continued to evaluate and find out even more efficient welding methods. Laboratory and analytical research was carried out of the possibility of welding hulls using ceramic backing and gain even bigger efficiency and lower costs and time consumption.

In the next stage data of welding costs of the 3 methods were collected and analysed. According to the research currently with the available facilities and personnel the most efficient way to produce aluminium hulls is using aluminium profiles (method 2 of the current paper).

Based on the study it can also be said that aluminium hull welding in the world is definitely a field that could still be developed and new methods of rising efficiency should be experimented. From the competitors' perspective and sustainability of high quality aluminium vessel production in Baltic Workboats it would be wise to keep the traditions of finding out new methods and carrying out research of aluminium handling.

The research and world's aluminium applications show that use of aluminium in different production fields is efficient and productive and subject to that the application areas grow and confirm the need for aluminium production studies and developments.

Overall it must be mentioned that the research and development work has been on one hand very challenging and difficult but on the other hand also very interesting and unexpectedly prosperous. The long research has achieved successful results and on the general basis the aluminium hull production is currently approximately 25 % more productive and efficient than before the study and concomitant education series.

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Appendix 1: Patrol 24 "Valve" Main Data

Baltic Workboats shipyard

BALTIC 2400 PATROL

24 METER FAST PATROL VESSEL

BALTIC 2400 PATROL

24 METER FAST PATROL VESSEL

Main dimensions

Lenght overall:	23,9 m
Breath:	5,3 m
Draught:	1,3 m
Displacement:	44 t
Power:	1800 - 2400 kW
Speed:	25 - 40 Kn
Range (estimated):	> 600 Nm
Capacity:	9 persons
Noise level in wheelhouse:	64 dB(A) at full speed

Material & construction

Marine aluminium, ice strengthened

Ambient conditions

Air:	-25°/ +40° C
Seawater:	0°/ +32° C

Tank capacities

Fuel:	8000 l
Water:	1000 l
Waste:	800 l

Propulsion concept

Main engine:	2 x MTU 10V or 2XMTU 12V or equivalent
Gearboxes:	Type ZF or equivalent
Propulsion:	Propellers or waterjets
Bowthruster:	27 kW

Users

Latvian Border Guard

Estonian Police and Borderguard

Baltic Workboats shipyard

BALTIC WORKBOATS AS: NASVA HARBOUR, NASVA KAARMA V, SAARE MK 93872, ESTONIA

T: +372 45 21140 F: +372 45 21145

info@bwb.ee www.balticworkboats.ee

Appendix 2: Patrol 24 "SG-112" Main Data

Baltic Workboats shipyard

BALTIC 2401 PATROL

24 METER FAST PATROL/COMMAND VESSEL

BALTIC 2401 PATROL

24 METER FAST PATROL/COMMAND VESSEL

Main dimensions

Lenght overall:	23,9 m
Breath:	5,3 m
Draught:	1,3 m
Displacement:	42 t
Power:	1100 - 1800 kW
Speed:	25 - 35 Kn
Range (estimated):	> 600 Nm
Capacity:	9 persons
Noise level in wheelhouse:	63 dB(A) at full speed

Ambient conditions

Air:	-25°/ +40° C
Seawater:	0°/ +32° C

Material & construction

Marine aluminium, ice strengthened

Tank capacities

Fuel:	6000 l
Water:	1700 l
Waste:	900 l

Propulsion concept

Main engine:	2 x SCANIA D16 M43 or equivalent
Gearboxes:	Type ZF or equivalent
Propulsion:	Propellers or waterjets
Bowthruster:	27 kW

Users

Polish Border Guard

Baltic Workboats shipyard

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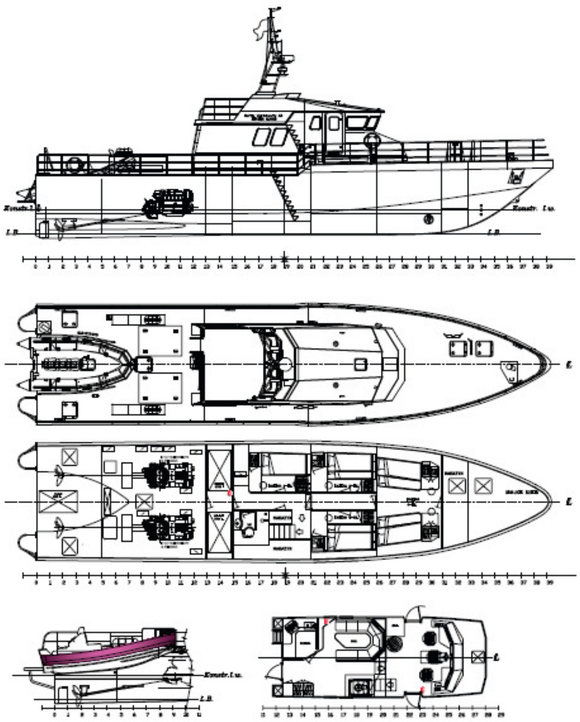
info@bwb.ee www.balticworkboats.ee



Appendix 3: Patrol 24 “Banríon Uladh” Main Data

Baltic Workboats shipyard

BALTIC 2402 PATROL

26 METER FAST FISHERY INSPECTION AND SURVEY VESSEL

BALTIC 2402 PATROL

26 METER FAST FISHERY INSPECTION AND SURVEY VESSEL

Main dimensions

Lenght overall:	25,9 m
Breath:	5,9 m
Draught:	1,47 m
Displacement:	51 t
Power:	1800 kW
Speed:	26 Kn
Range (estimated):	> 500 Nm
Capacity:	7 persons
Noise level in wheelhouse:	56 dB(A) at full speed

Ambient conditions

Air:	-25°/ +40° C
Seawater:	0°/ +32° C

Material & construction

Marine aluminium

Tank capacities

Fuel:	6000 l
Water:	500 l
Waste:	500 l

Propulsion concept

Main engine:	2 x MTU 10V 2000 or equivalent
Gearboxes:	Type ZF or equivalent
Propulsion:	Propellers or waterjets
Bowthruster:	27 kW

Users

Northern Ireland DARD

Baltic Workboats shipyard

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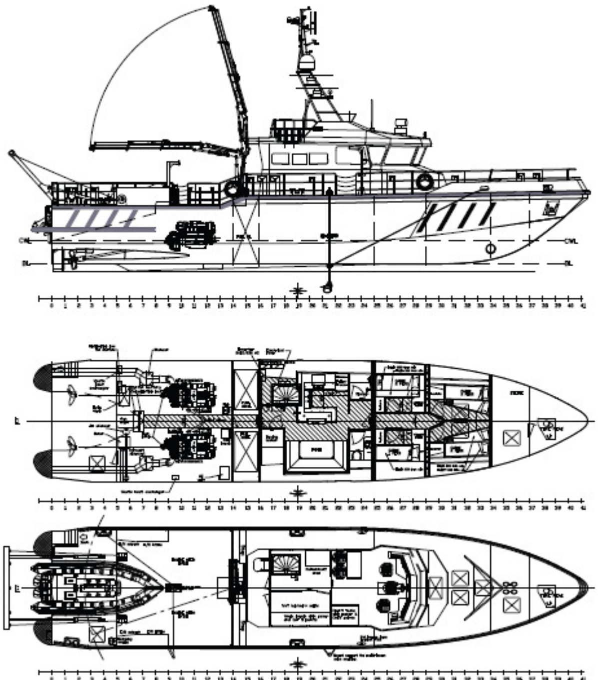
info@bwb.ee www.balticworkboats.ee



<u>Appendix 4:</u> Patrol 24 “KBV 312” Main Data

Baltic Workboats shipyard

BALTIC 2403 PATROL

27 METER FAST PATROL VESSEL

BALTIC 2403 PATROL

27 METER FAST PATROL VESSEL

Main dimensions

Lenght overall:	26,5 m
Breath:	6,2 m
Draught:	1,5 m
Displacement:	50 t
Power:	1764 kW
Speed:	31 kn
Range (estimated):	> 600 Nm
Capacity:	5 persons
Noise level in wheelhouse:	65 dB(A) at full speed

Ambient conditions

Air:	-25°/ +40° C
Seawater:	0°/ +32° C

Material & construction

Marine aluminium, ice strengthened

Tank capacities

Fuel:	5000 l
Water:	500 l
Waste:	250 l

Propulsion concept

Main engine:	3 x Volvo-Penta IPS 1050 or equivalent
Propulsion:	3 x IPS twin propellers
Bowthruster:	22 kW

Users

Swedish Coast Guard

Baltic Workboats shipyard

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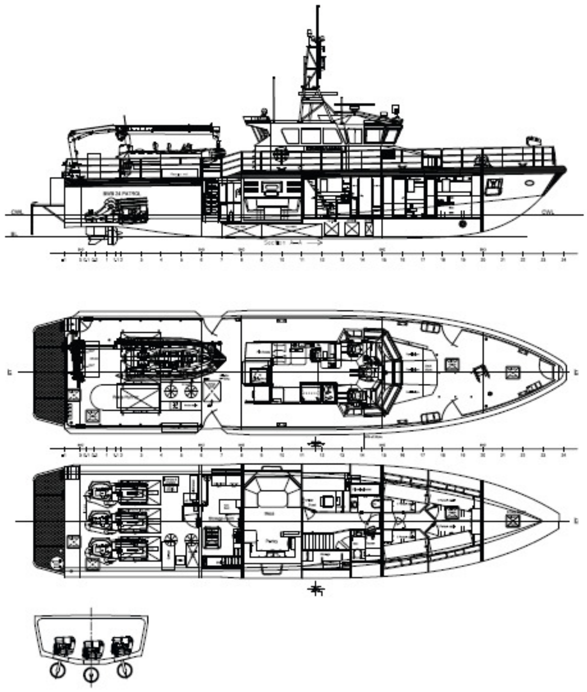

Appendix 5: Specimen Material Certificate EN AW 5083 H321 sheet

Alcoa Europe

European Mill Products
Alcoa Trasformazioni srl
Stabilimento di Fusina
Via dell' Elettronica 31
30030 Malcontenta
Loc. Fusina (Venezia)
Italia
Tel.: 39 041 2917111
Fax: 39 041 2917250

ALCOA

INSPECTION CERTIFICATE

ODS BV
DONK 6
2991 LE BARENDRECHT NL
NETHERLANDS

EN 10204 3.1

Ordernumber Alcoa	092554004
Date	17/12/09
Certificate number	W09513249
Shipment doc.ref.	000029

Your order nr	Your alloy	Your temper	Quantity	Your Art nr
4500015455	5083	H321	5536 kg	913001180

Global specification

SHATE 5083H H321 B928
Dimensions T x W x L 8,0000 x 2000,00 x 6000,0 mm

Remarks

EN 10204 3.2
This Certificate is issued under arrangements authorized by
Lloyd's Register EMEA in accordance with the requirements of
the Materials Quality Scheme and certificate number MQS 046
Designation of material according to L.R. Rules 5083 H321 M
Chemical composition and mechanical properties according to
Chaptper 8 section 1 Edition July 2009
Intended for storage (naval use)
Asset and NAMLT test 99/09 enclosed
Certificate no. 1757/LR dated 17-12-09
Hdrogen 0,2 ml/100 gr

Chemical composition 5083H

Cast no		%Si	%Fe	%Cu	%Mn	%Mg	%Cr	%Ni	%Zn	%Ti	Others %Each	Others Total
89331C1	1718A	0,12	0,25	0,011	0,57	4,41	0,079	0,0034	0,0047	0,011		
Limit	Min.				0,40	4,00	0,050					
	Max.	0,40	0,40	0,10	1,00	4,90	0,25		0,25	0,15	0,050	0,15

Mechanical properties

Coil nr:	Pallet	Rm N/mm2	Rp0.2 N/mm2	A50 %
1718A		329	231	17
1718A		330	230	18
1718A		330	234	18
	0712751			
	0712752			
	0712753			
	0712754			
	0712755			
	Min.	305	215	12
	Max.	380	295	

lcoa Trasformazioni S.r.l. – Sede legale: 09010 Portoscuso (Carbonia-Iglesias) Zona Industriale Portovesme – Società sottoposta a direzione e coordinamento di Alcoa Inc.
Cap. Soc. € 50.000.000 int. Vers. - C.F., P. IVA e Registro Imprese Cagliari n° 02640570921 – R.E.A. C.C.I.A.A. Cagliari n° 213339

We hereby certify, that the material described above has been tested and complies with the terms of the confirmation of order.

Appendix 6: Specimen Material Certificate EN AW 6082 T6 T-profile

Dokument ID 754-3 bil. till 167
Utfärdad av Ulf Svensson
Giltigt from 2005-10-13
Utgåva 02

sapa:

PROVNINGSINTYG
ABNAHMEPRUFZEUGNIS
INSPECTION CERTIFICATE

Type EN 10 204 - 3.2

Blad -Sheet -Blatt Nr-No

Tjänsteställe, handläggare - Our reference - Unser Zeichen	Datum - Dato	Intyg nr - Certificate No - Zeugnis Nr
Kjell Björk	2012-03-13	10496

Köpare - Customer - Käufer Baltic Workboats AS Nasava Sadam EE-93822.Saaremaa	SAPA ordernr/pos - SAPA order No - SAPA Order Nr/Pos 2761446/697696-30 Varuslag - Material - Materialform Profiles Dimension **369238**
Ordernr/ref - Order No/ref - Bestellung Nr/Ref 120061.Taavi Saksen	Leg/tillst - Alloy/Temper - Leg/Zust **EN AW - 6082-T6**
Märke - Mark - Bezeichnung 1004014	Norm - Specification **Lloyds Register EMEA**

Sapa Order No:	Pos no:	Weight:	Numbers:
697696	30	1179kg.	45st.

SAMMANSÄTTNING %, garantivärden -
CHEMICAL COMPOSITION %, guaranteed values - CHEMISCHE ZUSAMMENSETZUNG %, garantierte Werte

Charge No:	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
120215-2A	0,99	0,22	0,03	0,48	0,65	0,00	0,00	0,02	Balance
Min	0,70			0,40	0,60				Balance
Max	1,30	0,50	0,10	1,00	1,20	0,25	0,20	0,10	Balance

HÅLLFASTHET etc, provningsresultat -
MECHANICAL PROPERTIES etc, test results - FESTIGKEITSEIGENSCHAFTEN usw, Prüfresultate

Prov Nr Specimen No: Probe Nr	Rp 0,2 N/mm²	Rm N/mm²	A5 %	HV 20	Prov Nr Specimen No: Probe Nr	Rp 0,2 N/mm²	Rm N/mm²	A50 %	HV 20
1	315	334	11						
2	315	334	11						
3	302	323	12						
Spec.limits Min Max	260	310	8		Spec.limits Min Max				

We hereby certify that the material herin described has been made in accordance with the rules of **LLOYDS REGISTER EMEA** with resp. to chemical and mechanical properties. And is that has been tested in the presence of the Societys representative with satisfactory results.

Sapa Profiler AB / Quality department

Kjell Björk

DNV SS-EN ISO 9001

SICM 1200224

Lloyd's Register EMEA
Stockholm office
Ari Nieminen

Lloyd's Register

Finspång 13.03.2013

Appendix 7: Specimen Material Certificate EN AW 6082 T6 Panel

Dokument ID 754-11 bil. till 167
Utfärdad av Ulf Svensson
Giltigt from 2005-10-13
Utgåva 02

sapa:

PROVNINGSINTYG
ABNAHMEPRUFZEUGNIS
INSPECTION CERTIFICATE

Testing FSW welds
Type EN 10 204 - 3.2

Blad -Sheet -Blatt Nr-No

Tjänsteställe, handläggare - Our reference - Unser Zeichen Jan Wallin	Datum - Dato 2011-04-14	Intyg nr - Certificate No - Zeugnis Nr 10355
Köpare - Customer - Käufer Baltic Workboats AS	SAPA ordernr/pos - SAPA order No - SAPA Order Nr/Pos 639515-10-20 Varuslag - Material - Materialform Panels Dimension **369421, 369422**	
Ordernr/ref - Order No/ref - Bestellung Nr/Ref 110136	Leg/tillst - Alloy/Temper - Leg/Zust **EN AW - 6082-T6**	
Märke - Mark - Bezeichnung	Norm - Specification **Lloyds Register EMEA**	

Sapa Order No:	Pos no:	Panel number:	No of Welds	Number of panels	Total weld length
639515	10	369421	8st.	2st.	48m.
639515	20	369422	6st.	2st.	36m.

Certificate No:		Certificate No:	
10352			

HÅLLFASTHET etc, provningsresultat -
MECHANICAL PROPERTIES etc, test results - FESTIGKEITSEIGENSCHAFTEN usw, Prüfresultate **EN 755-2**

Prov Nr Specimen No: Probe Nr	Rm N/mm²	Bendtest No:	Prov Nr Specimen No: Probe Nr	Rm N/mm²	Bendtest No:
F1-10 S1-20	250 250	2pcs			
Spec.limits Min	185	Bendtest without remarks	Spec.limits Min	185	Bendtest without remarks

We hereby certify that the material herin described has been made in accordance with the rules of **Lloyds Register EMEA** with resp. to chemical and mechanical properties. And is that which has been tested in the presence of the Societys representative with satisfactory results.

Sapa Profiler AB / Quality department

Jan Wallin

DNV SS-EN ISO 9001

Witnessed: 14-04-2011
SKM1100289

Lloyd's Register EMEA
Stockholm office
Hans Ericsson
Lloyd's Register

Appendix 8: Quality Control Report Specimens 207

TALLINNA TEHNIKAÜLIKOOL
TALLINN UNIVERSITY OF TECHNOLOGY

MEHAANIKA JA METROLOOGIA KATSELABOR

Akrediteeritud
L 027

TESTING REPORT nr. 207

Tallinn 23.04.2012

Customer : Baltic Workboats AS
Nasva k. , Kaarma v. ,93872, Saaremaa

Assignment: Testing of butt weld N1 according to standards EN ISO 9606-2, EVS EN ISO 15614-2

Description. Butt weld of aluminium plates 8,0x200x300 mm, supplied by the customer,
marking of specimen:. made test pieces N1,N2-tensile test, N3, N3,N4, N5- bend test, material AW 6082 T6

Reception: 23.03.12
Testing: 23.04.12
Test equipment:
1.Test machine ZDMU-30, cal.03.2009.
2.Vernier calipper 150, cal.09.2009 .

Testing methods: Standards EVS EN 895,EVS EN 910, EVS EN ISO 10042, EVS EN 15614-2,classification EVS EN ISO 6520-1.

Test temperature: +23 °C

Results .1.Tensile test according to standard EVS EN ISO 4136-1 Lo=70 mm.

Test piece			Cross section area S	Max load P	Tensile strength R_m	Yield load $P_{0,2}$	Yield strength $Rp_{0,2}$	Precentage elongation at break	Remarks
	Dimension, mm								
Mark	thickness a	width b	mm^2	N	N/mm^2	N	N/mm^2	A, %	
N1	8,0	25,0	200	59000	295	42000	210	20	Failure in parent mat.
N2	8,0	25,0	200	57500	287	41000	205	16	Failure in HAZ

2. Bend test according to standard EVS EN ISO 5173.

Test piece			Impress mm	Span length l mm	Bend angle o	Remarks
	Dimension, mm					
Mark	thickness a	width b				
N3	8,0	20,1	92	108	180°	No cracks in TRBB
N4	8,0	20,1	92	108		No cracks in TRBB
N5	8,0	20,1	92	108		No cracks in TFBB
N6	8,0	20,1	92	108		No cracks in TFBB

Ülo Palmiste

Test Expert

Head of Laboratory

M.Eng. Riho Päärsoo

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Appendix 9: Quality Control Report Specimens 208

TALLINNA TEHNIKAÜLIKOOL
TALLINN UNIVERSITY OF TECHNOLOGY

Laboratory of Mechanical Testing and Metrology of TUT

Accredited
L 027

TESTING REPORT nr. 208

Tallinn 23.04.2012

Customer : Baltic Workboats AS
Nasva k. , Kaarma v. ,93872, Saaremaa

Assignment: Testing of butt weld N2 according to standards EN ISO 9606-2, EVS EN ISO 15614-2

Description. Butt weld of aluminium plates 8,0x200x300 mm, supplied by the customer,
marking of specimen:. made test pieces N1-tensile test, N3, N3,N4, N5- bend test, material AW 6082 T6

Reception: 23.03.12
Testing: 23.04.12
Test equipment:

1.Test machine ZDMU-30, cal.03.2009.
2.Vernier calipper 150, cal.09.2009 .

Testing methods: Standards EVS EN 895,EVS EN 910, EVS EN ISO 10042, EVS EN 15614-2,classification EVS EN ISO 6520-1.

Test temperature: +23 °C

Results .1.Tensile test according to standard EVS EN ISO 4136-1 Lo=70 mm.

Test piece			Cross section area S	Max load P	Tensile strength R_m	Yield load $P_{0,2}$	Yield strength $Rp_{0,2}$	Precentage elongation at break	Remarks
Mark	Dimension, mm thickness a	width b	mm^2	N	N/mm^2	N	N/mm^2	A, %	
N1	8,0	25,0	200	55000	275	43000	215	13	Failure in HAZ

2. Bend test according to standard EVS EN ISO 5173.

Test piece			Impress mm	Span length l mm	Bend angle o	Remarks
Mark	Dimension, mm thickness a	width b				
N3	8,0	20,1	92	108	180°	No cracks in TRBB
N4	8,0	20,1	92	108		No cracks in TRBB
N5	8,0	20,1	92	108		No cracks in TFBB
N6	8,0	20,1	92	108		No cracks in TFBB

Ülo Palmiste

Test Expert

Head of Laboratory

M.Eng. Riho Päärsoo

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ESTONIAN ACCREDITATION CENTRE 21.06.2010. ACCREDITION NO. L 027

Appendix 10: Quality Control Report Specimens 209

TALLINNA TEHNIKAÜLIKOOL
TALLINN UNIVERSITY OF TECHNOLOGY

Laboratory of Mechanical Testing and Metrology of TUT

Accredited
L 027

TESTING REPORT nr. 209

Tallinn 23.04.2012

Customer : Baltic Workboats AS
Nasva k. , Kaarma v. ,93872, Saaremaa

Assignment: Testing of butt weld N3 according to standards EN ISO 9606-2, EVS EN ISO 15614-2

Description. marking of specimen:. Butt weld of aluminium plates 8,0x200x300 mm, supplied by the customer, made test pieces N1,N2-tensile test, N3, N3,N4, N5- bend test, material AW 6082 T6

Reception: 23.03.12
Testing: 23.04.12
Test equipment:
1.Test machine ZDMU-30, cal.03.2009.
2.Vernier calipper 150, cal.09.2009 .

Testing methods: Standards EVS EN 895,EVS EN 910, EVS EN ISO 10042, EVS EN 15614-2,classification EVS EN ISO 6520-1.
Test temperature: +23 °C
Results .1.Tensile test according to standard EVS EN ISO 4136-1 Lo=70 mm.

Test piece			Cross section area S	Max load P	Tensile strength R_m	Yield load $P_{0,2}$	Yield strength $Rp_{0,2}$	Precentage elongation at break	Remarks
	Dimension, mm								
Mark	thickness a	width b	mm^2	N	N/mm^2	N	N/mm^2	A, %	
N1	8,0	25,0	200	58000	290	44000	220	26	Failure in parent mat.
N2	8,0	25,0	200	54000	270	42000	210	13	Failure in HAZ

2. Bend test according to standard EVS EN ISO 5173.

Test piece			Impress mm	Span length l mm	Bend angle o	Remarks
	Dimension, mm					
Mark	thickness a	width b				
N3	8,0	20,1	92	108	180°	No cracks in TRBB
N4	8,0	20,1	92	108		No cracks in TRBB
N5	8,0	20,1	92	108		No cracks in TFBB
N6	8,0	20,1	92	108		No cracks in TFBB

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Test Expert

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