CONTENTS AUTHORS

15th International Research/Expert Conference
"Trends in the Development of Machinery and Associated Technology"
TMT 2011, Prague, Czech Republic, 12-18 September 2011

# MECHANICAL PROPERTIES OF TWO Al-Mg WELDED PLATES AFTER APPLYING DIFFERENT WELDING PROCEDURES

**Endre Romhanji**
**Faculty of Technology and Metallurgy,**
**Karnegijeva 4, 11120 Belgrade, Serbia**

**Zijah Burzić**
**Military Technical Institute,**
**R. Resanovića 1, 11000 Belgrade, Serbia**

**Vencislav Grabulov**
**IMS Institute**
**Bul. V. Mišića 43, 11000 Belgrade, Serbia**

**Miljana Popović,**
**Faculty of Technology and Metallurgy,**
**Karnegijeva 4, 11120 Belgrade, Serbia**

## ABSTRACT
*Two Al-Mg alloys: (I) AA5182 and (II) AA5182+Zn and Zr (≈ 0.12%wt each) were processed to 6.5mm thick H116 and H321 marine grade plates. They were welded by applying Metal Inert Gas – 131, (MIG) and MIG-Pulsed welding process with AlMg4.5Mn and AlMg4.5MnZr filers. The given results indicate that the influence of added amount Zn and Zr was rather limited. The after welding yield stress degradation was 45%-%50% independently on the welding conditions, and the fracture was always located in the weld metal (WM). The impact toughness was found higher in the heat affected zone (HAZ) than in the WM in both alloys, although this difference was less pronounced in the case of alloy with added Zn and Zr. In order to estimate the weldability crack initiation and crack propagation absorbed energies were determined for both alloys, MIG and MIG-pulsed welding process and the crack position in the weld metal and heat affected zone were determined.*

## 1. INTRODUCTION
Aluminum and its alloys were assessed as a possible replacement for steel in shipbuilding [1] due to a high corrosion resistance and a potential of considerable weight saving, as its density is almost three times lower than the density of steel. The most often used Al-alloys for plates in shipbuilding are the 5083/5383 type Al-Mg alloys [2]. in specific tempers H116 and H321 appropriate for marine applications [3]. However, during welding a heat affected zone (HAZ) forms around the weld seam which in aluminum is much more pronounced than with steel alloys, and considerable can lower the strength properties. Nowadays, different alloys and welding procedures are under investigation [4-7] in order to improve the mechanical properties of the welded structures. Impressive results achieved by applying the friction steer welding, laser or hybrid procedures [5]. However, in respect the cost effectiveness and technical applicability in the marine industry, the MIG-pulsed procedure seems to be the most reliable one today [7]. The aim of this work was to consider the degradation of basic tensile properties in two type welded plates after applying different welding procedures.

## 2 EXPERIMENTAL
**Material.** Two Al-Mg type hot rolled plates were delivered by IPOL-SEVAL Rolling Mill. The chemical compositions are listed in Table 1. The basic difference is related to the Zn and Zr alloying contents. Alloy I is rather typical 5182 type alloy, while Alloy II is with added Zn (0.118%) and Zr

*Table 1. Chemical compositions of the hot rolled Al-Mg plates in wt.%*

| Alloy | Mg | Mn | Zn | Zr | Cu | Fe | Si | Ti | Na | Cr |
|---|---|---|---|---|---|---|---|---|---|---|
| Lot 5893 (**I**) | 4.25 | 0.67 | 0.0138 | 0.0006 | 0.008 | 0.24 | 0.085 | 0.007 | 0.0003 | 0.089 |
| Lot 63886 (**II**) | 4.85 | 0.77 | 0.118 | 0.121 | 0.0067 | 0.29 | 0.106 | 0.009 | 0.0003 | 0.109 |

(0.121%). The alloy with Zn and Zr meets the composition range of 5383 type alloy. Different TMT-s applied in order to achieve the H116/H321 conditions, and the processing route was defined for the final thickness of 6.5 mm. [8].

**Welding.** Two welding procedures were applied MIG and MIG – Pulsing process 131, according to EN4063, with AlMg4,5Mn and AlMg4,5MnZr type consumable materials for V butt welded joints (Figure 1).

**Tensile testing**. Specimens with a gauge length of 100 mm are tested on "Schenck" tensile testing machine at a crosshead rate of 10 mm/min. The yield strength and ultimate tensile strength of the butt-welded joints (YS* and UTS) were also determined using by shaped specimens, as it is shown in Figure 2. The YS* yield stress is not a material property but it is an approximative value for comparative considerations of welded plates properties.

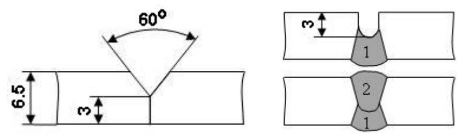



*Figure 1. a. Sketch of the welding groove, b. Sketch of the weld and welding layers*

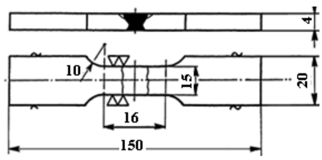



*Figure 2. Tensile specimens used for YS and UTS measurement in butt-welded joint.*

**Impact testing.** Impact Charpy test was used for measure the failure resistance in the base material **(BM),** weld metal (WM) and heat affected zone (HAZ). The specimens used for measuring the impact energy prior to fracture were V notched, as it is shown in Figure 3. The applied experimental procedure has given information on the total impact absorbed energy, and on components as the crack initiation or crack propagation energies, according to the SRPS EN 10045-1, or ASTM E23-02

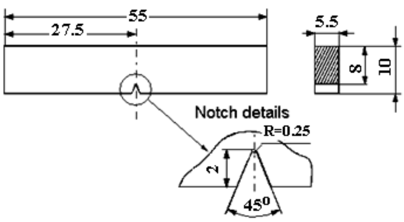



*Figure 3. V-notched Charpy specimen*

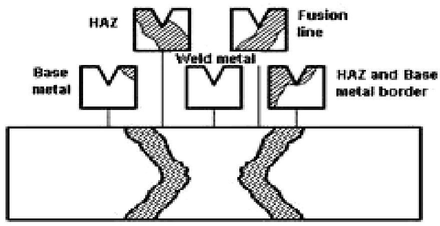



*Figure 4. Notch positions.*

standards.The **total** impact **absorbed energy** (J) was determined during testing the Charpy V notch specimens, dimensions 5.5mm x 10mm x 55mm, and the V notch depth of 2mm. (Fig.3). The notch position in respect the welded joint was defined according EN 875 standard (Fig.4). Also, the **instrumented** Charpy equipment was used to record the force (F-KN) – time (τ-μs) curves, enabling the calculus of total impact **absorbed** energy, the crack initiation and crack propagation energy.

## 3. RESULTS AND DISSCUSSION

**The tensile properties.** In Table 2 the mechanical properties of the two tested alloys after processing them to H116/H321 conditions are shown. The achieved mechanical properties in both conditions matching the properties of the 5083/5383 alloys in H116/H321 conditions ($YS_{min}$=215/220MPa, $UTS_{min}$=305 MPa and $e_{min}$= 10%, EN485-2:1999). The approximate yield strength (YS*) and the ultimate tensile strength (UTS) parameters for the two tested alloys, after welding by applying different conditions, are shown in Tables. 3 and 4. The YS* and UTS parameters are ranged to 120-130 Mpa and 230-300 Mpa, respectively. Those values are comparable to the

*Table 2. Tensile properties of the tested base materials in H116 and H321 condition [8]*

| Alloy | Temper | YS (MPa) | UTS (MPa) | **El. (%)** |
|---|---|---|---|---|
| **5182** (Lot 5893) | H116 | 240 | 307 | 13.5 |
| | H321 | 240 | 330 | 15 |
| **5182+Zn,Zr** (Lot 63886) | H116/ | 250 | 340 | 15 |
| | H321 | 240 | 350 | 14.5 |

earlier published data for the welded 5083 plates: $YS^{*}_{min} = 125 MPa$, UTS = 270MPa [9-11] for both conditions, but not for the 5383 type alloy, which attained the YS*~ 140 MPa and the UTS about 290 MPa. So, the chemistry change in respect the 5182 type alooy (alloy I in Table 1.) made by adding 0.118 wt.% Zn and 0.121 wt.% Zr in alloy II didn't bring any important change in the tensile properties of alloy II plates, as well as in the welded plates. The given results also indicate that the failure was mostly positioned in the weld metal (WM) and in some cases passes through the fusion line (FL). So, the WM appeared to be weaker than the heat affected zone (HAZ) in the base material, indicating that the heat input during welding was low enough to keep the HAZ harder than the WM. That problem of weaker WM in respect the surrounding material is known [12], but until now was not found a reliable way to improve the fracture resistance of the WM.

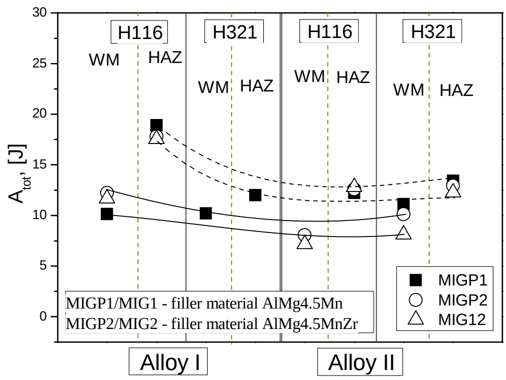
*Table 3. Tensile properties of the welded joint for the 5182 type plates (Lot 5893)*

| Alloy - Condition | Consumable material | Welding process | YS* (Mpa) | UTS (Mpa) | Fracture position |
|---|---|---|---|---|---|
| I-H321 | AlMg4,5Mn | MIG - PULS | 127.6 | 266.9 | WM -FL |
| I-H116 | AlMg4,5Mn | MIG - PULS | 120.3 | 277.1 | WM -FL |
| I-H116 | AlMg4,5MnZr | MIG - PULS | 124.3 | 273.4 | WM |
| I-H116 | AlMg4,5Mn | MIG | 133.0 | 256.2 | WM-FL |

*Table 4. Tensile properties of the welded joint for the 5182+Zn,Zr type plates (Lot 63886)*

| Alloy Condition | Consumable material | Welding process | YS* (Mpa) | UTS (Mpa) | Fracture position |
|---|---|---|---|---|---|
| II-H321 | AlMg4,5MnZr | MIG - PULS | 125.0 | 251.7 | FL-WM |
| II-H321 | AlMg4,5Mn | MIG - PULS | 123.4 | 288.3 | WM-FL |
| II-H321 | AlMg4,5MnZr | MIG | 128.9 | 257.6 | FL-WM |
| II-H116 | AlMg4,5Mn | MIG - PULS | 128.3 | 299.5 | WM |
| II-H116 | AlMg4,5MnZr | MIG - PULS | 121.9 | 265.4 | FL-WM |
| II-H116 | AlMg4,5MnZr | MIG | 129.2 | 269.9 | WM |

**The impact testing** results for both alloy types and H321/H116 conditions, after different welding conditions, are shown in Figs.3.5.a.-c. The shown parameters are the Impact Toughness i.e. total absorbed energy– $A_{tot.}$, Crack initiation energy - $A_I$, and Crack propagation energy - $A_P$, respectively. The impact thoughness in the HAZ of both alloys and both H116 and H321 conditions was ranged to 12-19 J (Fig.3.5a), and it was higher than in the WM with the thoghness of 10 - 12 J for all the tested cases. Similarly, the $A_I$ and $A_p$ energies were higher in the HAZ for both alloys and all welding conditions (Fig.3.5b and c, respectively). Also, it seems that the thoughness difference of the HAZ and WM was higher in case of alloy I (especially for the H116 condition), and it was lower in case of alloy II. Similar differences were noticed in respect the $A_I$ and $A_p$ energies (Fig. 5b and c). The results given in Figs.3.5-3.6 revealed that the values of $A_p$ are higher than $A_I$ in all cases, what is assumed to be favourable in respect the weldability [13]. Although the noticed differences are not significant, the best $A_p/A_I$ ratio was found for alloy I with the notch position in WM. When the welding processes were compared, the greatest differences appeared in the WM specimen of alloy II, H116 conditions (the highest $A_p$ values was found for MIG P1 process).




a.

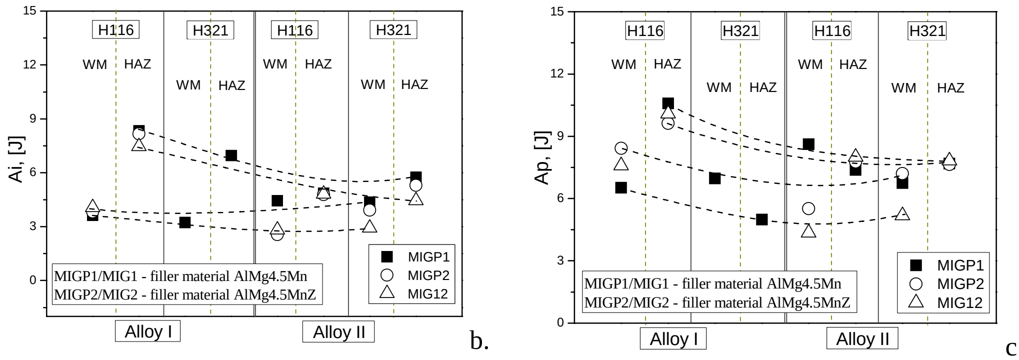



*Figure 5. The impact testing parameters: (a).Total absorbed energy (b) Ai-crack initiation energy, (c)Ap-crack propagation energy in WM and HAZ for all the tested alloys in H116 and H321 conditions after applaying different welding conditions.*

## 4. SUMMARY

Two Al-Mg alloys: (I) AA5182 type and (II) the same type additionally alloyed with a low amount of Zn and Zr (≈ 0.12%wt each) were processed to 6.5mm thick H116 and H321 marine grade plates. They were welded by applying MIG and MIG-Pulsed procedure with AlMg4.5Mn and AlMg4.5MnZr filers. The added Zn and Zr did not bring any improvement of the tensile properties. The after welding yield stress degradation was 45%-50% independently on the welding conditions, and the fracture was always located in the weld metal. The impact thoughness was found higher in the HAZ than in the WM in both alloys, but this difference was less obvious in the alloy with added Zn and Zr. In a similar way changed the level of crack initiation energy, and Crack propagation energy. Generally, the $A_p/A_I$ ratio for all the tested combinations has shown that both alloys in both conditions have a good weldability from the toughness viewpoint.

## 5. REFERENCES

[1] S. Brown, "Feasibility of Replacing Structural Steel with Aluminum Alloys in the Shipbuilding Industry", University of Wisconsin-Madison, April 29, 1999.

[2] G.M. Raynaud, Ph. Gomiero, "Aluminium Alloys for the Marine Market", Aluminium and its Alloys, No.79, June (1996) 73.

[3] M. Skillingberg, "Making aluminum alloy selection easier", Marine Log, Oct. 2004.

[4] M. Siegrist, “Aluminum Extrusions for Shipbuilding”, Alumitech `97, May 20-23, Atlanta, (1997)367-387.

[5] F. Roland, L. Manzon, P. Kujala, M. Brede, J. Weitzebock, “Advanced Joining Techniques in European Shipbuilding” in Journal of Ship Production, No3, 20(2004)200-210.

[6] R.C. Calcraft, M.A. Wahab, D.M. Viano, G.O. Schumann, R.H. Phillips, N.U. Ahmed, “The Development of the QWelding Procedures and Fatigue of Butt-welded Structures of Aluminum-AA5383” in Materials Processing Technology, 92-93(1999)60-65.

[7] P. Praveen, P.K.D.V. Yarlagadda, “Pulsed Gas Metal Arc Welding (GMAW-P) for Newer Challenges in Welding of Aluminum Alloys” in Proc.: Intern. Manufacturing Leaders Forum on Global Competitive Manufacturing, 27th February-2nd March, Adelaida, Australia, (2005).

[8] E. Romhanji at all, EUREKA Project 4569.

[9] G.M. Raynaud, Ph. Gomiero, “The Potential of 5383 Alloy in Marine Applications”, Alumitech `97, May 20-23, Atlanta, (1997)353-366.

[10] Rules for Classification of Ships, Materials and Welding, Part 2, Chapter 2, Metalic Materials. Det NorskeVeritas, January 96, p.63-66.

[11] S.Ferraris, L.M. Volpone, “Aluminum Alloys in Third Millennium Shipbuilding: Materials, Technologies, Perspectives”, *The Fifth Intern. Forum on Aluminum Ships*, Tokyo, Japan, 11-13 October, (2005)1-11.

[12] Wajira Mirihanage,Nanda Munasinghe, „Modification Of AA 5083 Weld Joint Characteristics“, International Symposium of Research Students on Materials Science and Engineering, December 20-22, Chennai, India, ISRS (2004)1-6.

[13] V. Grabulov: “Static and impact testing”, Monography, 8 International fracture mechanics summer school – IFMASS 8, From fracture mechanics to structural assessment, ISBN 86-905595-0-7, Belgrade (2004), 123-146