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INFLUENCE OF FRICTION STIR WELDING ON CORROSION PROPERTIES OF AW-7020M ALLOY IN SEA WATER

ABSTRACT

Friction Stir Welding (FSW), provides an alternative to MIG and TIG welding methods for joining aluminium alloys. The article presents the results of electrochemical corrosion resistance test of alloy AW-7020M and its joints welded by FSW. The study was performed using the method of electrochemical impedance spectroscopy (EIS). Impedance spectroscopy studies showed that both, the FSW welded joint and base material AW-7020M has a good resistance to electrochemical corrosion in sea water environment, wherein the welded joint has a higher susceptibility to this type of corrosion. Research has indicated the desirability of applying the FSW method for joining AW-7020M alloy in shipbuilding industry.

Keywords*: Electrochemical impedance spectroscopy (EIS), aluminium alloys, corrosion, FSW joining*

INTRODUCTION

Increased of designers interest in aluminium alloys to build the hulls of boats and ships is primarily dictated by the possibility of a significant reduction in weight. This increases the displacement of the watercraft, while maintaining a displacement of the load or an increase speed [1].

Joining of aluminium and its alloys by traditional welding methods is difficult because of its specific properties. The main difficulties, that occur during welding aluminium are: the high affinity of aluminium to oxygen and the formation of refractory (2060 °C) oxide Al_2O_3, high thermal conductivity, high expansion alloys, casting high shrinkage (cause welding stress and strain), significant temperature falls welding strength, loss of alloying elements during welding, such as magnesium, zinc and lithium [2]. Mentioned briefly the main difficulties associated with welding of aluminum alloys tend to seek other methods of combining these materials. Such an alternative to joining sheets made of aluminium alloy is a method of friction stir welding FSW [3,4,5].

Friction stir welding (FSW) was invented and patented in 1991 in the Welding Institute (TWI) in Cambridge, UK. In this method, the heating and plasticization of the material applied to the rotary shaft tool mounted in place of the pressed sheet metal joining. After putting the tool in rotation with the mandrel, the friction heat and heating of plasticized sheet material in the immediate vicinity thereof, there is free movement of the entire system along the contact line. FSW is a method of solid state welding, so far mainly aluminium, copper and stainless steel. The main advantage of this method is the easiness of obtaining joints with high, repeatable properties [6,7,8]. Because it is a method of welding in the solid state (below the melting point of the material) mechanical properties of joints obtained by this method may be higher than those obtained by arc welding techniques (MIG, TIG) [9,10]. This is particularly important considering the fact that often the aluminum alloy sheet are heat treated. For this reason, the traditional methods of welding, resulting in large amounts of heat, bring significant changes in the structure of the combined material (particularly in the heat affected zone). This results in a significant reduction in mechanical properties of joints, but most of all, a drastic decrease in corrosion resistance (stress and layered), especially in the aggressive environment of the sea water [1,2,8].

Among weldable wrought aluminium alloys the most popular group of alloys remains Al-Mg (5xxx series), with good weldability and relatively good properties under operating conditions. Alloys of the Al-Zn-Mg (7xxx series) have higher strength properties comparing to Al-Mg alloys, but they are more susceptible to stress corrosion cracking and layer corrosion [1,2,7].

The aim of this study was to determine the effect of Friction Stir Welding (FSW) on the electrochemical corrosion resistance in seawater of AW-7020M alloy.

RESEARCH METHODOLOGY

EN AW-7020M aluminium alloy was used for research. Chosen aluminium alloy was heat treated (T651). The chemical composition of the alloy is shown in Table 1.

Table 1. *Chemical composition of AW-7020M alloy*

Chemical composition (% wt.)										
Zn	Mg	Cr	Zr	Ti	Fe	Si	Cu	Mn	Ni	Al
5.13	1.9	0.16	0.15	0.071	0.27	0.15	0.08	0.057	0.006	bal.

Butt joints were made by FSW of AW-7020M plate thickness h = 6 mm. Plates were welded on both sides with the same parameters.

Diagram of friction stir welding is shown in fig. 1 while the parameters are shown in Table 2.

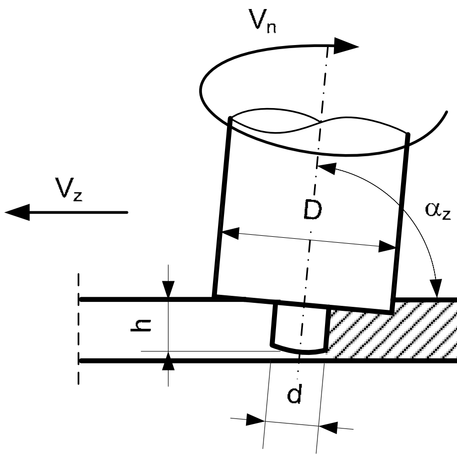

Fig. 1. The diagram of FSW [8]

Table 2. *Chosen FSW parameters of 7020 aluminium alloy sheets*

Tool dimensions			Angle of tool deflection α_z [°]	Mandrel's rotary speed V_n [rpm]	Welding speed V_z [mm/min]
D [mm]	d [mm]	h [mm]			
25	5.5	5.8	88.5	710	240

The measurement of electrochemical corrosion resistance was performed by electrochemical impedance spectroscopy method (EIS) in accordance with ASTM G 3 and ASTM G 106.

Used in studies three electrode system consists of the following elements: the sample, an auxiliary electrode (polarizing) of titanium and platinum reference electrode (saturated calomel electrode) [11, 12]. All electrodes were placed in a tank with 3.5% water solution of NaCl. Active surface samples was 1 cm^2.

During measuring the electrolyte was continuously mixed using a magnetic stirrer. The samples were degreased before the test.

Electrochemical impedance spectroscopy measurements were conducted at the corrosion potential. The amplitude of the voltage signal varied in the range ± 10 mV, and the extent of the changes was the signal frequency: 100 kHz - 0.1 Hz. Studies have been conducted from high to low frequencies [13].

Determination of the corrosion process parameters was performed with the use of computer programs: AtlasLab 2.0 and EIS Spectrum Analyzer.

Selected model of equivalent electrical circuit showing a replacement is presented in fig. 2.

In the selected model, the R_s element is the electrolyte resistance which is reflected in corrosive environment. R_{ct} element is characterized by the charge transfer resistance of the interface metal / electrolyte, associated with the process of oxidation of metal, while the capacitance C_{dl} - double layer capacitance, occurring on the border of phases under consideration [8]. In the assessment of the corrosive properties by EIS method the most important parameter is the R_{ct}, while n_{dl} allows you to determine the homogeneity of corrosion process. In the present case C_{dl} is an auxiliary parameter to determine corrosion process.

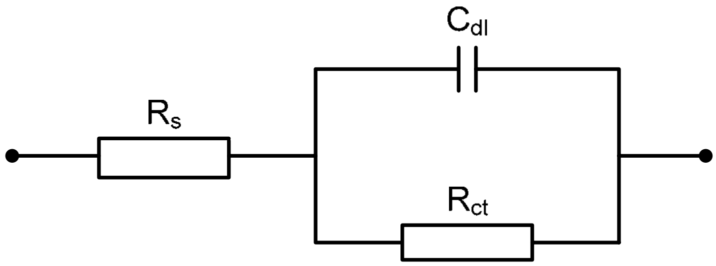

Fig. 2. The selected replacement of corrosion electrical circuit

For the selected alternative resultant impedance of the circuit can be described by the following relationship [13]:

$$Z = R_s + \frac{1}{\frac{1}{R_{ct}} + C_{dl}(j\omega)^{n_{dl}}} \tag{1}$$

where:
R_s – electrolyte resistance [Ω],
R_{ct} – charge transfer resistance [Ω],
C_{dl} – double layer capacitance [μF],
n_{dl} – exponent determining the homogeneity of corrosion process [-],
ω– pulsation, frequency derivative [rad/s],
j – unit imaginary number [-].

RESULTS

Registered results of electrochemical impedance spectroscopy (EIS) test of the base material 7020M alloy and its FSW joints were analyzed using EIS Spectrum Analyser. That analysis allowed to determine the parameters characterizing the process of corrosion. Mean values of parameters of five specimens are shown in Table 3. These parameters define the individual components of the model - the replacement of an electrical circuit, selected according to the test methodology.

Table 3. *Parameters of the replacement corrosive electrical circuit of AW-7020M alloy and its joint welded by FSW*

Specimen	R_s [Ω]	Std. Dev.	R_{ct} [Ω]	Std. Dev.	C_{dl} [μF]	Std. Dev.
Base material	0.28	0.07	1241.4	283.5	8.6	3.0
FSW	0.45	0.18	614.7	125.4	10.6	4.3

Std. Dev. – the standard deviation

The value of R_{ct} - charge transfer resistance through a double layer is twice lower for FSW welded samples then base material samples, indicating less resistance putting the charge exchange between the material and the electrolyte.

C_{dl} capacitive component reaches a similar values, but it is not as important in determining the electrochemical corrosion resistance as the charge transfer resistance R_{ct}.

Electrolyte resistance R_s which is corrosive environment for all the samples was the same level and to receive very low values (several hundred times smaller than the charge transfer resistance), which indicates a very high electrical conductivity of the solution. This parameter is not critical in the consideration of corrosion resistance of the samples [13].

The exemplary results of the electrochemical impedance spectroscopy are shown graphically in Nyquist charts (Fig. 3 and 4).

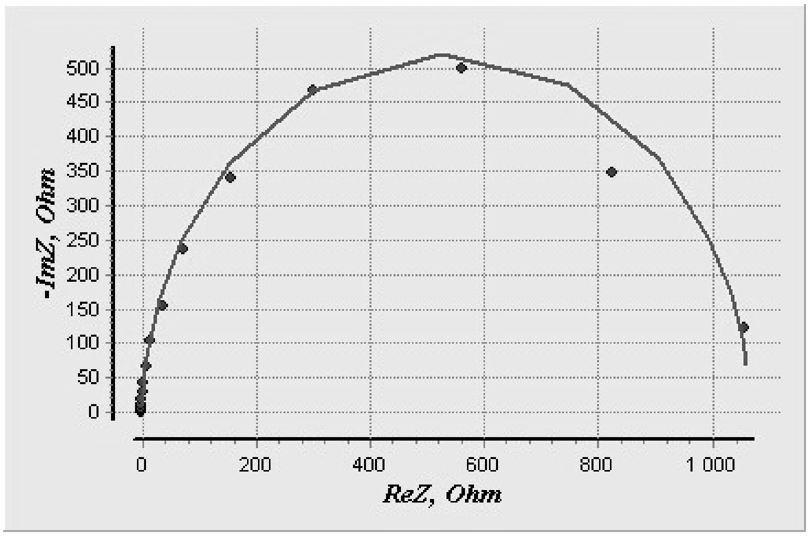

Fig. 3. An example of the Nyquist chart for a sample of the base material 7020M

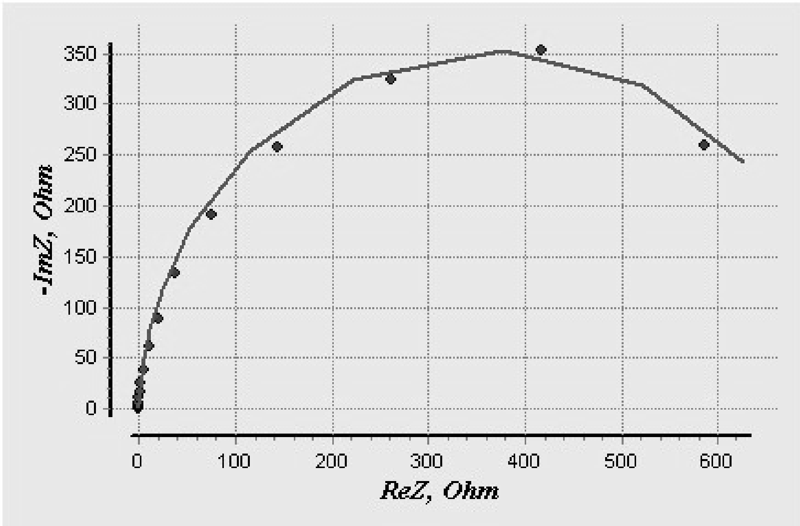

Fig. 4. An example of the Nyquist chart for a sample of the weld jointed by FSW

CONCLUSIONS

Analysis of the impedance spectroscopy results showed that the FSW welded joint has a lower resistance to electrochemical corrosion compared to the base material AW-7020M.

For both samples, it was found that the corrosion process is based on the activation control. There are no conditions for the formation of a stable passive layer, which indicates that the risk of pitting corrosion process is small.

The most important parameter of electrochemical corrosion resistance - R_{ct} (charge transfer resistance), reaches values twice as high in the case of a sample of the native material as compared to the FSW welded sample. This means a much higher resistance the base material AW-7020M then FSW welded joint on electrochemical corrosion in sea water environment.

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