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Noise Level Assessment and Mechanical Properties of Welded Joints of Aluminium Alloys of the Al-Cu-Li System in FSW and TIG Welding

This research paper presents hardness, structure and tensile strength analysis of 1460 alloy of Al-Cu-Li system, welded joints made by Tungsten Inert Gas (TIG) welding and Friction Stir Welding (FSW). Characteristics of acoustic noise at the welding operator workplace during mechanized TIG and FSW of aluminium-lithium alloy with the purpose to develop recommendations for the improvement of health and safety during welding processes were studied. Analyzing results, we concluded that during TIG welding the values of welding noise at the workplace, are much higher than the admissible noise level limit. Results showed that the values of the welding nose reach 95 dB. The noise level at the workplace for FSW is also dangerous and reaches up a value of 84.3 dB. Also, this paper presents hardness, structure, and tensile strength measurements of 1460 alloy welded joints made by TIG and FSW welding.

Keywords: *welding noise level, aluminium-lithium alloy, TIG, FSW, tensile strength, residual stresses*

1. INTRODUCTION

Health and safety characteristics are one of the most important among the quality characteristics of welding technology. Unsatisfactory labor conditions during some welding technologies are closely related to the fact that the possibilities of lowering the level of harmful factors in the working zone using technological measures.

The objective of our research is to study the regularities of the formation of harmful factor as acoustic radiation during mechanized TIG and at FSW welding of aluminum alloy 1460 of Al-Cu-Li type. We provided a recommendation for the improvement of health and safety at the welding operator workplace.

Research of health and safety norms of noise at the workplace was conducted in the laboratory on the plates of 2 mm thickness of high-strength aluminum-lithium alloy 1460 (*w*/%: Cu-3% Li-2% Mg-1% Ti-0.12% Sc-0.08%).

Before welding, chemical etching of the sheets was conducted by the generally accepted technology. After that, mechanical scraping of just the end face of the edges to be welded was performed for FSW, and for TIG also surface layers $0.10 - 0.15$ mm thick were additionally scraped to avoid porosity in the welded joints.

The ultimate strength of TIG welded joints was determined at static tensile testing on servohydraulic complex MTS 318.25 of standard samples with a 15 mm width of the working part as-welded with removed back bead of the weld and without reinfor-

cement. Fracture of the first samples ran in the zone of fusion of the weld with the base material, and that of the second samples – in the weld metal. Samples obtained by FSW were tested without weld reinforcement and back bead, as such geometry of the joints is due to the features of their formation process. Such samples fracture along the boundary of the ThermoMechanical Affected Zone (TMAZ) and Heat-Affected Zone (HAZ) from the retreating side of the joint.

When producing butt joints in the down hand position on the horizontal plane, the welding point moved away from the radiation sensor and then moved closer to it. Investigations were conducted indoors without exhaust ventilation, distance from the floor to plate top was equal to 100 cm; the air temperature was ~15 ºC at moderate relative humidity.

2. PROCEDURE OF NOISE LEVEL MEASUREMENT

Noise characteristics were measured using Precision Integrating Sound Level Meter, Type 2230 (Brüel & Kjær Company) of the first class of accuracy. Its functional and technical characteristics meet the requirements of Interstate Standard IEC 616 72-1:2002 [1]. The instrument allows determination of equivalent noise level L_{eq}, as well as maximum L_{pmax} and minimum L_{pmin} level of sound with the accuracy of up to 1 dB.

Assessment of noise at the workplace was performed in keeping with the requirements of DSN 3.3.6.037-99 [2]. An additional noise source when taking the measurements, was accessory equipment, namely welding rectifier, power source, etc. As background noise, generated by accessory equipment, was also present in the measured noise alongside the studied welding noise, measurements of background noise characteristics, con-

Table 1. TIG modes and noise parameters at the welder workplace during welding of 1460 alloy of 2 mm thickness

Welding current, I (A)	Welding speed, v (m/h)	Filler wire feed rate, v_f (m/h)	Tungsten electrode diameter, d (mm)	Diameter of torch nozzle, d_n (mm)	Argon amount, Q_{Ar} (l/ min)	L_{eq} (dB)	L_{pmax} (dB)	L_{pmin} (dB)
140	20	82	3	15	18	94.7	97.8	90.9

sidered as diffusion acoustic field, were conducted separately, in order to assess its contribution. The noise sensor was located at 0.5 m distance along the vertical to weld middle.

2.1 Noise at TIG welding of aluminium-lithium alloy 1460

Mechanized TIG welding of butt joints was performed using ASTV-2m welding head powered by MW-450 (Fronius®, Austria) power source at an alternating current of 200 Hz frequency with a square waveform. Plates of 400 mm length and 200 widths were placed so that the weld was oriented along their rolling direction. Batch-produced welding wire Sv1201 (w/%: Cu - 6% Ti - 0.1% Mn - 0.3% Zr- 0.2%) of 1.6 mm diameter was used as filler material. The size of the arc gap was 3-4 mm. High purity argon was used as an inert gas. Welding was performed with batch-produced non-consumable electrodes of EVL grade, the composition of which includes lanthanum oxide. The use of plate of different thickness allowed evaluation of the effect of welding current on the noise level at the welding operator workplace. Welding parameters and noise measures for TIG welding of alloy 1460 are given in Table 1.

As the sound level fluctuation range during measurement exceeds 5 dB, the noise is not constant [2]. In order to determine the effect of inconstant noise on the working staff, two measured values are sufficient: equivalent sound level L_{eq} and maximum sound level L_{pmax}. The level of inconstant noise at the welder's workplace is assumed to be the maximum permissible level (MPL) of the noise is equal to L_{eq}=80 dB. In keeping with the results of measurements at the welder's workplace (Table 1), the noise level exceeds MPL.

The magnitude of noise generated directly by the welding arc (welding noise) L_w. Measured noise L_{meas} consists of two parts: welding noise L_w generated by the welding arc, and background noise L_{back} generated by accessories operation. The welding noise level L_w is defined by using the principle of energy additivity of noise flows in the measurement point [3]:

$$L_w = L_{back} + 10 \cdot \log(10^{(L_{meas} - L_{back})/10} - 1). \qquad (1)$$

If $L_{meas} - L_{back} \geq 10$ dB, then $L_w \approx L_{meas}$. In this case, the background noise contribution can be neglected, and we can justifiably interpret the measured noise as the welding one. Note that if $L_{meas} - L_{back} = 10$ dB, then the error of the determination of equivalent level of welding noise is equal to ≈ 0.5 dB and is in the range of instrumental measurement error.

The level of background noise that is generated by accessory equipment when there is no welding performed is: L_{eq}=62.7 dB, L_{pmax}=68.3 dB and L_{pmin}=60.4 dB. Collected data show that $L_{meas} - L_{back} \geq 32$ dB and, therefore, it can be assumed that the magnitude of wel-

ding noise in the deposition of alloy 1460, is equal to that of measured noise.

2.2 Noise at FSW welding of aluminium-lithium alloy 1460

FSW process was performed in the PWI developed laboratory unit, which allows making butt joints of sheets of high-strength aluminum alloys up to 2.5 mm thick. During this process, the tool rotation speed is 1420 rpm, and the speed of its linear displacement (welding speed) is adjustable within 8-38 m/h.

FSW process (2 mm thick), the tool rotation speed is 1420 rpm, and the welding speed is 14 m/h, at which optimum conditions for their formation are provided [4]. The special welding tool was used with a shoulder diameter of 12 mm and the conical-shaped tip of 3.4 mm diameter at the base [5].

Level of background noise generated by accessory equipment, when welding is not performed is: L_{eq}=53.7 dB, L_{pmax}=75.3 dB and L_{pmin}=41.0 dB. Parameters of noise generated at FSW are given in Table 2.

Table 2. Noise parameters at FSW process of alloy 1460

№ of measurements	Noise, L_{meas}		
	L_{eq} (dB)	L_{pmax} (dB)	L_{pmin} (dB)
1.	82.7	94.0	81.1
2.	83.1	90.6	80.9
3.	83.4	100.3	81.6
4.	83.5	84.6	81.3
5.	83.5	87.4	81.4
6.	83.4	85.2	81.4
7.	83.6	90.5	82.1
8.	83.5	84.6	82.1

From the data, it follows that $L_{meas} - L_{back} \sim 30$ dB. Thus, it can be assumed that the magnitude of welding noise at FSW of alloy 1460 is equal to the magnitude of measured noise. The level of welding noise at the workplace at FSW of alloy 1460 is only slightly higher than MPL, but it is still dangerous.

Following the algorithm for measurement error calculation [6], we will find that the actual magnitude of noise level at the workplace is in the range of 83.3±1 dB, measurement error is determined solely by instrumental error, and the technological process proper is stable.

The level of noise generated at tool rotation (no movement) is: L_{eq}=79.2 dB, L_{pmax}=81.1 dB and L_{pmin}=78.0 dB. The level of noise generated at tool movement (no rotation) at speeds in the range of 14-32 m/h is given in Table 3.

Quadratic dependence of the noise level on movement speed value is given in Fig. 1. The square of the value of linear correlation ($R^2 = 0.998$) points to a very high probability of the derived dependence [6]. at an increase of movement speed close to 130%, the noise level increased only by 21 %.

Table 3. Parameters of noise from the table L_{mov}, that moves without tool rotation

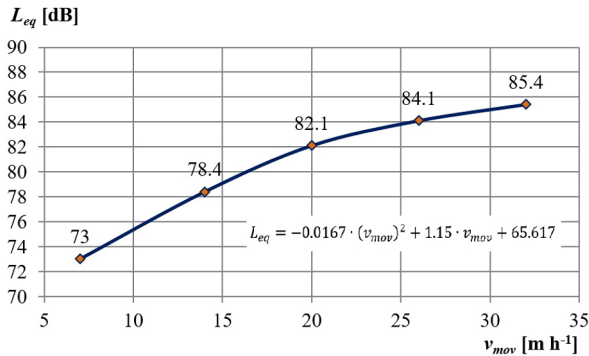| v_{mov} (m/h)	L_{eq} (dB)	L_{pmax} (dB)	L_{pmin} (dB)
14	78.4	82.1	77.3
20	82.1	83.2	70.8
26	84.1	85.6	76.3
32	85.4	87.8	75.8

Figure 1. Dependence of noise level L_{eq} on table movement speed without tool rotation

We needed to determine the movement speed, at which the level of welding noise will be lower than the limit value of 80 dB. From (1), it follows that the level of noise from table movement should be less than 73 dB.

Considerable lowering of the value of the process parameter is hardly justified for technical reasons, without the risk of deterioration of welding quality. The application of individual means for noise protection by the welder would be more acceptable.

3. MECHANICAL PROPERTIES AND DISCUSSION

In welding TIG and FSW, lowering the noise level at the workplace can be realized through "protection by the time" [2], as one of the organizational measures of collective noise protection. It should be noted that MPL = 80 dB was specified for the class of constant noises, during 8 hours work shift. Now, if the noise level is higher than MPL, safe operating conditions are preserved at the respective shortening of the time of staying in such a noise situation. Nowadays, there are existing methods and algorithms for operative control of aircraft noise [7]. At each increase of the noise level by 3 dB, safe operating time should be

reduced two times [2]. Therefore, for instance, at a sound level of 98 dB, continuous operation time should not exceed 7.5 min, which is hardly admissible from the viewpoint of the cost-effectiveness of the technology. Therefore, individual means of working staff noise protection should be used, alongside shortening of welding operator working time, namely: anti-noise earplugs or headphones, which allow reducing the sound load to safe values.

At this point in research and development of the industry, one of the main issues is obtaining quality welded joints of both steel and aluminum alloys. And at the same time work in a dangerous atmosphere corrosion environment with high resistance to cyclic loading is needed [8-11]. The analysis of fatigue crack propagation in a structure under cyclic loading aluminium alloy using the experimental method was the subject of research by Petrašinović et al. [12].

The main features that determine the fatigue life of welded joints specimens are microstructure, degree of softening and residual stresses (R). Fatigue testing that was previously performed shows that fatigue limit at stress ratio Rs =0.1 of FSW joints exceeds TIG joints in 1.3 time [13, 14]. Estimation of stress intensity factors using an approximate method using a computer program based on the finite element method is presented in the work by Kastratović et al. [15].

The analysis of the microstructure of welded joints of aluminum-lithium alloy 1460 has shown overheating in recrystallization areas (Fig. 2) in the HAZ close to a weld-base metal fusion line in TIG welding. Extension of the zone of structural components fusion is about 2.25 mm from weld joint to base metal (BM) fusion line. The grains of the HAZ directly adjacent to this line have the largest size. Near the boundary where the fine structure is visible, alloying the BM layer in the joint a sub dendrite (Fig. 2b, c, d). An interlayer with a fine sub dendrite structure (Fig. 2b, c, d) is observed close to the fusion line with the BM of the weld. The metal of TMAZ after friction stir welding smoothly changes grain orientation in the direction of the movement of the tools working surfaces. Extended elongated grains, oriented along the tool path, and equiaxial grains are formed in the area. Very small (3-5 μm) equiaxial grains (Fig. 2e, f, g) are formed in the central part (nugget) of the joint due to significant plastic deformations.
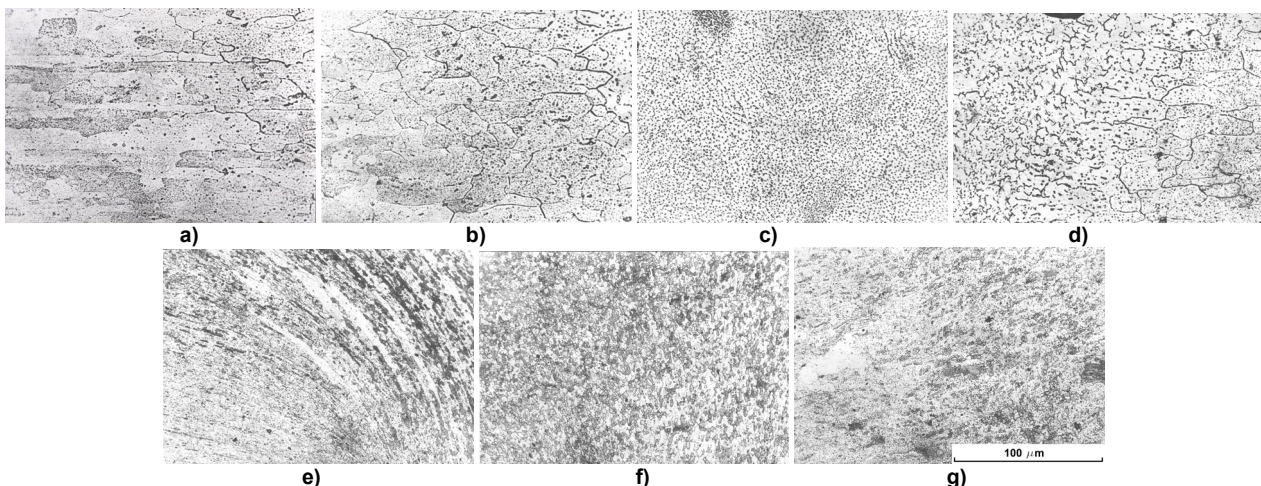

Figure 2. Microstructure of 1460 alloy BM (a) and welded joints produced by TIG using Sv1201 filler wire (b, d – weld to BM fusion zones, c – weld metal) and FSW (e – TMAZ from tool leading side, f - weld nugget, g – TMAZ from tool trailing side); x400

The temperature of metal heating in the zone of the weld formation affects the level of residual stresses. The maximum value of longitudinal residual stresses for TIG welding is 99 MPa. For FSW joints, the maximum value of tensile stress makes 75 MPa (Fig. 3).

Reducing the temperature of edges heating and the formation of the fine-grain structure of the weld in FSW the degree of metal softening is less than that in TIG welding. Measurements of metal hardness in the zone of welded joints made by FSW show that it is higher than in TIG welding. The hardness of the welded joint zone is up to 85-86 HRB. While in TIG welding with Sv1201 filler wire the minimum hardness of the metal in the central part of the weld is 71 HRB (Fig. 4).

The specimens of TIG welded joints without weld reinforcement fracture along with the weld metal and fracture of the specimens with weld reinforcement takes place in the weld to base metal fusion zone. FSW joints specimens fracture along the zone of thermomechanical influence. The mechanical properties are given in Table 4.
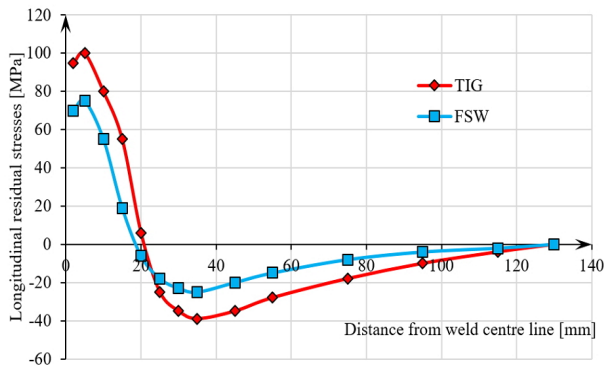

Figure 3. Distribution of longitudinal residual stresses in 1460 welded joint produced by TIG and FSW
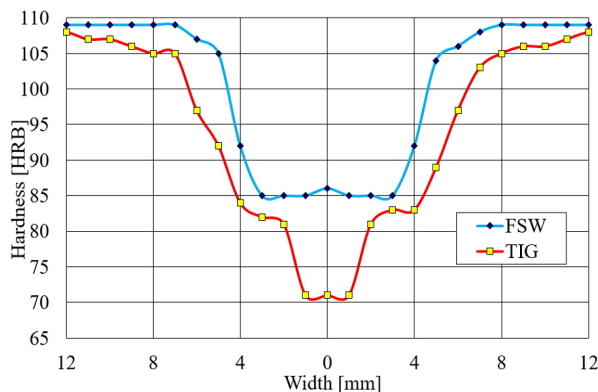

Figure 4. Distribution of hardness over the surface of welded joints from 1460 alloy of 2 mm thickness produced by TIG and FSW technology

Table 4. Mechanical properties of 1460 alloy welded joints of 2 mm thickness

TIG				FSW	
as welded		without reinforcement		as welded	
R_m (MPa)	Fracture zone	R_m (MPa)	Fracture zone	R_m (MPa)	Fracture zone
311	fusion line	262	weld metal	344	TMAZ

Note. Given values are average of 3- samples testing, cut out of welded joints.

4. CONCLUSION

Mechanized TIG welding of 2.0 mm aluminum-lithium alloy 1460 at a welding speed of 12 m/h in the range of welding current of 140 A and FSW with the rotation speed of 1420 rpm are dangerous and require the application of special methods and means of noise protection.

Formation of FSW permanent joint in solid-state phase allows eliminating the formation of cast coarse dendrite weld structure typical for fusion welding. In that case, refinement of base metal grain and formation of new disoriented uniform grain size structure, with 3-4 μm grain size and dispersed (≤1 mm) phases precipitations, takes place around the tool pin, in the place of the most significant thermomechanical effect on the metal.

Since in the solid phase stresses are formed at a lower temperature compared to fusion welding, the maximum level of longitudinal tensile residual stresses in the FSW joints of these plates aluminium-lithium alloy 1460 are 35% lower than that in TIG joints.

The thermomechanical effect in friction stir welding of heat-hardenable high strength 1460T1 alloy in addition to grain refinement in the welding zone leads to joint hardness decrease comparable to the base metal. However, the degree of metal softening in solid-phase welding of 1460T1 alloys is significantly lower than in fusion welding. Therefore, the tensile strength of the welded joints of these alloys, produced by the FSW, is higher than that in as-welded joints by the TIG welding.

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NOMENCLATURE

L_{eq} equivalent noise level
L_{pmax} maximum noise level
L_{pmin} minimum noise level
L_w welding noise level
L_{meas} measured noise level
L_{back} background noise level
I welding current
v welding speed

v_f giller wire feed rate
v_{mov} tool speed (no rotation)
d electrode diameter
d_n diameter of torch nozzle
Q_{Ar} argon amount
Rs stress ratio
HRB Brinell Hardness
R_m tensile strenght
R residual stresses

Acronyms

TIG   Tungsten Inert Gas
FFSW   Friction Stir Welding
TMAZ   ThermoMechanical Affected Zone
HAZ   Heat-Affected Zone
MPL   Maximum Permissible Level
HRB   Brinell Hardnes

ПРОЦЕНА НИВОА БУКЕ И МЕХАНИЧКА СВОЈСТВА ЗАВАРЕНИХ СПОЈЕВА АЛУМИНИЈСКИХ ЛЕГУРА СИСТЕМА Al-Cu-Li ПРИ ЗАВАРИВАЊУ ФСВ И ТИГ ПОСТУПКОМ

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Овај истраживачки рад презентује анализу тврдоће, структуре и затезне чврстоће заварених спојева легуре 1460 из система легура Ал-Цу-Ли, оства-рених ТИГ заваривањем и заваривањем са трењем мешањем (ФСВ). Испитиване су карактеристике акустичне буке на радном месту заваривача током механизованих ТИГ и ФСВ заваривања легуре алуминијума-литијума у циљу израде препорука за побољшање здравља и безбедности током процеса заваривања. Анализирајући резултате, закључили смо да су током ТИГ заваривања вредности буке заваривања на радном месту много веће од гранич-ног дозвољеног нивоа буке. Резултати су показали да вредности заваривачке буке достижу вредност од 95 дБ. Ниво буке на радном месту на ФСВ је такође опасан и достиже вредност од 84,3 дБ. Такође, у раду су представљена мерења тврдоће, структуре и затезне чврстоће legure 1460 заварених спојева израђених ТИГ и ФСВ заваривањем.