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Investigation of Fatigue Strength and Norms of Emission of Harmful Substances in the Air during MIG and TIG Welding of 1460 Aluminium-Lithium Alloy

This work presents the results of studying harmful substances in the air, released in the case of tungsten inert gas (TIG) and metal inert gas (MIG) welding of 1460 aluminum alloy (Al-Cu-Li). It is shown that the TIG process is accompanied by smaller evolution of the solid component and gas component of welding fumes than in MIG welding. Ozone concentrations during TIG and MIG welding are significantly (1.3 and 7.4 times, respectively) higher than the maximum permissible concentration. It is found that ultraviolet radiation, accompanying the welding process, is the main factor of toxic gas generation in the working zone of the studied aluminum-lithium alloys. Also, this paper presents analyses of microstructure, hardness, strength characteristics and fatigue behavior of 1460 TIG weld joints.

Keywords: *aluminum alloy, welding, labour safety, harmful substances, welding aerosols, microstructure, strength, fatigue behavior.*

1. INTRODUCTION

Aluminium-lithium alloys are widely used in aircraft and aerospace equipment design. Alloy 1460 of Al-Cu-Li system (nominal composition of 3% Cu, 2% Li) with zirconium and scandium additives, belongs the high-strength aluminium alloys (>500 MPa, density of 2.6 g/cm^3). Simultaneous increase in strength and ductility values of this alloy at super low temperatures makes it promising for application in welded cryogenic tanks [1]. Various fusion welding processes are used in most cases to produce permanent joints of different aluminium alloys. The weld forms as a result of melting a certain volume of material and filler wire in a common weld pool and their subsequent solidification in inert gas. This leads to structural transformations in the weld metal and adjacent sections, as well as appearance of defects in the form of pores, oxide film macro inclusions and hot cracks. As a result, the strength and durability of arc welded joints in most cases is 80…90% for non-heat-treated aluminium alloys [2] and not higher than 60…70% of base material strength for thermally treated aluminium alloys [3]. Application of modern aluminum alloys for welded structures was presented by Buyukyildirim at al [4].

It should be noted that welding wires are characterised by the emission of harmful gases and fumes into the working zone. Moreover, aluminium-lithium alloys welding conditions in terms of sanitary and hygienic requirements are insufficiently studied. It is known that lithium, representing the alkali metal group, belongs to low-melting materials of high toxicity [5] and with high chemical activity. However, lithium content within 1% in aluminium alloys allows for the reduction of density and increase in tensile and fatigue strength, that positively affects mass efficiency of welded structure [5]. Sanitary and hygienic assessment of aluminium-lithium alloys was mainly performed only at the stage of metallurgical production [6]. There is a little bit of data concerning the nature and degree of harmful emissions during welding production of aluminium-lithium alloys. Therefore, these data are very important and urgent, in connection with lithium toxicity [7].

The objective of the work is to perform a comparative study of sanitary and hygienic labour conditions of the operators, and establish the features of the tungsten inert gas (TIG) and metal inert gas (MIG) welding processes of 1460 aluminium alloy (Al-Cu-Li).

2. EXPERIMENTAL ANALYSIS

Studies were conducted on sheet-like semi-finished products of high-strength 1460 aluminium alloy of 3 mm made by TIG and 6 mm produced by MIG welding. Welding was performed using power supply source MW–450 and TPS 2700, Fronius® (Austria). For both welding methods welding current was equal to: I_w= 140 A. The condition of air environment in the welding zone was assessed according to the national standard [8].

Welding fume samples were taken by air intake using the complete trapping method. Samples were taken according to DSTU ISO 15011-1:2008 [9]. Not less than 6 samples were taken to ensure the validity of

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the obtained results. Welding fume concentration in the working zone air was assessed by gravimetric method [10], and the content of harmful compounds in the solid component of welding fumes (SCWF), namely aluminium (Al), manganese (Mn), copper (Cu), and lithium (Li) compounds, was assessed by the procedure described in [11]. Ozone concentration was determined using colorimetric method by taking appropriate samples with "Taifun" sampler and absorbing device with potassium iodide solution. Presence of carbon oxide (CO) and nitrogen dioxide (NO_2) was determined using Akvilon 1-1 and Akvilon 1-2 instruments.

Results of studying the welding fumes during MIG and TIG welding of 1460 alloy showed that SCWF components of complex chemical composition are released into the air within the working zone, which have different hazard class according to the GOST 12.1.005-88 national standard [8]. The main harmful substances of SCWF are aluminium, magnesium, copper, lithium.

Figure 1 shows that the intensity of formation (V_a) of welding fumes during MIG welding is 4 times higher, then during TIG welding, and depends upon welding current [12].

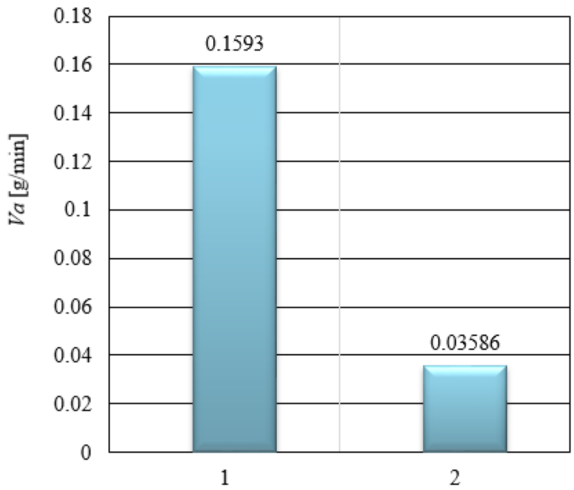

Figure 1. Intensity of welding fume formation during MIG (1) and TIG (2) welding of 1460 aluminium alloy

The weight fraction of the harmful aluminium (Al), manganese (Mn), and copper (Cu) substances in SCWF during MIG is much higher than during TIG welding (Fig. 2). Weight fraction of chemically active lithium (Li) during MIG is smaller than during TIG welding. Non-consumable tungsten electrode used in TIG welding does not participate in SCWF formation, and the volume of molten filler wire and the quantity of evaporating metal in this process is insignificant.

Alongside SCWF during welding a harmful gaseous component of welding aerosol (GCWF) forms in the air within working zone which belongs to the group of chemically dangerous and harmful productions factors [13]. The most hazardous of the toxic GCWF forming during TIG and MIG welding of 1460 alloy is ozone (O_3). According to the performed studies, ozone concentration was higher than the maximum permissible concentration (MPC) up to 7.4 during MIG and 1.3 times during TIG (Table 1). MPC of CO (≤ 2 mg/m^3) and NO_2 (≤ 20 mg/m^3) during both welding processes are not exceeded.

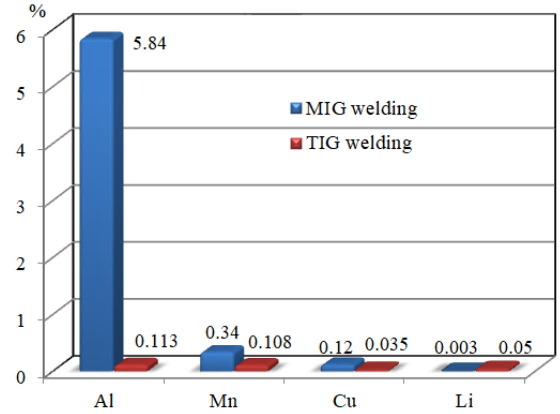

Figure 2. Weight fraction of the main harmful SCWF during MIG and TIG welding of 1460 aluminium alloy

Table 1. Concentrations of CO, NO_2, O_3 in the work place during TIG and MIG welding of aluminium alloy 1460

Welding process	Weight concentration, mg/m^3		
	CO	NO_2	O_3
MIG	0.3	2.1	0.74
TIG	0.4	1.1	0.13

Chemical kinetics of the studied substance points to the decisive role of ultraviolet radiation (UVR) during the formation of ozone and nitrogen oxides. Another factor, determining the volume of gases, forming in the welding zone, are overall dimensions of the weld pool under the high-temperature arc zone, as carbon oxide is the compound forming in the weld pool volume, and nitrogen oxide forms on the boundary of its contact with the surrounding air. UVR intensity depends on the values of temperature and electric current. Therefore, the welding mode can have a significant impact on the process of generation of ozone and nitrogen dioxide [12].

Concentration of CO and NO_2 in the welder's work place during MIG and TIG welding of 1460 alloy is presented in the Table 1. Changes of CO concentration and volume do not depend upon the size of welding pool. Performed measurements shows the dependence between NO_2 concentration and welding current. The concentration of CO does not change when welding current changes. According to the data of Lukianenko et al [12], the dependence of nitrogen dioxide concentration on welding current can be approximated by a parabola with a high degree of accuracy, and, therefore, the volume of the forming toxic gas, increases considerably with the increase in the value of electric current, accompanying the welding process.

Photodissociation of air oxygen molecules, under the impact of welding arc UVR, causes the release of atomic oxygen, with its subsequent binding to an oxygen molecule. Arc UVR impact on O_2 molecules, which depends on the wave length of radiation, generated by the welding arc, also leads to ozone formation intensification [14].

It was established that, in the breathing zone of welders, the amount of SCWF and GCWF components during TIG, is smaller than during MIG welding of aluminium-lithium alloy 1460. It is shown that ultraviolet radiation is the main factor of toxic gas generation in the working zone during aluminium-lithium alloy 1460 welding.

Therefore, studies of microstructure, hardness measurements, strength characteristics and fatigue behaviour of less harmful TIG welding method of 1460 aluminium alloy joints have been provided. Samples for microstructure studies, tensile test specimens (12.5 mm width) and fatigue test specimens (25 mm width) have been produced. Evaluation of structural characteristics of the welds was performed using optical electron microscope MIM-8. Mechanical testing was performed on the servo-hydraulic test system MTS 318.25. Fatigue tests were carried out to fracture at constant amplitude loading with the stress ratio of R_σ=0.1 and 15 Hz frequency. A batch of 8…12 specimens of the same type were tested in same conditions. Degree of metal softening in the weld zone was evaluated on "ROCKWELL" hardness testers with 1⁄16-inch-diameter steel sphere and 600 N loading. Hardness of the metal was measured on joint face.

Analysis of the microstructure of the welded joints of 1460 alloy has shown areas of overheating and recrystallization (Fig. 3) in the heat-affected zone close to weld-base material fusion line. Extension of the zone of fusion structural components is about 2.25 mm from weld joint to base material fusion line. The grains of the heat-effected zone (HAZ) directly adjacent to this line have the largest size. The weld metal is characterised mainly by fine grain structure, however, separately its areas demonstrate fragments of central crystallite. Near the boundary, the base material layer in the joint has a visible sub dendrite fine structure (Fig. 3 b, c, d). An interlayer with a fine sub dendrite structure (Fig. 3, b, d) is observed close to the fusion line of the base metal of the weld.

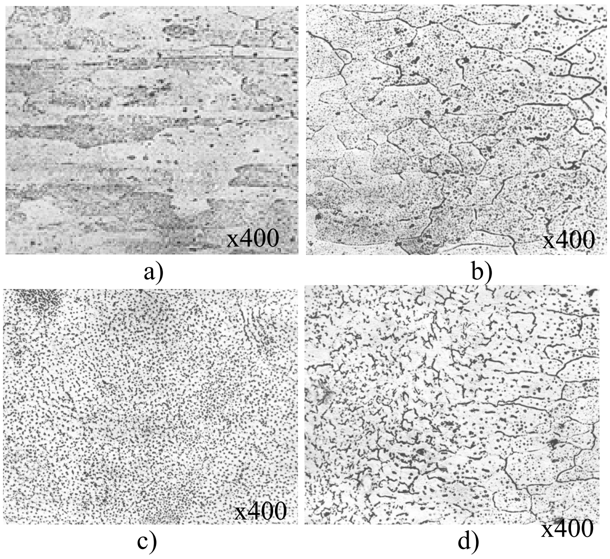

Figure 3. Microstructure of welded joints of 1460 alloy produced by TIG welding using Sv1201 filler wire: a) base metal, b) and d) base metal fusion zones, c) weld metal

Measurements of metal hardness in the welding zone made by TIG with Sv1201 filler wire shows that the minimum hardness (HRB71) is in the central part of the weld and up to HRB83 in fusion zone (Fig. 4). Base metal shows hardness near HRB109.

Under uniaxial static tension, specimens of welded joints with reinforcement obtained by TIG welding, shows tensile strength near 310 MPa and fracture occurs at the weld toe (Fig. 5 a). Specimens of welded joints without reinforcement have a minimum tensile strength of 257 MPa and fracture occurs in the weld metal (Fig. 5 b). Tensile strength of base metal is 565 MPa.

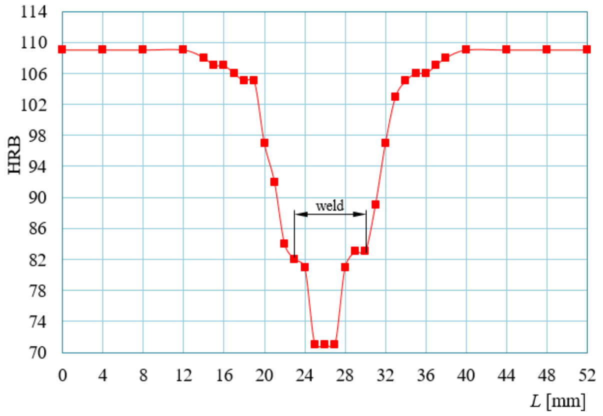

Figure 4. Distribution of hardness over the surface of 1460 welded joints produced by TIG welding

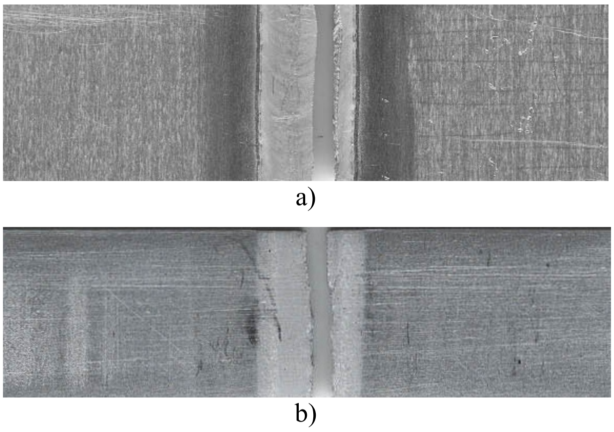

Figure 5. Fragments of specimens of welded joints produced by TIG after tensile loading: a) with reinforcement, b) without reinforcement

Obtained S-N curves of butt welded joints with reinforcement of aluminium alloys 1460 made by TIG demonstrate good level of fatigue strength for heat-treated aluminium alloy. Endurance limit of joints are 56 - 64% of the respective indices of the base metal in the entire region with the durability of $10^5…2·10^6$ cycles (Fig. 6). For 1460 alloy TIG welding joints, the maximum alternating stress range of $2·10^6$ cycles was 85 MPa which is only 44% lower than the corresponding values for the base metal (160 MPa).

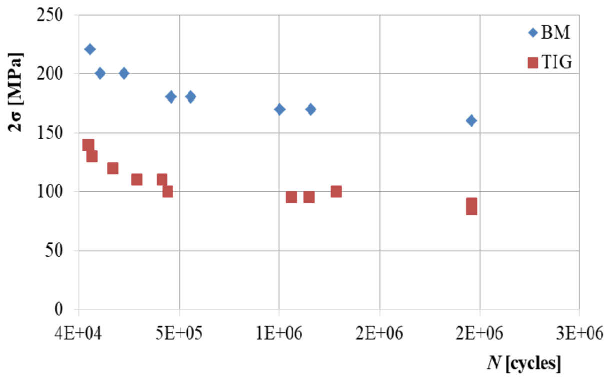

Figure 6. S-N curves of base metal and TIG welded joints of 1460T1 aluminium alloy at stress ratio R = 0.1

3. CONCLUSION

1. TIG welding of aluminium-lithium alloy 1460 has smaller amount of WFSC and WFGC compared to MIG welding process.
2. Ozone concentrations during aluminium-lithium alloy 1460 welding are higher than MPC level 1.3 times during TIG and 7.4 times for MIG process.
3. Ultraviolet radiation is the main factor of toxic gas generation in the working zone during TIG and MIG welding of aluminium-lithium alloy 1460.
4. Joints of high strength 1460 alloy obtained by TIG has coarse dendrite weld structure with no defects typical for fusion welding. Minimal hardness in central part of the weld is 35% lower than the base metal. Therefore, tensile strength of 1460 welded joints is 55% of the respective value of the base metal.
5. Fatigue tests show that endurance limit of heat-treated aluminium alloy 1460 TIG welding joints is 56 - 64% of the respective values of the base metal in high cyclic fatigue region 10^5 - $2·10^6$ cycles.

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NOMENCLATURE

I_w	welding current
V_a	welding fumes
R_σ	Stress
P	Force

Acronyms

TIG	Tungsten Inert Gas welding
MIG	Metal Inert Gas welding
SCWF	Solid Component of Welding Fume
GCWF	Gaseous Component of Welding Fume
GOST	GOsudarstvennyy STandart (standards of the Soviet Union)
MPC	Maximum Permissible Concentration
UVR	Ultraviolet Radiation
ISO	International Standards
S-N	Stress-cycle (S-N) curve
HRB	Rockwell hardness (ball)

ИСПИТИВАЊЕ ЗАМОРНЕ ЧВРСТОЋЕ И НОРМИ ЕМИСИЈЕ ШТЕТНИХ СУПСТАНЦИ У ВАЗДУХУ ТОКОМ МИГ И ТИГ ЗАВАРИВАЊА 1460 ЛЕГУРЕ АЛУМИНИЈУМ-ЛИТИЈУМ

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У раду су приказани резултати испитивања штетних супстанци у ваздуху, ослобођених у условима електролучног заваривања нетопљивом електродом у заштити аргона (ТИГ) и електролучног заваривања топљивом електродом у заштити аргона (МИГ) легуре алуминијум-литијумом типа 1460 (Al-Cu-Li). Показује се да ТИГ процес прати мање издвајање чврсте и гасне компоненте у заваривачкој атмосфери, него што је то случај при МИГ заваривању. Концентрација озона при ТИГ и МИГ заваривању (приближно 1.3-7.4 пута респективно) превазилази границу дозвољене концентрације. Утврђено је да ултраљубичасто зрачење, као пратећи ефекат процеса заваривања, представља основни генератор токсичних гасова у радној зони испитиваних алуминијум-литијум легура.