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The Effect of Shielding Gas on the Toughness of AlMg4.5Mn Weld Metals Made by GMAW

The effect of MIG/MAG shielding gas on the toughness of aluminium alloy AlMg4.5Mn weld metal has been analysed using the instrumented Charpy pendulum for standard toughness testing. The MIG/MAG welding was performed in the shielded atmosphere of Ar, as well as the mixtures of gases Ar + 0.0307 % O_2, Ar + 30 % He + 0.0317 %O_2 and Ar + 48 % He + 0.0290 % O_2. Metallographic tests have been performed in order to check the appearance and porosity of the weld metal, as well as its toughness testing at different temperatures (20, – 90, – 196 °C), using the instrumental Charpy pendulum, in order to separate the crack initiation and crack growth energy. In this way, a comprehensive insight of the effect of shielding gas on the weld metal toughness has been obtained.

Keywords: *aluminium alloy, AlMg4.5Mn, shielding gas mixture, MIG/MAG welding, impact testing, crack initiation energy, crack growth energy.*

1. INTRODUCTION

The AlMg4.5Mn alloy is used for transport and storage tanks, pressure vessels and vehicles, including yachts and small ships. It belongs to the group of non-heat treatable Al alloys with high strength, corrosion and wear resistance and good weldability. Nevertheless, welding of Al alloys is not a simple task due to several specific problems, including cracking due to relatively high thermal expansion coefficient and a wide solidification temperature range, oxide film that must be broken up before or during welding and high sensitivity to porosity [1,2]. To overcome these problems, the gas metal arc welding (GMAW) process has been developed, offering a wide range of shielding gases, from the inert ones (Ar, He) to the active one (CO_2), including different mixtures of gases. The latest possibility offers a number of advantages compared to pure gases, such as more efficient filler metal transfer, better liquidity, stabilization of the electric arc, as well as higher penetration, lower spattering and increase of welding speed [3,4]. Anyhow, the cracking and porosity remain major concerns in welding of Al alloys. Therefore, the effect of different shielding gases on the Charpy toughness has been investigated, focused on a weld metal as the most sensitive region of AlMg4.5Mn alloy welded joint.

2. EXPERIMENTAL PROCEDURE

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2.1 Welding

The plates of the aluminium alloy AlMg4.5Mn, sized 500 × 250 × 12 mm, were used (according to standard EN 288-4:1992) and "Y" groove has been made by milling, Fig. 1. The Al alloy wire AlMg4.5MnZr was used as the filler material. The chemical composition of base and filler metal is shown in Table 1, while the mechanical properties of the base metal is given in Table 2.

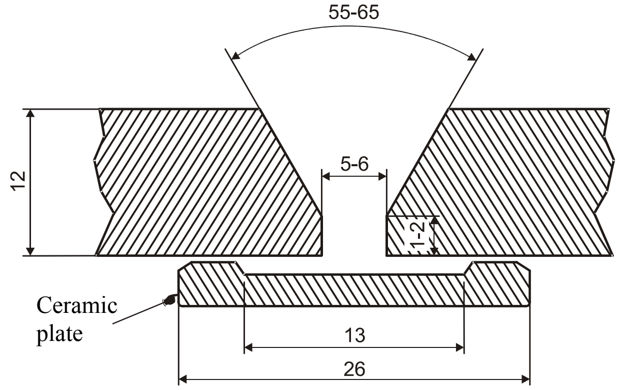

Figure 1. Shape and dimensions of "Y" groove

Table 1. Chemical composition of base metal AlMg4.5Mn and filler material [wt. %]

Element	Si	Fe	Cu	Mn	Mg	Zn	Cr	Ti	Zr
Base metal	0.13	0.21	0.04	0.66	3.95	0.03	0.06	0.025	
Filler metal	0.07	0.21	0.01	0.71	4.6	0.02	0.07	0.09	0.11

The welding of the testing plates was performed by GMAW procedure, using back-up ceramics plate, Fig. 2. As the shielding atmosphere, the mixtures of gases were used, whose chemical compositions are shown in

Table 3. The plates were welded in four passes: one root pass + three fill passes, with a large drop metal transfer in the root pass and spray metal transfer in the filler passes. All the passes were performed using the forward welding technique. The shielding gas flow was 15 – 16 l/min, and the filler wire rate 9.3 – 12 cm/min. The welding parameters (current, voltage, welding speed and the calculated welding heat input) are shown in Table 3. The surrounding temperature during welding was 20 °C. The preheating temperature of plates was above 110 °C (it was controlled by contact thermometer).

2.2 Specimens

Specimens for metallographic examination (micro and macro), and for standard Charpy specimens with "V" notch (Fig. 3) were cut out from welded plates in accordance with standard procedure, EN1321.

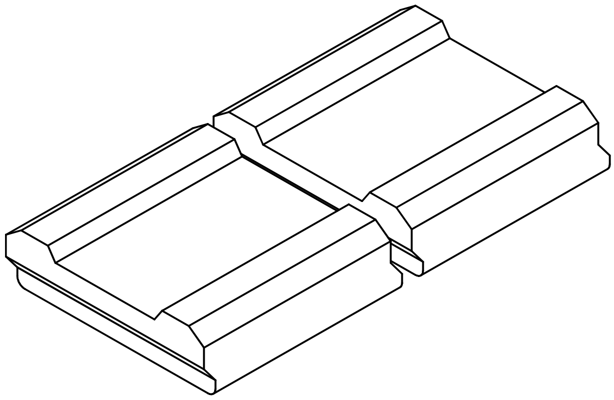

Figure 2. Back-up ceramics plate

Table 2. Mechanical properties of AlMg4.5Mn alloy

	Tensile strength, R_m [MPa]	Yield strength, $R_{0.2}$ [MPa]	Elongation, A [%]	Toughness, J
Longitudinal direction	293 – 294	131 – 135	23 – 26	41
Transversal direction	304 – 305	142 – 145	25 – 28	32

Table 3. Welding parameters

Shielding gas	Pass No.	Current [A]	Voltage [V]	Welding speed [cm/min]	Heat input [kJ/cm]	Interpass temperature [°C]
Ar	1	160	19.2	29.1	6.3	75
	2	171	22.9	26.5	8.9	80
	3	171	22.9	33.7	7.0	70
	4	167	23.5	26.5	8.9	73
Ar + 0.0307 % O_2	1	155	19.3	20.4	8.8	75
	2	171	23	24.2	9.8	75
	3	173	23	32.7	7.3	70
	4	174	23.4	24	10.2	70
Ar + 30 % He + 0.0317 % O_2	1	145	19.2	23.5	7.1	75
	2	159	22.9	21	10.4	65
	3	169	23.4	39.1	6.1	65
	4	201	24.9	43.48	6.9	65
Ar + 48 % He + 0.0290 % O_2	1	148	19.7	23.3	7.5	75
	2	186	25	24.2	11.6	70
	3	206	25.9	54.5	5.9	70
	4	198	25.9	42.4	7.3	70

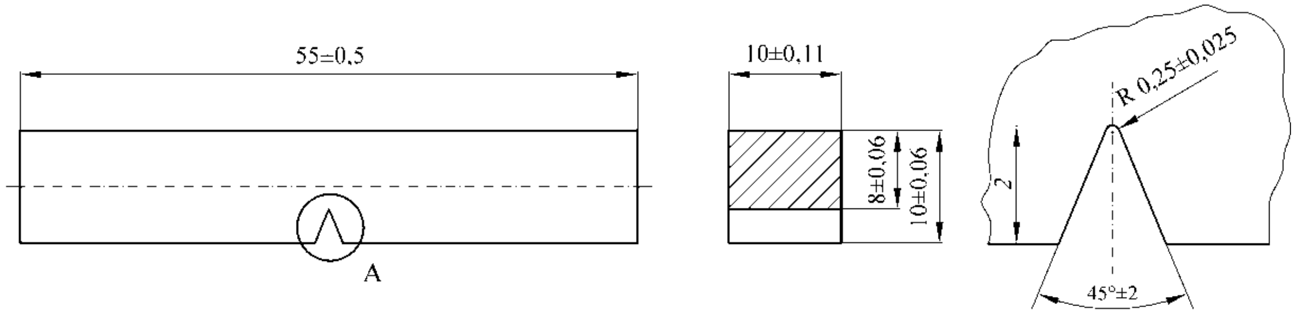

Figure 3. The geometry of standard Charpy specimens with "V" groove

3. RESULTS AND DISCUSSION

Macro- and micrographs are shown in Figures 4 and 5, respectively. In Figure 4 one can notice the effect of He on weld metal shape, being wider and having better spilling. The smallest face and the best appearance of the weld metal is with 30 % He. Figure 5 indicates that the weld metal microstructure of all welded plates is practically the same, consisting of directed dendrites and homogeneously distributed intermetallic particles. This was to be expected, since the welding conditions were approximately the same, the only difference being the shielding atmosphere. The basic difference in the microstructure is their porosity, being pronounced for pure Ar, including presence of gas pores, still present, but to much lesser content for Ar + 0.0307 % O_2 and practically absent when He is added. The presence of other types of defects that could affect the quality of welded joints was not observed.

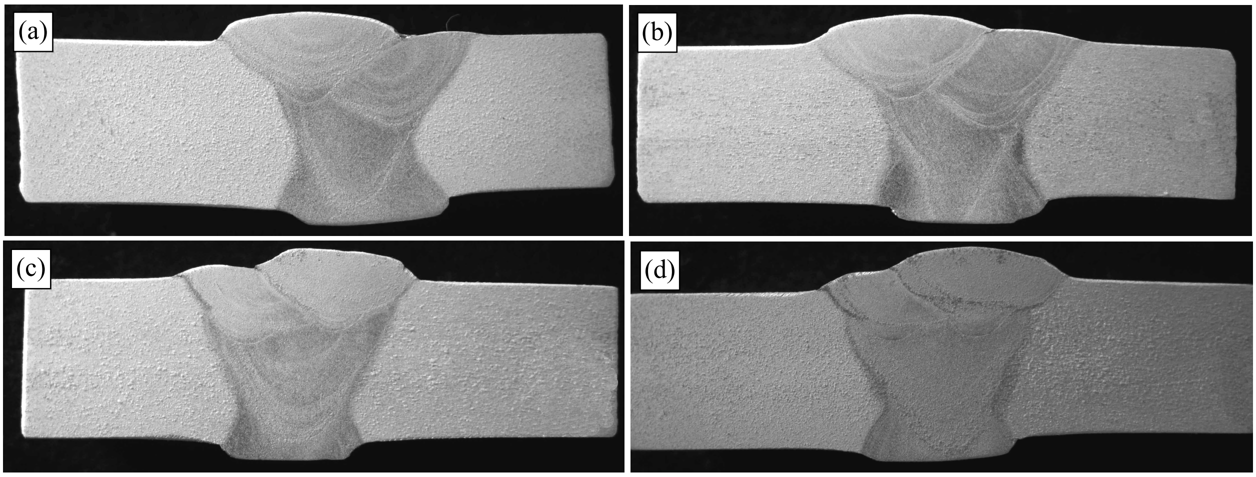

Figure 4. Macrographs of the weld joints: (a) Ar, (b) Ar + 0.0307 % O_2, (c) Ar + 30 % He + 0.0317 % O_2 and (d) Ar + 48 % He + 0.0290 % O_2

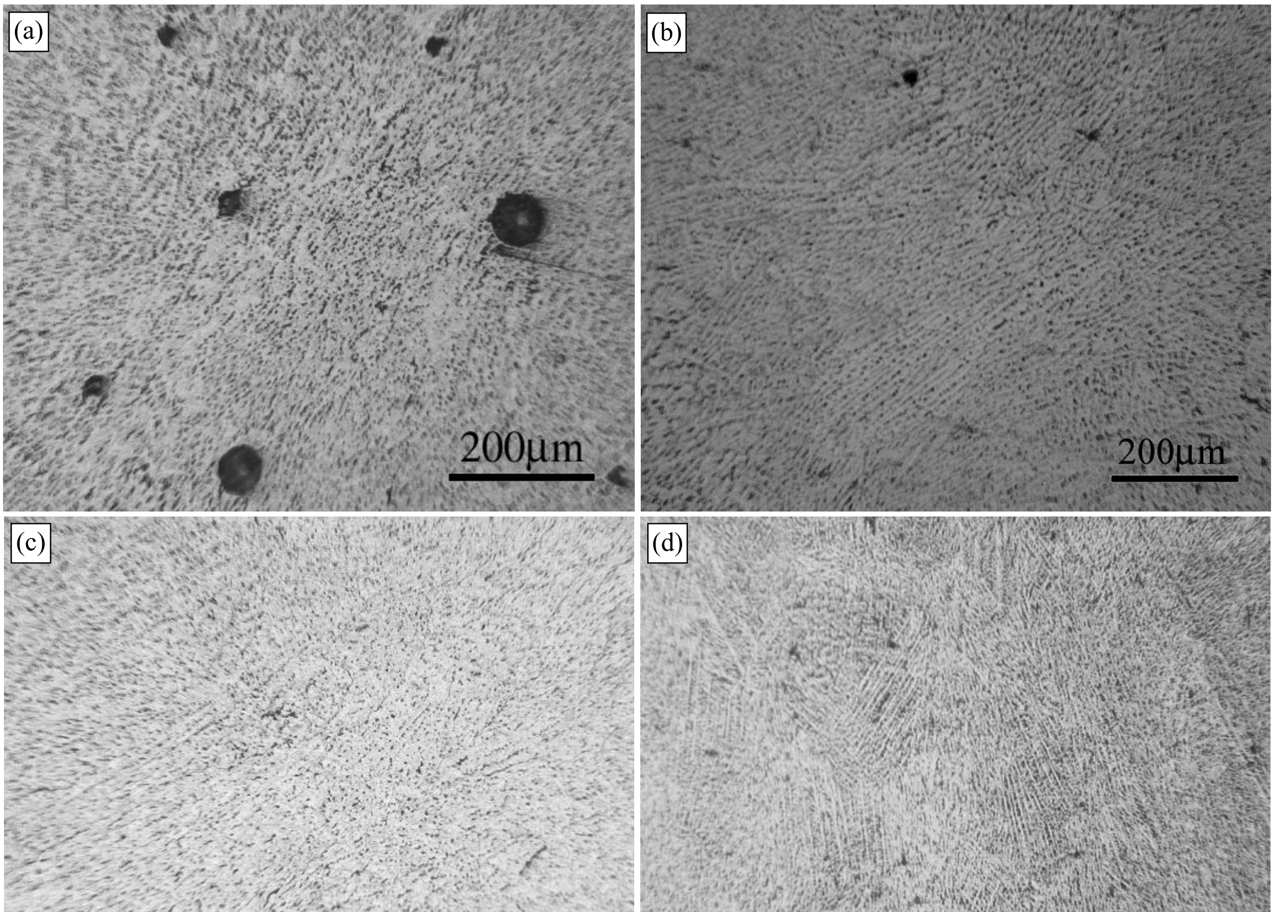

Figure 5. Microstructure: (a) Ar, (b) Ar + 0.0307 % O_2, (c) Ar + 30 % He + 0.0317 % O_2 and (d) Ar + 48 % He + 0.0290 % O_2

Results of impact testing using the instrumented Charpy pendulum are shown in Table 4 and Fig. 6 for three testing temperatures (20 °C, – 90 °C, – 196 °C). The total impact energy has been separated into crack initiation and crack growth energy, in accordance with the procedure described in [5], using diagrams of energy vs. time and force vs. time, shown in Fig. 7 for weld metal obtained by the gas mixture Ar + 30 % He + 0.0317 % O_2. This procedure provides better insight into the material crack resistance, as discussed in [6].

Impact toughness at room temperature for all shielding gases was 20 – 24 J, indicating weak effect of oxygen and helium. More important aspect of the total energy is the fact that cca 90 % belongs to crack

Table 4. Results for impact testing

Shielding gas	Specimen No.	20 °C			– 90 °C			– 196 °C		
		E_{tot} [J]	E_{in} [J]	Ef_{rac} [J]	E_{tot} [J]	E_{in} [J]	E_{frac} [J]	E_{tot} [J]	E_{in} [J]	E_{frac} [J]
Ar	1	23	3	20	19.5	2.5	17	9	2	7
	2	21	2.5	18.5	20.5	2.5	18	9	2	7
	3	23	3	20	21	2.5	18.5	11	3	8
Ar + 0.0307 % O_2	1	22	2.5	19.5	20	2	18	10	2.5	7.5
	2	22	2.5	19.5	19.5	2.5	17	8	2	6
	3	20	2.5	17.5	19.5	2.5	17	14	3	11
Ar + 30 % He + 0.0317 % O_2	1	23	2.5	20.5	22.5	2.5	20	12	3	9
	2	23	3	20	22	2.5	19.5	12	3	9
	3	–	–	–	20	2.5	17.5	12	2.5	9.5
Ar + 48 % He + 0.0290 % O_2	1	23	2.5	20.5	21	2.5	18.5	10	2.5	7.5
	2	24	2.5	21.5	21	2.5	18.5	10	2.5	7.5
	3	23	2.5	20.5	19.5	2.5	17	9	2	7

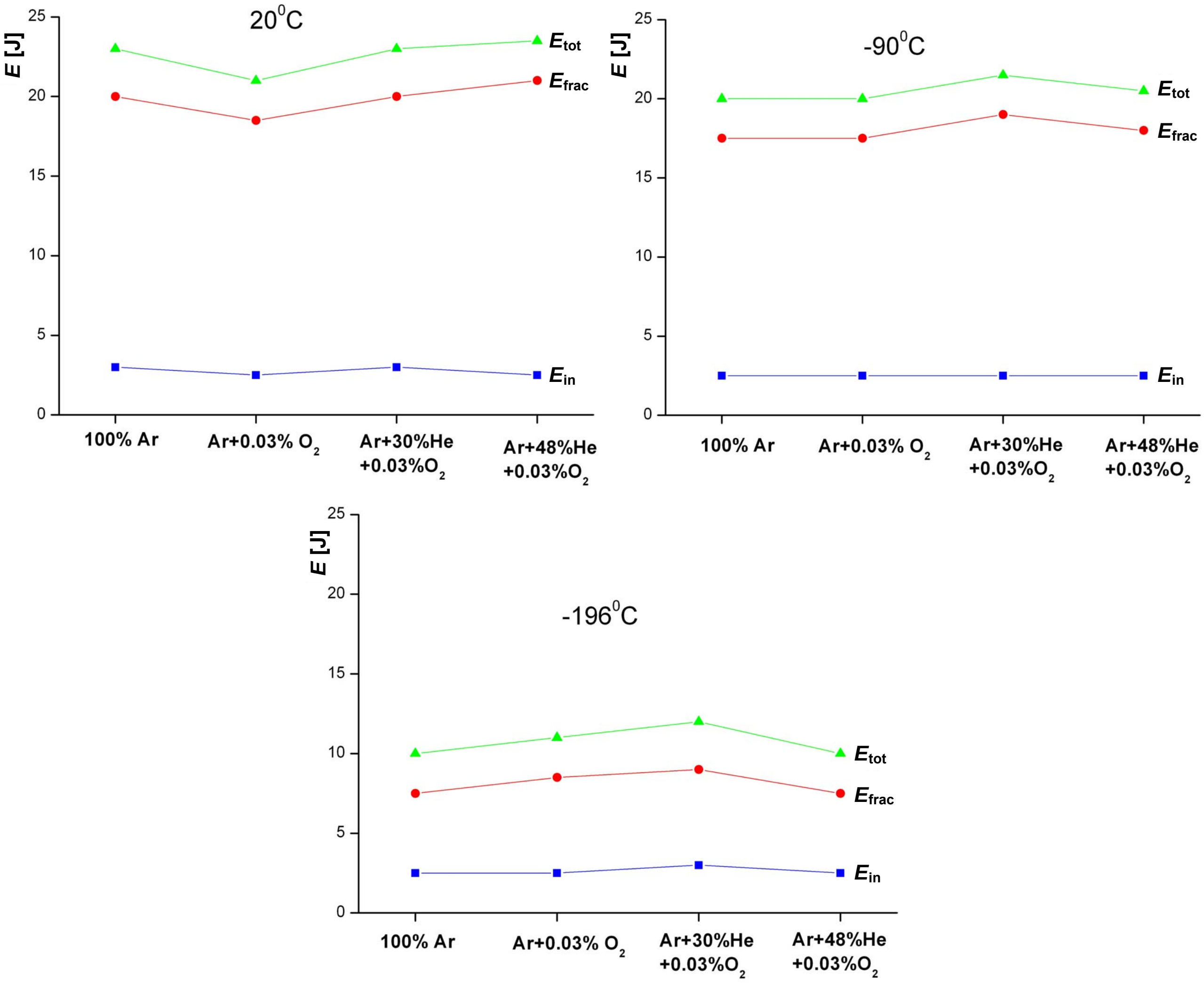

Figure 6. The total impact energy and its components vs. shielding gas at different temperatures

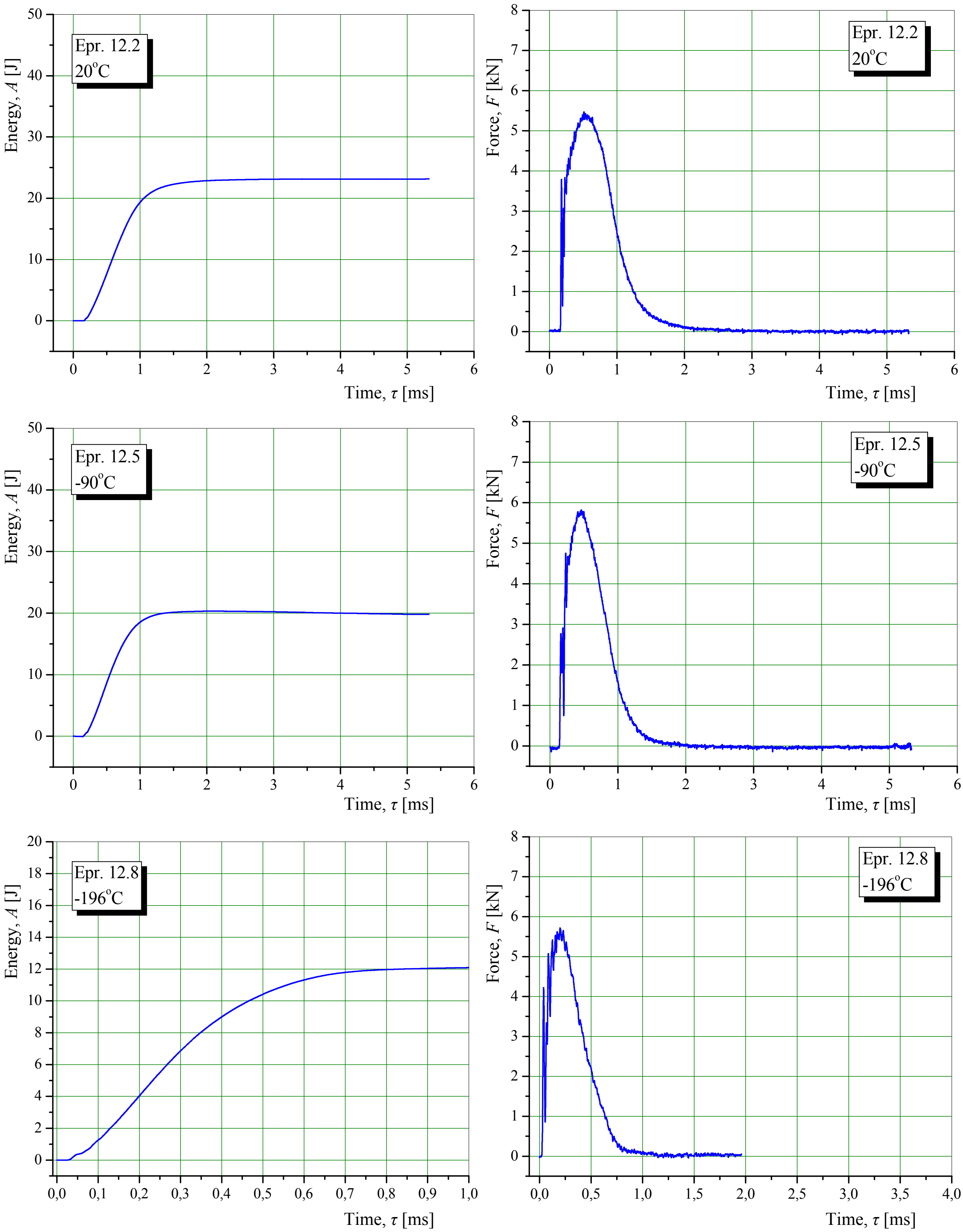

Figure 7. Diagrams energy vs. time and force vs. time

growth and only cca 10 % to crack initiation (2.5 – 3 J), indicating high notch sensitivity, i.e. low resistance to cracking, but reasonable resistance to crack growth. Impact toughness has not been significantly reduced at temperature – 90 °C. All results, including separated energies, are in the range of at least 90 % compared to the room temperature. Anyhow, significant reduction of impact toughness has been obtained by testing at temperature – 196 °C, producing cca 50 % of total energy and cca 40 % of crack growth energy, whereas crack initiation energy was practically the same, i.e. very low. It is interesting to note that oxygen and helium have also weak effect at both lower temperatures. The shape of the force vs. time diagrams also indicates more brittle behaviour of weld metal at – 196 °C.

4. CONCLUSIONS

Based on the results and discussion presented in this paper, one can make the following conclusions:

- Adding helium to Ar and oxygen mixture decreases the porosity level in weld metal, producing high quality welded joints with both 30 % and 50 % of He. The spilling of filler material increases due to the increased level of helium.
- The impact toughness, i.e. total Charpy energy, as well as crack initiation and crack growth energies have not been significantly affected by the shielding gases.
- The temperature effect on impact toughness is not significant at – 90 °C, whereas at – 196 °C it becomes significant, reducing total energy to cca 50 % and transforming weld metal behaviour to more brittle.
- Increasing the amount of helium in the shielding atmosphere has weak effect on the resistance to the crack initiation and growth, whereas it has significant effect on porosity reduction. Having in mind the cost of He compared to Ar and Oxygen and the fact that 30 % He also produces the smallest overlay and the best appearance of weld metal, one can conclude that more than 30 % of He is probably not a reasonable choice.

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REFERENCES

[1] Davis, J.R. (Ed): *ASM Specialty Handbook: Aluminum and Aluminum Alloys*, ASM International, Material Park, 1994.

[2] Kastelec-Macura, S., Prokić-Cvetković, R., Jovičić, R., Popović, O. and Burzić, M.: Porosity of welded joints of AlMg4.5Mn alloy, Structural Integrity and Life, Vol. 8, No. 2, pp. 114-120, 2008.

[3] Goecke, S.-F.: *Effects of Active Gas Admixtures in the vpm Range to Argon on Pulsed MIG Welding of Aluminium*, PhD thesis, University of Berlin, Berlin, 2004, (in German).

[4] *Welding Handbook, 9th Edition, Vol. 3*, American Welding Society, Opa-Locka, 2010.

[5] Momčilović, D., Delić, B. and Grabulov, V.: Behaviour of metals at impact loading, Structural Integrity and Life, Vol. 1, No. 1, pp. 23-28, 2001, (in Serbian).

[6] Sedmak, S.: A century of Charpy impact test, Structural Integrity and Life, Vol. 2, No. 1-2, pp. 3-4, 2002, (in Serbian).

УТИЦАЈ ЗАШТИТНОГ ГАСА НА ЖИЛАВОСТ МЕТАЛА ШАВА ЛЕГУРЕ AlMg4.5Mn ДОБИЈЕНОГ ПОСТУПКОМ ЗАВАРИВАЊА ЦИРКУЛАЦИЈОМ

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Анализиран је утицај заштитног гаса, на жилавост метала шава алуминијумске легуре AlMg4.5Mn добијеног МИГ/МАГ поступком заваривања. За мерење жилавости је коришћено инструментирано Шарпијево клатно са могућношћу раздвајања енергије настанка и енергије раста прслине. За МИГ/МАГ заваривање коришћене су четири различите заштитне атмосфере: чист Ar, као и мешавине гасова Ar + 0,0307 % O_2, Ar + 30 % He + 0,0317 % O_2 и Ar + 48 % He + 0,0290 % O_2. Металографска испитивања су урађена да би се испитала појава грешака и порозности метала шава, а жилавост метала шава је испитана на различитим температурама (20, – 90, – 196 °C). На овај начин је добијен свеобухватан увид у утицај заштитног гаса на жилавост метала шава као најкритичније области завареног споја легуре AlMg4.5Mn.