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THE EFFECT OF SHIELDING GAS COMPOSITION ON THE TOUGHNESS AND CRACK GROWTH PARAMETERS OF ALMG4,5MN WELD METALS

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Abstract

*The experiment have been performed using samples of welded joints of the three components aluminium alloy AlMg4,5Mn. The welding was performed with GTAW in the shielded atmosphere of Ar+0,015*N_2*, mixture of the inert gases Ar+50%He+0,015*N_2 *and Ar+70%He+0,015*N_2*. After welding has been completed, the metallographic tests, the tensile test and the tests of the hardness were performed. Also, the weld metal toughness was estimated, using the instrumental Charpy impact testing system, followed by estimating the crack initiation energy, crack growth energy and the fracture mechanics parameters. The goal was to establish the effects of shielding atmosphere composition on the mechanical properties and fracture mechanics parameters of weld metal.*

Keywords: AlMg4,5Mn; Aluminium alloys; GTAW; Welding, Shielding.

1. Introduction

The AlMg4,5Mn alloy is widely used as a construction material in different types of industries. It is suitable for liquefied gasses transport and storage tanks, high pressure vessels and vehicles. Nowdays, it has become the base material in building yachts and ships. It belongs to the group of non-heat treatable alloys. Its characteristics are high strenght,

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corrosion and wear resistance and good weldability. The fact that it is used more and more has contributed to the attempts to improve its characteristics, paying special attention to perfecting the welding and shaping procedures.[1, 2] Welding of aluminium alloys is more problematic than that of low carbon steels for many reasons, such as development of oxide film that must be broken up before or during welding, problematic correct feeding of aluminium wire, correct identification of weld pool, etc.[3, 4] Also, it has been reported that aluminium alloys are more sensitive to variations in the welding parameters as compared with steel.[5, 6, 7]

The welding procedure with shielding atmosphere offers a number of advantages comparated to pure gasses, 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.[8, 9]

Argon and helium are commonly used shielding gasses which affect on the appearance and decrease of welding defects. However, there are some differences between them. Helium is one of the lightest gasses, approximatly ten times lighter than argon. Also, it has a high ionisation potential, which is 25eV, compared to 16eV for argon, produces a significantly higher arc voltage. Contrary to the advantages of helium, argon`s higher density enables better shielding of the molten metal during welding. The price of helium is much higher then argon, so understandably, using helium is much more expensive than using argon. For this reason, it is comon to use the mixture of these two gasses. As of recently, the nitrogen is sometimes added to this mix as well (with MIG procedure), of a few hundreds of ppm.[10, 11, 12, 13]

The cracking and porosity are major concerns in welding of aluminium alloys. This is due to the relatively high thermal expansion coefficient of aluminium, the large change in volume upon solidification, and the wide solidification temperature range.[14] Presence of impurities, such as K, also contributes to high temperature embrittlement due to intergranular fracture and the formation of cracks.[15] Porosity occurs as the consequence of absorption, diffusion and dissolution of gasses on the surface and inside the hardened weld. This can result in micro porosity or the presence of the larger pores, 3-4mm in size. Unlike steel, the aluminium pores occur mostly inside the weld, but they can also be seen close to the fusion line. The porosity is mainly caused by hydrogen, which dissolves in aluminium. The hidrogen easily dissolves in the liquid aluminium, which opposite when the aluminium is solid.[16]

2. Experimental procedure

The plates of the aluminium alloy AlMg4,5Mn, sized 5000x250x12mm, were used (according to standard EN 288 - 4:1992) and “V” grooves had been made by milling. As the filler material, the aluminium alloy wire AlMg4,5Mn (classified as DIN1732 / SG - AlMg4,5Mn or BS2901 / 5183 or AWSA5.10 / ER5183) was used – 5mm wide and 1000mm long. The chemical composition of base metal AlMg4,5Mn and filler material is shown in Table 1, while their mechanical properties are given in Table 2.

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

Chem. Element (wt-%)	Si	Fe	Cu	Mn	Mg	Zn	Cr	Ti
base metal	0,13	0,21	0,04	0,66	3,95	0,03	0,06	0,025
filler material	< 0,40	< 0,40	< 0,10	0,5-1,0	4,3-5,2	<0,25	0,05-0,25	0,15

Table 2. Mechanical properties of aluminium alloy AlMg4,5Mn

	Tensile strenght, R_m (MPa)	Yield strenght, $R_{0.2}$(MPa)	Elongation A (%)	Ductility, J
Longitudinal direction	293-294	131-135	23-26	41
Transversal direction	304-305	142-145	25-28	32

The welding of the testing plates was performed with GTAW procedure. As the shielding atmosphere, the inert gasses were used, whose chemical compositions are shown in Table 3. The mixing to obtain the intended mixtures was carried out before welding. The plates were welded in four passes: one root pass + three fill passes, as shown in Fig.1. All the passes were performed using the forward welding technique. The welding parameters, current capacity, voltage, welding speed and the calculated welding heat input are shown in Table 4. The surrounding temperature during welding was 20°C. The preheating temperature of plates was above 110 °C (it was controled by contact thermometer).

During welding, it was observed that, with increasing the content of helium in the shielding gas, the arc stability was decreased, but weld appearance and spilling of filler material are better.

In order to determine the presence of defects in welded joints, the radiographic examinations were performed before the test plates were cut. The presence of porosity was observed in the weld metal that had been welded with the shielding atmosphere Ar+0.015%N_2, while this porosity wasn't observed in the other two plates welded in

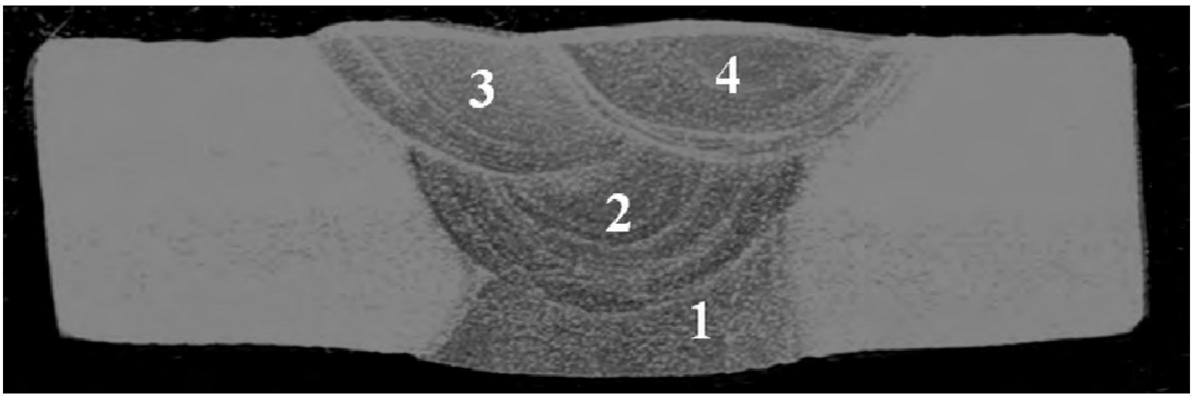

Figure 1. Macrograph of the weld with marked passes

Table 3. Chemical composition of the shielding gasses.

Chemical composition of shielding gasses, vol%		
Ar	He	N_2
Rest	-	0,015
Rest	50	0,015
Rest	70	0,015

the shielding atmosphere of Ar, N_2 and He. The presence of other types of defects that could affect on the quality of welds was not observed in none of the plates.

2.1. Specimens

Specimens for metallographic examination, tensile strenght testing, hardness testing, standard Charpy specimens with “V” notch for impact testing and fracture mechanic testing were cut out from welded plates. The geometry of standard Charpy specimens is shown in Fig.2.

Fracture mechanics tests aimed to estimate crack growth rate da/dN and fatigue threshold ΔK_{th} had been performed on the standard Charpy specimens, by bending method in three points on the CRACKTRONIC dynamic testing device. The measuring foils RUMUL RMF A-5, 5mm in length, were placed on the

Table 4. Welding parameters

Shielding gas	Current, (A)	Voltage, (V)	Welding speed, cm/min	Heat input (kJ/cm)
Ar+0,015%N_2	215-224	20-21	10-14	17-25
Ar+50%He+0,015%N_2	234	19-20	16-21	13-17
Ar+70%He+0,015%N_2	192-198	20-21	15-17	10-17

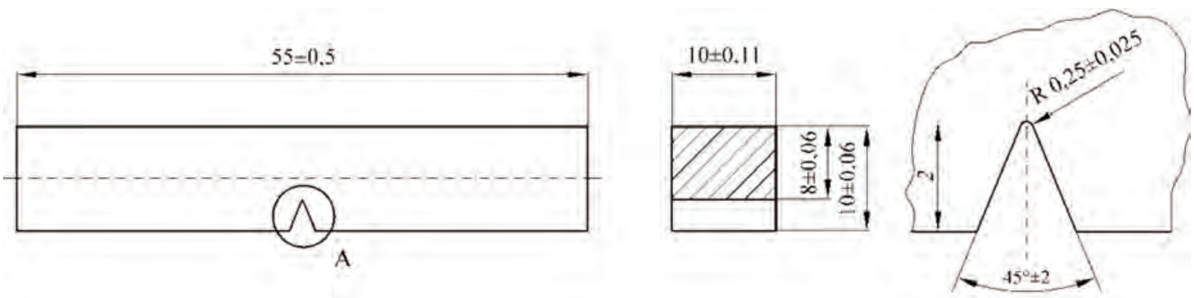

Figure 2. The geometry of standard Charpy specimens with “V” groove

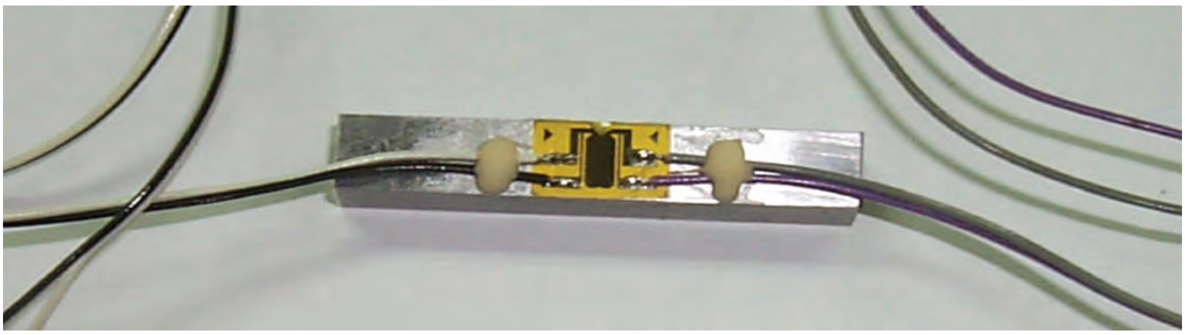

Figure 3. Prepared specimen for estimation fatigue crack growth parameters

mechanically prepared specimens. In this way, the crack growth was measured using the FRACTOMAT system, based on the electric potential of the foil, and connected with the instruments. The prepared specimen is shown in Fig 3. As the fatigue crack grows underneath the measuring foil, the foil becomes torn, following the surface of the fatigue crack. This changes the electrical resistance of the foil, linear with the change of the crack length.

3. Results and discussion

The microstructure of aluminium alloy AlMg4,5Mn, used in this experiment, is shown in Fig.4a. It consists of the metal grains with directional orientation, i.e., it is a tipical rolling structure with the fine grid of Mg_2Al_3, along the grain boundaries. Also, it can be seen larger and darker microconstituents, which are mostly Mg_2Si and $(Fe,Mn)Al_6$.

The weld metal structure of all welded plates is the same, which is to be expected, since the welding conditions are approximately the same. The only difference between the separate plates is the type of the used shieldihg atmosphere. In the weld metal, the intermetal phases along the grain boundaries can be found. The basic difference in the structure of the separate plates is in their porosity,which is dominantly found around the line of the joint between the two passes and HAZ. In Fig. 4b, the pore in the HAZ closer to the weld is

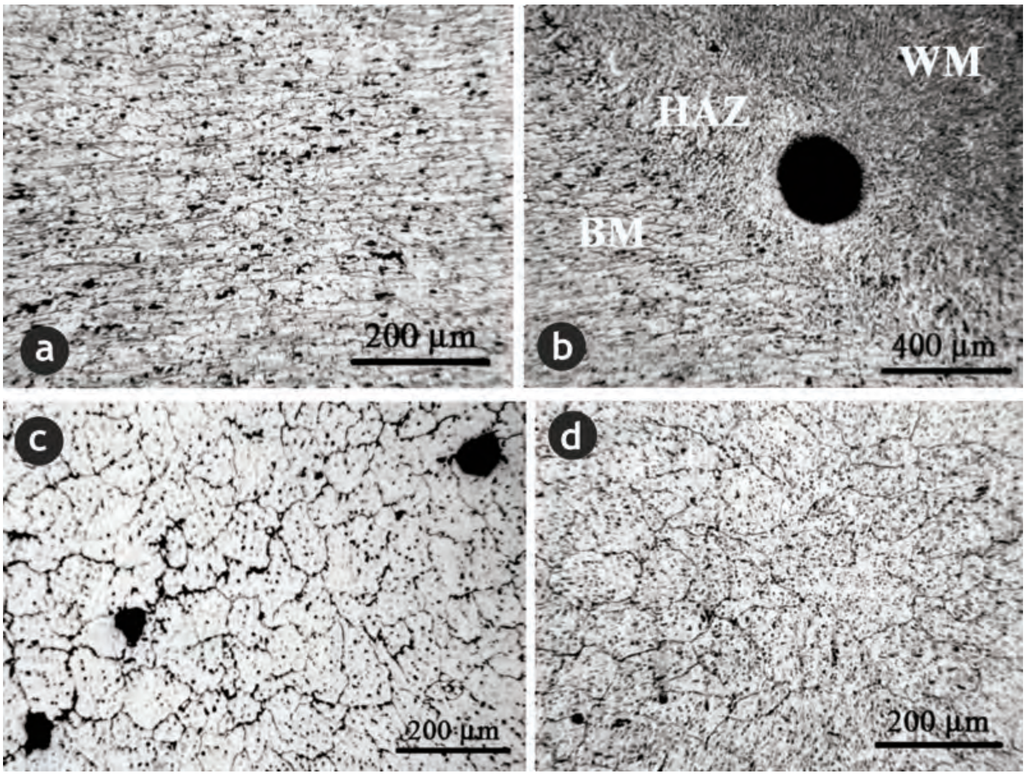

Figure 4. Microstructure of: a) base metal, b) the pore in HAZ, c) weld metal welded with Ar+0.015%N_2, d) Ar+50%He+0,015%N_2

shown. The highest porosity was found in the weld metal that had been welded with the shielding atmosphere Ar+0,015%N_2 (Fig. 4c). The Fig. 4d shows the weld metal structure, welded with Ar+50%He+0,015%N_2 which resulted in the considerable decrease of porosity.

The tensile tests were performed at room temperature. In the case of the specimens with parallel sides, due the tests were performed to estimate the tensile strenght of the weld in whole, the brake occurred between the HAZ and weld metal, regardless of the shielding atmosphere composition in mind the results shown, we can safely say that the tensile strenght of the weld in whole is not influenced by the composition of the shielding atmosphere.

The hardness of the welded joints was measured by Vickers method HV5. On the polished samples, the hardness of the welds was measured along the middle of the samples in base metal, the HAZ and the weld metal. The hardness of the base metal moved from 65-75 HV, while the values for the weld metal were 75-87HV, as shown in Fig 6. The hardness of the HAZ is not much different from the one in the base metal. As can be seen in Fig.6, the hardness of the weld metal is somewhat higher than the hardness of the base metal the most about 10%. Besides this, the hardness values for the weld metal in the helium shielding atmosphere were somewhat higher, leading to the conclusion that the larger amount of helium in the shielding atmosphere (up to 10%) results in the mild increase of hardness.

The weld metal impact test on the

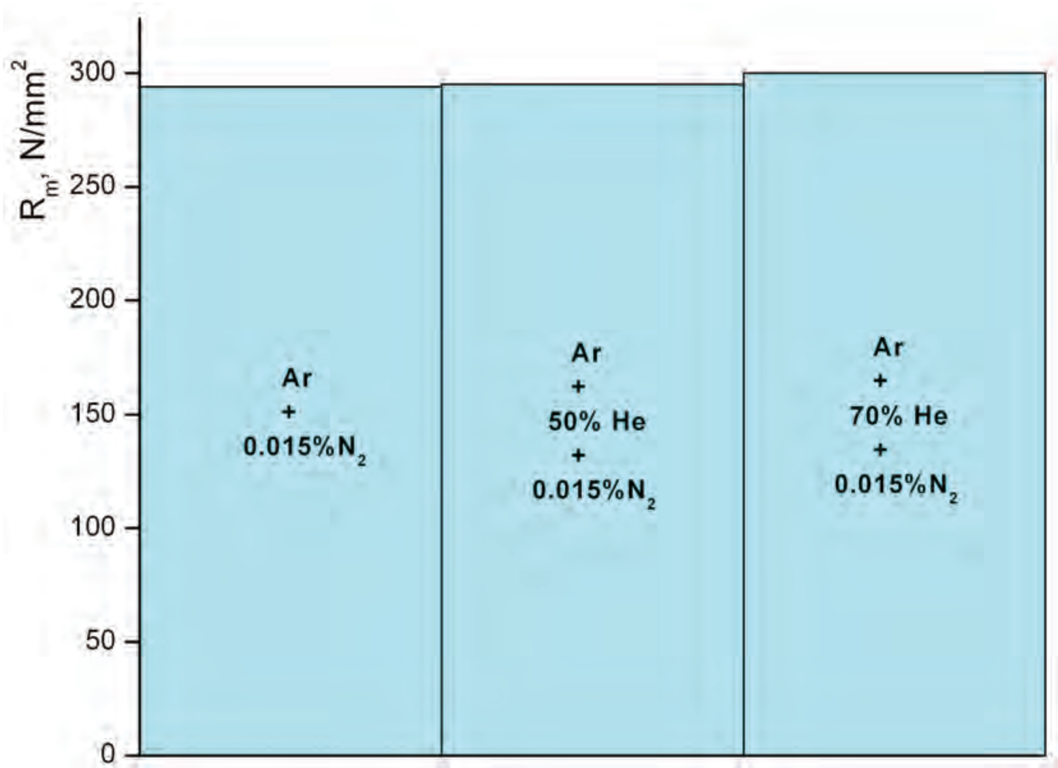

Figure 5. Tensile strenght of weld metal, depended of the composition of shielding atmosphere

standard Charpy specimens was performed on the instrumented Charpy system, where it is possible to divide the total impact energy, Et, on the crack initiation energy, Ein, and the crack propagation energy, Epr. The tests were done at temperatures of 20°C, -90°C and -196°C. The obtained results of impact energies are shown in Fig.7.

The total impact energy at 20°C, produced by welding in the shielding atmosphere Ar+0.015%N_2, is 24,5 J, while the crack growth energy is 21J. Adding large amounts of helium to the argon and nitrogen mixture causes the increase of toughness. This makes the toughness of the weld metal, produced in the shielding atmosphere Ar+50%He+0,015%N_2, 35J, and the crack growth energy 30J. As shown in Figure 7, the best toughness, as well as crack growth energy, has weld metal with the shielding atmosphere Ar+70%He+0,015%N_2. The total impact energy, at room temperature, of weld metal with shielding atmosphere of Ar+70%He+0,015%N_2, is 45J. At the same time, the crack growth energy is 41J. With the decrease of temperature to -90°C, the total impact energy and crack growth energy become 20-30% lower (depending on the type of the shielding atmosphere), when compared to the temperature of +20°C. At the temperature of -196°C, the drastic decrease of toughness is observed, e.g. the total impact energy and the crack growth energy. The crack initiation energy is very low, ranging from 3-5J at room temperature to 2-3J at -196°C. The crack initiation energy

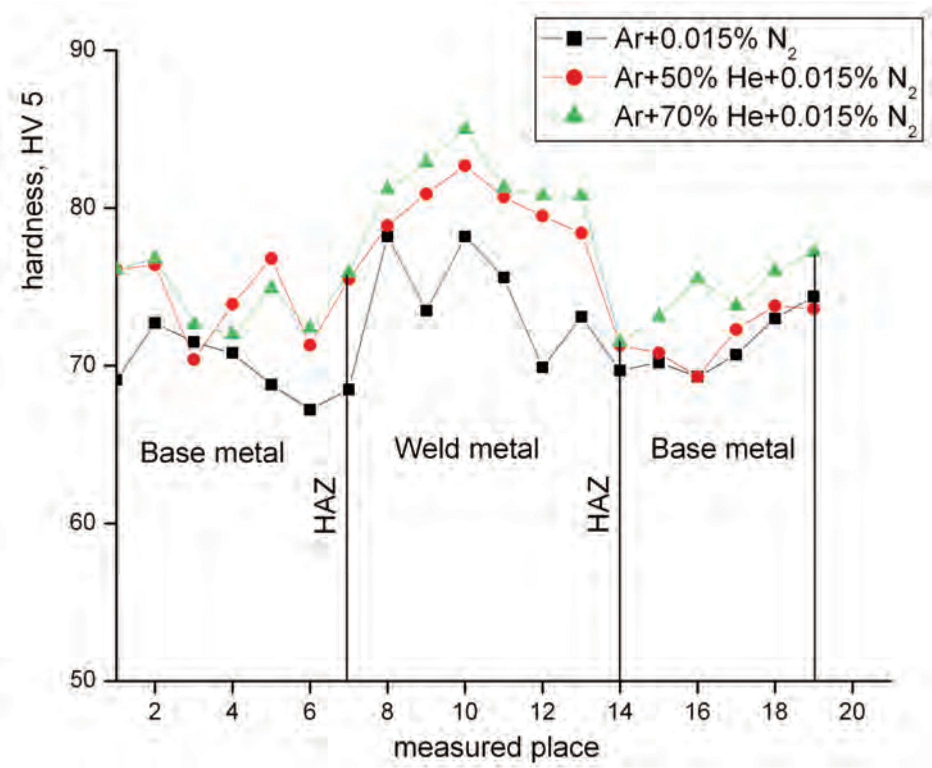

Figure 6. The hardness profile along the middle line of the weld metal in different shielding atmospheres

does not change with temperature. It is important to point out that the crack initiation energy, even at -196°C, is lower than the crack growth energy.

Estimation the dependency of the fatigue crack growth rate, da/dN, comes to defining the coefficient C and the exponent *m* in the Paris equation. Based on the testing results, the dependencies da/dN – ΔK are calculated and presented in the Table 5. The values of the coefficient C and the exponent *m* are given, which were taken from the samples welded with GTAW procedure, ih different shielding atmospheres. In this table, the values of the fatigue threshold ΔK_{th} are also given, next to the crack gowth rate da/dN, for all the zones of the stable crack growth on the Paris curve. The diagrams in the Figure 8 show the dependence between the crack growth rate, da/dN – strain intensity range ΔK.

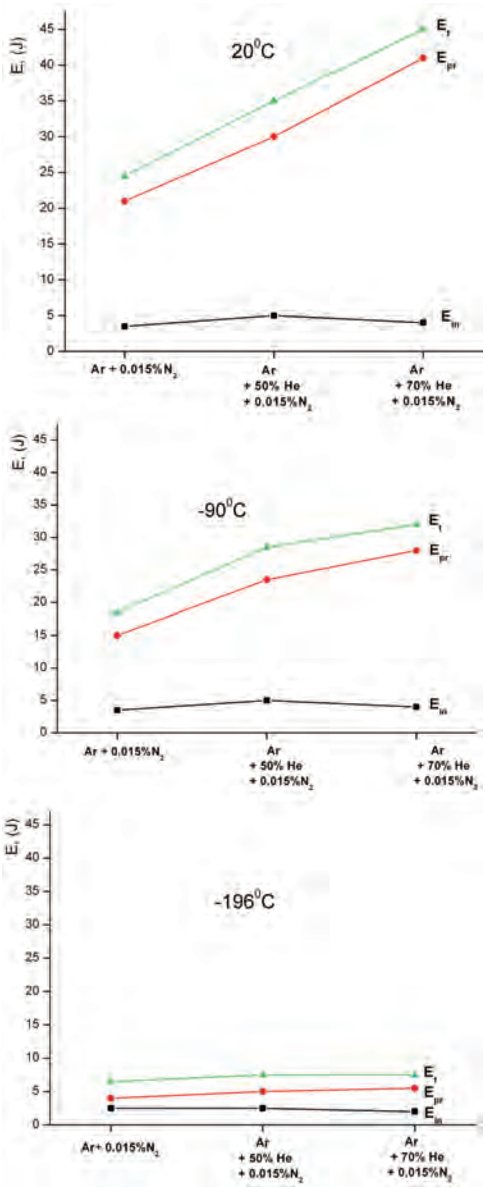

Figure 7. The total impact energy and its components vs. composition of shielding atmosphere at different temperatures

As seen in Table 5 and in Fig 8, the highest value of the fatigue threshold, e.g. the highest resistance to the crack initiation, belongs to the weld metal in the shielding atmosphere Ar+70%He+0,015%N_2. Precisely it is 3,13 MPa $m^{1/2}$. Among other samples, somwhat lower values were observed (3,06 -3,09MPa $m^{1/2}$), which still represents a significant resistance to the crack initiation. This means that the crack will initiated earlier, i.e. after less number of cycles, in the weld metal in Ar +0,015%N_2 shielding atmosphere, then in the Ar+50%He+0,015%N_2, and last, in the weld metal with the shielding atmosphere Ar+70%He+0,015%N_2.

Analyzing the results, it becomes obvious that the lowest fatigue crack growth rate, da/dN, e.g. the highest resistance to the crack growth of the existing crack is found in the weld metal with the shielding atmosphere Ar+70%He+0,015%N_2. The value is $0.7\cdot10^{-7}$m/cycle, which is three to four times less than the fatigue crack growth rate in the other samples ($2{,}78\cdot10^{-7}$m/cycle for the weld

Table 5. The coefficient in the Paris equation for the samples welded with GTAW procedure

Shielding atmosphere	**Fatigue threshold ΔK_{th}, MPa m$^{1/2}$**	**Coefficient C**	**Exponent m**	**da/dN, m/cycle ΔK = 7 MPa m$^{1/2}$**
Ar+0.015%N_2	3.06	$1.79 \cdot 10^{-11}$	4.96	$2.78 \cdot 10^{-7}$
Ar+50%He+ 0.015%N_2	3.09	$2.13 \cdot 10^{-11}$	4.74	$2.16 \cdot 10^{-7}$
Ar+70%He+0.015%N_2	3.13	$7.61 \cdot 10^{-13}$	5.88	$0,71 \cdot 10^{-7}$

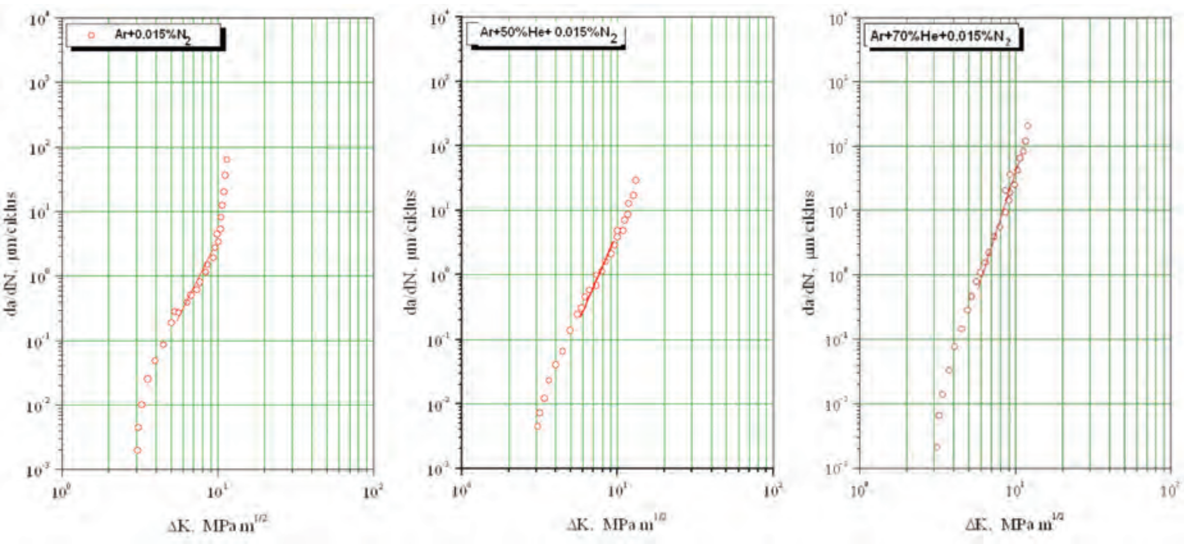

Figure 8. Diagrams da/dN – ΔK for weld metals, welded in different shielding atmospheres

metal with the shielding atmosphere Ar +0,015%N_2 and $2{,}16 \cdot 10^{-7}$m/cycle for the weld metal with shielding atmosphere Ar+50%He+0,015%N_2). In practice this means that the initiated crack will propagate three to four time faster, which will lead to the weld breakage in the other two samples. In the other words, the shielding atmosphere Ar+70%He+0,015%N_2 provides high resistance to the crack growth.

4. Conclusion

Adding helium to Ar and nitrogen mixture decreases the porosity level in weld metal, so the lowest porosity was observed in weld metal with Ar+70%He+0,015%N_2. The spilling of filler material increases due from the increased level of helium.

The shielding atmosphere composition has no significant affects on the tensile strenght of the weld in whole. Increasing the helium content in the shielding atmosphere leads to a mild increase of the weld hardness.

The testing temperature and the shielding atmosphere composition affect on the total impact energy and the crack growth energy. The crack initiation energy does not depend significantly on the testing temperature or the shielding atmosphere composition. The best toughness and the crack growth energy at all testing temperatures are found in the weld with the shielding atmosphere Ar+70%He+0,015%N_2.

The increase of helium content in shielding atmosphere significantly affects the weld metal toughness, so with adding 70 % helium to protective atmosphere the total impact energy and crack growth energy two times increases.

Increasing the amount of helium in the shielding atmosphere has slight effect on the increase of the resistance to the crack initiation, and moreover, on the decrease of the crack growth rate. This significantly increases the exploiting security and the lifetime of the construction.

Having in mind that the values of the fatigue threshold and the crack growth rate are analogue to the crack initiation energy and crack growth energy, a good correlation was achived in both cases. Increasing the amount of helium in shielding atmosphere results in an increase in the crack growth energy and the decrease of the crack growth rate. As for the energy needed to initiate the crack, the observed values come in small intervals, which is confirmed by the values of the fatigue threshold.

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