INFLUENCE OF SHIELDING GAS ON GMA WELDING OF Al ALLOYS

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The research is focused on influence of shielding gas on GMA welding process of precipitation hard enable Al alloys (6xxx and 7xxx). Pure Ar of different gas flow 0-35 l·min⁻¹, different Ar+He mixtures, up to 70 % He, active Ar+CO_2 gases were used. The optimum Ar shielding gas flow was found to be 15 l·min⁻¹, where under this value porosity and over this value decrease of weld penetration have been observed. He content in Ar+He shielding gas mixtures is changing heat input and therefore weld shape. Increase of He content improves heat transfer efficiency, weld penetration, weld width etc. Influence of theoretically known properties of gases on welding process (e.g. ionization potential, thermal conductivity etc.) is quite complex, so experimentally researched influence of gases and their mixtures done in this research with exact values and practical results are valuable for praxis.

Keywords
welding, GMAW, Al alloy, shielding gas, Ar, He, mixture

Introduction

For Al alloys and many other metals as well, strong oxidation occurs at elevated temperatures. In case of welding Al alloys use of inert gas is needed as gas mixtures with oxygen, so called active atmospheres, would cause weld porosity and embrittlement, welding process instability etc. This is because of oxide inclusions in WM and oxide surface layer that deteriorates arc stability and molten metal transfer.

Thus as shielding gas inert argon, helium and their mixtures should be used. Most often inert Ar is used. These inert gases have different physical properties, they influence the welding process and resulting weld significantly, so one of important parameters of welding process is selection of shielding gas composition, its flow volume etc.

Shielding gas during welding has several functions, e.g.:

1. weld protection from detrimental atmospheric gases (O_2, N_2, H_2),
2. creating environment for stable arc and
3. smooth molten metal transfer etc.

These functions are influenced by the physical, chemical, thermic properties of shielding gases and these properties are theoretically known and some of them are shown in Tab. 1 and Fig. 1. On the other hand it is difficult to know practical welding results just from theoretical data. This research focuses on practical influence of use of different gases as Ar, He and their mixtures, change of shielding gas flow rate on the GMA welding process and its results, so not only theoretical values, but practical results are shown.

Experimental

Experiment was done at robotic welding cell placed at interdepartmental Laboratory of welding technologies of CTU in Prague (Laboratoř výuky svářečských technologií na ČVUT v Praze) founded by Faculty of Mechanical Engineering in cooperation with other faculties of Czech Technical University. The shielding gases were supplied by Linde gas, a. s.

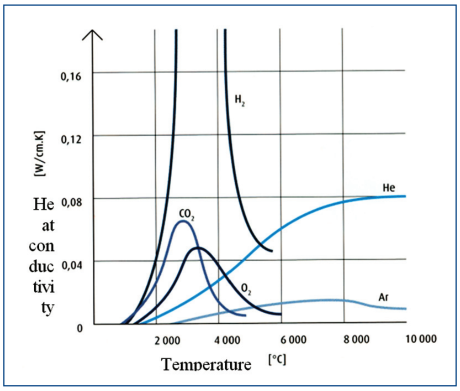

Figure 1. *Thermal conductivity of gases [Kopriva 2013]*

All the experiments were done by GMA welding with different shielding gas and positive wiring. Because Al alloys at high temperature oxidize easily and cover themselves with layer of aluminium oxide with high melting temperature, during welding the cleaning effect of positive ions disrupting this oxide layer, i.e. positive wiring needs to be used.

As base material two Al alloys were used: 1. EN AW 6082-T6 [AlSi1MgMn] sheets of thickness 3 mm and 2. EN AW 7022-T651 [AlZn5Mg3Cu] of thickness 6 mm were used. For first alloy, generally recommended filler metallic AlMg4,5MnZr and it was used. For the second alloy filler OK Autrod 5356 (AlMg5Cr) was used. These data are at Tab. 2.

Bead-on-plate welds of length 70 mm for 1st material and 160 mm for 2nd material were cladded on each sheet and gas shielding, gas flow rate were changed and welding parameters were adjusted to have stable welding. Shielding gases included in the research are Ar+CO_2, Ar, Ar+He mixture in different ratios. The welds were evaluated mainly by visual testing and optical microscopy of metallographic cuts. The welding process was observed by temperature measurement.

Forward welding, torch nozzle of diameter 16 mm, with inclination 18° and torch distance from the sheet surface 15 mm were typically used.

Gas	Density compared to air (air=1)	Ionization potential [eV]	Heat capacity (at 20°C, 1ATM) [kJ·kg⁻¹·K⁻¹]	Thermal conductivity (at 0°C) [W·m⁻¹·K⁻¹]
Ar	1.38	15.69	0.523	164 x 10^{-4}
He	0.14	24.49	5.230	1500 x 10^{-4}

Table 1. *Comparison of inert gases properties*

Material	EN denomination	Composition	Sheet thickness	Filler wire
1	EN AW 7022 T651	AlZn5Mg3Cu	6 mm	AlMg5Cr
2	EN AW 6082 T6	AlSi1MgMn	3 mm	AlMg4,5MnZr

Table 2. *Based materials and filler wire*

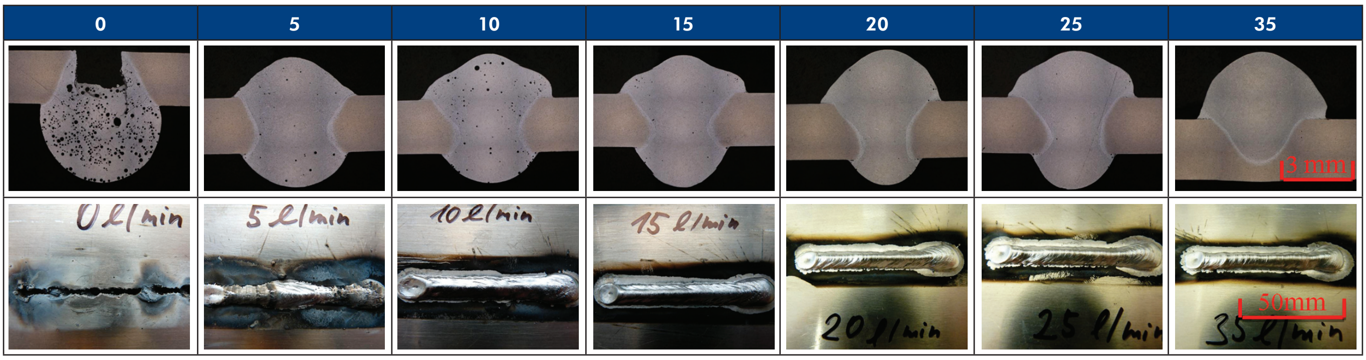

Table 3. *Cross section of welds created at different Ar shielding gas flow[l·min^{-1}]*

Gas mixture	Trademark	I [A]	U [V]	Welding speed [mm.s^{-1}]	Wire speed [mm.s^{-1}]	Real gas flow [l·min^{-1}]	q [kJ/mm]
100% Ar	ARGON 4.6	120	20.7	8.3	117	16	0.25
70% Ar+30% He	VARIGON He 30		22			22	0.25
50% Ar+ 50% He	VARIGON He 50		23			28	0.26
30% Ar+70% He	VARIGON He 70		24.5			34	0.28

Table 4. *Welding parameters*

Results

Use of active gas

The mixture of Arand CO_2 (82% Ar + 18% CO_2), Corgon 18, was used. This active gas is used typically for mild steels [Kopriva 2013], not for Al alloys, but to prove theoretically expected bad influence of oxygen presence, we executed this experiment. Welding current was 100 and 120 A, U=18 V, speed 8.4mm·s^{-1}, gas flow 15 l·min^{-1}.At Fig. 2, we can see that just slight change of welding current is causing big influence on weld shape, penetration etc. The difference of stability of welding process was also noted. For I=100 A the BM is almost not melted; it is like only the filler wire is laid on the surface of BM. The weld has very little penetration. The surface of the weld is very rough. The arc was unstable and caused unstable welding process.

On the other hand, increase of current to I=120 A, creates weld sagging. The arc is stable and constricted, narrow. This causes small width of the weld. The welding results are unacceptable.

These properties and weld shape are caused by presence of oxygen in shielding atmosphere. The oxygen presence is enabling oxidation, creation of thick oxide film and release of heat. This oxide film composed of ceramics Al_2O_3, acts as electric and heat insulator. This film interferes with electric arc, because through oxide film the current cannot flow steadily. Only in places of film disruption, places with the lowest potential barrier, which is moving on the surface the current can flow. Increase of current enables more oxidation, releases more heat, disrupts the oxide film in certain places, but still the arc is constricted to area of disrupted oxide film. All energy of the arc is concentrated on small area and its overheating causes weld sagging. It also needs to be considered that wettability of $Al_2O_3$with molten Al is bad. From the shape of the clad, we can notice very high contact angle between clad and BM. The low wettability of molten aluminium and aluminium oxide, high contact angle 100–180° at 700°C was measured by [Aguilar-Santillan 2008].

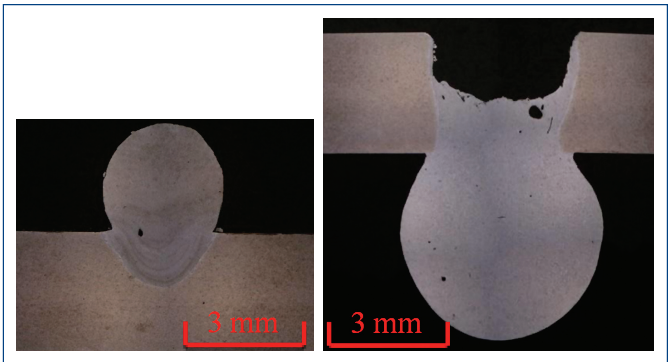

Figure 2. *Bead on plate welds in active gas, Left – I= 100 A, Right – I= 120 A*

These results give evidence that use of active shielding gases is not suitable for Al alloys and only inert gases, not reactive with the Al alloy, should be considered.

Ar gas – Influence of shielding gas flow

As standard inert gas, Ar 4.6 is used. The influence of flow volume on weld quality was to be observed. The gas flow was varied from 0-35 l·min^{-1}. The cross sections are shown in tab. 3.

For flow of 0 l·min^{-1}, i.e. no shielding, the porosity and weld sagging is visible. The nitrogen and other gases in the air create porosity and presence of oxygen, oxide film constricts the arc power into area too small, so weld sagging easily occurs. The results are similar with Ar+CO_2 welds at fig. 2. Flow of5 l·min^{-1} causes irregular welding process, especially at the beginning and end of the weld. For 10 l·min^{-1} the porosity was observed. The optimum results were obtained for 15 l·min^{-1}, which has good penetration, width and little porosity. Also the weld shape is optimal and weld bead is regular.

The flow volume over 15 l·min^{-1}was researched in other research by our group [Kolarik 2009]. From the tab. 3, it can be noted that for too high flow volume the weld shape is adversely influenced and at very high flow the full penetration is not reached. The decrease of weld width and depth is caused probably by cooling effect of flowing gas. Too high gas flow can also create turbulences and intakes air into shielding gas, affecting detrimentally the shielding quality.

Gas mixtures of Ar+He [Kolarik 2009]

For this experiment 6 mm thick sheets of EN AW 7022-T651 [AlZn5Mg3Cu] were used. The gas metal mixtures are as listed in tab. 4, from the mixing ration 100 % Ar to 30 % Ar+70 % He.As standard welding parameters are I = 120 A, U = 20.7 V, wire speed 117 mm.s^{-1} and welding speed 8.3mm·s^{-1}. Filler wire OK Autrod 5356 (AlMg5Cr). Because Ar, He gases have different densities, to maintain approximately the same shielding effect, the flow of the mixture needs to be changed. With increase of He content in the mixture, because of its low density, the flow needs to be increased. This correction was applied according to data supplied by Linde Gas [Kopriva 2013] and is noted in tab. 4. It is important to note, that

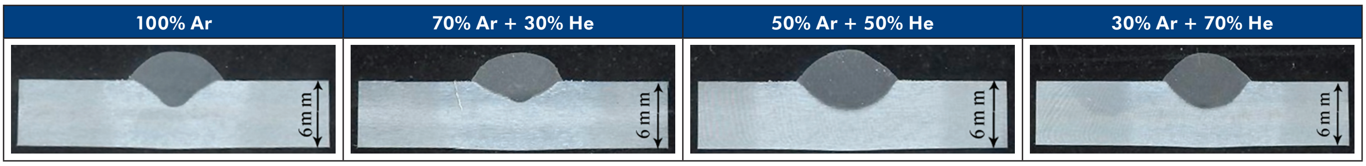

Table 5. *Metallography of welds made with Ar – He mixtures*

also voltage needed to be adjusted to have stable arc. The increase of He presence demanded setting higher voltage to have stable arc as it has higher ionization potential. The necessary voltage was the highest for the mixture containing He 70 %.

At the tab. 5, the cross sections of resulting welds are shown and at the tab. 6 the sizes of the welds are noted. Typical shape for Argon gas 4.6 has narrow root and use of helium widens and rounds the shape of root, weld and HAZ. This is in accordance with expected values and literature. It is caused by two factors – 1. He compared to Ar has higher thermal conductivity and 2. He has higher ionization energy, so more voltage of arc is needed. Both of these factors sum up to increase of heat input. The highest increase of weld depth and width was noted when pure Ar is compared to Varigon 70, where weld depth increased from 1.6 to 2.5 mm, width from 8 to 10.2. From this point of view, Varigon 50 and 70 are giving the best results. Tab. 6 also shows decrease of weld reinforcement with increase of He, which is good when dynamic properties of the weld are concerned. Generally increase of weld width and penetration depth is considered advantageous for welding.

Shielding gas	Weld reinforcement [mm]	Weld depth [mm]	Weld width [mm]	Width of HAZ [mm]
Argon 4.6	2.3	1.6	8	12.,5
Varigon 30	2.2	1.9	9	13.8
Varigon 50	2.0	2.3	9.5	15
Varigon 70	1.9	2.5	10.2	17

Table 6. *Size of the welds*

To evaluate in detail the influence of He and Ar gas on heat transfer, temperature measurement system was used. Monitoring system WIS (Welding Information System) by company TESYDO enables to measure in real time welding parameters, temperatures from up to 6 thermocouples. Thermocouples were placed 10, 20 and 30 mm from the weld axis, fig. 3. The geometry of the welds, metallography was observed and microhardness measured. These results were published in the previous research work [Kopriva 2013]. As an example, thermal cycle as measured by thermometer at distance 10 mm from the weld axis at fig. 4 is shown. It is obvious that the more He gas is present in the mixture, the higher the measured temperature, i.e. heat input into the weld.

From the graphs of thermal cycle, it is visible that the measured temperatures are increasing with the increase of He percentage in the mixture. For Ar 4.6 max temperature reached at 10 mm distance from weld axis was 240 °C, while it increased almost by 40 °C to 280°C using Varigon 70. All the He containing mixtures increased maximum temperature of thermal cycle, i.e. efficiency of welding.

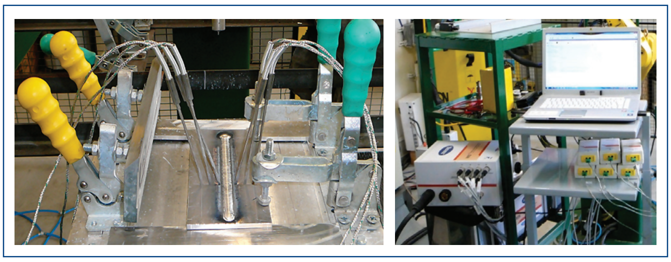

Figure 3. *Temperature measurement – position of thermometers and WIS systemTable 1 Comparison of inert gases properties*

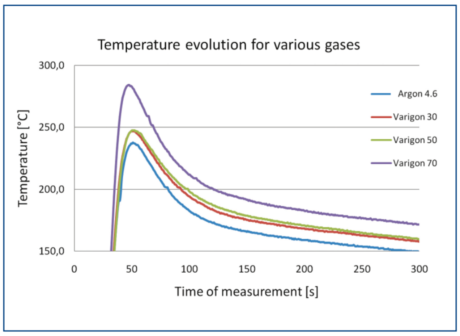

Figure 4. *Weld thermal cycle for different gases mixtures*

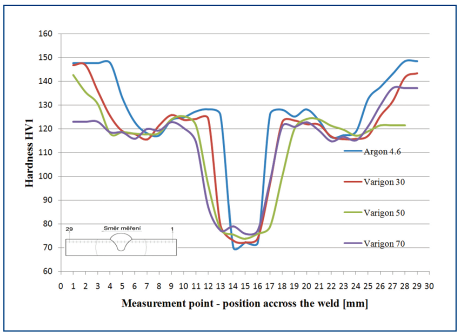

Figure 5. *Hardness profile using different gasses at EN AW 7022 T651 [Svanda 2012]*

At the fig. 5, hardness as measured across the weld is shown for alloy EN AW 7022 T651 welded with different gas mixtures. The distance of the indentations is 1 mm and line of indentation was 2 mm under the sample surface. In the WM and HAZ the decrease of hardness, i.e. strength was observed. Original hardness of BM is 150 HV1, in WM it decreased to approx. 75 HV1. In HAZ the hardness is between 115–130 HV1. In the hardness graphs is also visible that the weld width, width of HAZ are influenced by use of the gas. The root is widest with Varigon 50, Varigon 70 and pure Ar has the narrowest root.

The effect of welding upon decrease of hardness and strength in WM and HAZ is typical for precipitation hardened Al alloys, this is in concordance with [Davies 1993].

Conclusion

Several GMA welding experiments for Al alloys using different shielding gases, Ar+CO_2, Ar, Ar+He mixtures were done. Necessity to use inert shielding gas with right flow set accordingly to welding parameters was proved, because welding process in atmosphere with presence of oxygen resulted unstable as the oxide layer worsens arc stability, creates high contact angle of melt on BM, creates weld sagging and leads to porosity. Obviously the mechanical properties are adversely influenced. Use of inert gas is a must and suitable are Ar, He and their mixtures.

Optimum Ar shielding gas flow was found to be 15 $l \cdot min^{-1}$forused welding parameters. With lower flow porosity was formed and too high gas flow decreased weld penetration.

The experiments with varying He ratio in Ar gas has proved that increase of He content increases heat transfer into the weld, increases heat input. The increased heat input is caused by properties of He, higher ionization potential (i.e. arc voltage) and by thermal conductivity. Overall the He use can improve welding efficiency and speed. He gas is advantageous also for improved weld shape and decrease of porosity.

Acknowledgement
This research was supported by grant projects SGS ČVUT 2010 OHK2-038/10 and FRVŠ G1 611/2011. Authors would like to express thanks to Linde Gas a.s. for supplying the shielding gases.

Literature
[Aguilar-Santillan 2008] Aguilar-Santillan Joaquin, Wetting of Al Oxide by Molten Aluminum, Additions Journal of Nanomaterials, Volume 2008, doi:10.1155/2008/629185
[Davies 1993] Davies, Joseph. ASM Speciality Handbook: Aluminium and Aluminium Alloys, ASM International, 1993, 784 s. ISBN 978-0-87170-496-2
[Kolarik 2009] Kolarik, L., Dunovsky, J., Kovanda, K., Berka, J., Conventional welding methods-temperature influence of hardenable aluminium alloysof type Al-Mg-Si (in Czech) Techmat 2009. University of Pardubice, Svitavy, 2009
[Kolarik 2011] Kolarik, L., Kovanda, K., Valova, M., Dunovsky, J. Assessment on the porosity of the filler material in the welded joints MIG welding hardenable aluminium alloy of type AlMgSi (in Czech), Strojirenska technologie XVI, 1/2011, 2011
[Kopriva 2013] Kopriva, J.: Technical gases, Training base for welding engineer CTU (in Czech), 2013. 46 s.
[Svanda 2012] Svanda, Jiri. Diploma thesis: Shielding gas effect of weld quality by GMAW welding Al alloys (in Czech), 82 s. Prague CTU, 2012, ISSN 1211-4162

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