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TECHNICAL AND ECONOMIC ASPECTS OF PULSED MIG WELDING OF AL 5754

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ABSTRACT
Aluminium and its alloys represent very important group of structural materials. They have many applications in mechanical and civil engineering, and welding is considered to be principal joining technique. However, aluminium has several issues, like high thermal conductivity and easy formation of oxide layer. Welding also has its own issues related to heat input, and there are requirements regarding surface preparation as well. Among commonly used TIG and MIG processes, pulsed MIG (and its variants) are introduced to fulfil requests regarding both heat input and oxide layer removal during welding. This paper gives overview of technical aspects of these processes. In addition, more details regarding welding of widely used aluminium 5754 alloy with thickness of 4 mm is elaborated. Comparison of parameters, achieved weld quality, welding time and costs is given as well. In conclusion, all used processes are evaluated based on required criteria.
Keywords: aluminium, pulsed MIG, weld quality, costs

1. INTRODUCTION
Aluminium and its alloys have numerous applications for mechanical and civil engineering. The most important reasons are excellent corrosion resistance, high specific strength, and great technological properties. [1,2] Joining of aluminium alloys can be done by riveting, nuts and bolts, adhesive bonding, and welding. In particular, welding is used in automotive industry and vessel manufacturing, even though is more complex than welding of most of the steels [3]. Principal reasons for this are excellent heat conductivity, relatively low melting point, oxide layer on surface (with melting temperature slightly above 2,000 °C), and fact that aluminium alloys are prone to hot cracking. Therefore, welding of aluminium requires more detailed knowledge about alloy, specific welding equipment, precisely controlled welding conditions and well-trained welding personnel.
Many issues related to welding of aluminium and its alloys usually can be solved by precise control of heat input, i.e. if heat input is as low as possible, and as high as required. Therefore, solid-state friction stir welding process, and its variants, became often used to weld aluminium alloys. [4] Nevertheless, this process still has certain disadvantages, leaving significant part of aluminium welding industry to rely on fusion welding processes. Two main fusion welding processes used nowadays are tungsten inert gas welding (TIG or GTAW) and metal inert gas welding (MIG). [1] MIG process has evolved into several variants, with idea to reduce heat input and avoid problems induced by it. [5] Heat input control is achieved by using digitally controlled heat sources, automatization, and welder/operator training. However, it requires significant investment in equipment and training. [7D] It is necessary to evaluate feasibility of such investment for each case of welding, independently and ubiasedly.

2. PULSED MIG WELDING PROCESS

MIG process is usually used in serial or mass production. Several modifications of MIG process have been developed, and pulsed MIG is one of them. [5] It is a variant of the conventional MIG welding process in which the current is pulsed. Pulsed MIG welding is a modified spray transfer process, in which the power source switches between a high peak current and a low background current 30 to 400 times per second. During this switch, the peak current pinches off a droplet of wire and propels it to the weld joint. The background current maintains the arc, but have heat input low enough that metal transfer cannot occur. This action differs from a standard spray transfer process, which continuously transfers tiny droplets of molten metal into the weld joint. It also allows the weld puddle to freeze slightly to help prevent burn-through. [6] The cycle consists of applying the repeated pulse current over a constant background current, as illustrates Figure 1. Background current can be as low as 15 A.

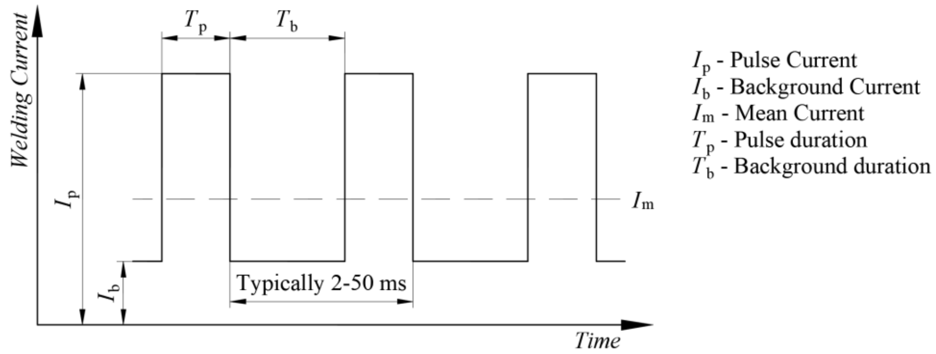

Figure 1. General principle of pulsed MIG [6]

Modern welding devices permit the use of a wide range of pulse amplitudes, durations and waveforms at frequencies from a few Hertz to a few hundred Hertz. Selection of pulse parameters for a given wire feed speed is a complex operation. Pulsing must provide enough heat to melt filler material (wire) and to detach exactly one drop of molten metal per pulse.
Pulsed MIG allows welding at higher deposition rates for all positions where dip or spray transfer is not applicable. It is used mainly for welding of aluminium and stainless steel [6]. Since this process uses advanced electronics to control process, it is not economical to use it where cheaper alternatives are available. Different manufacturers of welding equipment use various brand name for pulsed MIG, but the principle is the same [5,7,8].
Pulsed MIG offers advantages when welding aluminium. It yields the lowest possible heat input, and most of the issues regarding unnecessarily high heat input are avoided. However, it has also few disadvantages. Production rate (meters of weld per minute) is lower than with dip transfer (i.e. MIG) due to decrease of wire feed rate as heat input increases, and there are also limitations regarding usage of shielding gases in comparison with dip transfer. [9]

3. EXPERIMENT, EXAMINATION AND COST CALCULATION

Aluminium plates were welded and visually examined. This ensures that all considered welds have comparable quality. Costs are calculated based on measured parameters. The investment in welding equipment and welder training is not considered, because it can vary significantly.

3.1. Experiment

Sheets of aluminium alloy 5754 (chemical composition given in Table 1) with thickness of 4 mm were used. Several horizontal fillet welds were made, each 120 mm long, without weld preparation. All welds are made as single-pass. Table 2 gives data about filler material for welding process. It has been chosen according to recommendation given by filler material manufacturer. Filler material is Al 5356 wire with dimeter of 1.2 mm.

Table 1. Chemical composition of Al 5754 [10]

%wt									
Mg	Mn+Cr	Mn	Si	Fe	Cr	Zn	Ti	Cu	Al
2.60-3.60	0.10-0.60	0.50	0.40	0.40	0.30	0.20	0.15	0.10	bal.

Table 2. Chemical composition of filler material [11]

%wt									
Mg	Mn+Cr	Mn	Si	Fe	Cr	Zn	Ti	Cu	Al
4.50-5.50	-	0.05-0.20	0.25	0.40	0.05-0.20	0.10	0.06-0.20	0.10	bal.

All welds were made simulating shop floor conditions. Welding parameters were chosen according to recommendations from filler material manufacturer and available welding procedure specifications. Pulsing frequency has been chosen by recommendations given by manufacturer of welding equipment. Parameters are given in Table 3. Shielding gas is argon. No pre-heating has been applied, since it is recommended only for thickness greater than 16 mm [12].

Table 3. Welding parameters [10,11]

Current, A	Voltage, V	Pulsing frequency, Hz	Shielding gas, l/min
105	19.5	85	20.0

Aluminium sheets were cleaned with trichloroethylene, rinsed with distilled water, dried, and then cleaned with stainless steel brush. [13]

3.2. Examination of samples

Examination of welded samples has been done to ensure that all welds have comparable quality level in accordance with ISO 10042 (Welding - Arc-welded joints in aluminium and its alloys - Quality levels for imperfections). Welds were evaluated visually immediately after welding and, additionally, cross-sections were cut from each weld to evaluate weld geometry and porosity. Samples were visually examined in accordance with ISO 17637 (Non-destructive testing of welds - Visual testing of fusion-welded joints). Macro sections have been prepared and examined in accordance with ISO 17639 (Destructive tests on welds in metallic materials - Macroscopic and microscopic examination of welds).

Figure 2. Welded sample (left) and sample after cutting for macroscopic evaluation (right)

No cracks have been detected in welds. No porosity has been found after cutting and polishing of cross-section specimens, and no spattering has been found on the surface. All welds are symmetrical, with properly made root and full penetration. No root gap or excessive convexity has been detected.

3.3. Calculation of welding costs

Welding costs are one of the most important and limiting factors of application of certain welding process. In this study, simple method has been employed to calculate welding costs. [14] It is explanatory, yet avoiding relatively complicated cost calculation with amortization rates and additional expenses (e.g. weld preparation, pre- or post-welding heat treatment).

$$C = C_{\mathrm{w}} + C_{\mathrm{fm}} + C_{\mathrm{sg}} + C_{\mathrm{ee}} \tag{1}$$

Costs calculated in this study include only direct costs, as Equation 1 shows. That are costs of welder (C_{w}), filler material (C_{fm}), shielding gas (C_{sg}), and electricity (C_{ee}). Investments required for equipment and welder's training are not included. All costs were calculated using parameters measured during and after welding. Current and voltage were measured by independent devices. Weight of deposited metal has been determined by weighing samples before and after welding. Shielding gas flow was measured at reduction valve.

4. RESULTS AND DISCUSSION

As demonstrated, it is possible to successfully utilize pulsed MIG for welding of aluminium alloy 5754 in given conditions. Regarding filler metal, it is enough to follow recommendations of their manufacturers. After visual examination of welds and cross-sections, no unacceptable imperfections have been found. Based on visual examination and macroscopy, all welds could fit into highest quality class (class B) according to ISO 10042. The only difference among welds is subjective, and it considers aesthetical appearance of welds.

Analysing only direct welding costs (as Equation 1 shows) revealed that using pulsed MIG is just slightly more expensive than MIG. That is because pulsed MIG requires (a) higher flow rates of shielding gas than MIG and (b) well-trained welder, which is more expensive. On the other side, welding time is reduced if using pulsed MIG, so that reduces difference with MIG.

5. CONCLUSION

To evaluate pulsed MIG processes, an experiment has been conducted. Plates of aluminium alloy 5754 with thickness of 4.0 mm have been welded. Welds are examined visually and macroscopically. Based on information obtained through this, their quality is evaluated as acceptable. Subjectively, welds have excellent look.

Beside this, feasibility (i.e. costs and welding time) has been estimated. Certainly, pulsed MIG offers remarkable advantages regarding heat input control, thus reducing costs. However, it also requires significantly higher investment in equipment and training. If compared with regular MIG, it can be concluded that under circumstances presented in this paper, pulsed MIG could not be described as feasible.

6. REMARKS

Advantages offered by pulsed MIG could be visible in other conditions. That includes thin aluminium sheets (e.g. 1 mm), specific aluminium alloys, or specific products where heat input is strictly limited (e.g. measuring equipment). Regarding costs, two facts should be considered. Investment in equipment and training makes using pulsed MIG by far more expensive. However, pulsed MIG reduces heat input, avoiding necessity for post-weld heat treatment. Pulsed MIG is possible with digitally controlled welding devices, which also offer soft start, hence avoiding necessity for preheating as well. Further research could be done by analysing all abovementioned factors influencing total costs, together with weld quality achievable by using pulsed MIG.

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