COST COMPARISON OF FSW AND MIG WELDED ALUMINIUM PANELS

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ABSTRACT

Weld production tests were made using friction stir (FSW) and MIG welding for welding extruded panels. Production times were measured using a 2-m long double-skinned EN-AW 6005A-profile joint as a basic unit. Production time data were used for productivity calculations of different welding machine arrangements. Furthermore, a cost comparison was made based on the production time, machine investment, license, consumable and tooling costs. MIG welding costs were dominated by labour wages and machine investment and by a lesser degree by filler material costs. FSW costs were dominated by machine investment, fabrication license and labour wages. FSW was more economical than MIG when the annual production volume was large enough, in the order of some tens of km of weld per year.

IIW-Thesaurus key words: *Friction Stir Welding; MIG welding; Pulsed arc welding; Comparisons; Production time; Costs; Production; Fabrication; Efficiency; Aluminium; Extrusion; Human factors.*

1 INTRODUCTION

Friction stir welding, FSW [1] has made a break-through in extruded aluminium panel fabrication, where the technical process advantages are the greatest. In comparison to MIG welding in hot-, mixed-, pulsed- or tandem-arc mode, FSW is simpler joining process with no metal fusion, filler wire, shielding gas nor pre-welding oxide removal. It is specifically suitable for easily extruded materials such as 1000-, 3000- or 6000-series aluminium alloys. It is also capable for welding of all other aluminium alloys, including those not weldable by fusion welding processes. Even though many technological studies on FSW process principle, joint strength and microstructure have been published, papers concentrating on process productivity and other economical issues are rare.

Midling and Johansen [2] present a comparison of 12 m $\times$ 0,93 m freezer panel production using FSW and pulsed MIG from four 233 mm wide extrusions and from two large scale extrusions. Each panel consists of six 12-m long welds, three welds in the top and three welds in the bottom of the panel. The annual FSW production line capacity is 952 panels and that of the MIG line 434 panels per year. When full production capacity is in use, the FSW line produces 68,5 km of weld a year at a cost of 7.8 \$/m while the MIG line produces 31.2 km of weld a year at a cost of 14.3 \$/m.

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In this study, industrial welding fabrication was simulated using both FSW and MIG welding. Production times were shared to appropriate categories and measured. Furthermore, a demonstration of process cost calculation was made in order to show the economical possibilities and limitations of the two processes.

2 EXPERIMENTAL

A test profile was designed for FSW (Fig. 1). The current MIG-welded profile was redesigned from a V- to an I-groove configuration to meet the requirements of the autogenous FSW process. The vertical point load from the FSW tool shoulder was estimated to be some thousands of N, which a 2 mm thick web plate can withstand. The triangular shaped "anvil" under the welding position was dimensioned a little narrower than the width of the FSW tool shoulder diameter.

The profiles were FS-welded at ESAB in Sweden in a 2-m long laboratory welding machine (Fig. 2). The production cycle time was measured for a 2-m long profile joint. Welding was done from one side first, the specimen was turned and the other side was then welded. The total weld length in a specimen was thus 4 m. Welding speed was 150 cm/min.

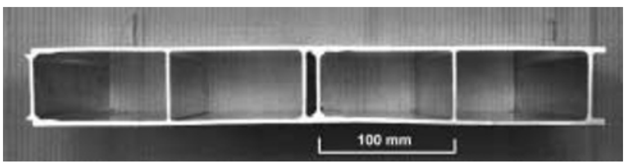

Fig. 1. Cross-section of the welded profile.

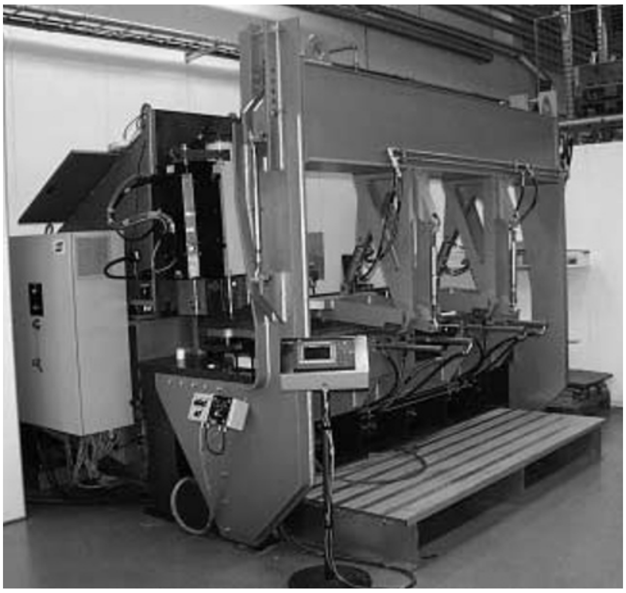

Fig. 2. ESAB laboratory FSW machine
(Photo: ESAB).

The MIG welding test for a similar profile joint was done in a workshop with a mechanised pulsed-arc MIG welding machine with a welding speed of 54 cm/min. Direct production times for both MIG and FSW were measured and are shown in Table 1.

Due to the faster welding speed, the "arc time" in FSW was only 34% of the MIG arc time. Pre- and post-welding oxide removal was not necessary in FSW. Clamping of the test profile needed some extra effort in the FSW machine, due to the distortion of the as-fabricated profiles. This distortion can be seen in Fig. 1. Set-up blocks were fitted under one of the profiles before clamping for the first weld seam of a joint. In the FSW machine, correct workpiece lining was checked after each clamping. The MIG machine was equipped with seam tracking, so that accurate lining was not necessary. Positioning of the welding head to the start position was semi-automatic in the FSW machine and hand-driven in the MIG machine. In FSW, no protection of personnel was needed, while in MIG welding protective head mask and leather gloves were put on and removed three times: before and after pre-welding oxide removal and when welding the first and second weld runs.

Table 1. Measured production times in test welding.

	FSW [min]	MIG [min]
"Arc time"	2:31	7:22
Oxide removal	–	6:14
Lifting & clamping	8:04	3:11
Lining check	6:40	–
Welding head positioning	2:25	5:13
Welding personnel protection	—	2:00
SUM	19:40	24:00

3 DISCUSSION

3.1 Production time estimation

Test conditions were not optimised for the production case. Consequently, measured times in Table 1 are not directly comparable to a real fabrication situation. It is thereby motivated to use measured data to calculate "what-if" scenarios for more relevant machine arrangements. Feasible machine arrangement options 1 and 2 will be used (Table 2). FSW option 1 contains no lining check and non-distorted profiles are used. This can be relatively easily arranged in the production. FSW option 2 contains no lining check, non-distorted profiles and uses two simultaneous welding heads, one in the flat position (PA) and one in the overhead position (PE). MIG option 1 contains automatic welding head return to home-position and MIG option 2 contains automatic return and two parallel welding heads in the flat position (PA). Use of parallel welding heads is naturally applicable only when wide panels are fabricated from three or more extrusions, since MIG welding is only done in the flat position (PA). MIG option 2 is therefore a calculation of the average welding time of one profile joint of a wide panel.

Calculated weld production times for machine options 1 and 2 are shown in Table 3. It is possible to save a considerable time if FSW is used instead of MIG-welding. This is mostly due to the time spent for oxide removal in MIG welding, lower welding speed in MIG welding and no time spent for personnel protection.

3.2 Production cost estimation

A spreadsheet-based calculation sheet was developed for comparison of direct welding costs of virtually any two welding methods. The cost elements are: machine investment cost, license (only FSW), labour wages, tool (FSW only), filler material (MIG only), energy, and shielding gas (MIG only).

Welding costs were calculated for several machine and license arrangements and annual production rates. Welding duty cycles were taken from the measurements shown above. Welding costs were calculated per meter of fabricated weld.

Generally, MIG welding was more cost effective in small-volume production, as can be seen schematically in

Table 2. Fabrication options 1 and 2.

	Option 1	Option 2
FSW	No lining check, straight profiles	No lining check, straight profiles and 2 simultaneous welding heads (up and down)
MIG	Automatic return	Automatic return and 2 simultaneous welding heads (parallel)

Table 3. Calculated production times for machine options 1 and 2.

	FSW opt. 1 [min]	FSW opt. 2 [min]	MIG opt. 1 [min]	MIG opt. 2 [min]
"Arc time"	2:31	1:15	7:22	3:42
Oxide removal	–	–	6:14	6:14
Lifting & clamping	5:34	2:20	3:11	2:08
Lining check	–	–	–	–
Welding head positioning	2:25	1:10	2:40	1:35
Welding personnel protection	–	–	2:00	1:20
SUM	10:30	4:45	21:27	14:59

Figure 3. As the annual production amount increases, FSW welding becomes more economical than MIG welding.

A calculation example of the costs in FSW option 1 and MIG option 1 is shown in Table 4. In this particular example 50 000 m annual weld production is assumed. Other arbitrary assumptions for the machine and production costs are shown in Table 4. TWI fabrication license is taken as 43 000 €/year, which is the estimated cost for non-member companies. Fig. 4 shows the same total weld costs for different amounts of annual production.

The costs per weld meter calculated in Table 4 are significantly lower than the costs shown by Midling and Johansen,(2) who used machine investment costs of 800 000 $ and 200 000 $ for FSW and MIG and labour wages of 100 $ per hour (2 operators). In this calculation (Table 4) the machine investments were taken as 160 000 € and 100 000 € and labour wage as 25 €/h (1 operator).

In practice, welding cost calculations have to be made for each specific production case. This calculation example should therefore not be taken as a reference before own calculations with specific costs (e.g. equipment, interest rate, license, labour wage and others) are made. However, a cost comparison with numerous informations shows the order of magnitude and the share of costs in different categories for a good overview information. It must also be stressed that none of the FSW process advantages, such as low distortion, high strength, uniform quality and improved occupational health issues, have been taken into account in the calculations due to the fact that no general valuation can be made for these issues.

4 CONCLUSIONS

FSW production time in the test evaluation was 82% of the corresponding MIG production time.

FSW production times for the calculated machine options were 22 – 70% of the corresponding MIG production times.

Machine investment, license and labour wages overrule in FSW production while other variable costs are small.

Labour wages overrule in MIG production while machine investment is lower than in FSW and no licensing is needed. Filler material and shielding gas costs make up some 15% of the total costs.

With increasing production amount, the curves intersect and FSW production costs become lower than MIG production costs. The justified choice of FSW instead of MIG before the intersection point can be due to the FSW process advantages such as low distortion, high strength, low amount of welding defects and improved occupational health issues.

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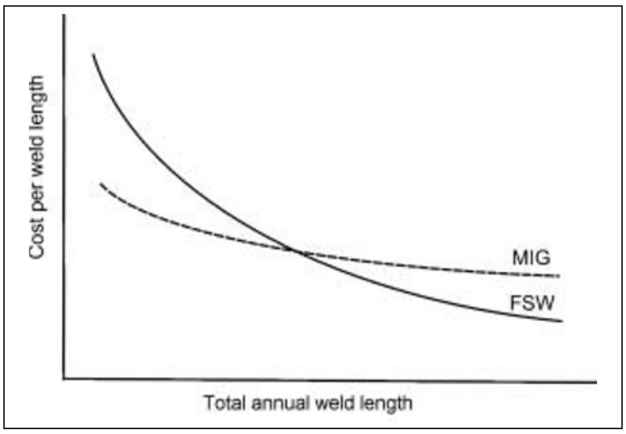

Fig. 3. Schematic representation of FSW and MIG welding costs per length vs. total annual production.

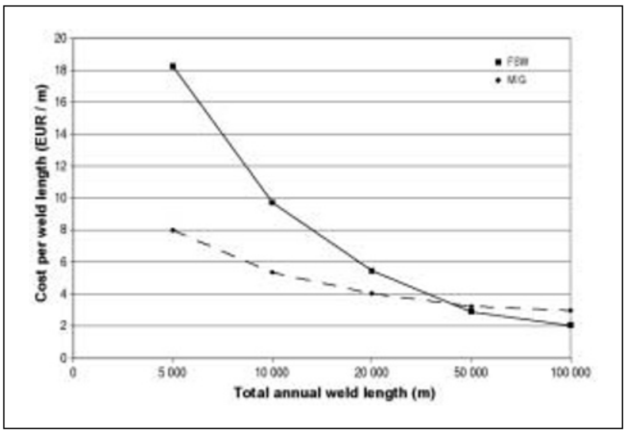

Fig. 4. FSW and MIG welding costs for different annual production amounts. Other parameters as in Table 4.

Table 4. Cost calculation example for 50,000 m annual weld production.

	Unit	FSW opt. 1	MIG opt. 1
Machine investment	€	160,000	100,000
Machine write-off period	years	5	5
Machine residual value	€	0	0
Interest rate	%	10	10
Annual maintenance cost	€	1,000	1,000
Annual weld length	m/year	50,000	50,000
Welding speed	m/min	1.50	0.54
Arc time per m	h/m	0.0111	0.0309
Duty cycle	-	0.24	0.34
Annuity of machine investment	€	42,208	26,380
Annuity of machine residual value	€	0	0
Annual machine service time	h	2,315	4,539
Machine cost per h	€/h	18	6
MACHINE COST	€/m	0.84	0.53
Annual license fee	€	43,000	0
LICENSE COST	€/m	0.86	0.00
Hourly wages	€/h	25	25
LABOR WAGES	€/m	1.16	2.27
Tool price	€	100	0
Tool replacement interval	m	2,000	2,000
TOOL COST	€/m	0.05	0.00
Amount of filler material	kg/m	0.000	0.049
Price of filler material	€/kg	0	5
Deposition efficiency	–	1.00	0.95
FILLER MATERIAL COST	€/m	0.00	0.26
Input power	kW	5	6
Energy cost	€/kWh	0.08	0.08
ENERGY COST	€/m	0.00	0.01
Shielding gas feed rate	l/min	0	20
Shielding gas price	€/m^3	0	5
SHIELDING GAS COST	€/m	0.00	0.19
TOTAL COST	€/m	2.92	3.25

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