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Simplified heat input control in manual and semi-automatic welding

Revision 2 : 27th March 2025

King's Centre, Great Yarmouth

(Revised from the presentation given to the London Branch;The Welding Institute 8th June 2022)

By Kevin Millican CEng, BSc, FWeldI

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Biography

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Kevin Millican CEng, BSc, FWeldI is an Engineering Metallurgist with 40 years of experience in the Oil & Gas and Wind Energy sectors. He began his postgraduate career at Oilfield Inspection Services in Great Yarmouth carrying out mechanical testing, metallurgical investigations, weld inspection and on-site PWHT.

In 1989 Kevin joined SLP Engineering in Lowestoft as a Welding & Materials Engineer and had responsibility for the welding of many offshore platforms and a number of renewable energy projects, until leaving to join Shell in early 2011 as a Senior Materials & Corrosion Engineer. Here he worked on numerous Greenfield and Brownfield Oil & Gas projects in the southern North Sea, along with several renewable projects including two offshore wind farms, hydrogen generation, and geothermal plants in the Netherlands.

He became Senior Inspection & Maintenance Lead in 2022, working on the transition of Shell Nigeria Gas pipelines and facilities from upstream to downstream (T&S) operations, as well as an SME (subject matter expert) for Welding & NDE for Civil, Offshore, and Pipelines, before semi-retiring in June 2023.

He works part-time for ASAMS in Great Yarmouth providing welding and fabrication support.

Kevin also works part-time as a Consultant Welding and Materials Engineer through Genesis Oil & Gas for Shell Aberdeen and is involved in the EEMUA Materials Technical Committee and BSI WEE/36 Welding Standards Committee.

Contents

The Problem

PARAMETER MONITORING IS IMPORTANT, BUT TIME-CONSUMING TO IMPLEMENT

HSE Report RR1215

A recent report by the HSE, **"When welding goes wrong: learning from past failures"**, identified lack of adequate parameter control as major factor in weld failures:

Cause	Percent of all occurrences within all incidents
No, or inadequate, welder supervision	34.8%
Incorrect application of, or no awareness/consideration of, welding parameters	66.5%

Welding is a Special Process

"A *special process* is a process, the results of which are highly dependent on the control of the process or the skill of the operators, or both, and in which the specified quality control cannot be readily determined by inspection or test of the product"

ISO 3834-2/-3 section 14.3 requires that:

"During welding, the following shall be checked at suitable intervals or by continuous monitoring:

– essential welding parameters (e.g. welding current, arc voltage and travel speed);
– preheating/interpass temperature;
– cleaning and shape of runs and layers of weld metal;
– back gouging;
– welding sequence;
– correct use and handling of welding consumables;
– control of distortion;
– any intermediate examination (e.g. checking of dimensions)."

Checking welding

Requirement	How?
Essential welding parameters (e.g. welding current, arc voltage and travel speed)	Electrical meters, arc monitoring systems, feeder/power supply meters
Preheating / interpass temperature	Temperature crayons / digital thermometers
Cleaning and shape of runs and layers of weld metal	Visual
Back gouging	Visual
Welding sequence	Visual
Correct use and handling of welding consumables	Visual
Control of distortion	Visual / gauges
Any intermediate examination (e.g. checking of dimensions)	Visual / gauges

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How does the welder check?

Requirement	How?
Essential welding parameters (e.g. welding current, arc voltage and travel speed) *	Electrical meters, arc monitoring systems, feeder/power supply meters
Preheating / interpass temperature	Temperature crayons / digital thermometers
Cleaning and shape of runs and layers of weld metal	Visual
Back gouging	Visual
Welding sequence	Visual
Correct use and handling of welding consumables	Visual
Control of distortion	Visual / gauges
Any intermediate examination (e.g. checking of dimensions)	Visual / gauges

* Most companies add arc energy or heat input in their parameter monitoring requirements

Issues

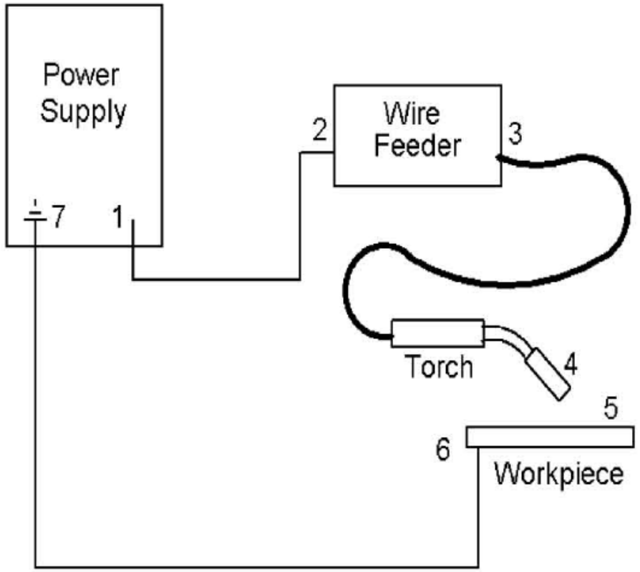
Monitoring of electrical parameters usually requires additional electrical measuring equipment, e.g. voltmeter, current clampmeter, or arc monitoring system.

Welders cannot read electrical gauges during welding.

Gauges on welding equipment are not always accurate, particularly voltmeters - depending on their connections.

Time-consuming to connect and disconnect monitoring equipment.

Accurate arc-time measurement.



Solutions

Gold Standard – regular use of dedicated arc monitoring system, such as ALX - which can also be used for machine calibration.

Improved welding equipment with accurate meters, voltage-drop compensation and average current recording.

Some welding equipment even has built-in arc monitoring capability (ESAB Weldcloud,
Kemppi ArcInfo / WeldEye, and others)

Another way?

Proposed Solution

FOR MANUAL & SEMI-AUTOMATIC WELDING, USE DEPOSIT LENGTH VS. CONSUMABLE LENGTH

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Acknowledgement

My sincere thanks to:

Bill Welland, for getting me interested in ROLs and Stub Lengths back in 1991 on the BP Bruce project, and also for (many) comments and suggestions on my spreadsheets and data.

Concepts – EN 1011/ISO TR 17671 symbols

$$Q = k \frac{U \cdot I}{v} \cdot 10^{-3} \quad \text{in kJ/mm}$$

where

Q is the heat input;

k is the thermal efficiency;

U is the arc voltage, measured as near as possible to the arc, in V;

I is the welding current, in A

v is the travel speed in mm/s.

Concepts - Traditional

Arc Energy (per unit length) = Arc_**V**olts * **A**mps * **T**ime / **R**un_**O**ut_**L**ength

or, **AE = VAT/ROL**

Heat Input (per unit length), **HI = k * AE**

where k is the thermal efficiency factor
(~ 0.8 for SMAW, GMAW, FCAW, 1.0 for SAW, 0.6 for GTAW/PAW)

This is easy to add later, so we'll stick with Arc Energies. Divide by 1000 to convert to kJ/unit length.

Arc energy is directly proportional to the cross-sectional area of the weld deposit.

SMAW: for a given length of electrode, the arc energy is inversely proportional to the run-out length (ROL)

GMAW & FCAW: for a given wire feed speed, the arc energy is inversely proportional to the travel speed.

Possible Objections

Objection	Mitigation
SMAW : the current might be high (*)	The electrode will burn off quicker and offset this, with a higher travel speed for a given ROL
SMAW : the voltage may be high (*)	See above, but also – some energy lost as additional light/heat radiation, that doesn't go into the weld
GMAW/FCAW : the current may be high (*)	Not usually a controlled variable as most machines are controlled by wire feed speed and arc voltage
GMAW/FCAW : the voltage may be high (*)	Likely to result in lower current, or longer stickout. Unlikely to change the amount of energy required to melt the consumable wire
GMAW/FCAW : are accurate wire feed speeds known?	Wire feeders with digital display/setting of wire feed speed are increasingly available
GMAW/FCAW : what about constant current wire feeders? – the wire feed speed may not be known	If volts and amps are accurately known, may as well directly calculate arc energy using travel speed.

** opposite condition has an inverse mitigation*

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Standards Support

Objection	Mitigation
Lack of support in welding standards?	Is supported, though often forgotten – see below

ASME IX

"**QW-409.1** An increase in heat input, or an increase in volume of weld metal deposited per unit length of weld, for each process recorded on the PQR. For arc welding, the increase shall be determined by (a), (b), or (c) for nonwaveform controlled welding, or by (b) or (c) for waveform controlled welding.

...

(b) Volume of weld metal measured by

(1) an increase in bead size (width × thickness), or

(2) a decrease in length of weld bead per unit length of electrode"

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Standards Support

BS 4515-1 (2009)

Electrical characteristics	i	Current (a.c. or d.c.) and polarity	Any change
Welding parameters	j	The following information is needed for each wire size (different values [B)] may be used for different runs):	
	j1	Electrical stick-out (SAW, MAG, FCAW) [B)]	Any change exceeding ±5 mm
	j2	Arc voltage [B)]	Any change exceeding ±10%
	j3	Wire feed speed (SAW, MAG, FCAW) [B)] or welding current [B)]	Any change exceeding ±10% (±15% for cellulosic electrodes)
	j4	Travel speed [B)]	Any change exceeding ±10%
	j5	Calculated value of heat input [B)]	No separate restriction

EN ISO 15614-1, 8.4.7

"For process 111, the heat input may also be measured by the run out length per unit length of electrode."

Advantages

Minimal equipment required;

- Steel rule for SMAW
- Steel rule and stopwatch for GMAW/FCAW

Quicker than conventional parameter monitoring – no set-up

Can be carried out by anyone, including the welder, with minimal training

Can supplement traditional methods; doesn’t need to replace them

Theory

SOME EQUATIONS

SMAW

Electrodes come in different diameters and lengths

The welder doesn't always burn the same amount of an electrode; there's a residual stub left over

Equation 1a:

$$Arc\_Energy = (Electr\_Len - Stub\_Len) / (ROL * factor) * Electr\_Dia^2$$

The electrode factor is typically around 17 for arc energy in kJ/mm and all dimensions in mm, but this can be refined by analysis of PQR data.

Typically this varies between 16-19 for most basic electrodes (both CMn steel and duplex stainless steel), and larger diameters tend to be higher factors than small diameter electrodes.

SMAW - π/4 ?

My friend, Bill Welland, recommended that I should include π/4 in the equation, ie.

Equation 1b:

Arc_Energy = (Electr_Len – Stub_Len) / (ROL * factor) * π/4 *$Electr\_Dia^2$

The advantage of this modification is that factor then becomes a direct measure (in mm^3/kJ) of the volume of electrode consumed per unit of energy.

The typical factor then becomes 13.4 mm^3/kJ instead of 17

From a calculation standpoint, I have not used this refinement; preferring to absorb the π/4 into a single constant, instead of repeating it with every calculation.

SMAW - π/4 ?

One consequence of including a π/4 in the factor would be that:

factor × arc energy = notional cross-sectional area of the deposit

(because $mm^3/kJ \times kJ/mm = mm^2$)

The factor would then link two measures recognised by QW 409.1 of ASME IX.

NB. the mm^2 is only the true cross-sectional area for 100% recovery electrodes.

GMAW/FCAW

Equation factors are likely to be product-specific, because:

- Wires come in different diameters
- Cored wires will have different burn-off ratios compared to solid wire
- Spray transfer may have different factors compared to dip transfer

Equation 2 - General form:

Arc_Energy = ƒ(WFS) / Travel_Speed

Equation 3 - Typical Function of Wire Feed Speed (WFS):

ƒ(WFS) = (Wire_Constant + WFS * Wire_Factor)

For 1.2mm Rutile FCAW wire, with WFS in m/min and travel speed in mm/min:
Wire_Constant ≈ 100
Wire_Factor ≈ 30

Define

HOW TO OBTAIN OR REFINE THE FACTORS USED IN THE EQUATIONS

SMAW

It's simple to rearrange Equation 1a to calculate the electrode factor:

Equation 1c:

$$factor = (Electr\_Len - Stub\_Len) / (ROL * Arc\_Energy) * Electr\_Dia^2$$

The data for this calculation can be obtained from existing PQR data if this includes all required variables, or

Conventional parameter monitoring can be adapted to collect the ROL and Stub Length data over time.

The calculated factors can just be averaged to obtain a working value.

GMAW/FCAW

Similarly, Equation 2 can be rearranged to:

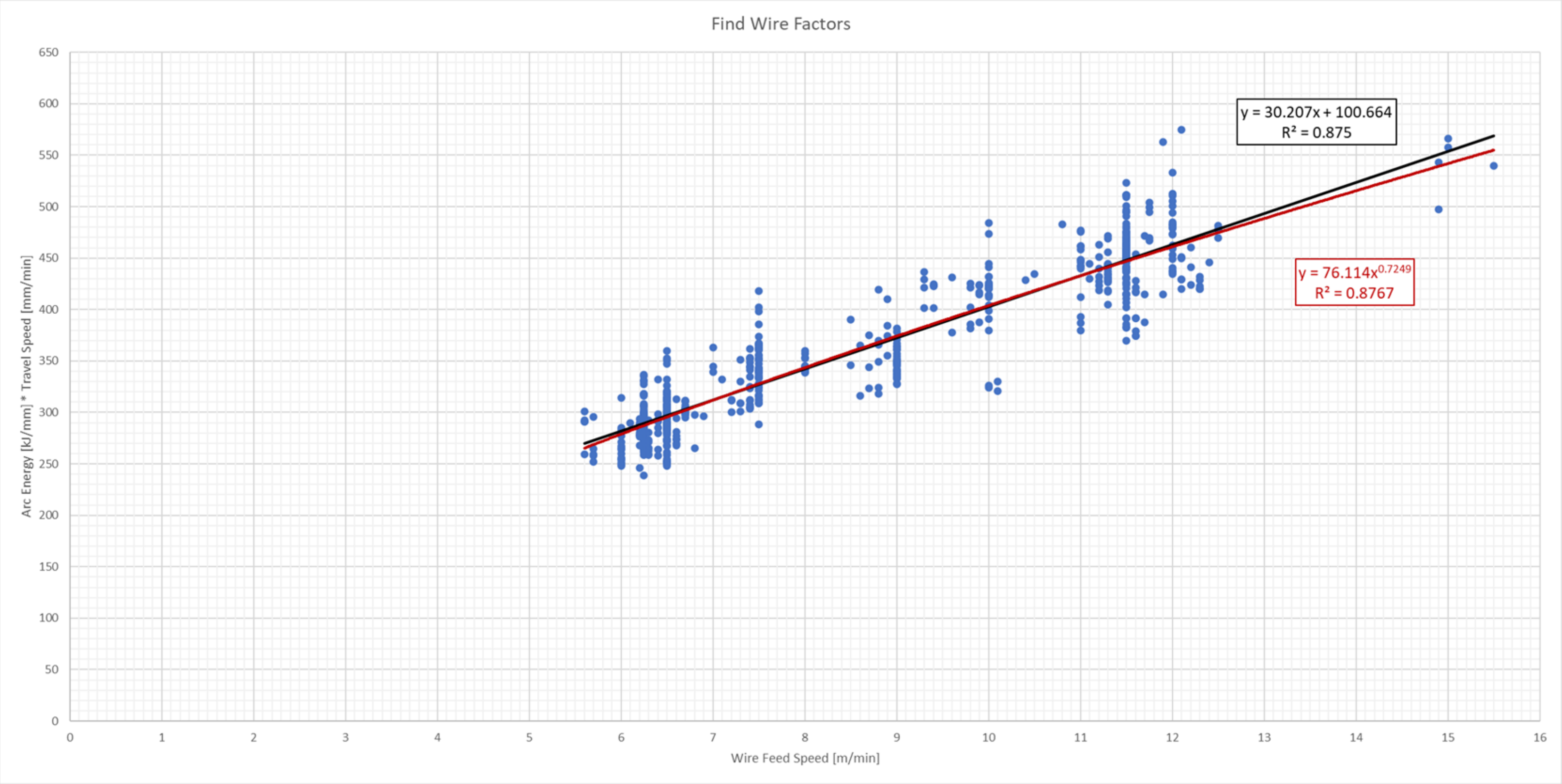
Equation 2b:

ƒ(WFS) = Arc_Energy * Travel_Speed

ƒ(WFS) can then be plotted on the y-axis against WFS on the x-axis, so that a regression line or curve is produced.

This correlation doesn't look that convincing initially
(though the graph on the next page actually includes 3 different wires and 3 different MIG machines that don't measure the arc volts in exactly the same way)

GMAW/FCAW



A marginally better fit is achieved with a power- instead of a linear-regression, but the difference is small and strongly affected by a small number of points mainly representing single-pass fillet welds

Additional Refinements

Electrode factors can be calculated for each brand and size of electrode.

Electrode and wire factors could be adjusted for welding position.

Wire factors could be adjusted for weld area, eg. it’s not uncommon to use a lower voltage for capping and the welding technique is slightly different.

Implementation

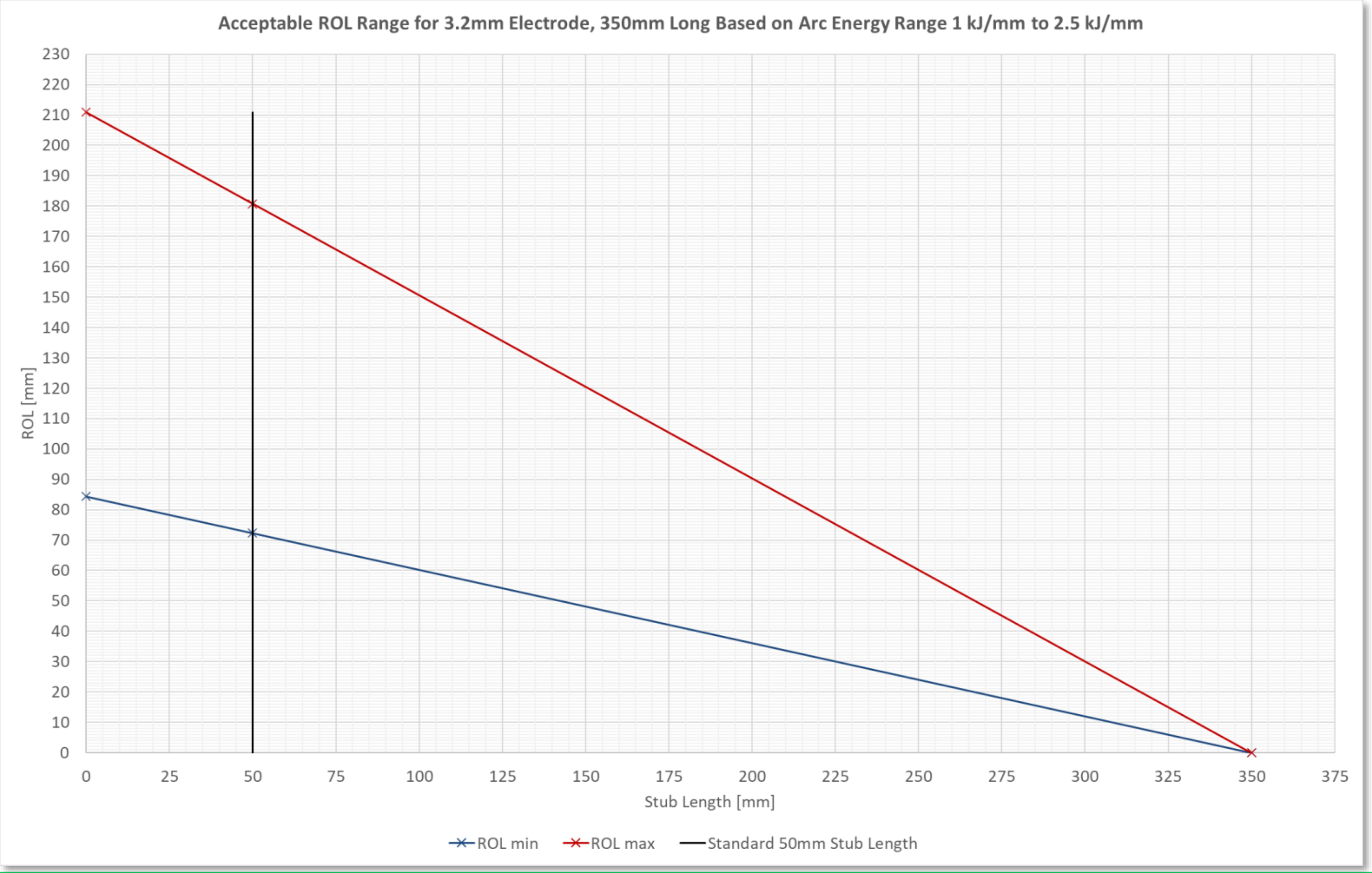
THREE BASIC WAYS…

SMAW

There are 3 main ways of using the ROL/Stub Length Arc Energy approximations:

Charts

These can be particularly useful during welder qualifications, because the welder can be asked to mark the chart and record their own parameters; thereby honing their own work to suit the WPS, and providing a permanent record of their ability to follow the WPS



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SMAW

There are 3 main ways of using the ROL/Stub Length Arc Energy approximations:

- Charts
- Tables

These are particularly useful for welding inspectors and can easily be incorporated into existing audit checksheets.
Read down from the Stub Length to the closest matching ROL and then across to the left column to read off the Arc Energy.

ROL/Stub Length Arc Energy Chart for 350mm long 3.2 mm Electrodes

Arc Energy	Stub Length [mm]																						
[kJ/mm]	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220	230	240	250
0.3	643	622	**602**	582	562	542	522	502	482	462	442	422	402	381	361	341	321	301	281	261	241	221	201
0.4	482	467	**452**	437	422	407	392	376	361	346	331	316	301	286	271	256	241	226	211	196	181	166	151
0.5	386	373	**361**	349	337	325	313	301	289	277	265	253	241	229	217	205	193	181	169	157	145	133	120
0.6	321	311	**301**	291	281	271	261	251	241	231	221	211	201	191	181	171	161	151	141	131	120	110	100
0.7	275	267	**258**	250	241	232	224	215	207	198	189	181	172	163	155	146	138	129	120	112	103	95	86
0.8	241	233	**226**	218	211	203	196	188	181	173	166	158	151	143	136	128	120	113	105	98	90	83	75
0.9	214	207	**201**	194	187	181	174	167	161	154	147	141	134	127	120	114	107	100	94	87	80	74	67
1	193	187	**181**	175	169	163	157	151	145	139	133	126	120	114	108	102	96	90	84	78	72	66	60
1.1	175	170	**164**	159	153	148	142	137	131	126	120	115	110	104	99	93	88	82	77	71	66	60	55
1.2	161	156	**151**	146	141	136	131	125	120	115	110	105	100	95	90	85	80	75	70	65	60	55	50
1.3	148	144	**139**	134	130	125	120	116	111	107	102	97	93	88	83	79	74	70	65	60	56	51	46
1.4	138	133	**129**	125	120	116	112	108	103	99	95	90	86	82	77	73	69	65	60	56	52	47	43
1.5	129	124	**120**	116	112	108	104	100	96	92	88	84	80	76	72	68	64	60	56	52	48	44	40
1.6	120	117	**113**	109	105	102	98	94	90	87	83	79	75	72	68	64	60	56	53	49	45	41	38
1.7	113	110	**106**	103	99	96	92	89	85	81	78	74	71	67	64	60	57	53	50	46	43	39	35
1.8	107	104	**100**	97	94	90	87	84	80	77	74	70	67	64	60	57	54	50	47	44	40	37	33
1.9	101	98	**95**	92	89	86	82	79	76	73	70	67	63	60	57	54	51	48	44	41	38	35	32
2	96	93	**90**	87	84	81	78	75	72	69	66	63	60	57	54	51	48	45	42	39	36	33	30
2.1	92	89	**86**	83	80	77	75	72	69	66	63	60	57	54	52	49	46	43	40	37	34	32	29
2.2	88	85	**82**	79	77	74	71	68	66	63	60	57	55	52	49	47	44	41	38	36	33	30	27
2.3	84	81	**79**	76	73	71	68	65	63	60	58	55	52	50	47	45	42	39	37	34	31	29	26
2.4	80	78	**75**	73	70	68	65	63	60	58	55	53	50	48	45	43	40	38	35	33	30	28	25
2.5	77	75	**72**	70	67	65	63	60	58	55	53	51	48	46	43	41	39	36	34	31	29	27	24
2.6	74	72	**70**	67	65	63	60	58	56	53	51	49	46	44	42	39	37	35	32	30	28	25	23
2.7	71	69	**67**	65	62	60	58	56	54	51	49	47	45	42	40	38	36	33	31	29	27	25	22
2.8	69	67	**65**	62	60	58	56	54	52	49	47	45	43	41	39	37	34	32	30	28	26	24	22
2.9	66	64	**62**	60	58	56	54	52	50	48	46	44	42	39	37	35	33	31	29	27	25	23	21
3	64	62	**60**	58	56	54	52	50	48	46	44	42	40	38	36	34	32	30	28	26	24	22	20
3.1	62	60	**58**	56	54	52	51	49	47	45	43	41	39	37	35	33	31	29	27	25	23	21	19
3.2	60	58	**56**	55	53	51	49	47	45	43	41	40	38	36	34	32	30	28	26	24	23	21	19
3.3	58	57	**55**	53	51	49	47	46	44	42	40	38	37	35	33	31	29	27	26	24	22	20	18
3.4	57	55	**53**	51	50	48	46	44	43	41	39	37	35	34	32	30	28	27	25	23	21	19	18
3.5	55	53	**52**	50	48	46	45	43	41	40	38	36	34	33	31	29	28	26	24	22	21	19	17

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There are 3 main ways of using the ROL/Stub Length Arc Energy approximations:

Charts

Tables

Apps / Spreadsheets

There are many ways these simple calculators can be implemented on phones, tablets, and laptops. At the simplest level, spreadsheets can be developed that will run on any device. Dedicated Apps for Android or iOS can be created, or online cloud applications that will run on any web browser.

ROL Calculation from Arc Energy

Electrode Diameter	3.2	mm	0.126	in
Electrode Length	350	mm	13.78	in
Stub Length	50.8	mm	2.00	in
Factor	17	*		
Arc Energy	1.5	kJ/mm	38100	J/in
ROL	**120**	**mm**	**4.73**	**in**

Arc Energy Calculation from ROL & Stub Length

Electrode Diameter	3.2	mm	0.126	in
Electrode Length	350	mm	13.78	in
Stub Length	50.8	mm	2.00	in
Factor	17	*		
ROL	120	mm	4.72	in
Arc Energy	**1.50**	**kJ/mm**	**38100**	**J/in**
Heat Input	**1.20**	**kJ/mm**	**30500**	**J/in**

SMAW

There are 3 main ways of using the ROL/Stub Length Arc Energy approximations:

- Charts
- Tables
- Apps / Spreadsheets

Including the WIMS Apps for Android and iPhone

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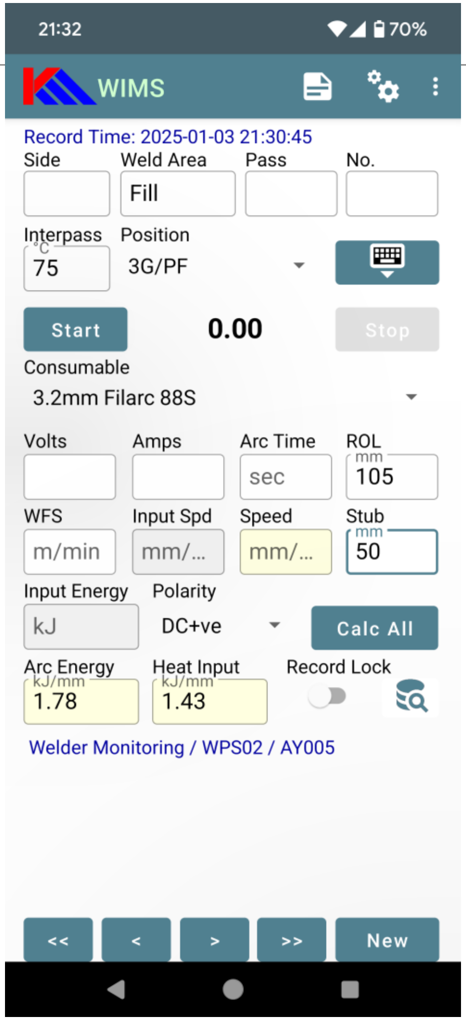
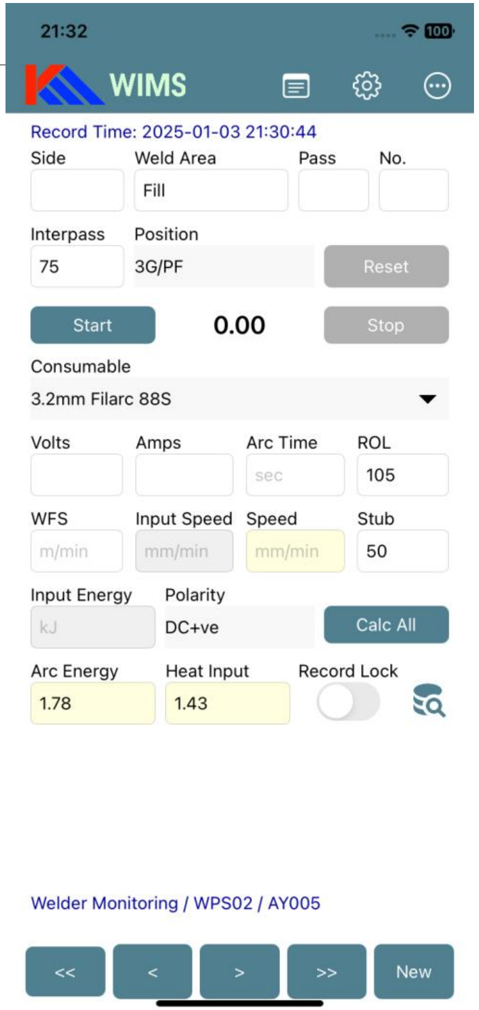


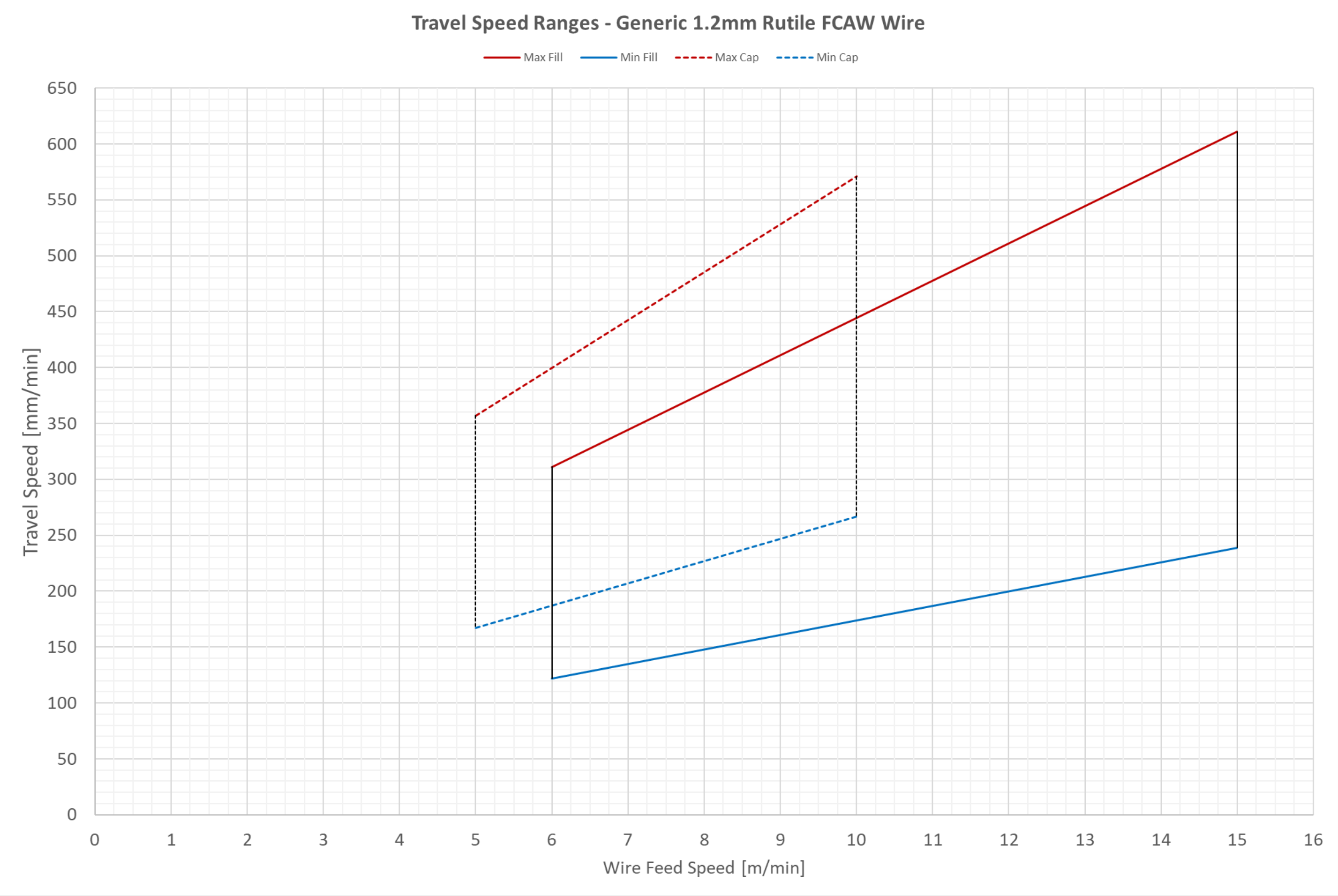


GMAW/FCAW

Once again, the approximations can be used in three ways:

Charts

Not as useful as the SMAW charts during welder qualifications, because the welder cannot easily check their travel speed, but still possible, and easy to use with an assistant. Presenting the acceptable travel speed ranges related to wire feed speed is an improvement on normal WPS ranges



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GMAW/FCAW

Once again, the approximations can be used in three ways:

- Charts
- Tables

The Arc Energy can be read from the intersection of the wire feed speed and travel speed.
Of course this does mean that some method for calculating the travel speed has to be provided…

Arc Energy Calculator : 1.2mm Rutile FCAW

Arc Energy [kJ/mm]	Wire Feed Speed [m/min]																				
Speed [mm/min]	**5.5**	**6**	**6.25**	**6.5**	**7**	**7.5**	**8**	**8.5**	**9**	**9.5**	**10**	**10.5**	**11**	**11.5**	**12**	**12.5**	**13**	**13.5**	**14**	**15**	**16**
100	2.7	2.8	2.9	3.0	3.1	3.3	3.4	3.6	3.7	3.9	4.0	4.2	4.3	4.5	4.6	4.8	4.9	5.1	5.2	5.5	5.8
120	2.2	2.3	2.4	2.5	2.6	2.7	2.8	3.0	3.1	3.2	3.3	3.5	3.6	3.7	3.8	4.0	4.1	4.2	4.3	4.6	4.8
140	1.9	2.0	2.1	2.1	2.2	2.3	2.4	2.5	2.6	2.8	2.9	3.0	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.9	4.1
160	1.7	1.8	1.8	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3.0	3.1	3.2	3.3	3.4	3.6
180	1.5	1.6	1.6	1.6	1.7	1.8	1.9	2.0	2.1	2.1	2.2	2.3	2.4	2.5	2.6	2.6	2.7	2.8	2.9	3.1	3.2
200	1.3	1.4	1.4	1.5	1.6	1.6	1.7	1.8	1.9	1.9	2.0	2.1	2.2	2.2	2.3	2.4	2.5	2.5	2.6	2.8	2.9
220	1.2	1.3	1.3	1.3	1.4	1.5	1.5	1.6	1.7	1.8	1.8	1.9	2.0	2.0	2.1	2.2	2.2	2.3	2.4	2.5	2.6
240	1.1	1.2	1.2	1.2	1.3	1.4	1.4	1.5	1.5	1.6	1.7	1.7	1.8	1.9	1.9	2.0	2.0	2.1	2.2	2.3	2.4
260	1.0	1.1	1.1	1.1	1.2	1.3	1.3	1.4	1.4	1.5	1.5	1.6	1.7	1.7	1.8	1.8	1.9	1.9	2.0	2.1	2.2
280	0.9	1.0	1.0	1.1	1.1	1.2	1.2	1.3	1.3	1.4	1.4	1.5	1.5	1.6	1.6	1.7	1.8	1.8	1.9	2.0	2.1
300	0.9	0.9	1.0	1.0	1.0	1.1	1.1	1.2	1.2	1.3	1.3	1.4	1.4	1.5	1.5	1.6	1.6	1.7	1.7	1.8	1.9
320	0.8	0.9	0.9	0.9	1.0	1.0	1.1	1.1	1.2	1.2	1.3	1.3	1.3	1.4	1.4	1.5	1.5	1.6	1.6	1.7	1.8
340	0.8	0.8	0.8	0.9	0.9	1.0	1.0	1.0	1.1	1.1	1.2	1.2	1.3	1.3	1.4	1.4	1.4	1.5	1.5	1.6	1.7
360	0.7	0.8	0.8	0.8	0.9	0.9	0.9	1.0	1.0	1.1	1.1	1.2	1.2	1.2	1.3	1.3	1.4	1.4	1.4	1.5	1.6
380	0.7	0.7	0.8	0.8	0.8	0.9	0.9	0.9	1.0	1.0	1.1	1.1	1.1	1.2	1.2	1.3	1.3	1.3	1.4	1.4	1.5
400	0.7	0.7	0.7	0.7	0.8	0.8	0.9	0.9	0.9	1.0	1.0	1.0	1.1	1.1	1.2	1.2	1.2	1.3	1.3	1.4	1.5
425	0.6	0.7	0.7	0.7	0.7	0.8	0.8	0.8	0.9	0.9	0.9	1.0	1.0	1.0	1.1	1.1	1.2	1.2	1.2	1.3	1.4
450	0.6	0.6	0.6	0.7	0.7	0.7	0.8	0.8	0.8	0.9	0.9	0.9	1.0	1.0	1.0	1.1	1.1	1.1	1.2	1.2	1.3
475	0.6	0.6	0.6	0.6	0.7	0.7	0.7	0.7	0.8	0.8	0.8	0.9	0.9	0.9	1.0	1.0	1.0	1.1	1.1	1.2	1.2
500	0.5	0.6	0.6	0.6	0.6	0.7	0.7	0.7	0.7	0.8	0.8	0.8	0.9	0.9	0.9	1.0	1.0	1.0	1.0	1.1	1.2
550	0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.6	0.7	0.7	0.7	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9	1.0	1.1
600	0.4	0.5	0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.6	0.7	0.7	0.7	0.7	0.8	0.8	0.8	0.8	0.9	0.9	1.0
700	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.6	0.6	0.7	0.7	0.7	0.7	0.7	0.8	0.8
	217	**236**	**246**	**256**	**276**	**295**	**315**	**335**	**354**	**374**	**394**	**413**	**433**	**453**	**472**	**492**	**512**	**531**	**551**	**591**	**630**
	Wire Feed Speed [ipm]																				

ASAMS

GMAW/FCAW

Once again, the approximations can be used in three ways:

- Charts
- Tables

This is the trickiest bit for MIG/MAG processes. Obviously, calculators (or possibly phones) can be used. It's also possible to provide simple tables, such as this one

Travel Speed Calculator (Metric)

Speed [mm/min]	Time Taken to Weld Length [seconds]																						
Length [mm]	**10**	**12**	**15**	**17**	**20**	**22**	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**70**	**80**	**90**	**100**	**110**	**120**	**130**	**140**	**150**
25	150	125	100	88	75	68	60	50	43	38	33	30	27	25	21	19	17	15	14	13	12	11	10
30	180	150	120	106	90	82	72	60	51	45	40	36	33	30	26	23	20	18	16	15	14	13	12
35	210	175	140	124	105	95	84	70	60	53	47	42	38	35	30	26	23	21	19	18	16	15	14
40	240	200	160	141	120	109	96	80	69	60	53	48	44	40	34	30	27	24	22	20	18	17	16
45	270	225	180	159	135	123	108	90	77	68	60	54	49	45	39	34	30	27	25	23	21	19	18
50	300	250	200	176	150	136	120	100	86	75	67	60	55	50	43	38	33	30	27	25	23	21	20
60	360	300	240	212	180	164	144	120	103	90	80	72	65	60	51	45	40	36	33	30	28	26	24
70	420	350	280	247	210	191	168	140	120	105	93	84	76	70	60	53	47	42	38	35	32	30	28
80	480	400	320	282	240	218	192	160	137	120	107	96	87	80	69	60	53	48	44	40	37	34	32
90	540	450	360	318	270	245	216	180	154	135	120	108	98	90	77	68	60	54	49	45	42	39	36
100	600	500	400	353	300	273	240	200	171	150	133	120	109	100	86	75	67	60	55	50	46	43	40
110	660	550	440	388	330	300	264	220	189	165	147	132	120	110	94	83	73	66	60	55	51	47	44
120	720	600	480	424	360	327	288	240	206	180	160	144	131	120	103	90	80	72	65	60	55	51	48
130	780	650	520	459	390	355	312	260	223	195	173	156	142	130	111	98	87	78	71	65	60	56	52
140	840	700	560	494	420	382	336	280	240	210	187	168	153	140	120	105	93	84	76	70	65	60	56
150	900	750	600	529	450	409	360	300	257	225	200	180	164	150	129	113	100	90	82	75	69	64	60
160	960	800	640	565	480	436	384	320	274	240	213	192	175	160	137	120	107	96	87	80	74	69	64
180	1080	900	720	635	540	491	432	360	309	270	240	216	196	180	154	135	120	108	98	90	83	77	72
200	1200	1000	800	706	600	545	480	400	343	300	267	240	218	200	171	150	133	120	109	100	92	86	80
220	1320	1100	880	776	660	600	528	440	377	330	293	264	240	220	189	165	147	132	120	110	102	94	88
240	1440	1200	960	847	720	655	576	480	411	360	320	288	262	240	206	180	160	144	131	120	111	103	96
260	1560	1300	1040	918	780	709	624	520	446	390	347	312	284	260	223	195	173	156	142	130	120	111	104
280	1680	1400	1120	988	840	764	672	560	480	420	373	336	305	280	240	210	187	168	153	140	129	120	112
300	1800	1500	1200	1059	900	818	720	600	514	450	400	360	327	300	257	225	200	180	164	150	138	129	120
325	1950	1625	1300	1147	975	886	780	650	557	488	433	390	355	325	279	244	217	195	177	163	150	139	130
350	2100	1750	1400	1235	1050	955	840	700	600	525	467	420	382	350	300	263	233	210	191	175	162	150	140
375	2250	1875	1500	1324	1125	1023	900	750	643	563	500	450	409	375	321	281	250	225	205	188	173	161	150
400	2400	2000	1600	1412	1200	1091	960	800	686	600	533	480	436	400	343	300	267	240	218	200	185	171	160
450	2700	2250	1800	1588	1350	1227	1080	900	771	675	600	540	491	450	386	338	300	270	245	225	208	193	180
500	3000	2500	2000	1765	1500	1364	1200	1000	857	750	667	600	545	500	429	375	333	300	273	250	231	214	200
600	3600	3000	2400	2118	1800	1636	1440	1200	1029	900	800	720	655	600	514	450	400	360	327	300	277	257	240

GMAW/FCAW

Once again, the approximations can be used in three ways:

- Charts
- Tables
- Apps / Spreadsheets

There are many ways these simple calculators can be implemented on phones, tablets, and laptops. At the simplest level, spreadsheets can be developed that will run on any device. Dedicated Apps for Android or iOS can be created, or online cloud applications that will run on any web browser.

Arc Energy Calc. from WFS and Travel Speed

Wire Factor	30		Constant	100
Arc Efficiency	0.8			
ROL	200	mm	7.87	in
Arc Time	45	sec		
Travel Speed	267	mm/min	10.51	in/min
Wire Feed Speed	10	m/min	394	in/min
Arc Energy	**1.50**	**kJ/mm**	**38100**	**J/in**
Heat Input	**1.20**	**kJ/mm**	**30400**	**J/in**

GMAW/FCAW

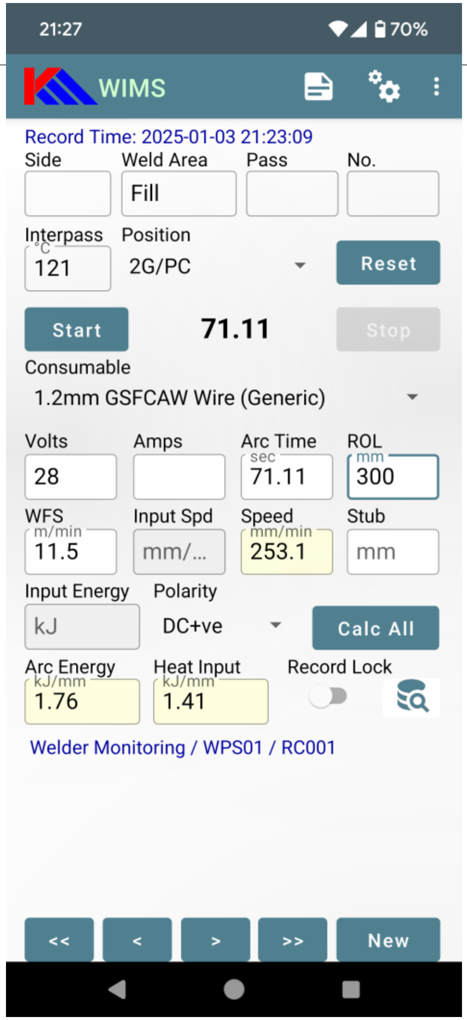
Once again, the approximations can be used in three ways:

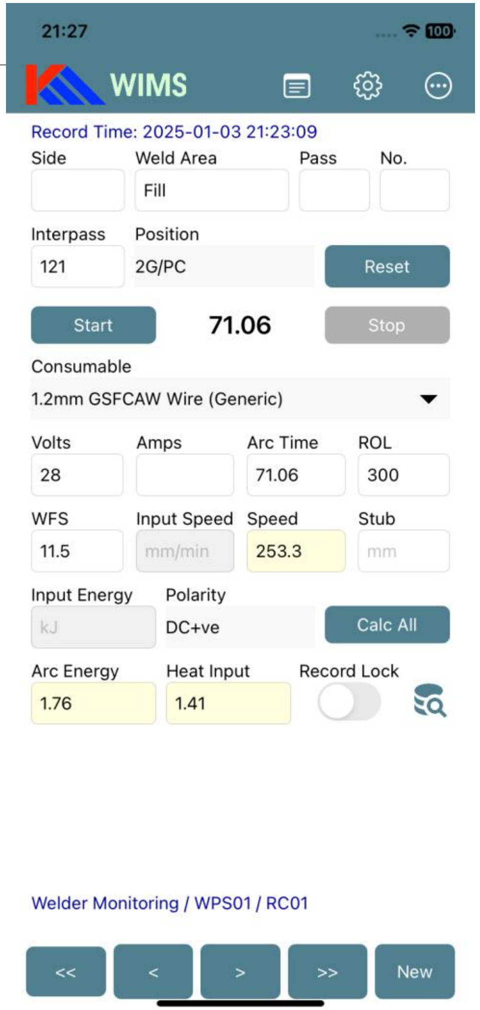
- Charts
- Tables
- Apps / Spreadsheets

Including the WIMS Apps for Android and iPhone

GET IT ON Google Play

Download on the App Store





Accuracy

HOW DO THE RESULTS COMPARE?

SMAW Accuracy

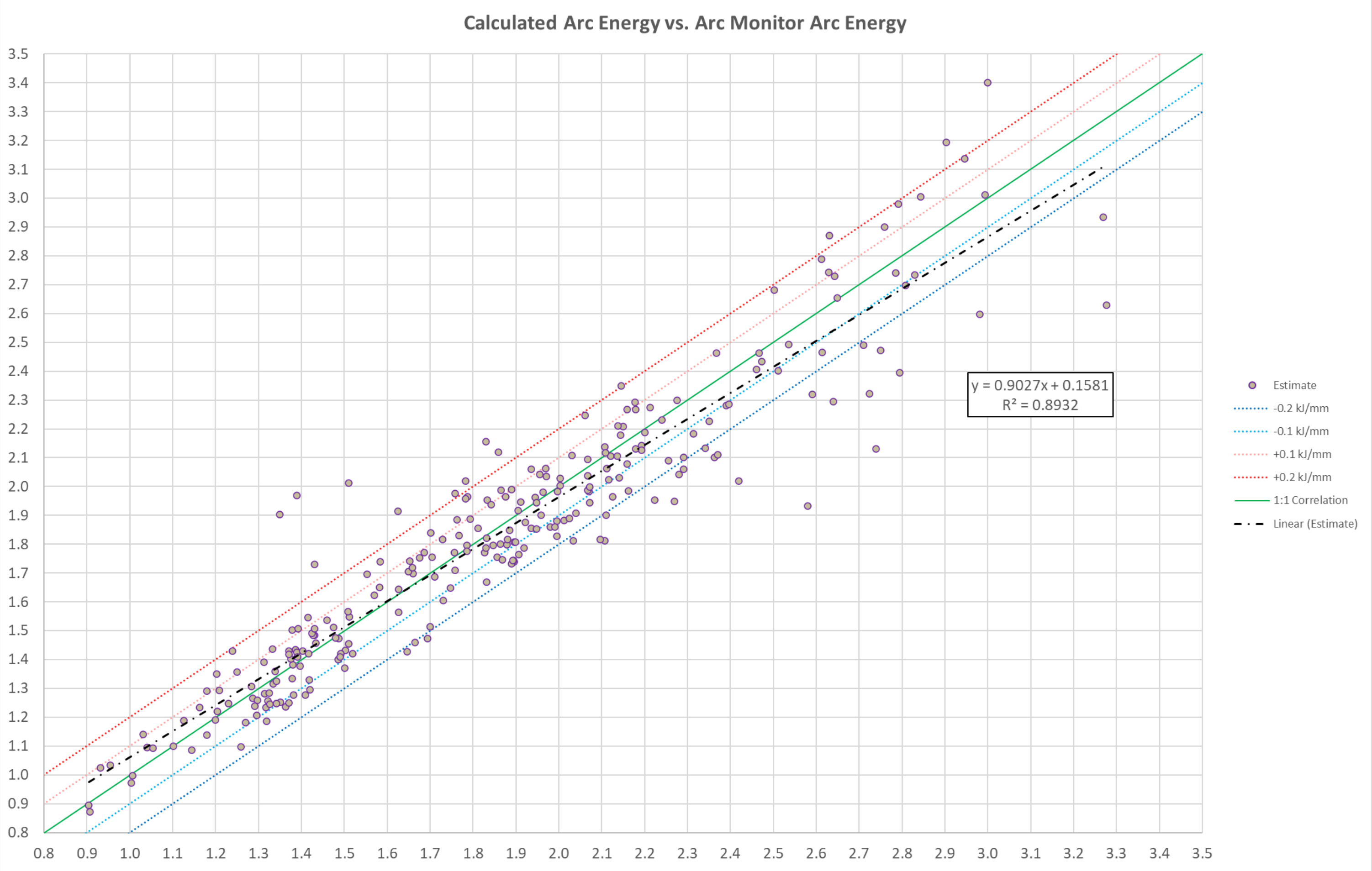
The electrode factors that I derived and used at SLP, used a dataset that examined a substantial number of welder parameter checks, carried out using BCM/PAMS units and individual ROL/Stub lengths

This dataset produced a very high confidence of estimates being within 0.2kJ/mm

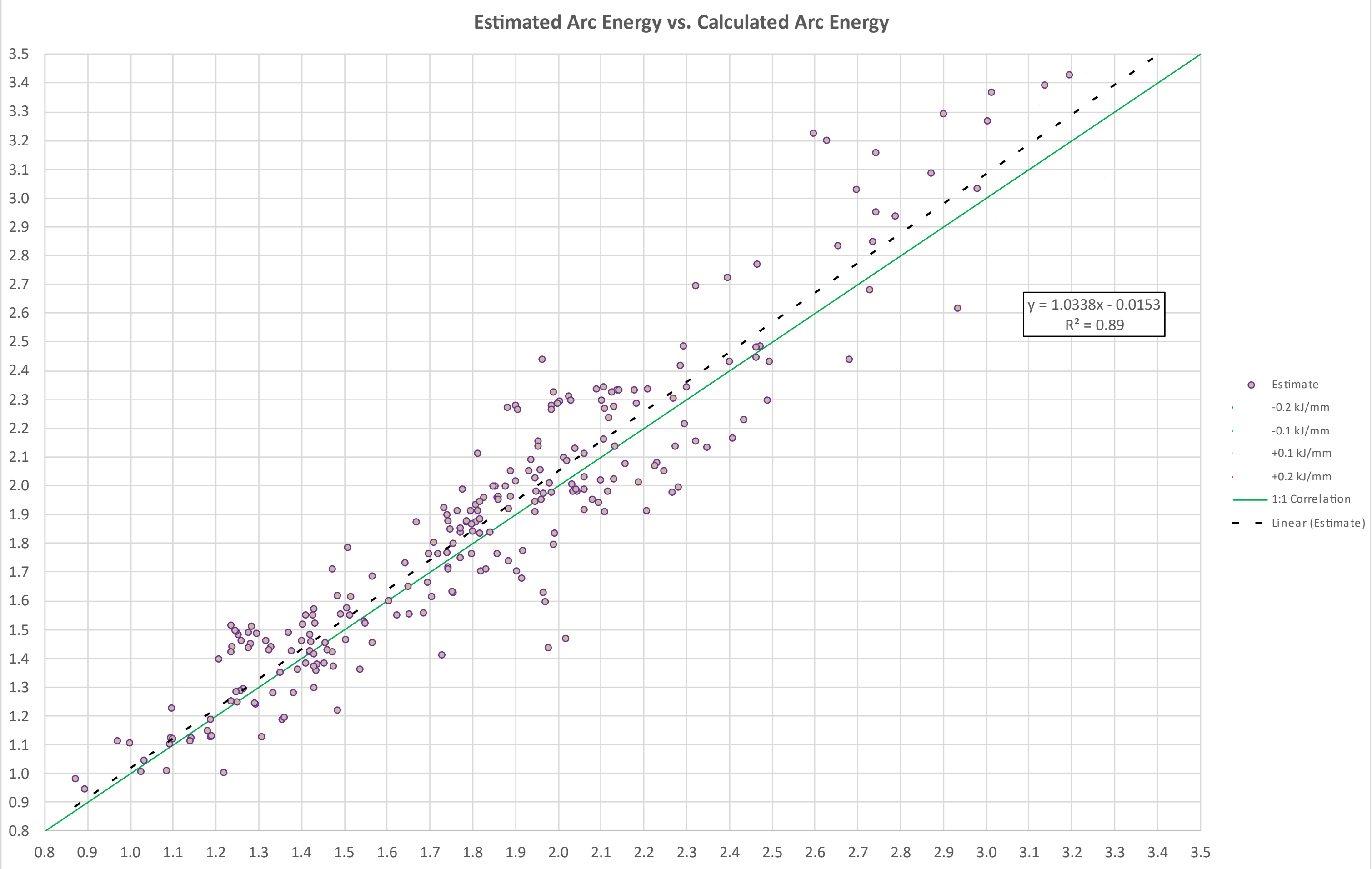
It should be noted that the following graphs use a relatively small set of data that is of inferior quality to that used to obtain the original nominal electrode factors

This can be illustrated by the next slide which plots Arc Energy calculated from V*A*T/ROL vs Arc Monitor Energy/ROL

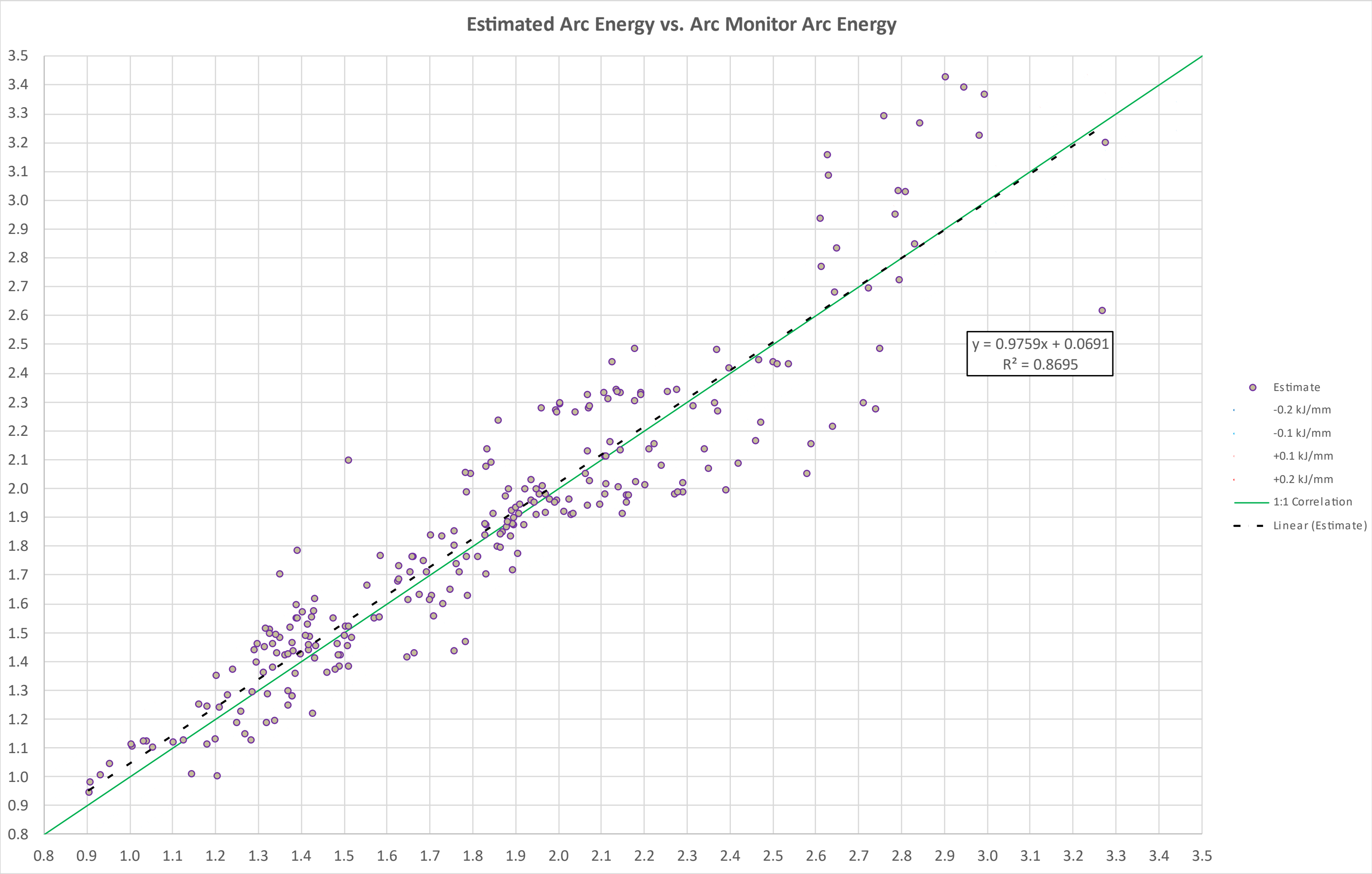
VAT/ROL vs Arc Monitor



ROL/Stub Length Estimate vs VAT/ROL (f=17)



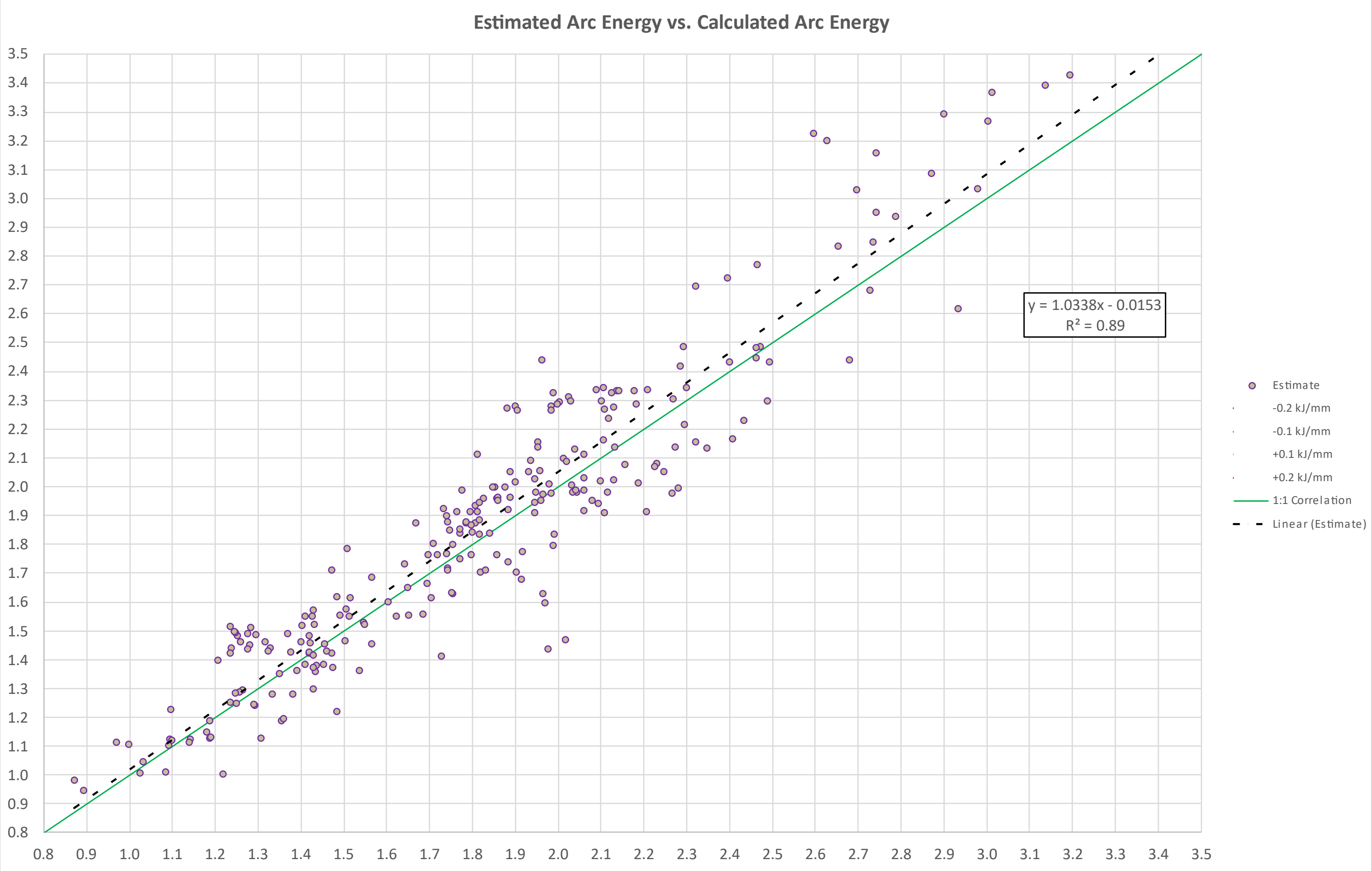
ROL/Stub Length Estimate vs Arc Monitor (f=17)



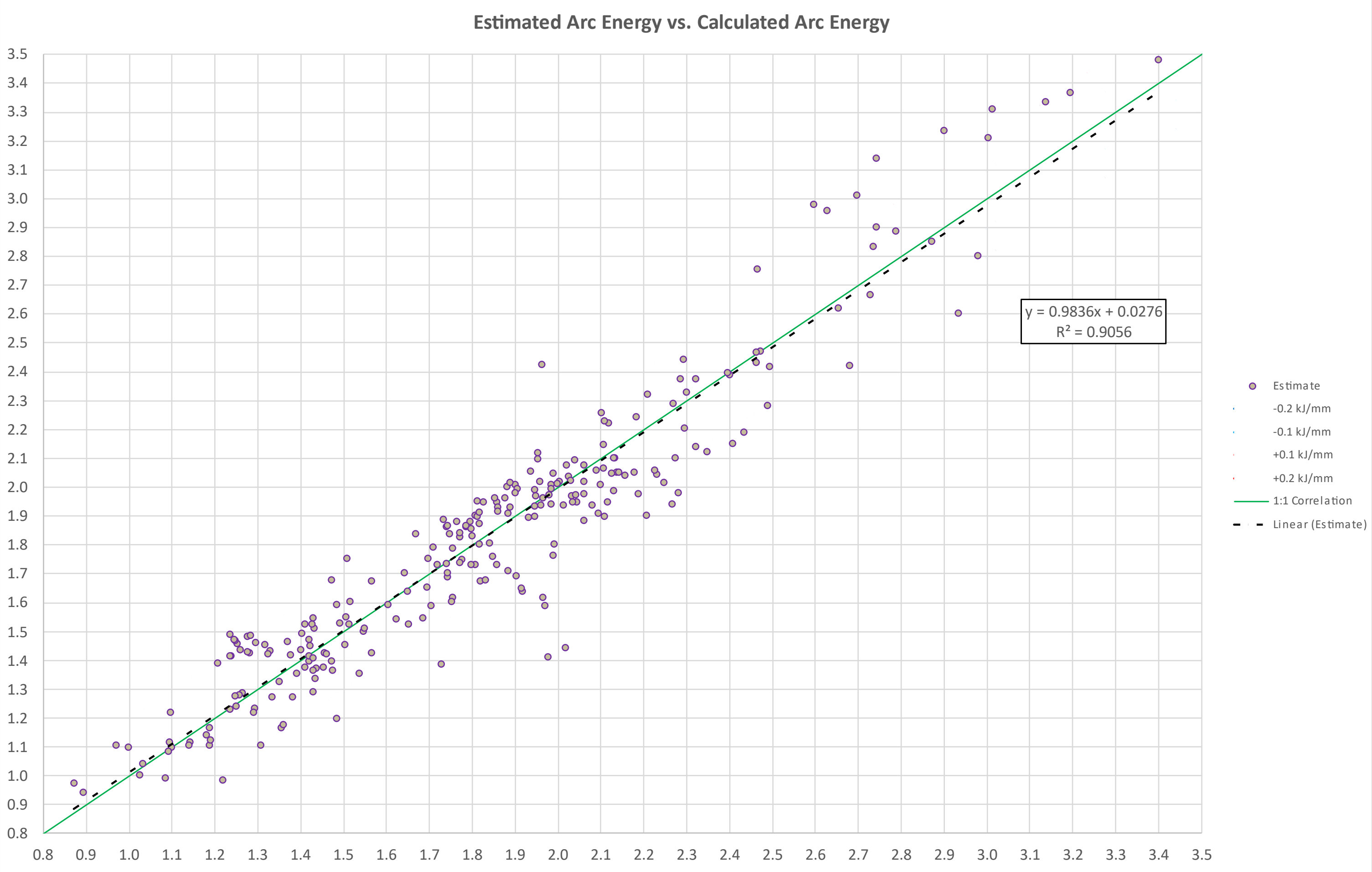
Using Specific Electrode Factors

Results can be improved if factors are developed for each size of electrode.

ROL/Stub Estimate vs VAT/ROL (f=17)



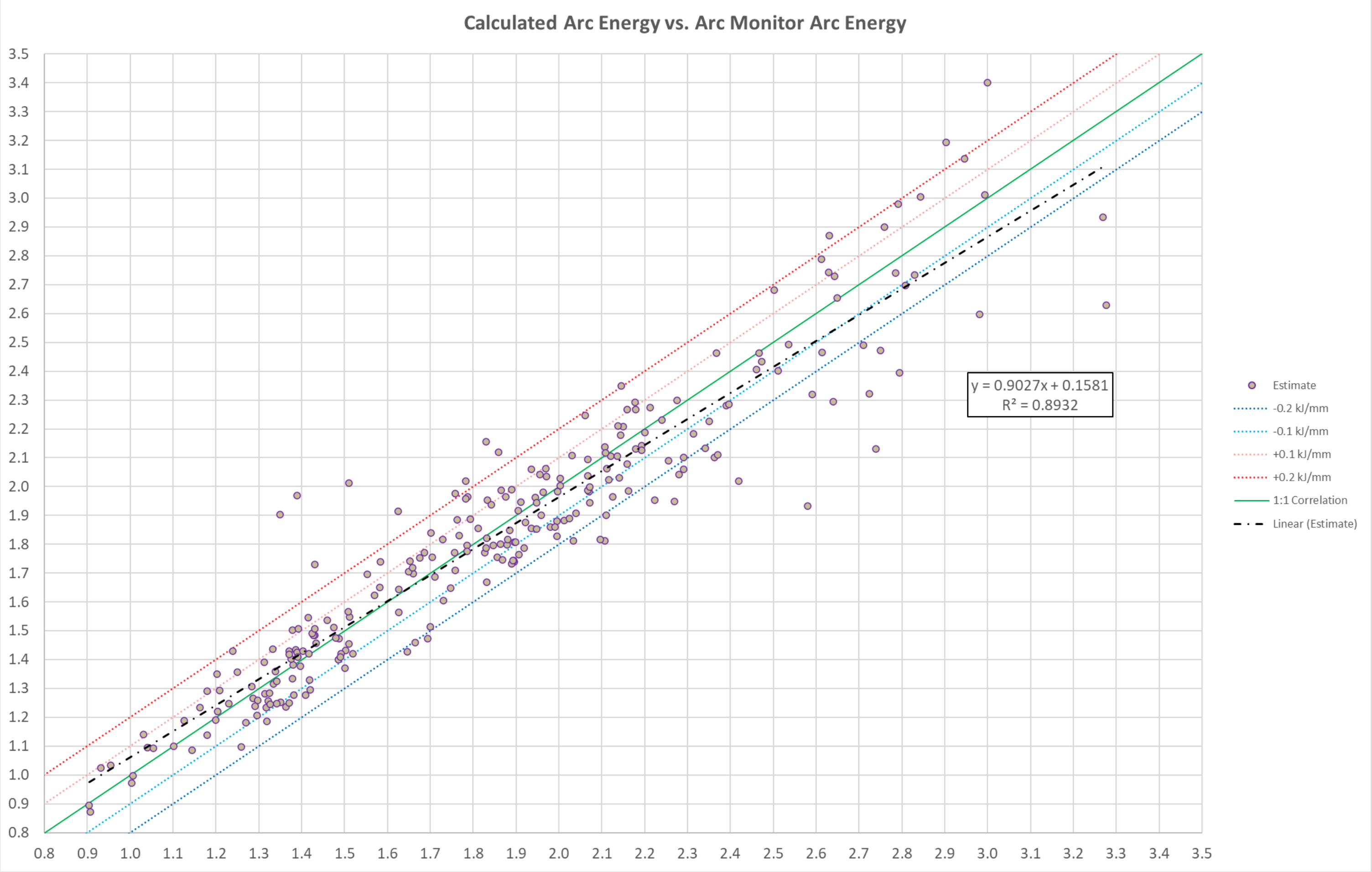
ROL/Stub Estimate vs VAT/ROL (electrode-specific f)



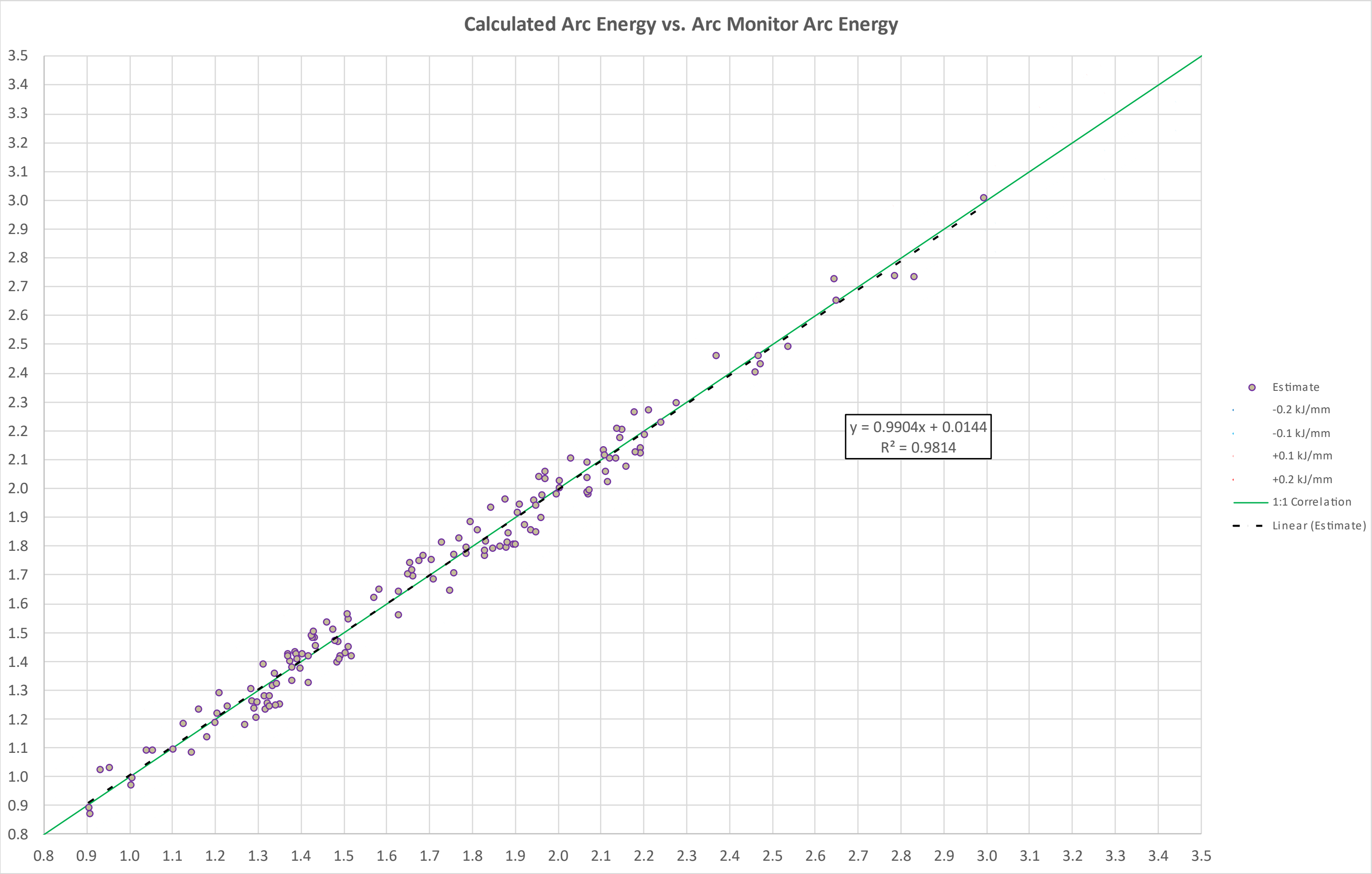
Filtering Data

Electrode factors may be more consistent when we filter out results where the VAT/ROL calculated Arc Energy is significantly different to the Arc Monitor Energy/ROL

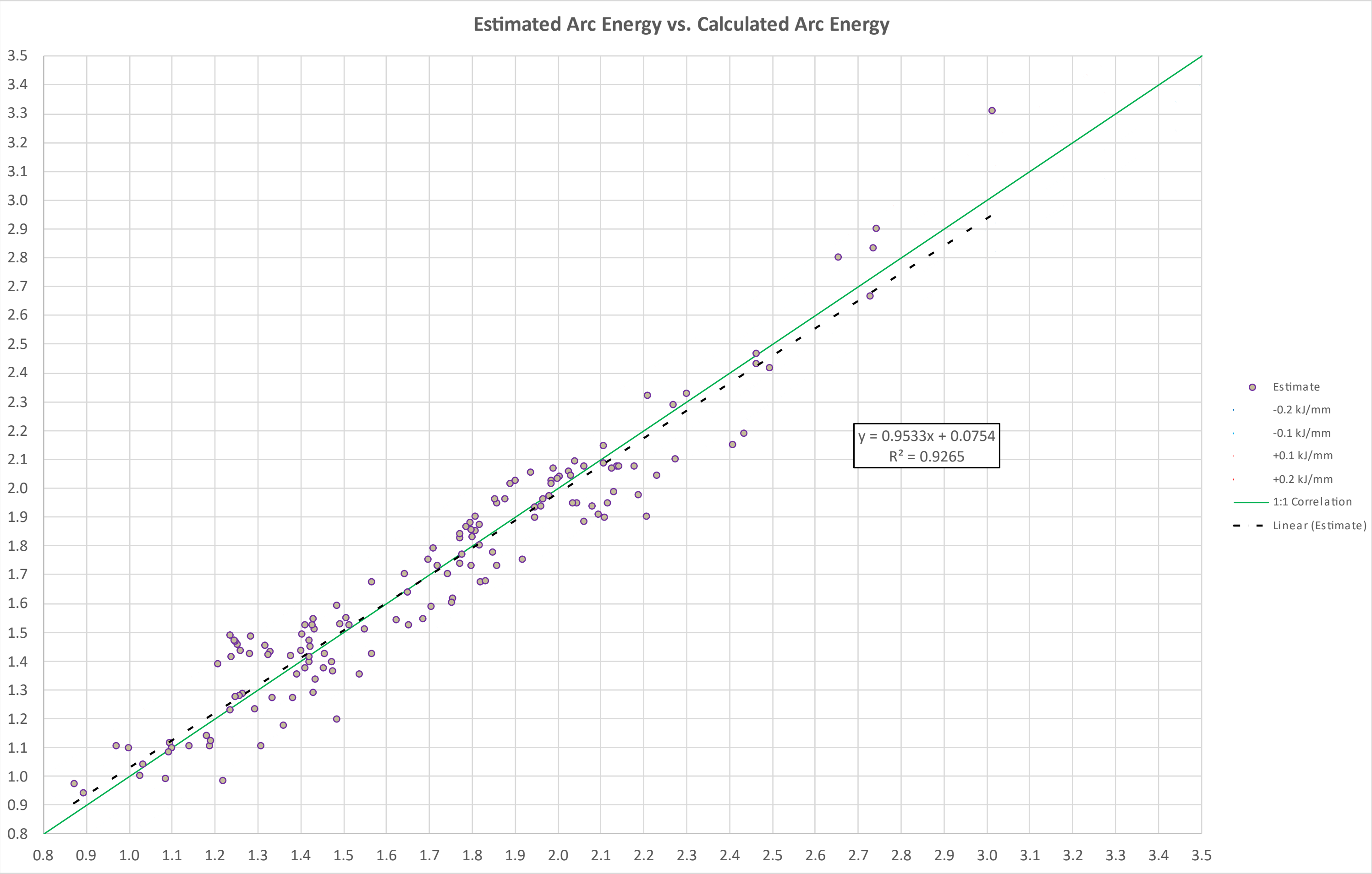
VAT/ROL vs Arc Monitor



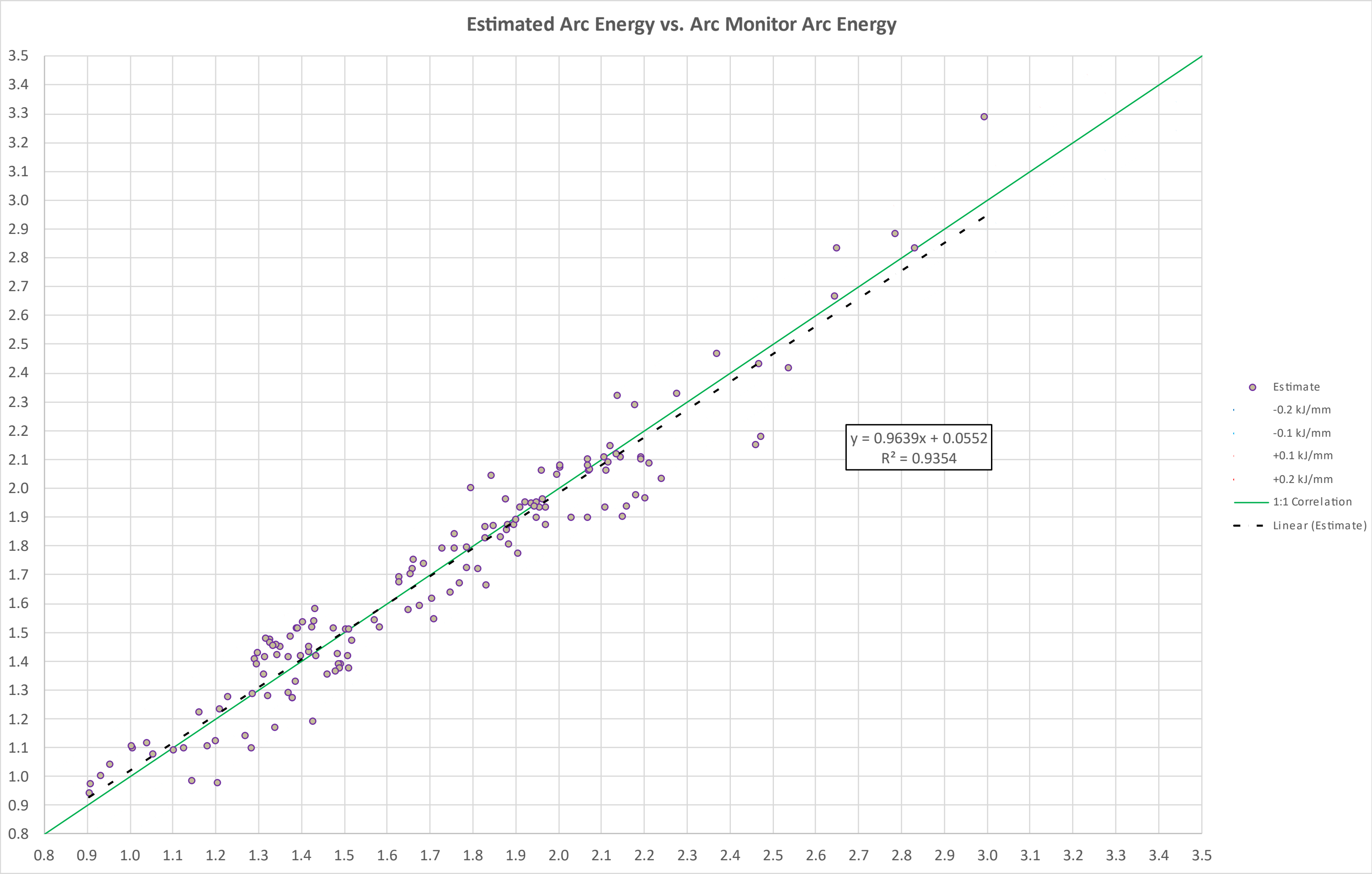
VAT/ROL vs Arc Monitor (filtered, max 0.1KJ/mm)



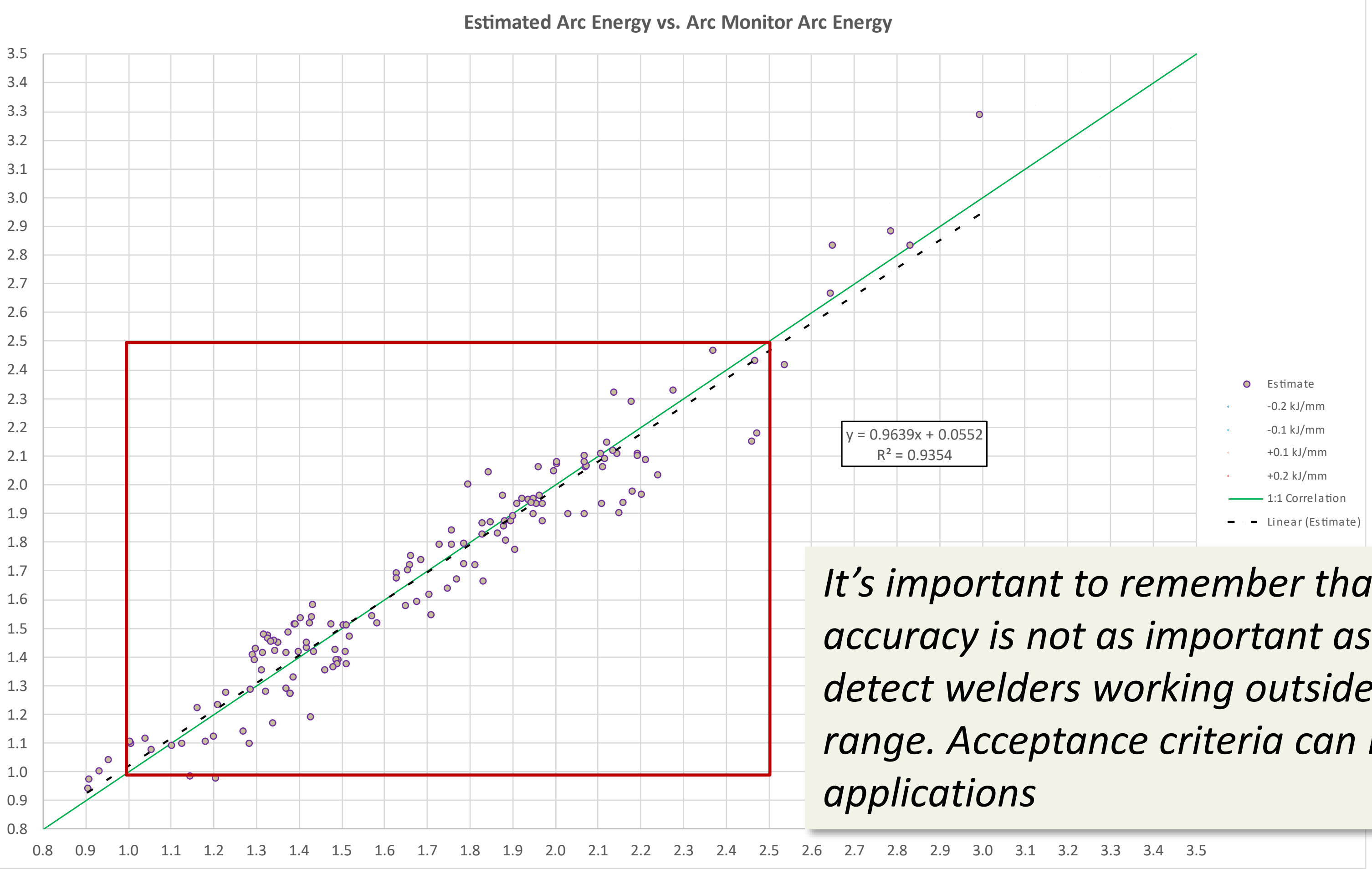
ROL/Stub Est. vs VAT/ROL (filtered, specific f)



ROL/Stub Est. vs Arc Monitor (filtered, specific f)



ROL/Stub Est. vs Arc Monitor (filtered, specific f)



It's important to remember that the absolute accuracy is not as important as whether we can detect welders working outside of the approved range. Acceptance criteria can be tweaked for critical applications

FCAW Results

The correlation between the Arc Energy recorded by an arc monitoring system and that calculated by 1st principles (V*A*T/ROL) is very good for rutile FCAW wires as they operate on spray transfer with uniform volts and amps.

However Travel Speed vs WFS correlations can be affected by the welding position and application (eg. fill vs. cap)

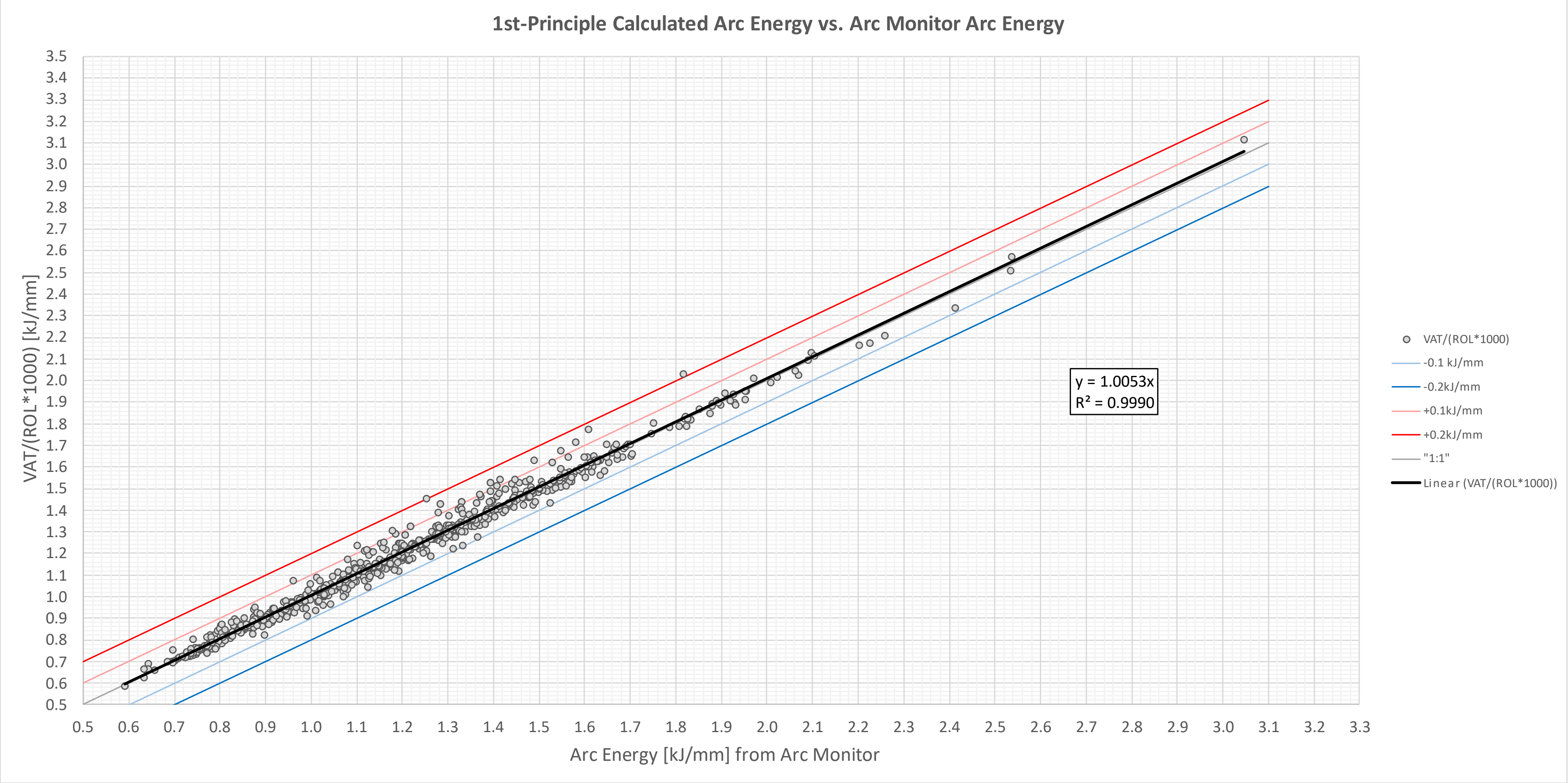
It should also be noted that the dataset used for the following graphs uses 3 different wires and 3 different wire feeder manufacturers.

One wire feeder had fully compensated voltage setting.

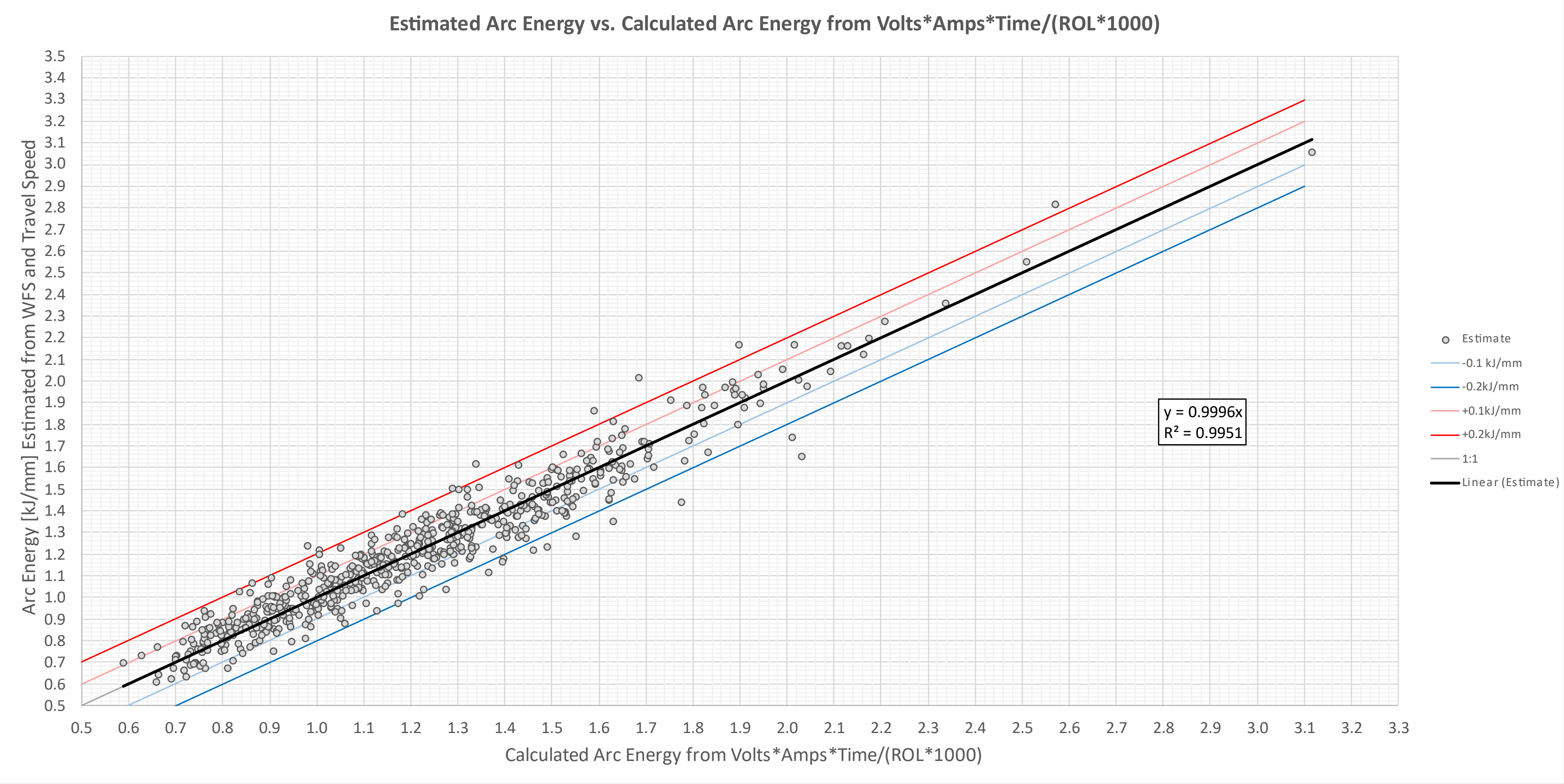
The other two wire feeders had zero-volt compensating leads, but used different torches.

These differences can cause slight variations in measured arc energies due to the arc monitor connection points.

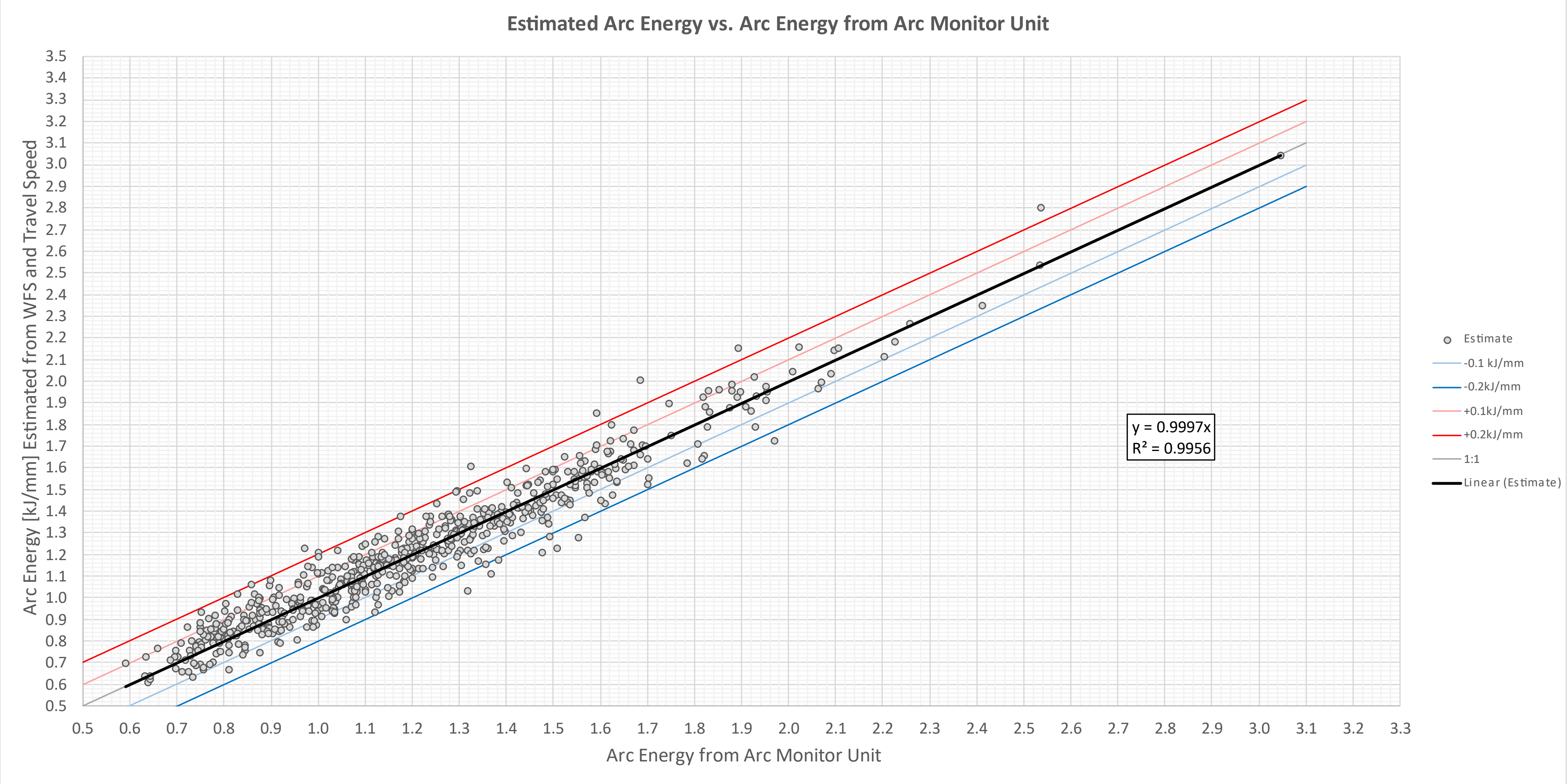
FCAW : VAT/ROL vs Arc Monitor



FCAW : Estimate vs VAT/ROL



FCAW : Estimate vs Arc Monitor



Comments

SMAW ROL/Stub and GMAW/FCAW WFS/Speed correlations both provide practical alternatives/supplements to conventional monitoring

SMAW ROL/Stub estimates offer a significant advantage because this method can easily be carried out by the welder on their own

WFS/Speed correlations are independent of equipment, and are easy to implement, provided that the WFS is accurately known

The monitoring checks are quick, and only require a steel rule (SMAW) or steel rule and stopwatch (GMAW/FCAW)

Tools

SPREADSHEETS AND WEB APPLICATION

Spreadsheets

Spreadsheet tools are provided to enable users to develop their own electrode and wire factors, and include sheets for spot calculations, charts and tables to be produced in metric and US customary units:

SMAW-ROL-AE-HI Calculator.xlsx

FCAW-WFS-AE-HI Calculator.xlsx

These files can be downloaded from https://wims.org.uk/files_list.php

This link also includes a PDF version of this presentation.

ASAMS

Web Application

A website has been created to allow people to test out these techniques, and implement them if required. Visit:

wims.org.uk

This website can be used by anyone with a phone, tablet, or laptop – provided that there is an active internet connection. You just need a steel rule.

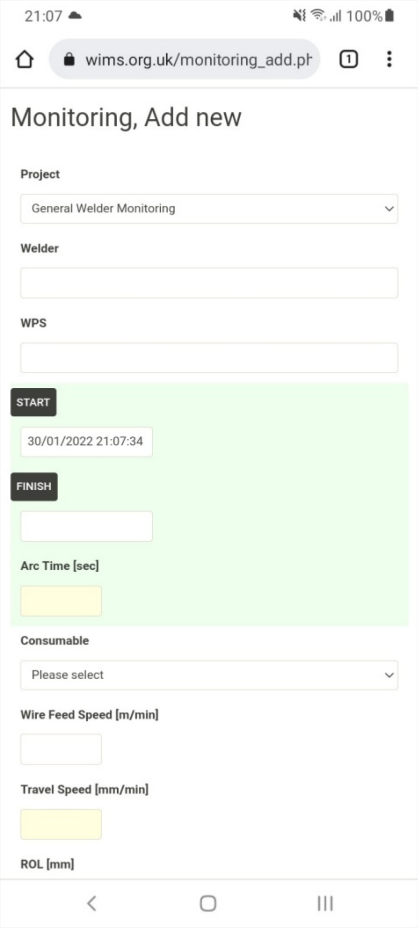
Registration is required; please check spam and junk email folder for the activation email

Data can be shared by colleagues in the same company using a ‘Shared Key’

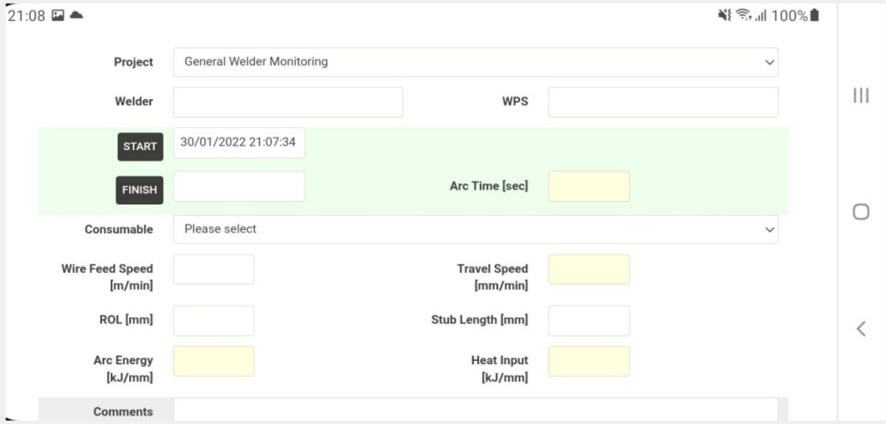
Users can download and print their own data, and also others if they use the same Shared Key

Other utilities will also be made available to the public via this site

wims.org.uk



21:07
100%
wims.org.uk/monitoring_add.ph
Monitoring, Add new
Project
General Welder Monitoring
Welder
WPS
START
30/01/2022 21:07:34
FINISH
Arc Time [sec]
Consumable
Please select
Wire Feed Speed [m/min]
Travel Speed [mm/min]
ROL [mm]



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100%
Project
General Welder Monitoring
Welder
WPS
START
30/01/2022 21:07:34
FINISH
Arc Time [sec]
Consumable
Please select
Wire Feed Speed [m/min]
Travel Speed [mm/min]
ROL [mm]
Stub Length [mm]
Arc Energy [kJ/mm]
Heat Input [kJ/mm]
Comments

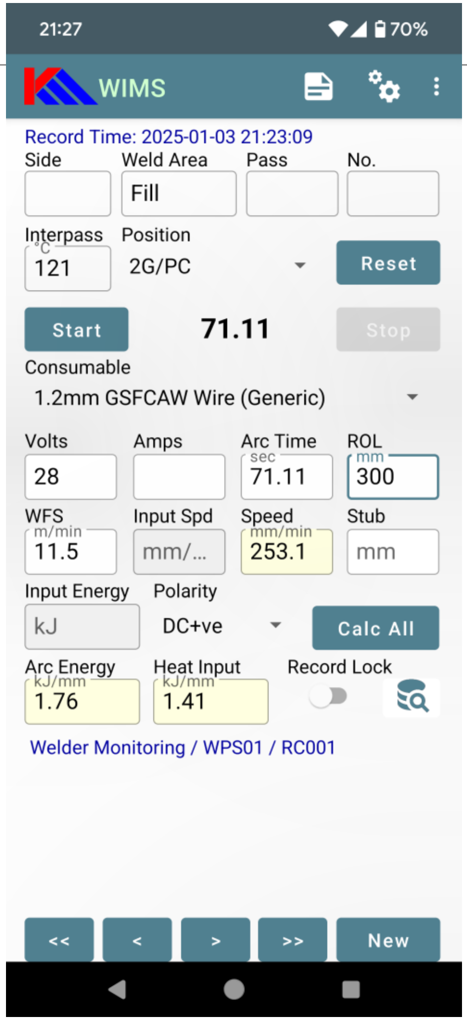
ASAMS

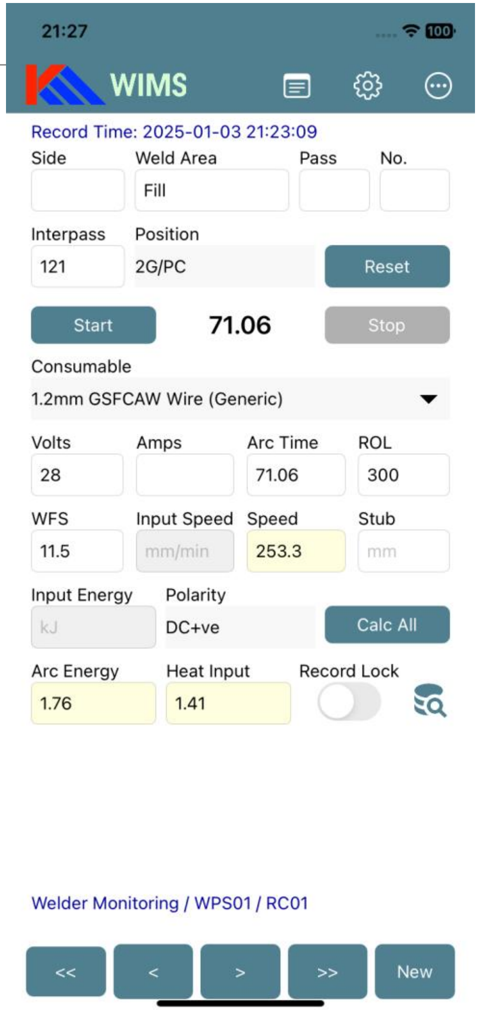
Apps

And obviously you can just install the WIMS Apps for Android and iPhone

GET IT ON Google Play

Download on the App Store





Follow-up Talks

If you enjoyed this talk, we have a number of titles available for future sessions:

1. Standard Parameters & SWIS Cards – *An easier way for everyone?*
2. Steel Metallurgy – Interstitials – *A deep dive into the effects of carbon, hydrogen, nitrogen and oxygen*
3. LTCS Charpy Toughness Considerations – *Trouble getting good results at -50 deg. C or below?*
4. Using EEMUA 235 to Determine PWHT Thickness Thresholds – *Is your client still stuck on 20mm?*

Let us know what interests you…

Q&A

Simplified heat input control in manual and semi-automatic welding

Thank you for listening/reading

Kevin Millican CEng BSc FWeldI