Arc Efficiency for Gas Tungsten Arc Welding DCEN-GTAW

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ABSTRACT

Published data in the literature between 1955 and up to 2011 shows a wide spread in arc efficiency data, between 0,36 up to 0,90. In the present study the experiments was planned using factorial design at two levels for each of the variables; current, arc length, gas type-pure Ar and Ar+2H_2. Each of the variable combinations was replicated five times. The substrate used was a water cooled Cu-block. Inlet and outlet cooling water, flow and temperature to the GTAW torch and Cu-substrate was measured. Total energy input to the TIG torch, current x voltage, energy going to the substrate and the torch was determined. The results were evaluated using statistical software programs MINITAB® and MODDE®. This resulted in a model for the energy distribution and the arc efficiency for gas tungsten arc welding with DCEN.

Key words: Gas Tungsten Arc Welding, arc efficiency, TIG welding, energy input, energy losses, process parameters.

List of symbols and abbreviations:

n	Arc efficiency
q_t	Power input to torch
q_s	Power input to substrate
U	Arc voltage
I	Welding current
t	Measurement time
ΔT	Temperature difference for cooling water
c_p	Specific heat
v	Cooling water volume
AL	Arc length
DCEN	Direct current electrode negative

1. Introduction

Why is it important to know the arc efficiency of TIG welding more precisely? GTAW is one of the most widely used arc welding methods for welding of stainless steel. It is important to know how much of the energy input to the torch that actually transfers to the base material. Arc efficiency plays an important role in many aspects of welding, for example in cooling rate calculations, for duplex weld metal the cooling rate from 1200^{o}C down to 800^{o}C is critical for the formation of the correct phase balance between austenite and ferrite.

Arc efficiency (n) is defined as:

$n = q_s/q_t$

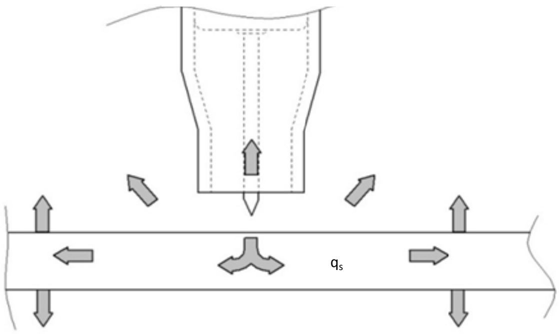

Figure 1 Schematic heat transfer, energy to substrate, losses to torch and radiation losses.

Where q_s is power input transferred to the substrate and q_t is the total power input to the arc from the power source. In the case of DC arc welding used in the present study; q_t= arc voltage x current x arc time. Two different approaches to determine arc efficiency are used by different researchers; one is based on the use of calorimetric experiments and the other method uses different heat flow models calibrated with measured parameters. The use of calorimetric experiments is a direct approach, whereas the modelling approach is an indirect approach. Examples of calorimetric approaches are given in reference [1,2,3,4], modelling approach examples are given I reference [5,6,7]. Review of arc efficiency studies between 1955 until 2011 is given in reference [8] (also published in the open document database DIVA - http://www.diva-portal.org). In the present study a direct calorimetric approach was used.

2. Experimental procedure

A fixed TIG torch was used and the substrate was a water cooled Cu-block, for the setup see figure 2.

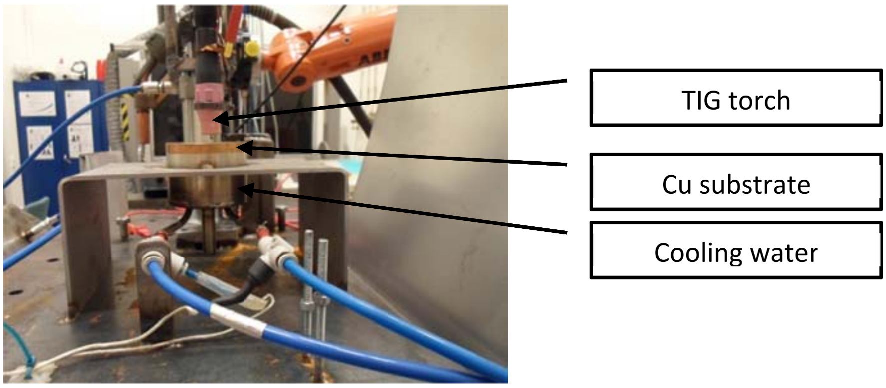

Figure 2. Experimental setup

Power source: Migatronic Commander 400 AC/DC

TIG torch: Binzel Tornado WH0

Electrode: 2,4 mm WT20 98 % wolfram 2 % Thorium attached to the negative pole, tip angle 60^o

Gas: Ar, Ar+2%H_2 gas flow 10l/min

The Cu-substrate was cooled with fresh water and the temperature and flow rate was measured continuously. Welding voltage was measured at the torch and the welding current was measured with a Hall element. The cooling water to the welding torch was also measured regarding temperature and flow rate.

All of the measurement signals was collected by a measurement module from National Instruments and presented in a LabView-interface, the signals was also logged to a file. Sampling frequency during the test 50 kHz, total sampling time after reaching a steady state condition; 120sek.

Energy input to the torch $q_t = U \times I \times t$.

Energy input to substrate, q_s, and torch losses $q = v \times \Delta T \times c_p$

c_p=specific heat for water 4,181[kJ/(kg·K)]

Experimental matrix for the factorial design:

Arc length [mm]	Current [amp]	Shielding gas
2 (giving~10,5V)	75	Ar
5 (giving~12,5V)	150	$Ar2H_2$

This design matrix gives total 8 experiments which were replicated 5 times.

3. Results

In table 1 the results of the 40 test runs are shown.

	test 1				losses	test 2				losses	test 3				losses
	E, kJ	Tot	Substr	Gun		E, kJ	Tot	Substr	Gun		E, kJ	Tot	Substr	Gun	
2_60-0_75_AR	90,0	0,980	0,880	0,100	0,020	89,3	0,908	0,853	0,055	0,092	88,4	0,889	0,853	0,054	0,111
2_60-0_150_AR	195,1	0,961	0,834	0,127	0,039	200,9	0,930	0,819	0,111	0,070	193,3	0,938	0,815	0,123	0,062
5_60-0_75_AR	107,5	0,943	0,848	0,095	0,057	106,3	0,919	0,844	0,075	0,081	102,4	0,951	0,841	0,110	0,049
5_60-0_150_AR	230,8	0,931	0,814	0,118	0,069	223,9	0,924	0,815	0,109	0,076	218,4	0,931	0,806	0,124	0,069
2_60-0_75_AR+2%H	92,5	0,992	0,875	0,117	0,008	94,8	0,931	0,872	0,059	0,069	93,3	0,970	0,861	0,109	0,030
2_60-0_150_AR+2%H	189,2	0,981	0,842	0,139	0,019	200,2	0,949	0,838	0,111	0,051	198,5	0,965	0,834	0,131	0,035
5_60-0_75_AR+2%H	112,6	0,955	0,853	0,101	0,045	111,4	0,953	0,862	0,091	0,047	108,8	0,921	0,846	0,075	0,079
5_60-0_150_AR+2%H	231,8	0,928	0,821	0,107	0,072	227,5	0,938	0,827	0,110	0,062	223,2	0,918	0,810	0,108	0,082

	test 4				losses	test 5				losses
	E, kJ	Tot	Substr	Gun		E, kJ	Tot	Substr	Gun	
2_60-0_75_AR	89,6	0,928	0,869	0,059	0,072	88,4	0,877	0,823	0,054	0,123
2_60-0_150_AR	198,2	0,941	0,820	0,121	0,059	202,2	0,908	0,800	0,109	0,092
5_60-0_75_AR	105,7	0,932	0,848	0,084	0,068	104,6	0,876	0,816	0,060	0,124
5_60-0_150_AR	224,1	0,913	0,800	0,113	0,087	222,6	0,883	0,771	0,113	0,117
2_60-0_75_AR+2%H	94,1	0,956	0,861	0,095	0,044	94,0	0,935	0,854	0,081	0,065
2_60-0_150_AR+2%H	192,3	0,967	0,844	0,123	0,033	192,0	0,925	0,807	0,118	0,075
5_60-0_75_AR+2%H	108,9	0,927	0,851	0,076	0,073	123,6	0,934	0,857	0,077	0,066
5_60-0_150_AR+2%H	224,6	0,918	0,806	0,112	0,082	236,1	0,896	0,790	0,107	0,104

Table1. E (q_t) total energy input to the TIG torch, Substr = the arc efficiency, Gun= losses to the cooling of the torch, losses= other losses, for example, irradiation to the surroundings.

The results from the experiments were evaluated using the statistical software programs MINITAB® and MODDE®.

In figure 3 the normal probability plot for the tree energy parts can be seen.

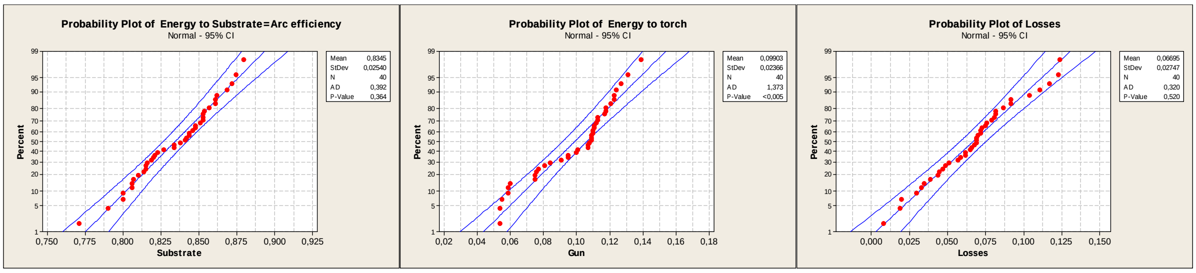

Figure 3. Probability plots.

The arc efficiency and other losses are normal distributed but losses to the torch are not normal distributed at the 95% confidence level. This is probably due to the closed cooling system used for the torch.

3.1Arc efficiency:

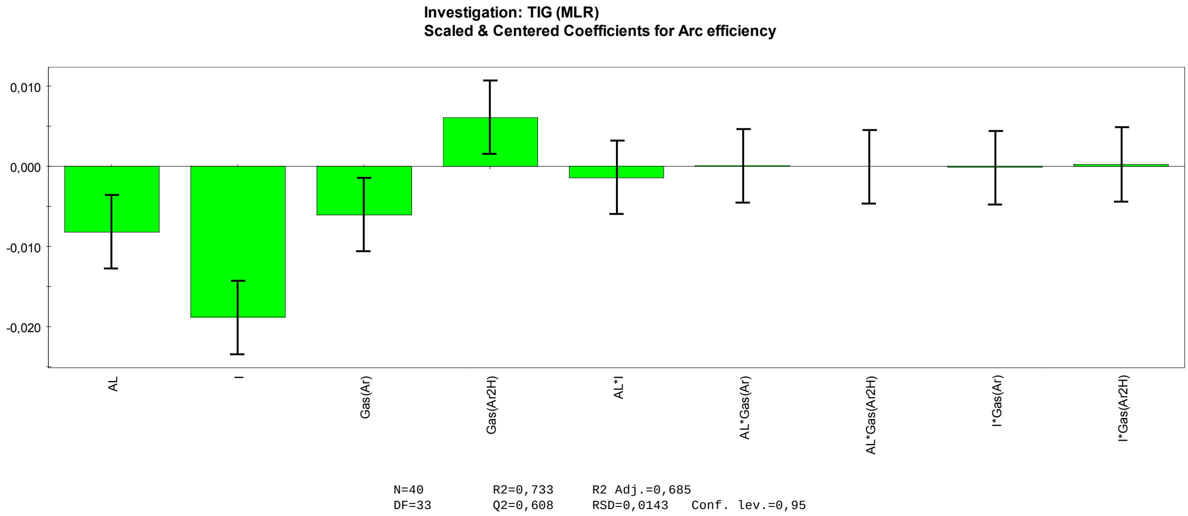

Figure 4. Factors affecting the Arc Efficiency.

As can be seen in figure 4, increasing the current and arc length will reduce the arc efficiency and the use of an $Ar2H_2$ mixture compared to pure Ar shielding gas gives a positive effect. All of the interaction effects fall outside of the 95% confidence interval. Regression coefficients for the arc efficiency:

Sub	Coeff. SC	Std. Err.	P	Conf. int(±)
Constant	0,8345	0,00225422	0	0,00458625
AL	-0,00820002	0,00225422	0,000928942	0,00458625
I	-0,01885	0,00225422	1,16569e-009	0,00458625
Gas	DF = 1			
Gas(Ar)	-0,00604997	0,00225422	0,0112907	0,00458625
Gas(Ar2H)	0,00604997	0,00225422	0,0112907	0,00458625
*AL*I*	*-0,00144999*	*0,00225422*	*0,524517*	*0,00458625*
*AL*Gas*	*DF = 1*			
*AL*Gas(Ar)*	*4,99711e-005*	*0,00225422*	*0,982442*	*0,00458625*
*AL*Gas(Ar2H)*	*-4,99711e-005*	*0,00225422*	*0,982442*	*0,00458625*
*I*Gas*	*DF = 1*			
*I*Gas(Ar)*	*-0,000200055*	*0,00225422*	*0,929821*	*0,00458625*
*I*Gas(Ar2H)*	*0,000200055*	*0,00225422*	*10,92982*	*0,00458625*
N = 40	Q2 =	0,608	Cond. no. =	1,0000
DF = 33	R2 =	0,733	Y-miss =	0
	R2 Adj. =	0,685	RSD =	0,0143
			Conf. lev. =	0,95

Not significant at 95% confidence level

Observed versus model prediction can be seen in figure 5.

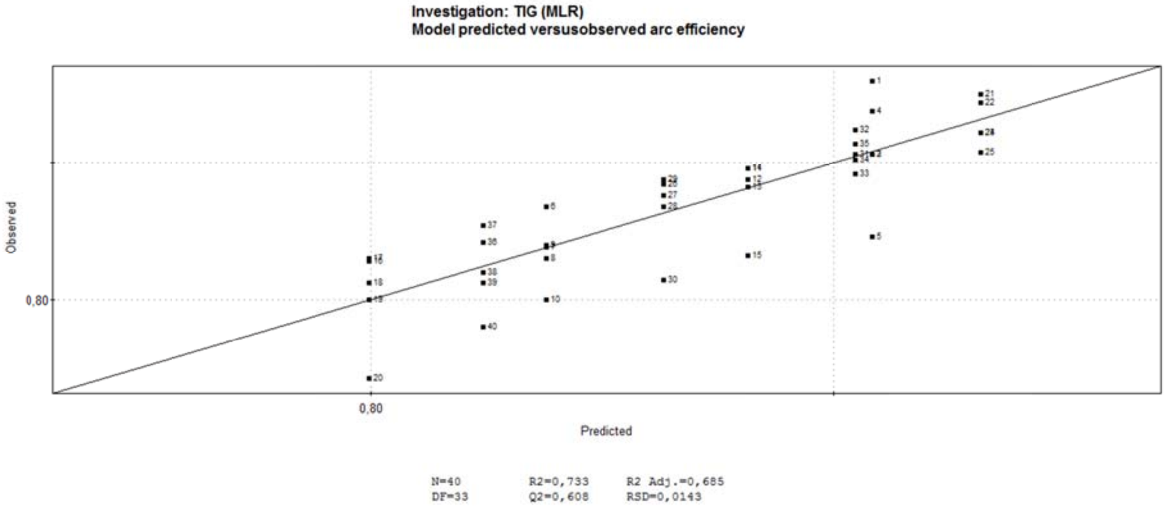

Figure 5. R^2 a measure of the fit for the model and Q^2 a measure of how well the fitted model will predict new experimental conditions.

Model mapping for the different shielding gases used in the investigation can be seen in figure 6.

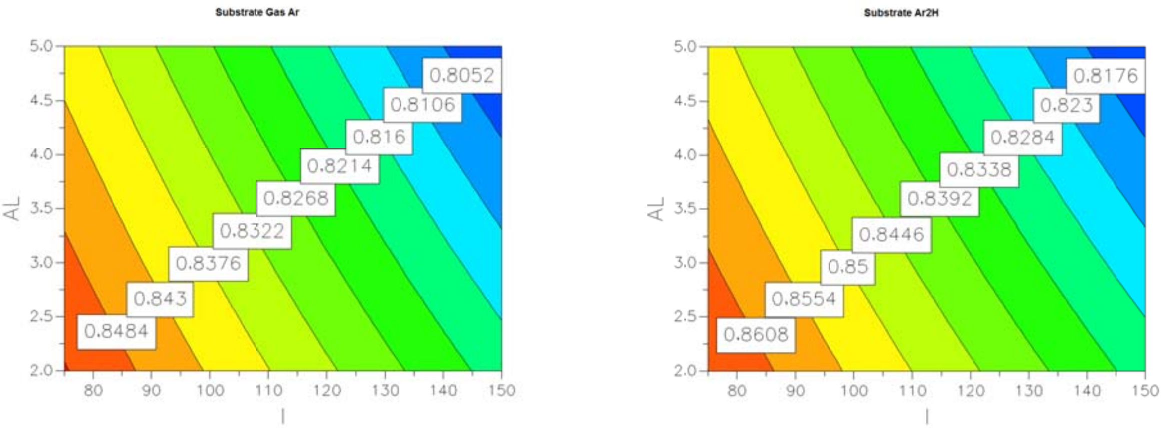

Figure 6 Model mapping of arc efficiency for the different shielding gases; Ar and Ar2H.

3.2 Energy losses in the torch:

Approximately 5-10% of the energy supplied to the torch is lost due to torch-cooling. As can be seen in figure 7 torch losses are increasing with higher welding current, as can be expected. The welding current is the only parameter significant at the 95% confidence interval affecting torch losses.

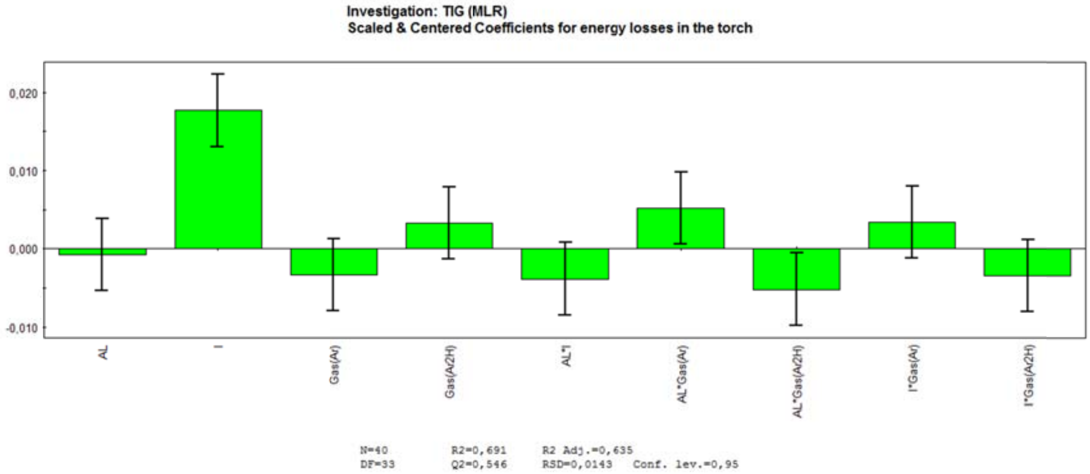

Figure 7. Factors effecting energy losses in the torch.

The model fit for torch losses explains 69% of the results (R^2=0,691). The model mapping of torch losses shows a quiet different behavior for the two tested shielding gases, see figure 8.

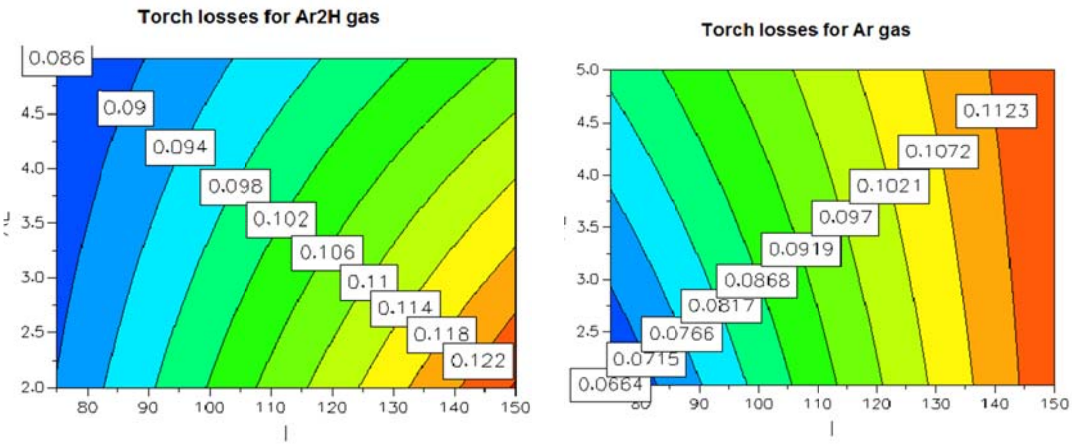

Figure 8. Mapping of torch losses

If we compare the model predictions for torch losses to the mean value of the 5 replicates for each parameter setting we can see that the model fit is quite god, table 2.

Test series	MV measured	Mod. Value	Diff Meas-ModValue
2-75-Ar	0,064	0,066	-0,002
2-150-Ar	0,118	0,112	0,006
5-75-Ar	0,085	0,085	0,000
5-150-Ar	0,115	0,115	0,000
2-75-Ar2H	0,092	0,090	0,002
2-150-Ar2H	0,124	0,122	0,002
5-75-Ar2H	0,084	0,083	0,001
5-150-AR2H	0,109	0,112	-0,003

Table 2. Mean value measured – model value.

3.3 Other losses

The mean value for other losses is 7% with a rater wide spread 2-12%. The model for these losses based on the experimental data shows a very low prediction power with an R^2 value of 33% and a Q^2 value of 3%.

5. Discussion

The raw data are normal distributed except for the energy losses in the torch. The reason for this is that the closed loop cooling system is not powerful enough to give a constant temperature difference between inlet- and outlet water temperature during the measurement time. This can be seen in figure 9, showing two examples of the temperature difference changes during the test cycle, at low welding current the temperature difference is going down, the cooling is effective, but at high current the situation is changed.

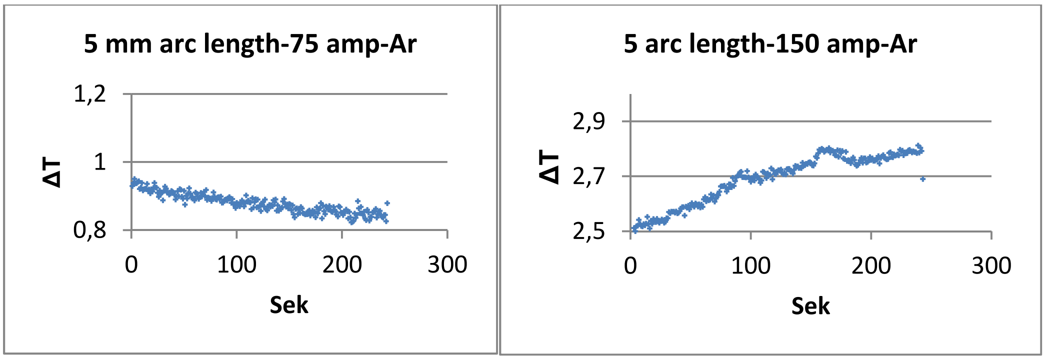

Figure 9. Temperature difference cooling water out-in to the torch during test cycle.

In spite of this the measured torch losses compared to the model predictions are quite god.

A question not answered by this investigation is if the arc efficiency and torch losses are influenced by different torch designs.

4. Conclusions

Increased arc length and current gives reduced arc efficiency for the GTAW-DCEN welding process.

Ar2H shielding gas gives a positive effect on arc efficiency compared to a pure Ar gas, but the effect is small, ~+1,5%.

GTAW-DCEN is an effective welding process with an arc efficiency value in the range 0,81-0,86.

5. Acknowledgments

Financial support for the study given by the KK-foundation is gratefully acknowledged.

6. References

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