A STUDY OF ARC AND MELTING EFFICIENCY IN GTAW PROCESS

A.W. ORŁOWICZ¹, A. TRYTEK²
Department of Foundry and Welding Engineering, Technical University Rzeszów
ul. W. Pola 2, 35-959 Rzeszów, Poland, zois@prz.rzeszow.pl

SUMMARY

A study was conducted on the arc and melting efficiency of the gas tungsten arc welding process. The application of the flow type calorimeter for the measurement of arc efficiency is described. The experiment compared worpice materials (spheroidal graphite cast iron) and varied arc power and travel speed. Arc and melting efficiency was determined as a function of current and travel speed as a function of energy input per unit fusion length and as function the product of net arc power and travel speed. A stepwise regression method was used to develop relationship between GTAW process parameters and those of fusion geometry, arc efficiency and melting efficiency for the obtained set.

Keywords: arc efficiency, melting efficiency, GTAW process, fusion zone, calorimeter.

1. INTRODUCTION

The GTAW method has already archived a high degree of perfection and has been finding wide application in the recent years both for joining and post-casting treatments of cast machine and equipment parts. This method is particulary interesting in technological and economic respects. Due to progress in the building of suitable equipment a broad range of possibilities to shape and monitor the welding currents runs is now available. In combination with good gas shielding of the molten pool it guarantees high quality of fusions.

¹ dr hab. Inż., prof. PRz: aworlow@prz.rzeszow.pl
² dr inż. trytek@prz.rzeszow.pl
In the GTAW process the arcing takes place between tungsten electrode and the workpiece, with respective flow of a stream of electrons and ionized gas particles. Knowing the quantity of heat supplied by electric arc to heated area is the basis for developing of correct surfacing process for castings. The total energy generated by the process \( E_t \) is distributed in two ways: a portion is lost to the environment and the second portion is delivered to the work piece. The net energy transferred to work piece is also basically distributed in two ways [1]; a portion is used for melting of the fusion zone \( E_{fz} \) and second portion is lost to the adjacent base metal \( E_{bm} \) outside of the fusion zone primarily by thermal conduction. These portion of energy contributes to formation of the heat-affected zone (HAZ) and heating of the base metal outside the HAZ above the ambient temperature.

The arc efficiency \( \eta \) and the melting efficiency \( \eta_m \) are given as:

\[
\eta = \frac{(E_{fz} + E_{bm})}{E_t}
\]

(1)

\[
\eta_m = \frac{E_{fz}}{(E_{fz} + E_{bm})}
\]

(2)

Experimental measurements have shown that arc efficiency varies only slightly with change in processing parameters [1,2]. The melting efficiency depends strongly on the arc power and travel speed [2,3].

The primarily objective of a welding process is to provide energy to the base metal for the melting of the fusion zone. After this point adjustment in processing parameters provide to maximize the melting efficiency and reduce the size of the HAZ and minimize wasted process energy.

Research on the effect of process parameters on the thermal efficiency, melting efficiency and fusion geometry applies mainly to steel and aluminium alloys. Less attention is given to those questions to spheroidal graphite cast iron. The results of this work will be used to predicting the fusion geometry the thermal and melting efficiency of the welding process from the welding parameters.

2. EKSPERIMENTAL PROCEDURE

2.1 Material and casting procedure

The material tested was a non-alloyed spheroidal graphite cast iron (3.5%C, 2.3%Si, 0.66%Mn, 0.019%S, 0.039%P, 0.17%Cu, 0.01%Ni and 0.07%Mg, Fe balance. The samples of dimensions 250x50x10mm were cut out from the cast plate of dimensions 300x100x10mm. The surface of samples was fused under protective argon atmosphere using direct current electrode negative (DCEN) polarity with a 2.4 mm diameter, 2% toriated tungsten electrode. The measured voltage represents the sum of voltage drops across the electrode and arc. Current was measured by a calibrated shunt placed in series with the current carrying cable.
2.2. Arc and melting efficiency

Arc efficiency measurements were conducted using a flow calorimeter. This calorimeter is described for arc efficiency measurements in work [4]. After determining the total heat content of the weld sample, the arc efficiency was calculated by:

$$\eta = \frac{E_{\text{meas}}}{U \cdot I \cdot t}$$

(3)

where: $U$ is the voltage, $I$ is current, $t$ is the welding time.

The heat of the weld volume was determined by multiplying the fusion zone volume, $V_{fz}$, by heat required to bring a unit volume of the metal from room temperature to the liquid state and includes the heat of fusion. It is given by the following expression:

$$Q_H = \Delta Q_f + \int_{T_1}^{T_2} c_p \, dt$$

(4)

where: $Q_f$ is latent heat of fusion, $c_p$ is specific heat, $T_1$ is room temperature, $T_2$ is liquidus temperature.

2.3. Fusion geometry examination

Weld cross-sectional area was determined from the average of three transverse metallographic sections taken from each weld. These areas were multiplied by the weld length (200mm) to determine the total fusion zone volume ($V_{fz}$).

3. RESULTS AND DISCUSSION

3.1. Microstructure

The casting had a pearlite–ferrite matrix structure and spheroidal graphite precipitates (Fig. 1). The casting hardness was 175 BHN. Precipitates of fibrous and lamellar cementite eutectic were obtained in the fusion area.

As a result of rapid heat extraction to substrate a rapid crystallization of material takes place in the area fused by electric arc. Solidification begins epitaxially at the bottom surface and grows to the upper free surface [5]. Lamellar and fibrous cementite eutectic were formed on fused area. The eutectic spacing is sensitive to growth rate and to the thermal gradients across the liquid. Thus, the change in $\lambda_e$ can probably be explained by change in the thermal gradients across the liquid as the pool size changes with the electric arc energy distribution on pool surface. The electric arc energy distribution determines temperature gradients, which in turn affect the flow of metal in the pool [6].
Fig. 1. Typical microstructure of spheroidal graphite cast iron: in as cast condition - (a), in the fused area ($I=300\,A, \, v_s=800\,mm/min$) - (b)

Rys. 1. Struktura żeliwa sferoidalnego w stanie surowym - (a) i w obszarze nadtopienia ($I=300\,A, \, v_s=800\,mm/min$) - (b)
3.2. Arc characteristics

Considering the stability criterion of Kaufmann an arc burns stable if the voltage drop increase with the current; i.e. \( \frac{dU}{dI} > 0 \). This criterion was used to qualify the welding process considering the arc characteristic. The arc characteristic are plotted in figure 2.

![Fig. 2. Voltage (U) - current (I) arc characteristics](image)

Rys. 2. Charakterystyka łuku elektrycznego

3.3. Fusion geometry

The effect of welding current intensity and travel speed on fusion geometry is presented graphically in figure 3.

As can be seen from the figures, the values of depth of the fusion geometry rise with rising current intensity and with slowing travel speed, i.e. with rising quantity of heat input into molten pool. The width of the fusion zone are observed to grow much stronger than its depth. The width of the fusion zone exhibits similar sensitivity to changes in \( I \) and \( v \), values in the whole analyzed range of parameters.

The relationship between the fusion process parameters \( U, I, v \), i.e. the energy input per unit fusion length is often applied in the welding practice as a useful combination of the fusion process parameters.

Correlation and multiple regression analyses were applied in order to determine the effect of the GTAW process parameter on the fusion geometry. As a results of such analysis, the relationships described by the following equations have been obtained:

\[
w = 2.29 + 0.96E \quad R=0.96
\]
\[ d = 0.79 + 0.91E \quad R=0.91 \]  \hspace{1cm} (6)

All obtained relationships are characterized by high value of correlation coefficient, thus indicating its usefulness for prediction purposes.

\textbf{Fig. 3.}\ The effect of current intensity \( I \) (a) and electric arc advance speed \( v_s \) (b) on the width \( w \) and depth \( d \) of the fusion zone

\textbf{Rys. 3.}\ Wpływ natężenia prądu \( I \) (a) i prędkości skanowania łukiem elektrycznym \( v_s \) (b) na szerokość \( w \) i głębokość \( d \) nadtopień
3.4. Arc and melting efficiency

Figure 4 shows the arc efficiency $\eta$ and melting efficiency $\eta_m$ as a function of welding current $I$ and travel speed $v_s$.

The data also shown there is little variation in arc efficiency over the current range investigated for the same travel speed. The highest arc efficiency of the process is achieved by choosing small travel speed and as high as possible current intensity. For the parameter range used in this paper the highest arc efficiency $\eta=0.77$ was obtained by using low travel speed. These values are in good agreement with other arc efficiency reported in the literature for GTAW process [1,7]

Correlation and multiple regression analyses were applied in order to determine the effect of the GTAW process parameter on the the arc efficiency. As a result of such analysis, the relationships described by the following equations have been obtained:

$$\eta = 0.49 + 0.67E \quad R=0.67$$

The functional relationship between melting efficiency and energy input per unit fusion length predicted by equations (8) is similar to the trend seen, but otherwise, they do not correlate.

Okada [3] and Du Pont and Marder [1] sugesting a synergistic relation, have shown the melting efficiency as a function of $\eta UI$, the product of net arc power and travel speed $v_s$. The relationships described by the following equations have been obtained:

$$\eta_m = -0.019 + 0.97v_s + 0.49 \eta UI \quad R=0.90$$

The data also shown there is little variation in arc efficiency over the current range investigated for the same travel speed. The highest arc efficiency of the process is achieved by choosing small travel speed and as high as possible current intensity. For the parameter range used in this paper the highest arc efficiency $\eta=0.77$ was obtained by using low travel speed. These values are in good agreement with other arc efficiency reported in the literature for GTAW process [1,7]

Correlation and multiple regression analyses were applied in order to determine the effect of the GTAW process parameter on the the arc efficiency. As a result of such analysis, the relationships described by the following equations have been obtained:

$$\eta = 0.49 + 0.67E \quad R=0.67$$

Du Pont, et al [1], and Fuersbach, at al [2] found that there is a little difference between the observed melting efficiencies welding processes when the arc power, travel speed and heat flow patterns are the same.

A review of the literature on melting efficiency has found that very little empirical data has been published [1,2,8]. Fuersbach and Knorovsky [2] reported a maximum melting efficiency of 0.46, Du Pont and Marder [1] reported a maximum melting efficiency of 0.35. The maximum melting efficiency measured in this study was 0.37.

Figure 4 shows the melting efficiency $\eta_m$ as a function of welding current $I$ and travel speed $v_s$. Figure 4 show that the melting efficiency increased with increasing travel speed and welding current.

Correlation and multiple regression analyses were applied in order to determine the effect of the GTAW process parameter on the the melting efficiency. As a result of such analysis, the relationships described by the following equations have been obtained:

$$\eta_m = 0.22 - 0.21 E \quad R=0.21$$

The functional relationship between melting efficiency and energy input per unit fusion length predicted by equation (9) is similar to the trend seen, but otherwise, they do not correlate.

Okada [3] and Du Pont and Marder [1] sugesting a synergistic relation, have shown the melting efficiency as a function of $\eta UI$, the product of net arc power and travel speed $v_s$. The relationships described by the following equations have been obtained:

$$\eta_m = -0.019 + 0.97v_s + 0.49 \eta UI \quad R=0.90$$
In this formula, the variable $v_s$ has the strongest effect.

**Fig. 4.** The effect of current intensity $I$ (a) and travel speed $v_s$ (b) on the arc efficiency $\eta$ and the melting efficiency $\eta_m$.

**Rys. 4.** Wpływ natężenia prądu $I$ (a) i prędkości skanowania $v_s$ (b) na sprawność cieplną procesu $\eta$ i sprawność topienia $\eta_m$. 
4. CONCLUSIONS

1. Through changes in current and travel speed of electric arc, thermal efficiency, melting efficiency and quantity of net heat input to fused area may be influenced. It enables controlling of fusion size and geometry.

2. The arc efficiency for the GTAW process decreased with increasing travel speed and with decreasing total heat generated by the arc and electrode. It is impossible to know the melting efficiency when an incorrect determination of the arc efficiency has been made.

3. The melting efficiency for the GTAW process increased with increasing travel speed and the product of net arc power. It was shown that the expression $\eta \cdot U \cdot I \cdot v$ proposed by Okada may be successfully applied in the welding practice.

REFERENCES

STRESZCZENIE


Recenzował: prof. dr inż. Józef Gawroński