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Diagnostics of plasma arc during the process of remelting of surface layer in 40Cr4 steel

A. Dudek*, Z. Nitkiewicz
Institute of Materials Engineering, Częstochowa University of Technology,
Al. Armii Krajowej 19, 42-200 Częstochowa, Poland
* Corresponding author: E-mail address: dudek@mim.pcz.czest.pl

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ABSTRACT

Purpose: The purpose of this work is to propose a research method for diagnostics and determination of temperature and shape of plasma arc used for surface treatment of 40Cr4 steel with TiO_2 coating.

Design/methodology/approach: The surfaces of samples, previously coated with ceramic coating, have been remelted with plasma arc. For investigations of arc shape the high-resolution modern visible light camera and thermovision camera have been used.

Findings: The temperature distribution in plasma arc with percentage quantity of temperature fields has been determined. The arc limiting profiles with isotherms have also been determined.

Research limitations/implications: Further research is aimed to assign the identified spatial points of the arc with the appropriate values of temperature.

Practical implications: Selection of remelting parameters is performed by trial and error method, which is time-consuming and expensive. In-depth recognition of parameters, which characterise the source, will be useful in creation of the method of fast prognosis of parameters for the used source with the effects of remelting.

Originality/value: The diagnostics of plasma arc which consists in estimation of the temperature and the shape of the arc by means of high-resolution visible light camera and the thermovision camera.

Keywords: Welding; Plasma arc

MATERIALS MANUFACTURING AND PROCESSING

1. Introduction

The requirements imposed on materials by modern, ever-developing technology can be met due to e.g. application of surface treatment which enables formation of surface layer [1-15].

For the processes of manufacturing of surface layers, wide application was found for concentrated sources of energy, such as plasma, laser or welding technologies, whose application leads to improvement in usage properties of a processed element.

Growing interest and wide use of arc plasma in industry makes researchers recognize and explain the phenomena which occur in the plasma. Selections of parameters for remelting process is usually made on the basis of trial and error method which is usually time-consuming and expensive. Therefore, in-depth analysis of e.g. parameters which characterize the source will be very useful in creation of the method which would enable fast correlation of parameters of used source with effects of remelting. This will enable wide application of the technology.

One of the most important parameters which determine the plasma arc is the temperature which has direct influence on all remaining parameters of the process. Thus many researchers have made attempts to investigate this parameter [1-8, 11-15].

Depending on current-voltage parameters or the type of gas, the temperature in the arc is from 5000 to 30000 K. On the basis of literature, the following methods, whose aim is to determine the temperature of the plasma arc, can be listed:

- numerical method,
- spectrometric method,
- fast filming method.

These methods consist in some assumptions, according to the structure of the arc itself [1]:

- arc is stable, axis of symmetry and plasma flow are stable,
- plasma is in the state of local thermodynamic equilbrium (LTE),
- gravity, scattering and radiation loss are neglected,
- electromagnetic force is considered only for mass force inside arc.

Numerical method consists in application of finite element method or boundary element method and the following equations which determine the plasma arc:

Mass conservation equation:

$$\frac{1\partial}{r\partial r}(\rho r u)+\frac{\partial}{\partial z}(\rho w)=0 \quad (1)$$

Radial momentum conservation equation:

$$\frac{1\partial}{r\partial r}(\rho r u^2)+\frac{\partial}{\partial z}(\rho u w)=-\frac{\partial P}{\partial r}+\frac{2\partial}{r\partial r}(\mu r\frac{\partial u}{\partial r}) \quad (2)$$
$$-2\mu\frac{u}{r^2}+\frac{\partial}{\partial z}\left\{\mu\left(\frac{\partial w}{\partial r}+\frac{\partial u}{\partial z}\right)\right\}-j_z B_\Theta$$

Axial one:

$$\frac{1\partial}{r\partial r}(\rho r u w)+\frac{\partial}{\partial z}(\rho w^2)=-\frac{\partial P}{\partial r}+\frac{\partial}{r\partial r} \quad (3)$$
$$\left\{\mu r\left(\frac{\partial w}{\partial r}+\frac{\partial u}{\partial z}\right)\right\}+2\frac{\partial}{\partial z}\left(\mu\frac{\partial w}{\partial z}\right)+j_r B_\Theta$$

Energy conservation equation:

$$\frac{1\partial}{r\partial r}(\rho r u h)+\frac{\partial}{\partial z}(\rho w h)=\frac{1\partial}{r\partial r}(r\frac{k\partial h}{C_p\partial r}) \quad (4)$$
$$+\frac{\partial}{\partial z}(\frac{k\partial h}{C_p\partial z})+\left[\frac{j_r^2+j_z^2}{\sigma}-S_t+\frac{5k_B}{2e}(\frac{j_r\partial h}{C_p\partial r}+\frac{j_r\partial h}{C_p\partial z}\right]$$

where:
C_p – constant-pressure specific heat (J/kg K)
e-elektron charge, 1.60 x 10^{-19}C
h – enthalpy (J/kg)
j_z, j_r – axial and radial current density (A/m^2)
k – thermal conductivity (W/m K)
k_B – Boltzmann's constant
w,u – axial and radial velocity component (m/s)
z,r - axial and radial coordinate
σ - electrical conductivity
μ - dynamic viscosity
S_t – radiation loss per velocity component
ρ - density
B_θ - self-induced magnetic flux density

The numerical method has however some limitations and requires construction of a complex mathematical model.

Spectrometric method [6], found generally as a most universal one, uses Abel's law and consists in measurement of radiation of the arc for selected spectral lines, reading (from the tables) the data which characterize waves and, after rearranging of the equation, in calculation of arc temperature. This method enables measurements within wide range of remelting current intensity with changing arc length.

Fast filming method is the least usable method, which requires application of complicated patterns and long-lasting analysis.

The authors of this paper made an attempt to propose a new method which consists in diagnostics of plasma arc which aimed to assess the shape and determine the temperature by means of thermovision camera and high-resolution visible light camera.

2. Experimental results

During the investigations the diagnostics of plasma arc column was performed using thermovision Therma Cam P65 camera and the vision system of ProgRes C10Plus for high-temperature measurements, computer controlled. The system's task was to:

- obtain an arc picture in digital form,
- initial processing of the picture, filtering,
- calibration of visible light camera and thermovision camera,
- localization in anode picture the places with highest temperature and measurement of the geometrical parameters,
- visualization and recording of arc picture.

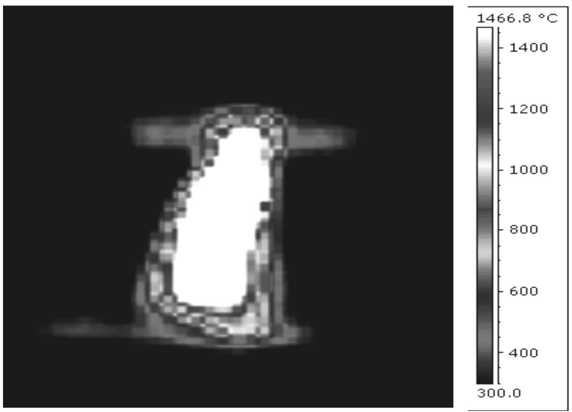

Fig. 1. Picture of plasma arc from thermovision camera

It is generally known that to assess the temperature of the bodies the infrared cameras are used, however, their high price and low temperature scale limits its wider use.

During investigations the infrared camera was used only for calibration of high-quality visible light camera.

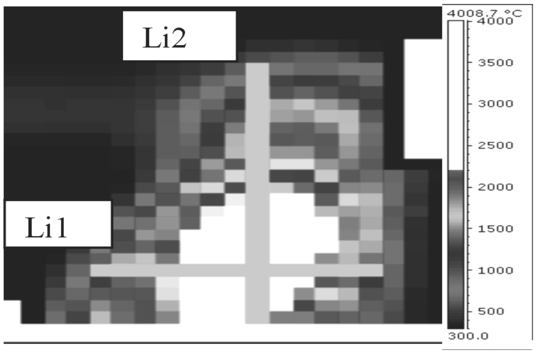

Fig. 2. Picture of plasma arc from thermovision camera with the directions of arc temperature measurements

The samples made of steel for toughening and surface treatment (40Cr4) were used for investigations; on their surfaces the ceramic 100 and 200 μm coating of TiO_2 had previously been produced by means of plasma spraying.

The surfaces of the samples were remelted by means of arc plasma using the following parameters: remelting current of 10-140 A, source feed rate 220-580 mm/min, blowpipe distance from sample surface 3 mm, shielding gas flow rate 8 l/min.

During the experiment wide modification of surface layer in the tested samples was performed, starting from melting of the coating itself to melting it together with the basis material.

Diagnostics of the arc was performed only for selected optimal current and voltage parameters.

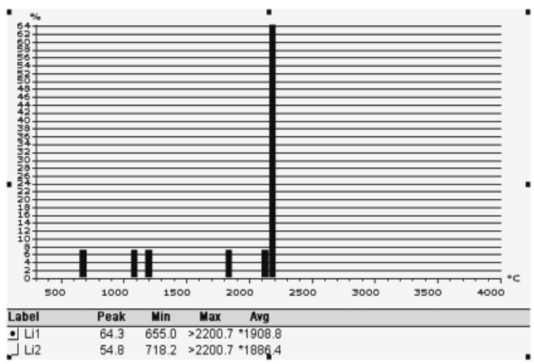

Fig. 3. Temperature distribution in two perpendicular directions of the arc Li1 and Li2

The arc pictures obtained from thermovision camera are presented in Fig. 1. The recorded axis of arc column, as results from further measurements and remelting process analysis, is deviated in relation to the line perpendicular to the sample surface.

During further investigations the measurement of the temperature of arc in two perpendicular directions, parallel to the vertical axis (Li2) and the perpendicular to this axis, (Li1) was made (Fig. 2).

Examples of the results were presented in the form of the chart, which presents the change in temperature depending on the direction of measurement (Fig. 3). The chart enables measurement of arc geometry and determination of its length (a) and width (b).

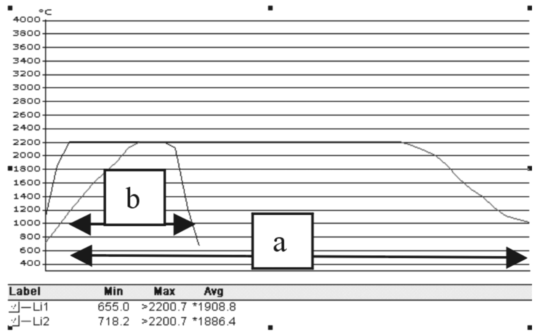

Fig. 4. Histogram of participation of individual temperature fields

The histogram (Fig. 4.) is a graphic representation of the distribution of temperature peaks which exist in the arc column. Considering fields with the temperature below 2000^0C, it could be assumed that they contain ca. 30% of the volume of the whole arc.

For further investigations the visible light camera was used, previously calibrated. The analysis of the obtained data enabled to obtain the central profile with division into individual isotherms within the whole volume of the arc.

To provide more comprehensive picture of arc shape, the profiles limiting the arc for various levels of radiation brightness were determined – for 3, 25, 50 i 75%. The example of the central profile with the isotherms, obtained for the narrow arc is presented in Fig. 5.

3. Conclusions

Diagnostics of arc column is a very important aspect and its aim is a continuous search for possibilities of improvement and precision of performed surface treatment.

The attempt made by the authors of this paper to solve such problems seems therefore to be fully justified.

The surface treatment performed on the samples made of 40Cr4 steel with ceramic coating of TiO_2 was supposed to obtain a modified surface layer. The optimal remelting conditions and parameters have been determined; they served as a material for further analysis.

Use of thermovision camera and visible light camera enabled to diagnose the arc in terms of geometry and temperature distribution. This method can be used for further analysis of the processes associated with plasma arc.

Thermovision camera enabled to determine the percentage concentration of the individual temperature fields treating, however, the field with highest temperature, being over the detection threshold, as a whole of around 70% of the wholeness.

The temperature profiles in the whole arc volume were obtained by application of high-resolution visible light camera.

Further investigations are aimed to assign the defined spatial points of the arc the individual values of the temperature.

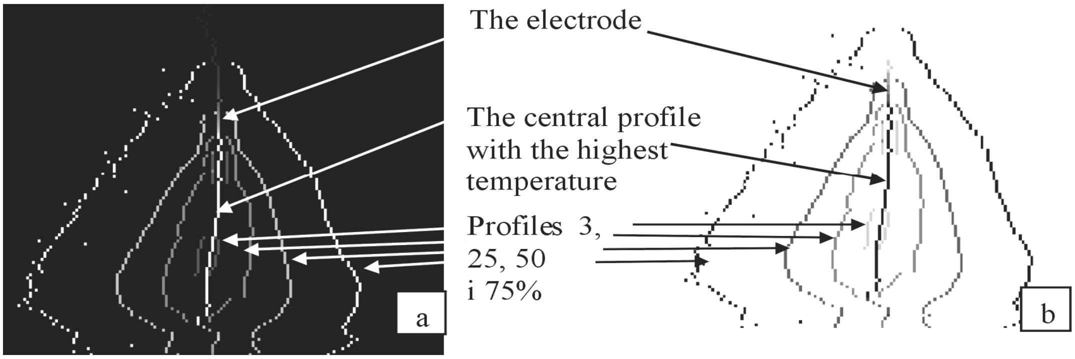

Fig. 5. Temperature distribution in two perpendicular directions of the arc Li1 and Li2

References

[1] J.H. Lee, S.J. Na, An analysis of volumetric radiation heat flux and experimental comparison with arc light sensing in GTA welding process, Journal of Materials Processing Technology 110 (2001) 104-110.

[2] I.S. Kim, J.S. Son, H.J. Kim, B.A. Chin, Development of a mathematical model to study on variation of shielding gas in GTA welding, Journal of Achievements in Materials and Manufacturing Engineering, 19 (2006) 73-80.

[3] I.S. Kim, J.S. Son, H.J. Kim, B.A. Chin, A study on variation of shielding gas in GTA welding using finite element method, Journal of Achievements in Materials and Manufacturing Engineering 17 (2006) 249-252.

[4] L. Achab, E.H. Amara, N. Mebani, N. Allalou, F. Hamadi, Numerical thermodynamic field modelling of a metallic substance during laser welding , Journal of Achievements in Materials and Manufacturing Engineering 15 (2006) 212-215.

[5] Z. Hou, I.S. Kim, J.S. Son, H.H. Kim, J.H. Seo, K.C. Jang, D.K. Lee, J.M. Kuk, A study on numerical analysis of the resistance spot welding process, Journal of Achievements in Materials and Manufacturing Engineering 14 (2006) 140-145.

[6] M. Węglowski, The temperature of welding arc in GTA and GMA methods, Bulletin of Welding Institute 4 (2004) 51-59 (in Polish).

[7] Z. Nitkiewicz, The application of the arc shapes in surface engineering, Publishing House of Częstochowa University of Technology, Częstochowa, 2001 (in Polish).

[8] A. Dudek, Z. Nitkiewicz, H. Stokłosa, The analysis of the arc shape during remelting proces, Material Engineering 5 (2005) 142-148 (in Polish).

[9] T. Burakowski, T. Wierzchoń, Surface engineering of the metals, WNT, Warszawa, 1995 (in Polish).

[10] A. Dudek, Z. Nitkiewicz, The structure properties of surface layers wich was obtained by alloying process, Acta Metallurgia Slovaca 8 (2002) 339-343 (in Polish).

[11] P. Mondenesi, E. Apolinario, I. Pereira, TIG welding with single-component fluxes, Journal of Materials Processing Technology 99 (2000) 260-265.

[12] F. Lu, S. Yao, S. Lou, Y. Li, Modeling and finite element analysis on GTAW arc and weld pool, Computational Materials Science 29 (2004) 371-378.

[13] M.A. Ramirez, G. Trapaga, J. McKelliget, A comparison between diffrent numerical formulations for welding arc representations, Journal of Materials Processing Technology 155-156 (2004) 1634-1640.

[14] H.G. Fan, H.L. Tsai, S.J. Na, Heat transfer and fluid flow in a partially or fully penetrated weld pool in gas tungsten arc welding, International Journal of Heat and Mass Transfer 44 (2001) 417-428.

[15] V.V. Goncalves, L.O. Vilarinho, A. Scotti, G. Guimaraes, Estimation of heat source and thermal efficiency in GTAW process by using inverse techniques Journal of Materials Processing Technology 172 (2006) 42-51.