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Study on the Lowest Energy Density of Welding Heat Source Required by Fusion Welding Metal

DU Shi-guo[a], CHANG Wen-ping[a], JIANG Jin-yong[b], LU gui-e[b], HUANG Jia-qi[c]a*

[a]*Shijiazhuang Mechanical Engineering College, Shijiazhuang 050003, China*
[b]*Ordnance Technical Research Institute, Shijiazhuang 050003, China*
[c]*Luzhou North chemical industry incorporated company, Luzhou 646605, China*

Abstract

Welding is a common metal-processing method, which uses heating or press or both, at the same time, uses or disuses filled composites to achieve the atomic binding of workpieces. The basic welding methods are usually divided into three classes according to the conjunct property of weld metal, namely fusion welding, press welding and braze welding[1-2]. Powder composite welding rod is constituted with powder and termites, which belongs to fusion welding[3]. In order to make sure that the energy of this welding rod can achieve the requirement of fusion welding, so the lowest energy density required by fusing melt should be determined firstly.

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Key words: thermodynamical equilibrium equation; welding heat source; energy density

1. Introduction

Welding is a common metal-processing method, which uses heating or press or both, at the same time, uses or disuses filled composites to achieve the atomic binding of workpieces. The basic welding methods are usually divided into three classes according to the conjunct property of weld metal, namely fusion welding, press welding and braze welding[1-2]. Powder composite welding rod is constituted with powder

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* DU Shi-guo. Tel.: 0311-87974240.
E-mail address: nuanyangqing@163.com.

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and termites, which belongs to fusion welding[3]. In order to make sure that the energy of this welding rod can achieve the requirement of fusion welding, so the lowest energy density required by fusing melt should be determined firstly.

2. Computational Methods

During welding process, the welding object is heated by heat source, at the mean time, the acquired energy of metal is transferred to external constantly. The three main transfer paths of heat are heat conduction (HCD), heat convection (HCV) and heat radiation (HR) [4]. At the fusion critical condition of metal, if the heat quantity offered by heat source is higher than its dissipated heat, then the metal can change into liquid stage. Otherwise, it will always stays at solid state.

In order to ascertain the quantity of dissipated heat of metal at its fusion critical condition, the quantity of dissipated heat caused by heat conduction, heat convection and heat radiation is calculated detailed. In this article, selecting the aluminium wire, bronze wire and iron wire as subjects investigated. The length and external diameter of the wire are 50cm and 2mm respectively. Assume the metal wire can meet the following 2 conditions: (1) One side temperature of the wire is nearly its fusing temperature; the other side is about room-temperature 300K. The fusing temperatures of above metals are 933K, 1356K and 1733K orderly. (2) The temperature distribution of the metal wire is linear relationship. So the equations of temperature distribution of the three metal wires can be described with Eq.(1).

$$\begin{aligned} T_{Al} &= 300 + 12.7x \\ T_{Cu} &= 300 + 21.1x \\ T_{Fe} &= 300 + 28.7x \end{aligned} \qquad (1)$$

2.1. Heat Conduction

Heat conduction is one style of energy transmission, which depends on the motions of the microscopic particles, such as molecules, atoms, electrons etc. The condition of this style of energy transmission is that different substances must be contacted together or in the inner of the substance. The fundamental law of describing heat conduction is Fourier Heat-transfer Law. One dimension Fourier Heat-transfer Law is shown in the following equation:

$$q = -\lambda \frac{dT}{dy} \qquad (2)$$

Where q is the thermal flux of unit area, namely thermal flux density in W·m^{-2}, λ is the conductivity factor of the object in W/m·K.

Assume the sectional area of the metal wire is A, the Eq.(2) can be converted to Eq.(3).

$$Q = -\lambda A \frac{dT}{dy} = \frac{\lambda A \left(t_{w1} - t_{w2}\right)}{l} \qquad (3)$$

Where A is the sectional area of the metal wire in m^2, t_{w1}, t_{w2} are the temperatures of the two sides of the metal wire in K, l is length of the metal wire in m.

The value of conductivity factor dues to the kind of the substance, the temperature and the other factors. The conductivity factor of metal is higher than other materials. The conductivity factors of common metals are shown in table 1.

Table 1. Conductivity factors of common metals

Materials	conductivity factor λ(W/m·K)						
	Temperature (K)						
	473	573	673	873	1073	1273	1473
Aluminum	238	234	228	215			
copper	389	384	379	366	352		
iron	63.5	56.5	50.3	39.4	29.6	29.4	31.6

2.2. Heat Convection

When the fluid flowing the surface of the solid, the heat exchange between fluid and solid happens, this process is called heat convection. The heat exchange quantity of heat convection can be expressed with Newton Cooling Equation, see Eq.(4).

$$Q = A_1 h \Delta t_m \tag{4}$$

Where A_1 is the area of the interface (m^2), Δt_{m} is the mean temperature difference of the heat exchange area (K), h is surface heat-transfer coefficient (W/m^2·K). The value of h depends on many factors including the physical features of fluid (λ、η、ρ、c_p), the shape and the size of the interface, velocity of flow, etc. In this article, the value of h is 2.5 W/(m^2·K).

2.3. Heat Radiation

Heat radiation uses electromagnetic wave to transfer energy, in the vacuum; this style of heat transfer is very efficient. The heat exchange quantity of heat radiation can be calculated with Eq.(5).

$$\Phi = \varepsilon A_1 \sigma \left(T_1^4 - T_2^4\right) \tag{5}$$

Where T_1 and T_2 are the temperatures of metal wire and circumstance (K), ε is the emissing ability of the substance, A is radiation superficial area (m^2), σ is radiation constant, here its value is 5.67×10^{-8} W/(m^2·K).

In this article, the heat radiation quantity of the three metal wires can be calculated with the following equations:

$$\begin{aligned} \Phi_{Al} &= \varepsilon A_1 \sigma \int_0^{50} \left((300+12.7x)^4 - 300^4\right)dx \\ \Phi_{Cu} &= \varepsilon A_1 \sigma \int_0^{50} \left((300+21.1x)^4 - 300^4\right)dx \\ \Phi_{Fe} &= \varepsilon A_1 \sigma \int_0^{50} \left((300+28.7x)^4 - 300^4\right)dx \end{aligned} \tag{6}$$

3. Results and Discussion

Table 2 lists the heat dissipation quantity caused by heat conduction, heat convection and heat radiation, which were obtained at the fusing critical condition of the three metal wires. From the results we can see that the effect of heat radiation on the heat dissipation of metal wire is very obvious. Furthermore, the heat dissipation of the three metals has some other features: (1) the heat dissipation caused by heat conduction and heat convection is approximate for Aluminum wire, (2) the heat conduction quantity of copper wire is very higher than its heat convection quantity, the reason is that the conductivity factor of copper wire is larger, (3) the heat conduction quantity of iron wire is very small.

The total heat dissipation powers of the three metal wires at the fusing critical conditions are 18.82, 40.09 and 52.75 J/s respectively. The calculation of energy density was performed by using energy density equation, $\mu_{\max}=W_{\max}/A$ [5], where μ is the energy density in J/s·cm2, W the heat dissipation power in J·s-1, A the sectional area of the metal wire in m2. The results show that the lowest energy densities of welding heat source required by fusion welding these three metals are 509.41, 1031.5and 1649.14J/s·cm2 respectively.

Table 2. The heat dissipation power at fusing critical condition

Materials	HCD/W	HCV/W	HR/W	Total /W
Aluminum	4.22	4.96	9.64	18.82
copper	11.52	8.29	20.28	40.09
iron	1.40	11.25	40.10	52.75

4. Conclusion

During the process of energy transmission, the heat dissipation quantity caused by heat radiation is biggest. In order to achieve fusion welding, the lowest energy densities of welding heat source required by Aluminum wire, copper wire and iron wire are 509.41, 1031.5and 1649.14J/s·cm^2 respectively. This result is very useful for the energy design of powder composite welding rod.

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