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Temperature profiling during the extinction phase of laser keyhole welding using the Boubaker Polynomials Expansion Scheme (BPES)

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ABSTRACT

In this study, we have used dimensional analysis to solve the heat equation inside an experimental laser welding setup. The solution for the heat equation is based on the assumption that heat energy diffuses equally on both sides of the laser beam axis and that the temperature along the axis through which the laser beam moves is constant. The amount of heat energy delivered by the laser to the keyhole is analyzed using the Boubaker polynomial expansion scheme BPES.

1. Introduction

Laser beam welding (LBW) is a modern welding process [1–5]. It is a high energy beam process that continues to expand in modern industries and new applications because of its many advantages like deep weld penetration and minimizing heat inputs [3–5]. Manufacturers can automate the welding processes in order to improve the product quality through more accurate control of welding processes.

In laser beam welding, the focal spot is targeted on the work piece surface to be welded. At the surface the large concentration of light energy is converted into thermal energy. The surface of the work piece starts melting and the heat progresses through it by surface conductance [6–8]. For welding, the beam energy is maintained below the vaporization temperature of the work piece material. Since the penetration of the work piece depends on conducted heat, the thickness of the materials to be welded is generally less than 0.80 inch if the ideal metallurgical and physical characteristics of laser welding must be realized.

Concentrated energy produces melting and coalescence before a heat affected zone is developed. When the materials to be welded are thick and have high thermal conductivity (like aluminum), the advantage of having a minimal heat affected zone can be seriously affected [8]. Because the heat source in this type of welding process is in the form of light, the work piece will be welded purely which means the fatigue strength of the welded joint will be excellent.

All laser beam welding processes whether they may be gas (carbon dioxide, helium, neo, etc.) or other lasing sources are based on the principles of the excitation of atoms using intense light, electricity, electron beams, chemicals, etc., and the spontaneous and stimulated release of photons. The role of focusing lenses in this process is really important because it concentrates the beam energy into a focal spot as small as 0.005 in diameters or even less

1.1. Heat equation

In respect to the assumptions expressed in [4–8], the main heat equation inside the keyhole is

$$\begin{cases} \dfrac{\partial T(x,t)}{\partial t} = D\dfrac{\partial^2 T(x,t)}{\partial x^2}, \quad t>0,\ |x|<b \\ T(x,t)\big|_{t=0} = T_0 \times e^{-x^2/2b^2},\ T(x,t)\big|_{t\to\infty} = T_\infty \end{cases} \tag{1}$$

where T_∞ is the room temperature and $D=\kappa/\rho \times c_p$ the thermal diffusivity, c_p the specific heat capacity, κ the thermal conductivity and ρ the mass density of the material.

To solve the above heat equation, we need to add another boundary condition; if we assume that heat energy diffuses equally on either sides of the axis of the laser beam (shown in Fig. 1), then the temperature along the axis through which the laser beam moves is constant in x and hence, the temperature

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