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Behaviour of spreading molten metal drops deposited by fusion

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ABSTRACT

Liquid droplet deposition on solid surfaces has an important role in the industrial and research activities. The behaviour of such deposit is influenced by volume and interfacial phenomena and involves a large number of mechanisms such as gravity effect, mass transfer, capillary forces, and wetting. For the case of metal deposition the analysis of the problem is more complex because of the importance of thermal effects, involving steep gradients and phase changes. A unique experimental approach is presented in order to study the evolution of the spreading of a large drop of liquid metal called "macro-drop". The objective of this work is to supply qualitative and quantitative information during the deposit of liquid metal in relation with process parameters. The overall shape of the macro-drop, especially its spreading and contact angles are studied in detail. The gradual spreading of the macro-drop is mainly governed by mass and heat transfers. The initial rapid spreading is due to kinetic energy of depositing droplets and direct arc heating on the solid target. All experimental results are analysed in the light of process parameters to identify the physical mechanisms involved and appreciate their effects on the behaviour of such a macro-drop.

1. Introduction

Deposition of small liquid droplets on solid surfaces is an active research topic in a large panel of industrial applications such as ink printing, thermal spray coating, micro-fabrication, soldering or welding [1–4]. The impact of droplet on solid surface has been extensively studied and the evolution of spreading base and height of impacted drop have been described. Whatever the material used (ink, wax, solder, etc.), one of the most important shape parameter is the contact angle, which affects the processes of flattening or wetting on the solid surfaces. The contact angle could be considered as an equilibrium contact angle in the case of isothermal problems or as solidification or apparent dynamic contact angles in the case of non-isothermal problems. For example, Schiaffino and Sonin studied apparent dynamic contact angles and the shape of drops obtained by continuous droplets deposition of wax [5]. When inertia effects are negligible and the evolution is mainly dominated by capillary and viscous forces, they show that the apparent dynamic contact angle seems to obey Hoffman's law [6]. The spreading and wetting are then closely linked to the behaviour of contact line and contact angles. The presence of solid–liquid–gas interfaces, and related interfacial phenomena, play also an extremely important role in the process called "to high temperature" such as welding [7,8], even in normal conditions of operating. In Gas Arc Metal Welding (GMAW) process particularly, these interfaces take an important place in the metal transfer both in the arc and in the weld pool (Fig. 1). The shape of the droplets is directly linked to the competition between volume forces, such as gravity or electromagnetic forces, and interfacial phenomena such as surface tension or drag forces. The heat and mass transfers and the above mentioned interfacial phenomena have a great influence on the evolution and behaviour of the weld pool. The shape of the weld pool thus determines the final quality of the welding operation. The main goal of the present work is to better understand the physical mechanisms involved in the behaviour of liquid metal deposition in relation with pulsed Gas Arc Metal Welding parameters (P-GMAW). Their relative importance can be appreciate through the study of the spreading and wetting of a stationary weld pool (called macro-drop in this paper) obtained by liquid metal droplets deposition on a solid target. These problems are mainly studied by numerical approach and compared with experimental results [3,9,10]. A specific experimental study will be presented in this work; it focuses on the effects of the modification of the process parameters on the behaviour of the macro-drop. The experimental approach is described (Sections 2 and 3) and the results are discussed in relation with the welding parameters (Section 4).

2. Deposition of liquid metal droplets on a solid target

The purpose is to study the shape and the spreading of the macro-drop according to the heat and mass transfers supplied by

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Nomenclature

C_a	capillary number
B_o	Bond number
c_p	specific heat
h	height of the macro-drop
L	enthalpy of melting
R	base radius of the macro-drop
T	temperature
V	volume of the macro-drop
u	speed of the contact line
W_e	Weber number
Greek symbols	
θ	contact angle
ϕ	wire diameter
ρ	density
μ	viscosity
γ	surface tension
λ	thermal conductivity

the deposition of droplets from feed solid wire with the stationary P-GMAW process. This operation produces a direct heating at the surface of the macro-drop (liquid–gas interface) and heat transfer by convection in the liquid macro-drop and conduction in the solid. The macro-drop shape evolves with the heat and mass supplied by the GMAW process. The formation and spreading of the macro-drop result from the energy (heat) and mass conservations; the arc supplies direct heating to the liquid–gas surface of the macro-drop and to the solid target whereas liquid droplets input heat and mainly mass in the macro-drop. The global shape and behaviour are also influenced by the balanced effects of several physical mechanisms such as gravity, capillarity, inertia, thermic effects, and viscosity.

The macro-drop is assumed to be axisymmetric with low penetration (the liquid metal forms a drop of liquid at the surface of the solid target). Fig. 2 presents the main geometric parameters necessary to describe the evolutions of the shape of the macro-drop and of the contact line (line at the solid–liquid–gas interface). The geometry of the macro-drop is defined by the height h, the base radius R defining the base length and the contact angle θ at the solid–liquid–gas interface. These measured parameters are used to determine other parameters describing the behaviour of the macro-drop such as its volume V or the speed of spreading u corresponding to the contact line speed.

The physical characteristics required to describe and to analyse the phenomena involved in the behaviour of the macro-drop are given in Table 1.

3. Experimental method

This section presents the unique experimental setup dedicated for multiphysics studies, the experimental matrix for the study of macro-drop behaviour and the developed numerical libraries to analyse experimental data by a systematic way.

3.1. Experimental setup

Experiments are realised on a platform dedicated to the study of arc welding processes [11].

This platform allows the synchronised data acquisition of different kinds of signal (process, thermal, mechanic) and high speed video during arc welding. Arc welding is a really harsh environment because of the perturbation due to electromagnetic noise and radi-

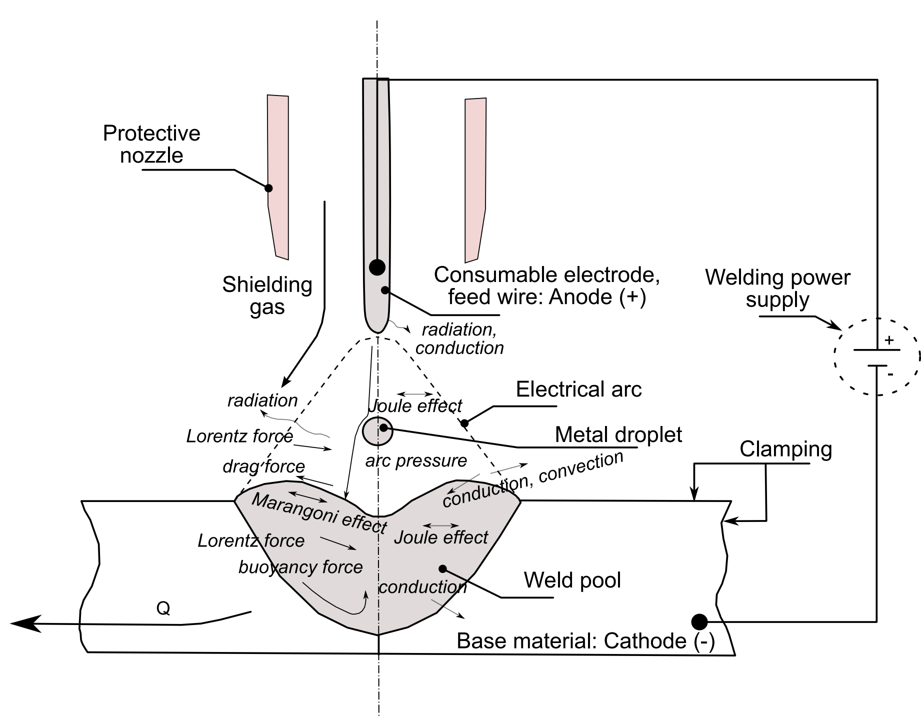

Fig. 1. Physics description of Gas Metal Arc Welding (GMAW) during a static operation.