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Research Article

Impact and Deposition of Single and Dual Metal Droplets on Solid Substrate

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Abstract– Thermal spraying is a technique within the field of surface treatment processes. It involves the ejection of molten or semi molten droplets onto a prepared substrate, where the droplets deposit successively to produce splats. The accumulation of these splats subsequently forms the coating. Achieving desired coating properties required comprehensive understanding of droplets impact and deposition. Metal droplets deposition on solid surfaces is complex process that combines heat transfer, fluid dynamics and solidification. In order to simulate the dynamics of spreading, deformation and solidification of droplets during the formation of metallic lamella, we developed two-dimensional model in Ansys code. The simulation is conducted by using the volume of fluid method to track the free surface of the impinging droplets. The current study investigates both normal and oblique impact of single and dual aluminum droplets with a diameter of 3.92 mm and an impact velocity of 3 m/s on stainless-steel substrate. The model predicts the morphology of the resulting splat, it was found that the behavior of the dual droplets shows a pattern similar to that of single droplet only with a higher rite of spreading. The simulation results have shown an asymmetric spreading in the oblique impact. Furthermore, the spreading rate of dual droplets is higher than of single droplet in both normal and oblique impact.

Keywords – spreading, solidification, volume of fluid method, normal impact, oblique impact.

I. INTRODUCTION

A better understanding of plasma spraying process and splat formation can offer a solution to nearly any coating problem such as porosity, cracking and adhesion failure. Furthermore, obtain material properties with high performance. A vast number of papers in literature have been dedicated to simulate the impact and deposition of metal droplets on a solid substrate. In contrast, researches on multiple impacts are rarer. Among these, we mention the following:

The impact of molten tin droplets on a splat formed of previous droplets which they already have been solidified was investigated by R. Ghafouri-Azar et al [1]. With changing the distance between the centers of the two drops, it was found that droplets landing at small offset distances landed on the surface of the first splat. In contrast, at larger spacing the second droplet landed on the surface of the substrate and then spread to the edge of the first droplet. Cédric Le Bot et al [2], studied the simultaneous impact of an infinity of identical indium droplets equidistant on a cold substrate. The results indicate that, the impact of successive droplets creates an air bubble at the substrate surface. These air bubbles can be expelled when the dynamics is significant enough, or trapped when the solidification is fast enough. Another work has been done by Cédric Le Bot et al [3], the successive impact of particles (three particles) on a cold substrate. The findings indicate that an offset in impact position influenced the surface morphology of the splat, and due to the irregular shape of the first splat two types of porosity could appear: small pores and inter-lamella cracks. The Oblique impacts of water nanodroplets on superhydrophobic surfaces was study by Ning-Ning Han et al [4]. There findings demonstrate that a transition from drop rebound to partial rebound and sliding, and ultimately to rivulet, was caused by a rise in both surface tilting and impact Weber number.

In the present work, a 2D numerical model was developed using computational fluid dynamics software Ansys to simulate the spreading and solidification of dual aluminum droplets on a H13 stainless-steel substrate. Additionally, this paper focuses on both normal and oblique impacts, given that the impingement of droplets on surfaces are often oblique rather than perfectly normal.

II. Materials and Method

The deposition of 3.92mm aluminum droplets, initially at 630°C on a stainless-steel substrate was simulated using 2D/axisymmetric domain on Ansys software. The impingement droplets are initially assumed to be spherical, and completely molten with an impact velocity of 3 m/s. The thermo-physical properties of the materials are given in Table 1.

The Navier-Stokes equation is used to model the fluid dynamics. Considering the fluid flow to be incompressible, laminar and Newtonian.

The continuity and momentum equations (Navier Stokes equation) are given by:

$$\nabla.\vec{u} = 0 \qquad (1)$$

$$\rho\left(\frac{\partial \vec{u}}{\partial t} + \vec{u}\nabla\vec{u}\right) = -\nabla P + \nabla.\vec{\tau} + \vec{F_b} \qquad (2)$$

Where $\vec{u}$ is the velocity vector, ρ is the fluid density, P is the pressure, μ is the dynamic viscosity, and the body forces $\vec{F_b}$ include the gravity and surface tension forces, and τ is the viscous stress tensor defined as:

$$\vec{\tau} = \mu\nabla\vec{u} \qquad (3)$$

The Volume-Of-Fluid (VOF) method is used to track the interface between two immiscible fluids (the free surface of the impinging droplet) [5].

This method defines the volume fraction of the fluid α as follows:

$$\begin{cases} \alpha = 1 \text{ the cell is entirely occupied by the fluid} \\ \alpha = 0 \text{ the cell is empty of the fluid} \\ 0 < \alpha < 1 \text{ the interface between the fluid phase and the other fluids} \end{cases}$$

Table 1. Properties of the materials used [6].

Properties	Alumina	Steel H13	unity
Density	2570	7800	(Kg/m³)
Viscosity (liquid)	°c 0 4.5 E-7 700 4 E-7		(m²/s)
Thermal conductivity	70	26	(W/m K)
Liquid specific heat	1000		(J/Kg K)
Solid thermal conductivity	°c 400 144 500 147 630 70		(W/m K)
Specific heat	°c 100 400 300 500 400 800 570 1050 580 1038	°c 20 460 200 502 500 550	(J/Kg K)

III. RESULTS

A. Normal Impact of Dual Droplets

The first section of this study investigates the impact and deposition behaviour of dual- aluminium droplets on a solid substrate (40mm x 3mm). During the impingement of multiple droplets, in addition to the interactions between the droplets and the substrate, there are interactions between the droplets themselves, thus, it is more complex compared to the single impact. When two droplets collide, they combine into one larger droplet. Therefore, there behavior shows a pattern similar to that of single droplet deposition, as it's seen in Fig. 1, the resulting aluminium splat has a flat circular shape with a raised rim. Coalescence of these droplets leads to an increase in the amount of the fluid, which accelerates spreading and allows to cover a larger surface on the substrate (large contact area between the droplets and the surface), this is particularly beneficial for improving wetting properties. However, at t=7ms, the mass accumulation at the edges is higher than in the single droplet, and about to break up from the splat and forming secondary droplets (splashes). Fig. 2 depicts a comparison of the splat diameter between a single droplet and dual droplets. It was measured to quantify the spreading rate of the droplets, which differs between the two cases. In addition, for the multiple droplet impact, the spreading time is affected by the combined momentum and mass of the resulting larger droplet. The spreading time of this case is higher than the one obtained from the single droplet impact.

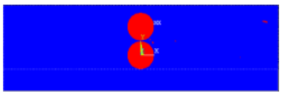
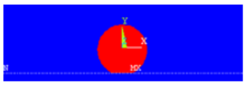
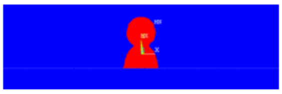
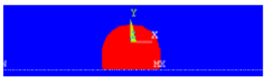
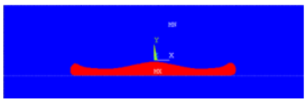
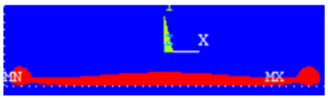
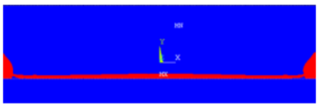
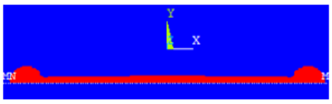
Dual droplets	Single droplet
	
t=0ms	t=0.1ms
	
t=0.3ms	t=0.3ms
	
t=3ms	t=3ms
	
t=7ms	t=7ms

Fig. 1 Normal impact of droplets. a) Impact of dual droplets on solid substrate of 40mm x 3mm. b) Impact of single droplet on solid substrate of 25mm x 3mm.

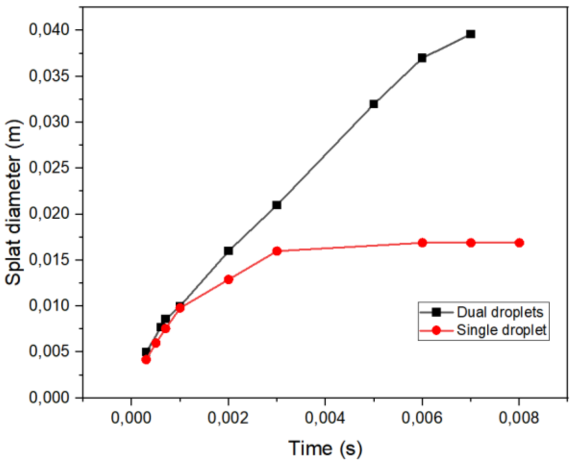


Fig. 2 The evolution of splat diameter of single droplet and dual droplets over time.

B. Oblique Impact of Dual Droplets

This section investigates the oblique impact of droplets, given that the impingement of droplets on surfaces are often oblique rather than perfectly normal. The inclined impact of single aluminum droplet was examined by M. Zirari et al [7]. It was found that the spread factor in the normal impact is higher than in the inclined impact. In this part, we focus on the oblique impact of dual aluminum droplets on horizontal substrate with an oblique angle of 15°. As it shown in Fig. 3, the oblique impact reveals that the spreading of the droplets is asymmetric upon the point of impact.

Additionally, a comparison of splat diameter of the oblique impact between dual droplets and single droplet is illustrated in Fig. 4(a). Another comparison is conducted between the normal and the oblique impact of dual aluminium droplets (Fig. 4(b)). The results of oblique impact of single droplet were found by Zirari et al [7]. When there is an inclined impact, the rate of spreading of the dual droplets is higher than the single drople, which is similar to the first case of the normal impact. The rate of spreading of the binary droplets at the inclined impact, is not as high as in the normal impact, this could be explained by the distribution of kinetic energy.

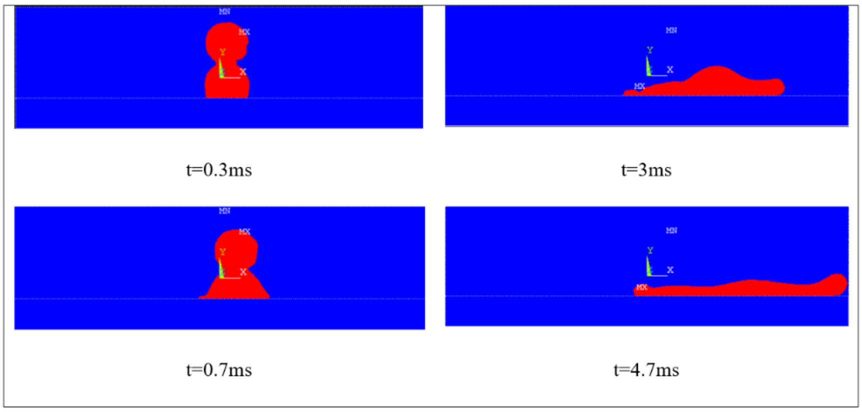
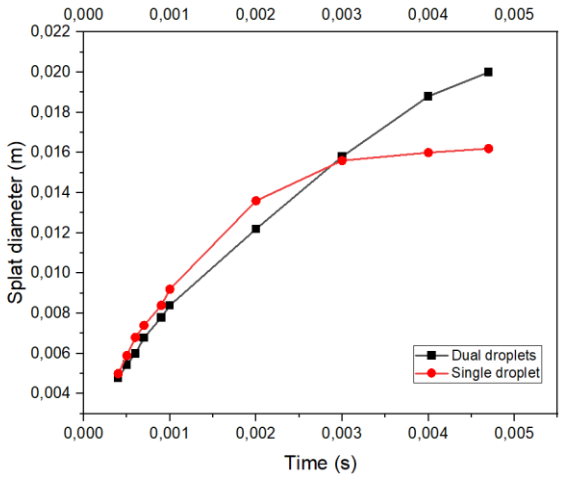
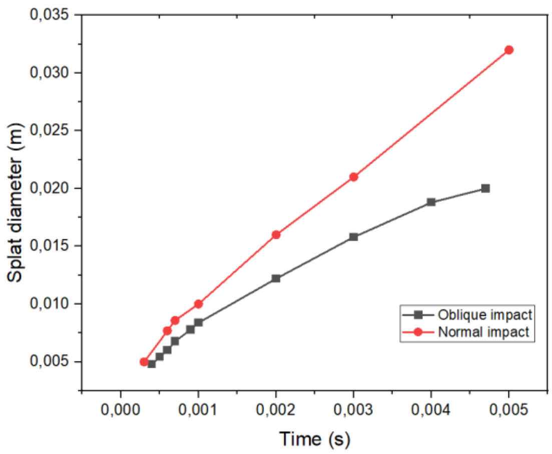


Fig. 3 The oblique impact of dual aluminium droplets.



(a)



(b)

Fig. 4. The evolution of splat diameter over time. a) Splat diameter of the oblique impact of dual droplets and single droplet. b) Splat diameter of normal and oblique impact of dual droplets.

IV. DISCUSSION

This study aimed to investigate the normal and oblique impact of single and dual aluminum droplets on a stainless-steel substrate. The results demonstrate that the dynamics of the spreading of binary droplet differ from that of a single droplet impact. However, both cases have a similar deposition morphology, represented by a circular shape with a raised edge. When multiple droplets impact a substrate successively, the amount of the fluid available for spreading is higher than a single droplet, leading to an increase in spreading diameter (Fig. 2). Furthermore, the kinetic energy transferred to the substrate is higher due to the combined energy from multiple droplets, as larger kinetic energy drives the droplet to cover larger area of the surface.

In normal impact, where the droplets impact the substrate perpendicularly, the spreading is generally symmetrical in all directions from the point of impact. In contrast, in the oblique impact more fluid spreads in the tangential direction of impact, i.e. asymmetrical spreading. Additionally, the rate of spreading is higher in the normal impact, this could be explained by the distribution of kinetic energy, which is transferred into a radial spreading. For the oblique impact, the droplet's velocity is decomposed into normal and tangential components relative to the surface, since the kinetic energy is related with tangential velocity, the kinetic energy is greater in the direction of impact.

V. CONCLUSION

A two-dimensional numerical model of droplet deposition on solid surface during splat formation was developed using Ansys software. The volume of fluid technique was used to track the free surface of the droplet and capturing the spreading, solidification and possible splashing of the fluid. This study targets both normal and oblique impact of single and dual aluminium droplets. The main findings demonstrate that at the inclined impact, the spreading rate is lower than at the normal impact. In addition, it is higher for multiple droplets impact than it is in single droplet impact.

ACKNOWLEDGMENT

Overall, this study advances our understanding of the dynamics of droplets deposition to optimize and enhance coating properties in industrial applications.

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