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Characterization the contribution and limitation of the characteristic processing parameters in cold metal transfer deposition of an Al alloy

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ABSTRACT

Cold metal transfer (CMT) depositing processes in aluminium alloy were conducted using various characteristic parameters which represent for the control of current output and wire motion. The effects of characteristic parameters on the energy input characteristic, metal transfer behavior, weld geometry, and microstructure of deposited weld metal were investigated. There were some limitations for characteristic parameters to achieve stable CMT process. For stable CMT process, the three distinct energy input periods of CMT cycle were controlled by characteristic parameters and thereby affect the features of deposited weld metal. The speed of wire feed motion affected not only burn phase duration but also short-circuiting duration. With the increased speed of wire feed motion, the whole energy input first increased and then decreased; the weld width and contact angle decreased, which was different from the effects of other characteristic parameters. An increment in short-circuiting current resulted in an increase in dilution ratio and grain size of weld metal although whole energy input was essentially constant. In conclusion, adjusting characteristic parameters can control the energy input process coupled with metal transfer behavior to design and optimize the weld properties for each special CMT application, which is suitable for additive manufacturing of aluminium alloy.

1. Introduction

Cold metal transfer (CMT), which was invented by Fronius Company as a relatively new welding technology, is a modified metal inert gas (MIG) welding process based on short-circuiting (SC) transfer process. Feng et al. (2009) showed that the key feature of CMT welding process is that an innovative mechanical control of the wire motion has been integrated into the overall control of the process; the back-drawing force assists droplet detachment during SC phase, which allows the SC current is consistently kept small. As a result, the energy input can be reduced compared with the conventional MIG welding process for the same amount of deposition, reported by Pickin and Young (2006). Schierl (2005) pointed out that CMT process has the excellent characteristics in terms of low energy input, high deposition rate, no spattering, and extremely stable arc. Thus, CMT process has become a frontier, as well as a hotspot in the welding field.

CMT process is being increasingly implemented in manufacturing industry, and most of them focus on the four main application areas as follows. Firstly, welding of heat sensitive material. CMT is suitable to weld aluminium which was once considered limited due to the problems such as strength reduction in the weld and heat affected zone (HAZ) caused by high energy input. Elrefaey (2015) reported that CMT provides better joint tensile strength and ductility compared to MIG welding process for 7075-T6 aluminium alloy. Moreover, Ahsan et al. (2016b) claimed that CMT is a suitable option for joining thin sheets of high strength zinc coated steel which has encountered porosity issues. The weld pool viscosity and vapor pressure of zinc as the temperature- dependent properties determine the porosity formation, growth, and escape mechanisms at different energy inputs, and the results showed that energy input conditions below 250 J/mm and above 350 J/mm cause the least amount of porosity, as reported by Ahsan et al. (2016a). Secondly, welding of dissimilar metals. CMT can reduce the volume fraction of intermetallic compounds which are detrimental to the joint strength during dissimilar metals welding process, as demonstrated by Cao et al. (2013) for Mg/Al and Liu et al. (2015) for Al/Ni. Lin et al. (2013) claimed that CMT is a promising method to join aluminium and steel for vehicle body assembly and studied the influencing factors on the strength of CMT brazed joints. Thirdly, cladding. Pickin et al. (2011) examined the weld dilution ratios

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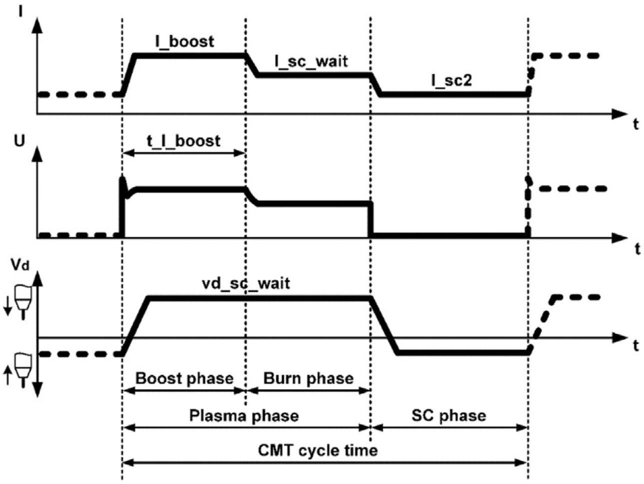

Fig. 1. Overview of the characteristic of CMT welding process.

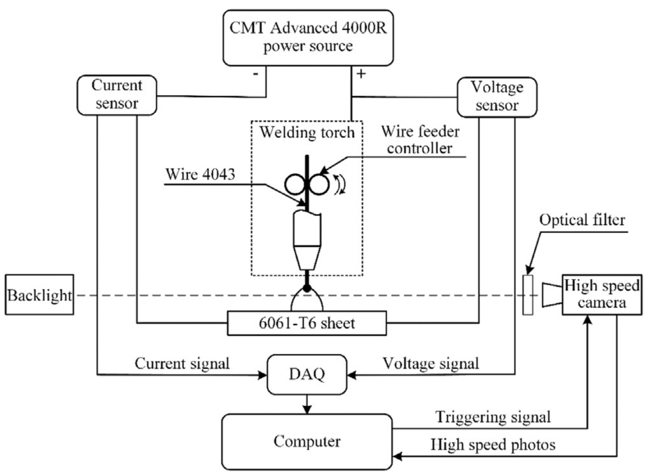

Fig. 2. Schematic of the experimental set-up of CMT welding process.

for both CMT and pulsed MIG welding process across the available parameter range of aluminium alloy and reported that CMT process exhibited greater control of dilution that enabled deposition of a quasi-binary (Al–Cu) layer exhibiting a less crack susceptible composition. Ola and Doern (2014) suggested that CMT is also suitable for low dilution cladding of nickel-based INCONEL718 superalloy and pointed out that the ease of adding successive weld passes for material build-up depends significantly on the contact angle. Fourthly, Wire + Arc Additive Manufacturing (WAAM). Since CMT has excellent arc characteristics and flexibility for automatic process, it shows a large potential to be used in WAAM process which is a state-of-the-art additive manufacturing method for large structural components manufacture, as demonstrated by Almeida and Williams (2010) for multilayer Ti-6Al–4 V deposition. Cong et al. (2015) performed additively manufactured Al-6.3%Cu alloy using CMT process and reported that deposit porosity is significantly influenced by the arc mode of CMT process.

According to these previous studies, it is obviously that the weld properties of the CMT applications are all directly dependent on and sensitive to its low energy input process coupled with the metal transfer behavior. But how to control this process as required for each special application are still unknown. There are only limited studies to examine or describe the arc waveforms and metal transfer process. Zhang et al. (2009) reported that the CMT cycle can be divided into three phases according to the current waveform: peak current phase, background current phase, and SC phase. Pickin et al. (2011) pointed out that the CMT transfer mode is based on SC transfer at the lower power range and a combination of both spray and SC transfer at the mid to upper range. Hu et al. (2016) showed that the stable CMT welding process using magnesium alloy wire AZ31 can be achieved when wire feed speed is no more than 4 m/min.

It should be noted that all the previous studies were operated in CMT synergic mode which has the constant energy input processes as the consequence of invariable waveforms, so that most CMT applications were limited to obtain the properties as good as expected. Moreover, one of the most important differences of CMT process is geometry of the deposited materials tending to be somewhat spherical, which changes the state of stress concentration during the loading of the welded samples. Meanwhile the lower energy input process made by CMT has two consequences including finer microstructure in fusion zone (FZ) and lower temperature induced effects in HAZ; these two let the welds to exhibit better mechanical responses even with smaller weld sizes. Therefore, studying how to controll the energy input process coupled with metal transfer behavior in order to design and optimize the geometry and quality of deposited weld beam is of great importance for each CMT applications, especially for the additive manufacturing process. However, no exhaustive work concerning about this has been reported yet.

In the present study, aluminium alloy wire ER4043 was deposited on 6061-T6 sheets by CMT process using various characteristic parameters which represent for the control of current output and wire motion. The primary aim of this study is to characterize the contribution and limitation of the characteristic parameters in CMT deposited aluminium alloy process. Therefore, the effects of characteristic parameters on the energy input characteristic, metal transfer behavior, weld geometry, and microstructure of deposited weld metal were investigated.

Table 1
The characteristic parameters of CMT synergic welding processes.

Characteristic point WFS (m/min)	I_boost (A)	t_I_boost (ms)	I_sc_wait (A)	vd_sc_wait (m/min)	I_sc2 (A)
3.7	150	2	50	20	40
4.9	150	5	70	35	40
6.2	170	30	70	45	40

Table 2
The welding conditions experienced for understanding the effects of characteristic parameters in CMT welding processes.

Influence factor	I_boost (A)	t_I_boost (ms)	I_sc_wait (A)	vd_sc_wait (m/min)	I_sc2 (A)
I_boost	**120**	5	70	35	40
	180	5	70	35	40
	210	5	70	35	40
t_I_boost	150	**1**	70	35	40
	150	**3**	70	35	40
	150	**7**	70	35	40
	150	**10**	70	35	40
I_sc_wait	150	5	**40**	35	40
	150	5	**100**	35	40
vd_sc_wait	150	5	70	**5**	40
	150	5	70	**10**	40
	150	5	70	**20**	40
	150	5	70	**60**	40
I_sc2	150	5	70	35	**10**
	150	5	70	35	**70**