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Experiment on determining CMT parameters of 2A12 aluminum alloy material arc additive based on ABB robot control

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Abstract. This paper introduces the methods of arc addition and CMT welding. Through reasonable experimental design and intuitive experimental results, combined with 2A12 aluminum alloy material, This paper provides a feasible method for determining the CMT parameters of 2A12 aluminum alloy arc additive, and gives a set of CMT parameters.

1. Introduction

Wire Arc Additive Manufacture (WAAM) is a technology that utilizes the principle of layer-by-layer cladding. It uses an arc generated by a welder such as MIG, TIG, and plasma welding power source (PA) as a heat source [1]. CMT (Cold Metal Transfer Technology) is a new MIG/MAG welding process. Because its heat input is lower than that of ordinary MIG/MAG welding. When welding, many materials cannot withstand the continuous heat input during the welding process. In order to avoid droplet penetration, achieve spatter-free droplet transfer and good metallurgical connection, the heat input must be reduced [2].

2. Cmt Characteristics Introduction And Parameter Impact Analysis

2.1. Introduction of CMT features

The characteristics of CMT (Cold Metal Transfer Technology) are mainly reflected in the following aspects: 1. Uniformity of wire feeding monitoring and process control. 2. Low heat input. CMT technology enables droplet transfer in a no-current state. 3. No splash transition.



2.2. CMT process

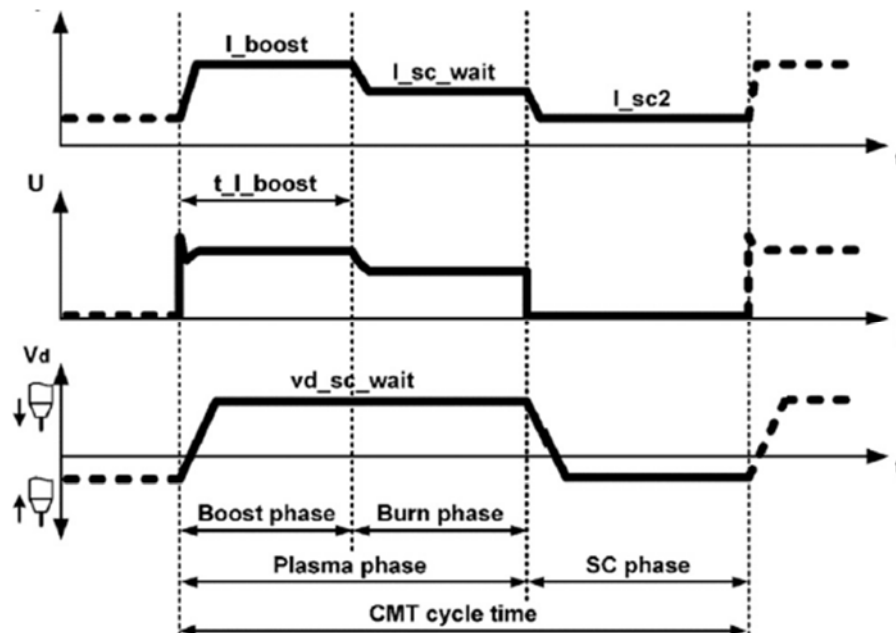


Figure 2-1. CMT process control parameters

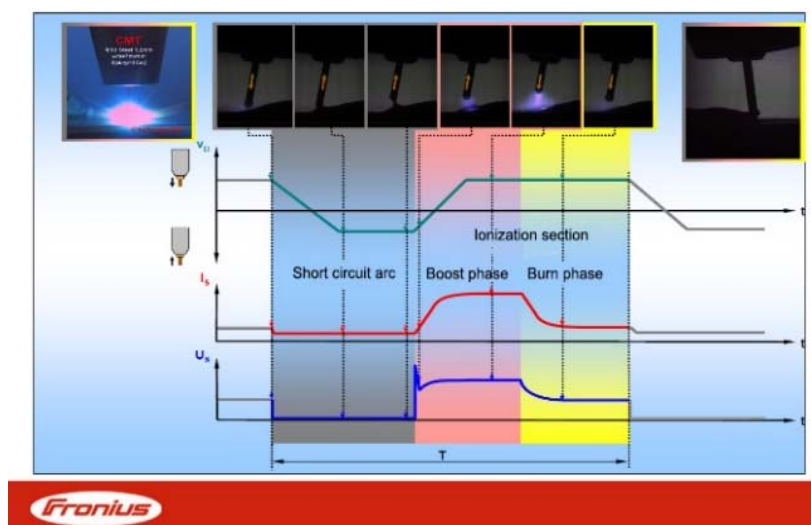


Figure 2-2. CMT process and parameters

The 2A12 material CMT parameters explore the following five variables: I_{boost} : arcing current, $I_{\text{sc_wait}}$: short circuit waiting current (combustion phase current), I_{sc2} : short circuit current, $t_{I_{\text{boost}}}$: arcing phase duration, $vd_{\text{sc_wait}}$: the speed of wire movement in the plasma phase (starting arc + combustion phase). At the beginning of the start-up phase, the arc is ignited with the aid of the retraction movement of the wire. When the power source detects arc ignition, it will shift from retraction to a constant speed of $vd_{\text{sc_wait}}$ and adjust the welding current with I_{sc2} to increase the speed of the arc. After the duration of the I_{boost} controlled by $t_{I_{\text{boost}}}$, the current becomes $I_{\text{sc_wait}}$ at the beginning of the combustion phase, which is low enough to ensure that the droplets (wire electrode tip) are gradually approaching the weld pool. The time of the combustion phase (T_{burn}) cannot be set, depending on when the droplets can contact the surface of the weld. As long as the droplet eventually

contacts the molten pool, causing the arc to extinguish, it means that the SC phase occurs and the current is immediately adjusted from I_{sc_wait} to I_{sc2} to avoid current pulses, while the wire is pumped back. Thus, in the SC phase, the wire electrode enters the weld pool at a slow feed rate at the beginning and gradually moves away from the weld pool after the wire begins to shrink. Finally, the droplets are separated from the electrode and the CMT cycle after the arc is reignited [3].

3. 2A12 Material Cmt Parameter Determination Method

3.1. Experimental hardware platform construction and wire material selection

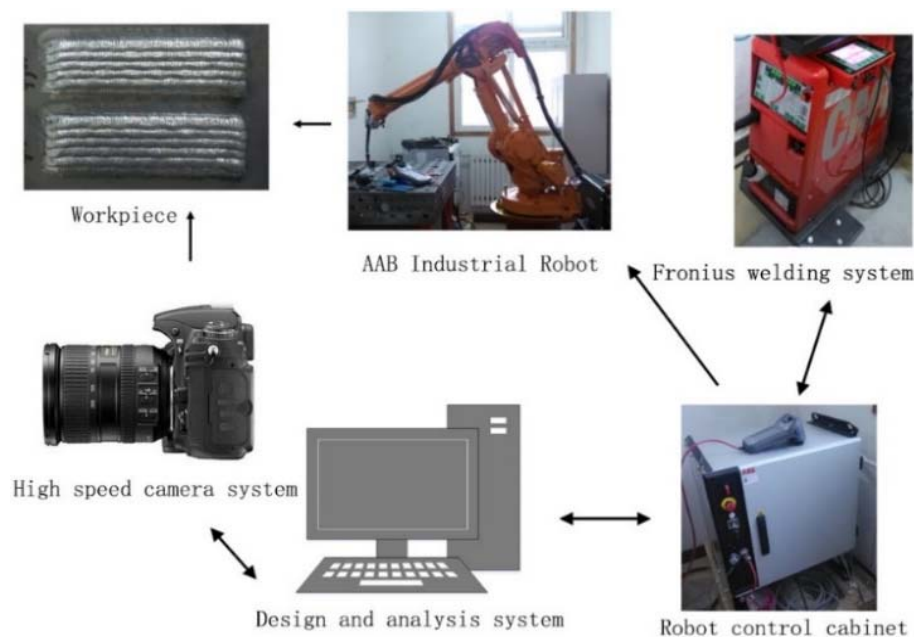


Figure 3-1. Robotic arc additive forming system.

This paper combines arc welding robot and High speed camera system to design and establish an arc additive manufacturing system. The structure of the system is shown in the figure. The system consists of the ABB Industrial Robot 1410 System, the Funis Welding System, the High Speed Camera System, and the Design and Analysis System.

3.2. 2A12 material CMT parameter determination method

This experiment changes one of the five parameters I_{boost} , I_{sc_wait} , I_{sc2} , t_{I_boost} , vd_{sc_wait} by a single variable method. Through the analysis of high-speed camera and the judgment of the periodic standard deviation curve, the appropriate parameter range is determined, and the most suitable parameter selection under the specific wire feeding speed is determined by the parameter selection with smaller range.

4. 2A12 Material Cmt Parameter Impact Analysis Experiment

The basic parameters of the CMT of the Fonnis welding are as follows, and one of the five variables is changed to perform a single variable experiment.

Table 4-1. Fronius welding machine CMT welding basic parameters

I_{sc_wait}	vd_{sc_wait}	I_{sc2}	I_{boost}	t_{I_boost}
40	25	80	150	2.5

4.1. Analysis experiment affected by I_{boost}

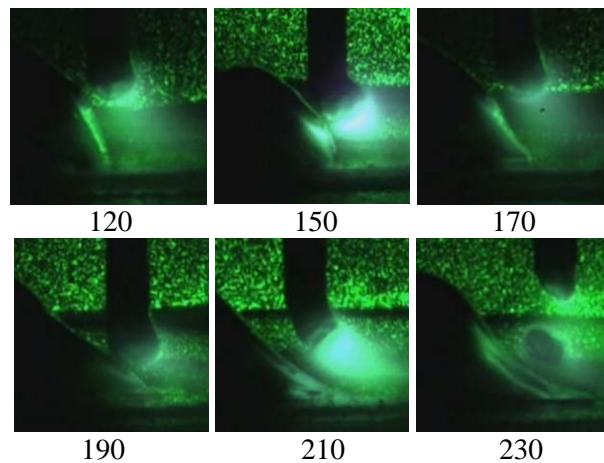


Figure 4-1. Image of different I_{boost} (A) values

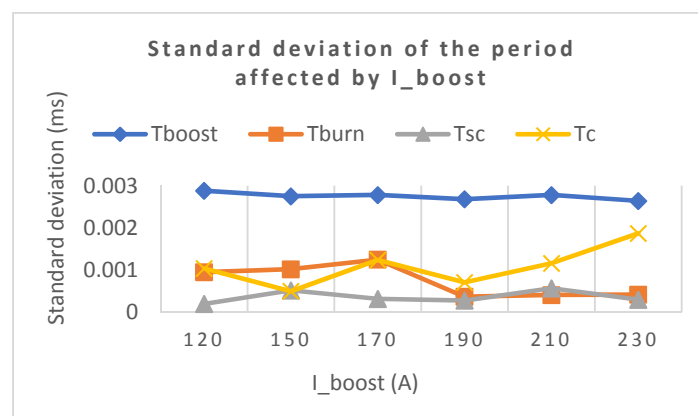


Figure 4-2. The standard deviation

In this study, I_{boost} was selected for 120A, 150A, 170A, 190A, and 210A, and the high-speed so if I_{boost} is too high, there will be a serious splash phenomenon. Below 190A is a stable range that can be selected; if I_{boost} is too low, a slight splash will occur, and above 120A is a stable range that can be selected. From the cycle standard deviation line graph, it can be analyzed that the value of I_{boost} is above 190A, the variance of T_c (full process period) is obviously increased, and the instability is intensified. Therefore, I_{boost} is in the range of 120-190A, and the additive is relatively stable.

4.2. Analysis experiment affected by $t_{I_{\text{boost}}}$

Select $t_{I_{\text{boost}}}$ to take the experiment as 1.5ms, 2ms, 2.5ms, 3ms, 3.5ms. When we analyze the high-speed camera image, we can get the following conclusion: When the value of $t_{I_{\text{boost}}}$ is 3.5ms, the splash phenomenon begins to appear. Therefore, the value of $t_{I_{\text{boost}}}$ should be lower than 3.5ms. From the cycle standard deviation line graph, it can be analyzed that when the value of $t_{I_{\text{boost}}}$ is 2 to 3 ms, the standard deviation is low.

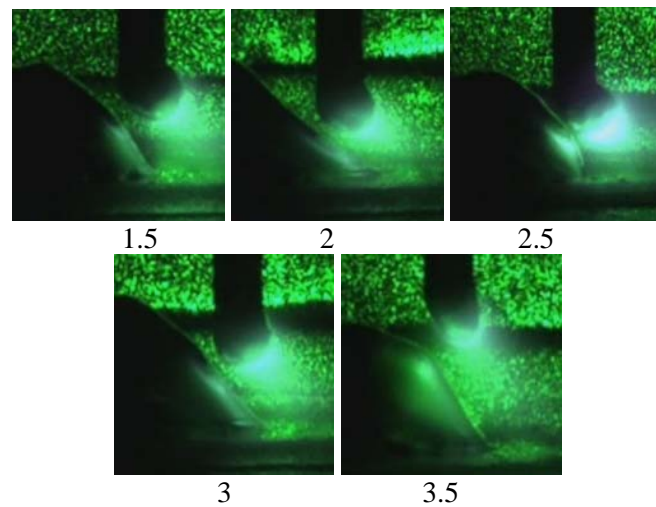


Figure 4-3. Image of different t_{I_boost} (ms)

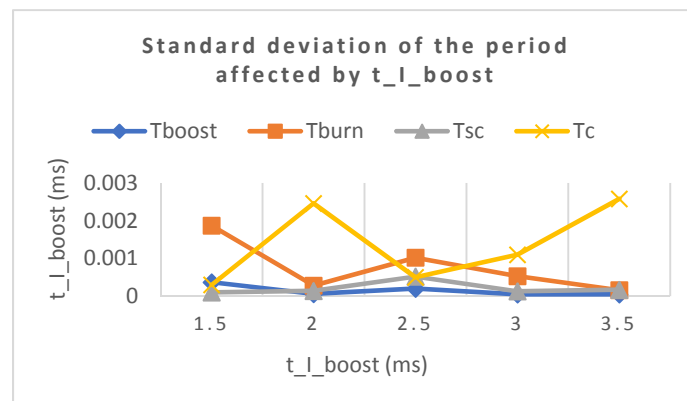


Figure 4-4. The standard deviation

4.3. Analysis experiment affected by I_{sc_wait}

I_{sc_wait} is selected as 50A, 70A, 90A, 100A, 130A for experiments, and the high-speed camera image, voltage and current waveforms are as follows:

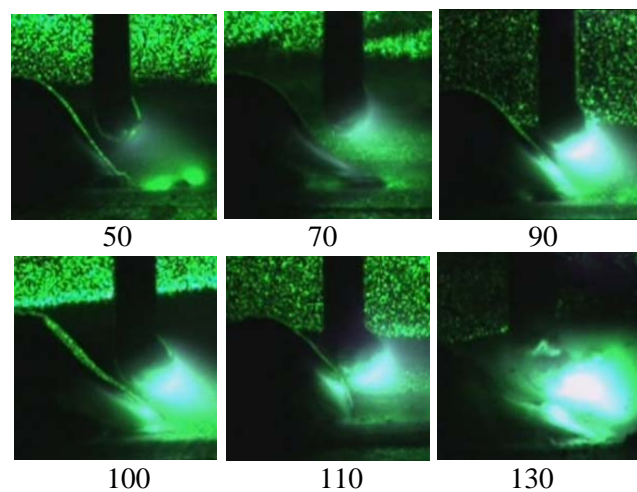


Figure 4-5. Image of different I_{sc_wait} (A)

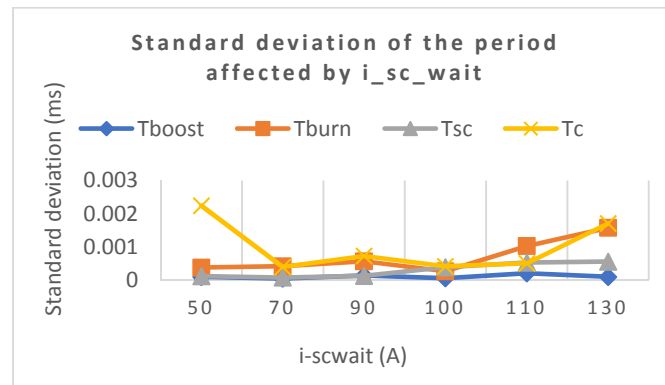


Figure 4-6. The standard deviation

So the value of I_{sc_wait} cannot be too high. It is observed that when the value is 100A, there is a weld without transition; when the value is 130A, a very serious splash is observed. Therefore, I_{sc_wait} must be a certain range lower than I_{boost} . If the value is close to I_{boost} , a very serious flying spatter will occur, the value of I_{sc_wait} can't be too low. The experimental results show that when I_{sc_wait} takes 50A, the additive process will splash and the voltage instability will be serious. According to the above analysis, the following conclusions can be drawn: I_{sc_wait} should not be too high, and must not be lower than I_{boost} 30-50A; the value should not be too low, above 50A. From the cycle standard deviation line graph, it can be analyzed that the standard deviation is lower when I_{sc_wait} is 50-100A. Therefore, the value of I_{sc_wait} is 50-100A, and lower than I_{boost} 30-50A, the additive manufacturing process is relatively stable.

4.4. Analysis experiment affected by vd_{sc_wait}

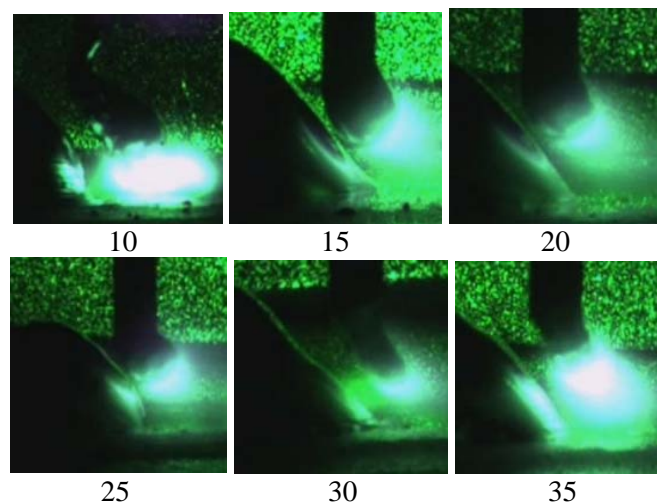


Figure 4-7. Image of different vd_{sc_wait} (m/min)

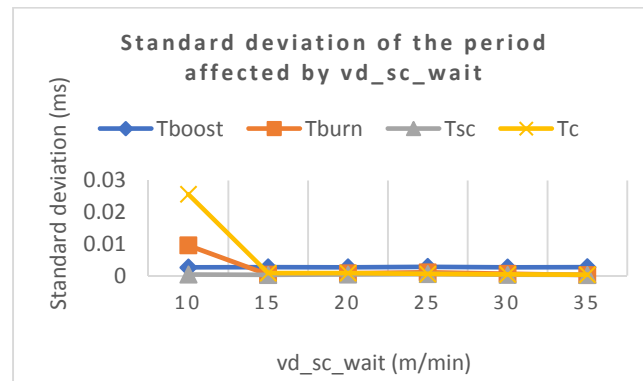


Figure 4-8. The standard deviation

Experiments were performed with values of vd_{sc_wait} of 10, 15, 20, 25, 30, and 35 m/min, respectively. The high-speed camera image, voltage and current waveform, and surface shape are obtained as follows:

So Vd_{sc_wait} directly affects the speed and time of droplet drop and the period of additive during the additive process vd_{sc_wait} . When the value is 10m/min, the flying splash occurs, and the process is extremely unstable; when the value is too large (at 30, 35m/min), the unstable condition occurs, and the drop of the droplet appears in a falling state. According to the above analysis, the following conclusions can be drawn: when the value of vd_{sc_wait} is 15-25 m/min, the additive process is stable. From the cycle standard deviation line chart, it can be analyzed that when the vd_{sc_wait} is 15-35m/min, the standard deviation of the cycle is low. Therefore, the value of vd_{sc_wait} is 15-25m/min, and the additive is relatively stable.

4.5. Analysis experiment affected by I_{sc2}

Experiment with I_{sc2} values of 40, 60, 80, 90, 110, 130A

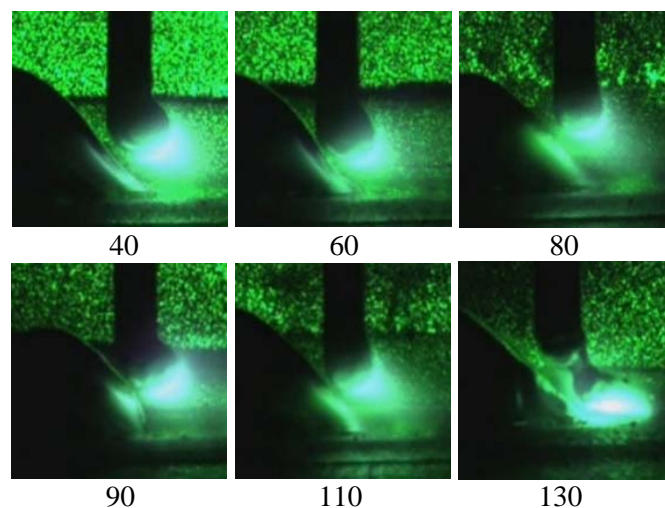


Figure 4-9. Image of different I_{sc2} (A)

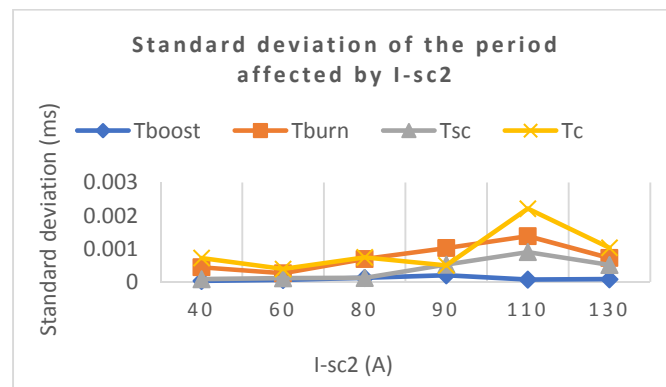


Figure 4-10. The standard deviation

So if the value of I_{sc2} is too large, the additive process will be unstable. When I_{sc2} is larger than I_{sc_wait} , instability will occur. It was observed that when $I_{sc2} = 130A$, a severe splash occurred. Therefore, the value of I_{sc2} should be lower than I_{sc_wait} . From the cycle standard deviation line graph, it can be analyzed that when the value of I_{sc2} is 40-90A, the standard deviation of the cycle is low. Therefore, the value of I_{sc2} is 40-80A, and must be lower than I_{sc_wait} . The additive manufacturing process is stable.

5. 2A12 Material Cmt Parameter Determination Experiment

In the previous experiment, the determined stable additive range is I_{boost} with a value of 120-190A, t_{I_boost} with a value of 2-3ms, I_{sc_wait} with a value of 50-100A, and lower than I_{boost} 30-50A, and vd_{sc_wait} has a value of 15- 25m/min, the value of I_{sc2} is 40-80A. I_{boost} directly affects the arcing current, t_{I_boost} affects the duration of the arcing current, I_{sc_wait} affects the current in the combustion phase, I_{sc2} affects the current in the transition phase, and vd_{sc_wait} affects the wire feeding speed in the arcing and combustion stages.

5.1. Analysis experiment affected by I_{sc2}

According to the parameter range of the previous chapter and the experience of the experiment, the following parameters are selected and tested, and the high-speed camera image is as follows:

Table 5-1. Wire feeding speed 4.5, group 1

I_{sc_wait}	vd_{sc_wait}	I_{sc2}	I_{boost}	t_{I_boost}
70	25	50	130	2.5

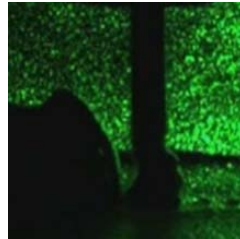


Figure 5-1. Image of group 1

We analyze the high-speed camera image to show that there is a splash in the two-state transformation —that is, from I_{sc2} to I_{boost} , there is a slight splash, and the additive process is discontinuous. For the discontinuity of the additive process, it is determined that the additive speed is too slow — increasing vd_{sc_wait} to 27m/min.

Table 5-2. Wire feeding speed 4.5, group 2

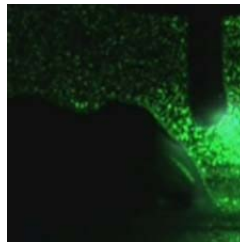
I_sc_wait	vd_sc_wait	I_sc2	I_boost	t_I_boost
70	27	50	130	2.5

**Figure 5-2.** Image of group 2

We analyzed the high-speed camera and determined that the adjustment failed, and the additive was still discontinuous. We judged that the energy in the combustion phase of the additive process was insufficient, resulting in less melting of the wire——increasing I_sc_wait to 75A.

Table 5-3. Wire feeding speed 4.5, group 3

I_sc_wait	vd_sc_wait	I_sc2	I_boost	t_I_boost
75	25	50	130	2.5

**Figure 5-3.** Image of group 3

The adjustment works well, but the surface is not flat enough. We try to increase I_sc_wait to 80A——the effect is very good, the surface is flat .Let's try again and increase I_sc_wait to 85A.

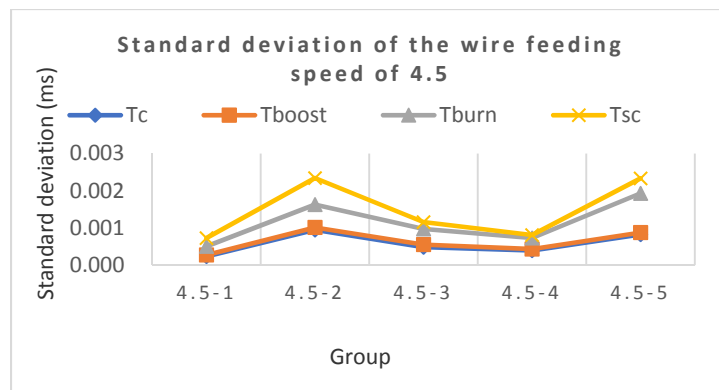
Table 5-4. Wire feeding speed 4.5, group 4

I_sc_wait	vd_sc_wait	I_sc2	I_boost	t_I_boost
80	25	50	130	2.5

**Figure 5-4.** Image of group 4

Table 5-5. Wire feeding speed 4.5, group 5

I_sc_wait	vd_sc_wait	I_sc2	I_boost	t_I_boost
85	25	50	130	2.5

**Figure 5-5.** Image of group 5**Figure 5-6.** Cycle standard deviation of 4.5

The effect is not good, the energy is too large, and the surface is formed intermittently. The cycle standard deviation of the five groups of experiments was counted, and the following line chart was obtained. So, According to the high-speed camera and the standard deviation of the cycle, the 4.5-4 parameter is selected as the CMT stability parameter.

5.2. CMT parameter exploration process of wire feeding speed 5.0

According to the parameter range of the previous chapter and the experience of the experiment, the following parameters are selected and tested, and the high-speed camera image is as follows:

Table 5-6. Wire feeding speed 5.0, group 1

I_sc_wait	vd_sc_wait	I_sc2	I_boost	t_I_boost
85	25	60	150	2.5

**Figure 5-7.** Image of group 1

When the droplets fall, the sway is large, and the additive is crowded. We observed that the drop sloshing and the crowding of the additive, it is determined that the energy is too large - adjust I_{sc_wait} to 80A.

Table 5-7. Wire feeding speed 5.0, group 2

I_{sc_wait}	vd_{sc_wait}	I_{sc2}	I_{boost}	$t_{I_{boost}}$
80	25	60	150	2.5

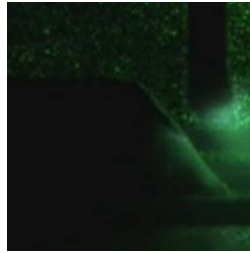


Figure 5-8. Image of group 2

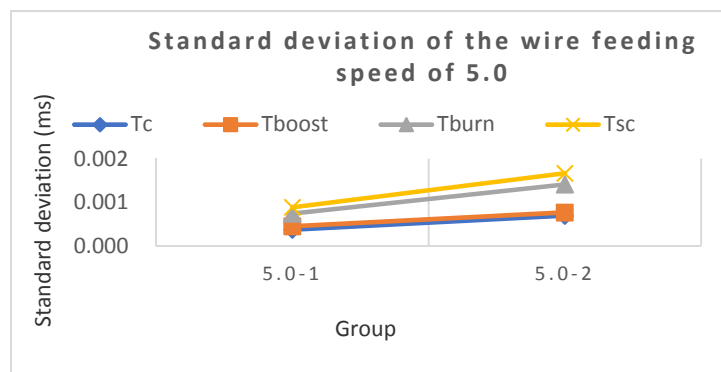


Figure 5-9. Cycle standard deviation of 5.0

The crowded material is solved, the droplet sloshing amplitude is in a reasonable range, and the adjustment effect is good. So, According to the standard deviation of the cycle and the actual situation, the 5.0-2 parameter is selected as the CMT stability parameter.

5.3. CMT parameter exploration process with wire feeding speed of 5.9

Table 5-8. Wire feeding speed 5.9, group 1

I_{sc_wait}	vd_{sc_wait}	I_{sc2}	I_{boost}	$t_{I_{boost}}$
85	25	70	170	2.5

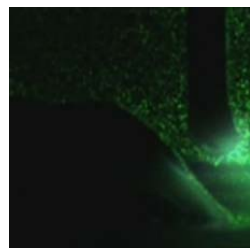


Figure 5-10. Image of group 1

The droplets swayed when they fell, and there is a crowd on the forming surface. We observed that the drop sloshing and the crowding of the additive, the energy is too large, and I_{sc_wait} is adjusted to 80A.

Table 5-9. Wire feeding speed 5.9, group 2

I_{sc_wait}	vd_{sc_wait}	I_{sc2}	I_{boost}	$t_{I_{boost}}$
80	25	70	170	2.5

The problem is solved and the adjustment effect is good. So, According to the standard deviation of the cycle and the actual situation, the 5.9-2 parameter is selected as the CMT stability parameter.

5.4. CMT parameter exploration process with wire feeding speed of 7.0

Table 5-10. Wire feeding speed 7.0, group 1

I_{sc_wait}	vd_{sc_wait}	I_{sc2}	I_{boost}	$t_{I_{boost}}$
80	25	80	190	2.5

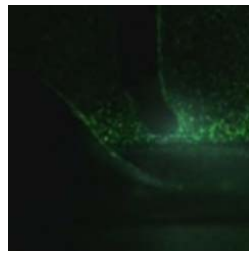


Figure 5-11. Image of group 1

The droplets swayed when they fell, and there was a crowding of the forming surface at the fast extinction. The drop of the drop is swaying and the material is crowded. It is judged that the energy is too large——adjust I_{sc_wait} to 70A

Table 5-11. Wire feeding speed 7.0, group 2

I_{sc_wait}	vd_{sc_wait}	I_{sc2}	I_{boost}	$t_{I_{boost}}$
70	25	80	190	2.5



Figure 5-12. Image of group 2

Adjustment failed, the weld bead was more crowded——adjust I_{sc_wait} to 90A

Table 5-12. Wire feeding speed 7.0, group 3

I_{sc_wait}	vd_{sc_wait}	I_{sc2}	I_{boost}	$t_{I_{boost}}$
90	25	80	190	2.5

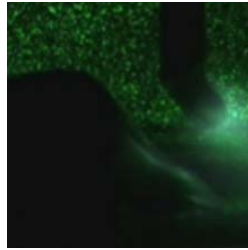


Figure 5-13. Image of group 3

The adjustment failed, the droplet energy was too large, and it swayed when falling. We observed that the droplets are shaking and unstable when falling——adjust I_{sc_wait} to 85A.

Table 5-13. Wire feeding speed 7.0, group 4

I_{sc_wait}	vd_{sc_wait}	I_{sc2}	I_{boost}	$t_{I_{boost}}$
85	25	80	190	2.5

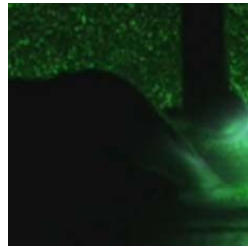


Figure 5-14. Image of group 4

The adjustment was successful, the drop was in a stable state, and the surface morphology was poor——adjust $isc2$ to 70A

Table 5-14. Wire feeding speed 7.0, group 5

I_{sc_wait}	vd_{sc_wait}	I_{sc2}	I_{boost}	$t_{I_{boost}}$
85	25	70	190	2.5

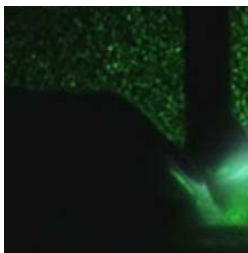


Figure 5-15. Image of group 5

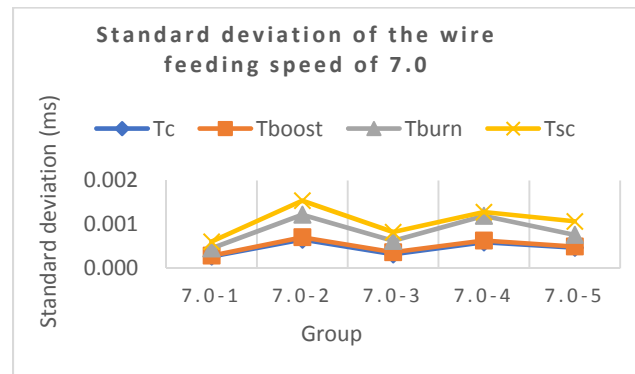


Figure 5-16. Cycle standard deviation of 7.0

The additive process is stable and the surface morphology is good. So, According to the standard deviation of the cycle and the actual situation, the 7.0-5 parameter is selected as the CMT stability parameter.

5.5. CMT parameter exploration process with wire feeding speed of 7.4

Table 5-15. Wire feeding speed 7.4, group 1

I_sc_wait	vd_sc_wait	I_sc2	I_boost	t_I_boost
85	25	70	210	2.5

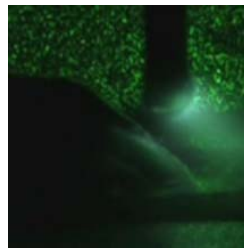


Figure 5-17. Image of group 1

We observed the high-speed camera and found that the effect is good. Try to adjust I_sc_wait to 80A.

Table 5-16. Wire feeding speed 7.4, group 2

I_sc_wait	vd_sc_wait	I_sc2	I_boost	t_I_boost
80	25	70	210	2.5

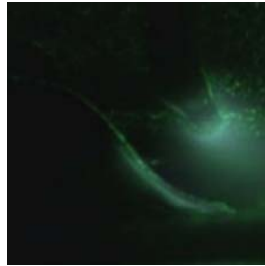
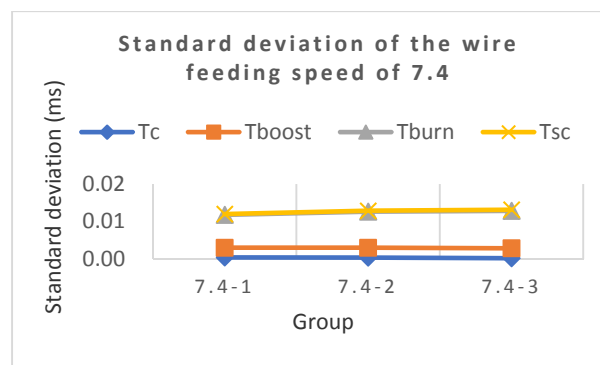


Figure 5-18. Image of group 2

Adjustment failed, droplet sloshing, forming fluctuations, adjusting I_sc_wait to 90A.

Table 5-17. Wire feeding speed 7.4, group 3

I_sc_wait	vd_sc_wait	I_sc2	I_boost	t_I_boost
90	25	70	210	2.5

**Figure 5-19.** Image of group 3**Figure 5-20.** Cycle standard deviation of 7.4

Adjustment failed, droplet sloshing, forming fluctuations, adjusting I_sc_wait to 90A. So, According to the standard deviation of the cycle and the actual situation, the 7.4-1 parameter is selected as the CMT stability parameter.

6. Conclusion

Considering the stability, surface morphology and cycle standard deviation under high-speed imaging, the CMT parameters of the final selected 2A12 material are as follows:

Table 6-1. Final selected CMT parameters

Wire feeding speed	I_sc_wait	vd_sc_wait	I_sc2	I_boost	t_I_boost
4.5	80	25	50	130	2.5
5	80	25	60	150	2.5
5.9	80	25	70	170	2.5
7	85	25	70	190	2.5
7.4	85	25	70	210	2.5

In this study, a method for exploring the parameters of CMT welding of arc additive is introduced. Through the influence analysis experiment of CMT parameters, the five parameters directly affecting the experiment were explored in a single variable manner to determine the reasonable range of parameters. Then, through a dynamic experimental exploration method, a set of feasible CMT parameters are given, which correspond to the incorrect wire feed speed labels.

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