Mechanism of undercut in high speed welding based on moveless TIG welding†

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KEY WORDS: (high speed welding)(undercut)(surface tension)(temperature gradient)

1. Introduction

Undercut is the main form of welding defect with the increasing of welding speed. In order to improve the appearance of the weld, the mechanism of undercut needs to be analyzed. The flow direction of liquid metal in a welding pool near the periphery is the main factor that decides undercut

The surface tension is the main driving force of liquid metal movement in a welding pool, moreover, the distribution and the direction of surface tension are decided by the surface temperature of the liquid metal. If the temperature coefficient of surface tension $\partial\sigma/\partial T<0$, the liquid flow from the center of the welding pool to the periphery appears in the surface of the welding pool, so undercut can't occur easily. On the contrary, if $\partial\sigma/\partial T>0$, the flow direction of liquid metal is reversed, so undercut occurs easily. When there is no surface active element in the metal, $\partial\sigma/\partial T<0$. Under the driving force of surface tension, a single circulation flow of liquid metal, which is from welding pool center where the surface temperature is high and the surface tension is small to welding pool edge where the surface temperature is low and the surface tension is large, appears in the welding pool. However, when there is some surface active element existing in metal, the temperature Tc in certain places of the welding pool surface is the right temperature it changes the sign of the temperature coefficient of surface tension. Based on the sign of $\partial\sigma/\partial T$, two regions are formed in the welding pool surface, so two or more circulation flow will appear in welding pool, as shown in **Fig. 1**. When liquid metal flows from the center of the welding pool to the periphery, undercut doesn't occur, but when liquid metal flows from periphery to the center of welding pool, undercut is likely to appear.

Sketch map of surface tension

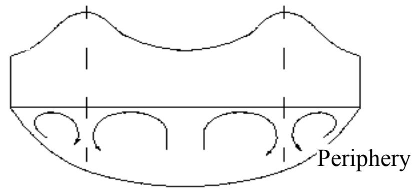
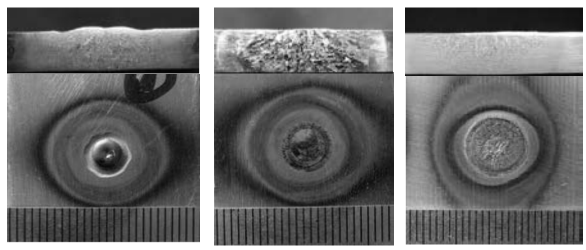


Fig.1 Schematic diagram of motionless arc pool

2. The influencing factors of undercut

The experiment was also done with the base metal in which the content of S is individually 0.02% ,0.01% and 0.004%. The experimental results are shown as **Fig.2**. For the metal in which the content of surface active element is low, undercut will not appear in the moveless welding. When surface active elements exist in metal (e.g the content of S is about 0.02-0.04% in steel), undercut occurs in the moveless TIG spot weld without. Whereas, the results of welding experiment have no undercut with the iron-base metal in which the content of S is very low (e.g S% is less 0.01%).



S=0.02% S=0.01% S=0.004%

Fig.2 Appearance of weld spot under the same welding condition

When the energy input is equal, with different welding current and different welding time, the depth of undercut will rise with the increase of welding current and the decrease of welding time, because the temperature gradient is large when the high-current is used to weld for a short

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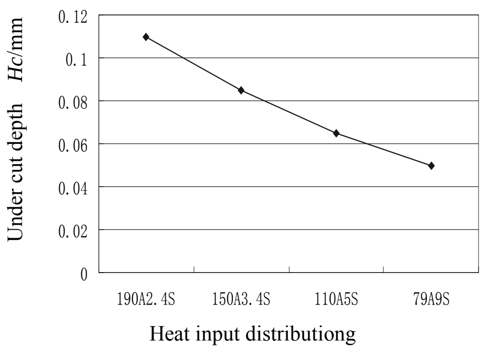

Fig. 3 Undercut depth of different welding current under the same input energy

time, during which the surface tension gradient will increase, which enhances the trend that liquid metal flows from periphery to welding pool center, so the depth of undercut increases, as shown in **Fig. 3.**

As described in **Fig. 4**, the molten angle is expressed by α . A liquid element near the periphery whose volume, of which the volume is V, is chosen in this article. L_o is the outflow of liquid metal, and L_i is the inflow of liquid metal. When other conditions are the same, the lower the α is ,the higher the Li will be. On one hand, it is because the distance between L_o and L_i decreases with the decrease of α, which makes the two reverse liquid flows that, effected by the viscous force of liquid and restricted by each other, and the liquid can't reach the region near the periphery easily. On the other hand, this is also because the cooling velocity of the welding pool is higher in the condition of smaller α, which makes the columnar crystals grow up quickly from periphery to form a mushy region near the periphery area , and the flow of L_i is blocked. Both of them will cause the deficiency of liquid near the periphery area, so the trend of undercut is enhanced.

It can be seen from the fore analysis, that increasing molten angle can decrease the drag of liquid flow near the periphery area efficiently, and can slow down the freezing rate, which is favorable for the metal of welding bottom to supply the area of periphery. So this has obviously effect to restrain undercut.

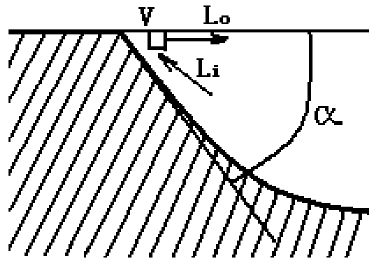

Fig. 4 Schematic diagram of flow in welding pool

The filling metal is another factor to effect undercut. When other conditions have no change, the depth of undercut will decreases along with the quantity of filling metal increase, and will disappear finally, as shown in **Table 1**. This is mainly because the addition of filling metal makes trend of flow from periphery to welding pool center lower, which will counteract the effect of liquid metal flow to inner absolutely, when its quantity reaches a definite value. Therefore, undercut can be restrained.

Table 1 Quantity of filling metal

Mass of filling metal（mg）	Depth of undercut （mm）
0	0.1
30	0.066
70	0.018
100	0
150	0

3. Conclusions

To sum up, the existance of surface active elements, temperature gradient, molten angle and filling metal, all of those have important effects on undercut. When the content of a surface active element reaches definite values (e.g the content of S is about 0.02-0.04% in steel), undercut will occur. Temperature gradient makes the degree of undercut increase along with its augment. Increasing molten angle can restrains undercut efficiently. Adding the quantity of filling metal can also reduces the degree of undercut.

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