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Some Characteristics of the Electrode Melting Phenomena in Narrow-gap MIG-arc Welding*

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Abstract

Effect of groove width on wire melting rates and characteristics of welding arcs have been studied in DCSP and DCRP-MIG arc welding (shielding gas composition; 80 %Ar+20 %CO_2).

In DCSP, it was found that wire melting rate increased as groove width increased, and wire melting rate became a constant value as groove width exceeded a certain boundary value. In cases where groove was narrow, welding arcs burned not only at groove bottom but also on both groove faces. Their arc flames were extended and wire tapered end had a tendency to be lengthened and sharpened. At the same time droplets became small and transferred smoothly (spray transfer).

On the other hand, in DCRP, characteristics of arc and wire melting rates were not affected by groove width.

The results are explained in terms of a change in magnetic force and wandering area of cathode spot around the conical tapered wire end.

1. Introduction

Up to this time, many studies on the melting rate of electrode wire have been carried out in bead on plate welding[1,2,3,4]. But it is considered that the melting rate is affected by groove width and its shape[5], because the arc behavior is influenced by change of groove width.

This paper has made clear the relation between the melting rate of electrode wire and the groove width in MIG-arc welding. The groove was changed by varying the angle of V-groove and the root gap of I-groove. Particularly, an interesting difference in arc phenomena between straight polarity and reverse polarity has been observed in narrow groove.

2. Experimental procedures

2–1 *Material*

The base metal was a mild steel. The electrode wire was the MIG welding wire (1.6 mmϕ) for a mild steel and 50 Kg/mm^2 grade high tension steel. The chemical compositions of the base metal and the wire are shown in Table 1. The shielding gas composition was 80 %Ar+20 % CO_2. The shapes and dimensions of test specimens are shown in Figure 1. All the surfaces of grooves were ground to remove their mill scale.

Table 1 Chemical compositions of base metal and electrode wire

Material	Chemical composition (Wt %)					
	C	Si	Mn	P	S	Ti
Electrode wire (1.6mmϕ)	0.07	0.81	1.51	0.015	0.008	0.16
Base metal (SS41)	0.20	0.05	0.95	0.02	0.02	—

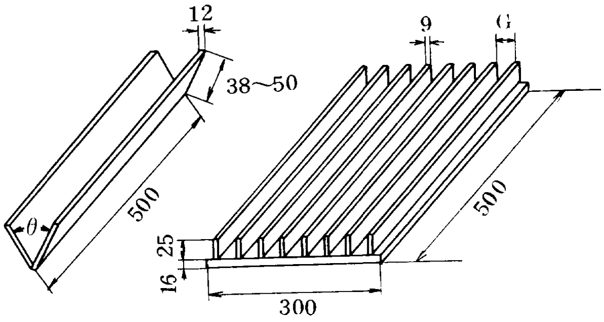

Fig. 1 Shapes and dimensions of test pieces

2–2 *Experimental method and apparatus*

The welder used in this test was an automatic one reconstructed from the conventional CO_2 gas shielded semi-automatic welder.

The experimental apparatus is shown in Figure 2 and a schematic explanation of optical system for observing the weld arc is shown in Figure 3. The adopted automatic arc welding method was designed with that the welding torch was fixed and the specimens could move along the weld line on a carriage. And the behavior of arc was observed by a high speed cine photography taking 500 frames per second.

The method of wire melting rate measurement is as follows; First, the number of revolutions of electrode feed roller was measured, and this measured value was to be the electrode melting rate by conversion. The electrode extension was set by an optical method as shown in Figure 3–a. That is, a tungsten measuring scale rod previously set to a prearranged electrode extension was fixed on the welding torch. The optical axis of camera was set

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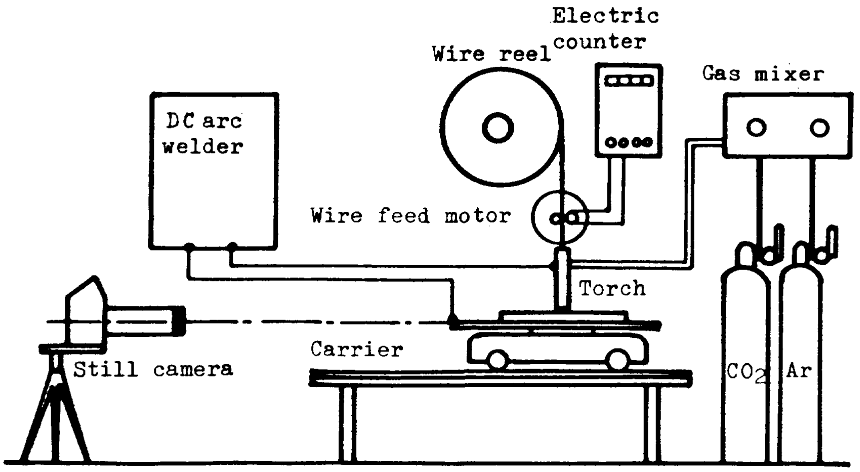


Fig. 2 Schematic explanation of experimental apparatus

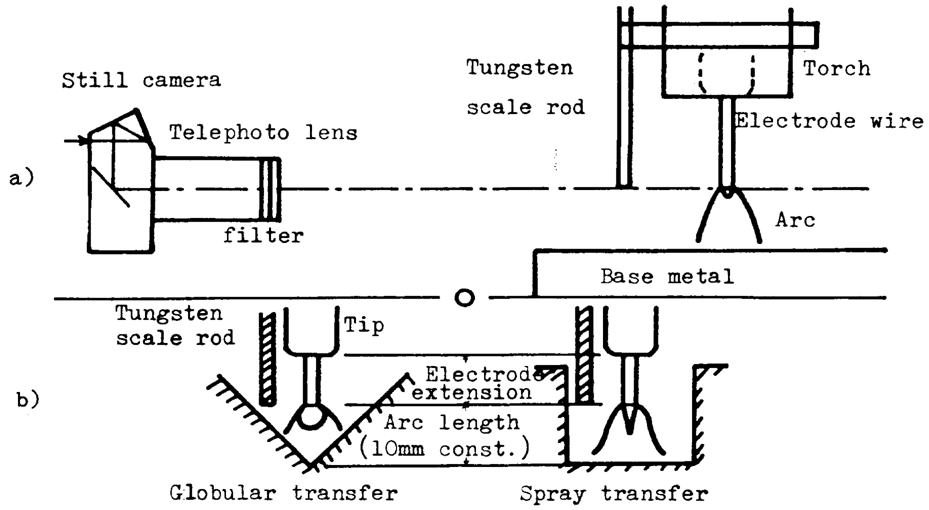


Fig. 3 Schematic explanation of measuring electrode extension and arc length

Table 2 Items of experiment and welding conditions

Items of experiment	Welding conditions				
	Welding current (Amp.)	Arc length (mm)	Welding speed (cm/min)	Groove shape	Wire extension (mm)
Relation between welding speed and wire melting rate.	250 350 450	10	38 57 76	I (gap. 10mm)	20
Relation between arc length and wire melting rate.	350	2 ~ 10	38	Bead on plate I (gap. 10mm)	30
Relation between groove shape and wire melting rate.	250 350 450	10*1	38*2	I-groove (gap. 5~31mm) V-groove (Angle. 15~180°)	10 15 20 30

*1 In case that arc length does not reach 10 mm owing to the lack of welder's capacity, arc length is taken as long as possible.
*2 In case that molten metal flows out before the weld pool, the welding speed is set at 57 cm/min or 76 cm/min.

horizontal with the specimens. The arc voltage was adjusted after beginning the welding operation and thereafter the defined electrode extension could be gained by making the end point of tungsten measuring scale rod coincide with the end of wire as shown in Figure 3–b. And the distance from the bottom of groove to the end of wire was called an apparent arc length and this value was kept at 10 mm constant as shown in Figure 3–b. The welding conditions used in this test are shown in Table 2.

3. The melting characteristics and arc behavior in grooves

Two kinds of grooves as shown in Fgiure 1 was used in this experiment. The welding operations have been performed under the welding conditions shown in Table 2, by changing the groove angle θ at V-groove and the root gap G at I-groove. The electrode melting rates have been measured with the method shown in the section 2–2. The results of measured values are shown in Figure 4. According to these results, under straight polarity the electrode melting rate $M_{RO}^{*)}$ has a tendency of decreasing when the root gaps or the groove angles became narrower than a certain value.

This tendency became remarkable with a higher welding current, and the critical value of the root gap or the groove angle to decrease the electrode melting rate lowered with an increasing current. However, under reverse polarity the electrode melting rate did not change depending on the value of the root gaps or the groove angles. Here, the width of root gaps and groove angles were considered to be equivalent to the distances between the welding arc point (electrode wire end) and the surfaces of groove.

The electrode extension was determined under the constant distance between the nozzle and the base metal in measuring the electrode melting rate. Therefore, it is considered that the surface level of molten pool goes up in proportion to the groove becoming narrower and the actual arc becomes shorter. As for these facts, the result obtained from the preliminary experiment that the arc length did not affect the electrode melting rate is shown in Figure 5. According to this result, the electrode melting rate is not affected by the arc length (arc voltage), only exception being an area out of the range of so-called intrinsic self-regulation where the end point of melting wire contacts instantly with the molten pool.

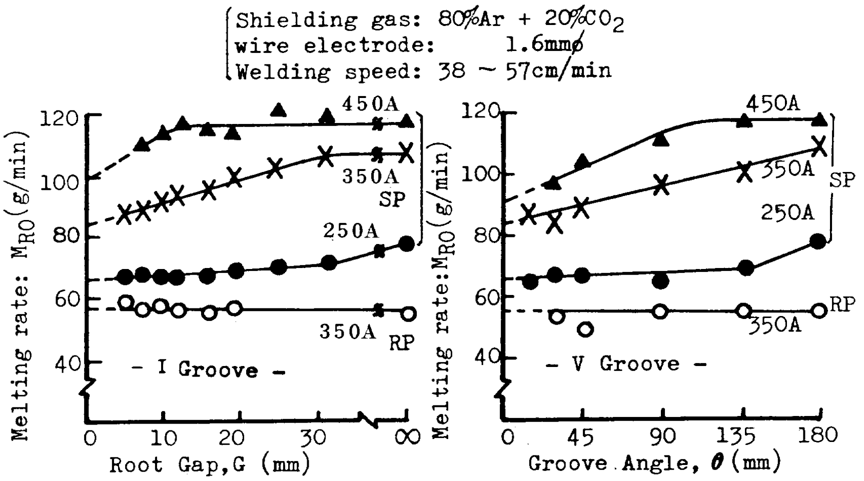
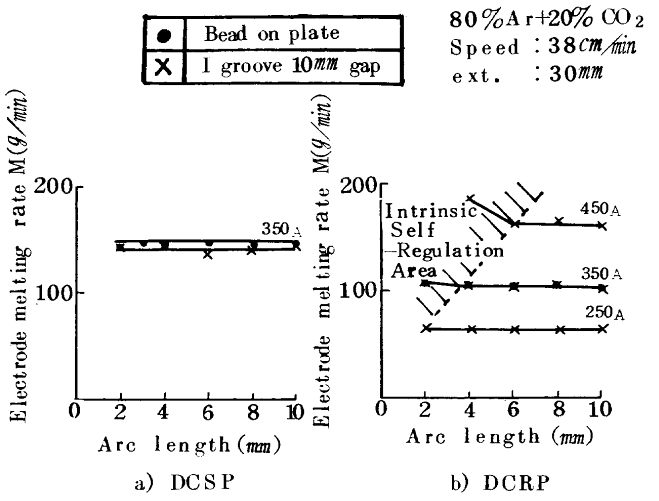


Fig. 4 Effects of root gap and groove angle on M_{RO} (zero electrode extension melting rate)



a) DCSP b) DCRP

Fig. 5 Effect of arc length on electrode melting rate

The variation of arc behaviors when the groove with changed was observed with the high speed cine photography. A schematic diagram of the end shape of melting wire in I-groove and V-groove under straight polarity is shown in Figure 6. According to this observation, the melting portion of wire end became longer as both side faces of grooves came closer to each other and also the arc tended to extend laterally. Some droplets tended to accumulate on the end of wire while the welding current was relatively low, but, with a higher current, the end of wire became sharper and this tendency was more distinguished at a high welding current. On the other

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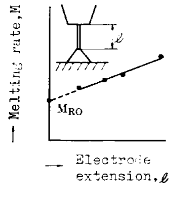
*) In general, it is considered that the electrode melting rate (M) is the sum of the melting rate (M_{RO}) owing to arc-heating and the melting rate (M_l) depending on I^2R heating produced at the portion of electrode extension. Accordingly, the value M is measured in practice for various electrode extensions (l); and from an extrapolation of these results, the value of M at $l=0$ is obtained and this is to be M_{RO}[2].



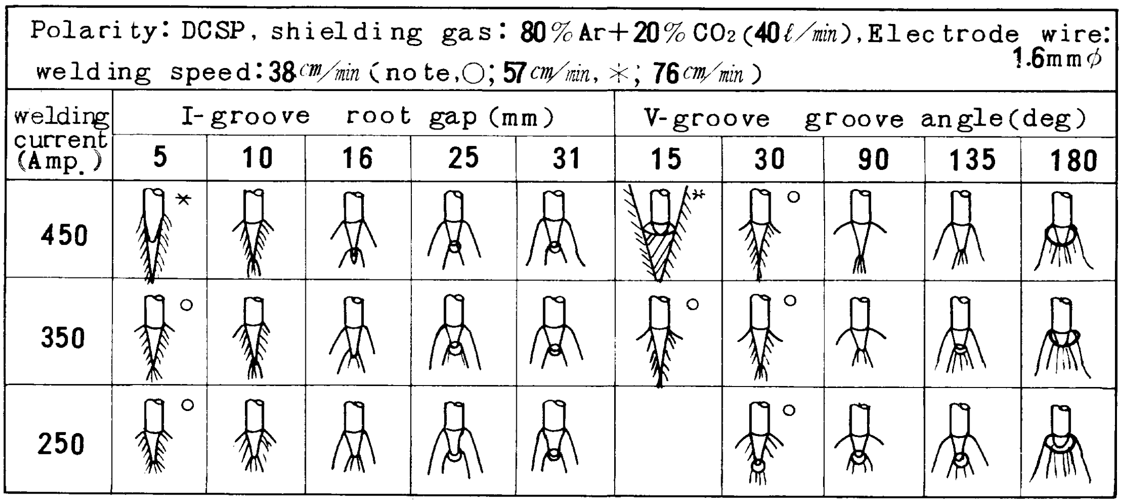


Fig. 6 Schematic explanation of MIG arc flames and electrode end shape in steel electrode (DCSP)

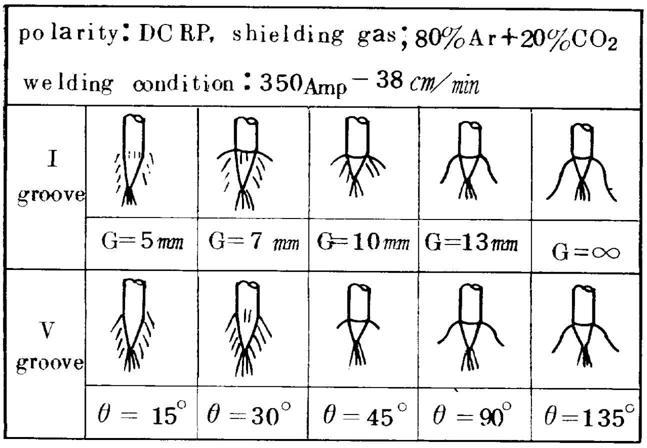


Fig. 7 Schematic explanation of MIG arc flames and electrode end shape in steel electrode (DCRP)

hand, under reverse polarity, the end of melting wire became somewhat obtuse and shorter than under straight polarity and the shape of wire end did not change with the distance between both side faces of grooves as shown in Figure 7.

Figure 8 shows the relation between *a*, that is, the representing value of arc extension rate (reference figure 8) and the root gap of I-groove; therefrom it is found that the arc extends rapidly as the distance between both side faces of grooves becomes narrower under straight polarity as described above.

Figure 9 shows the relation between the length of end of melting wire L and the root gap of I-groove.

As mentioned above, under straight polarity there was a distinguished tendency that the melting portion of wire end stretched longer and the arc extended as the groove became narrower. However, under reverse polarity, the variation of arc phenomenon with a changing groove width did not appear.

Under straight polarity, the transfer forms of molten metals changed with the distance between the arc and the faces of grooves. That is, as the arc was more distant from the side faces of grooves, the droplets became larger to 2～3 times the wire diameter and

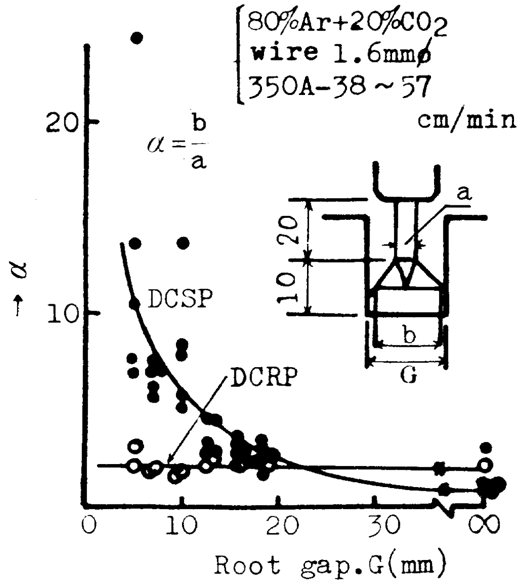


Fig. 8 Effect of root gap on $\alpha(=b/a)$

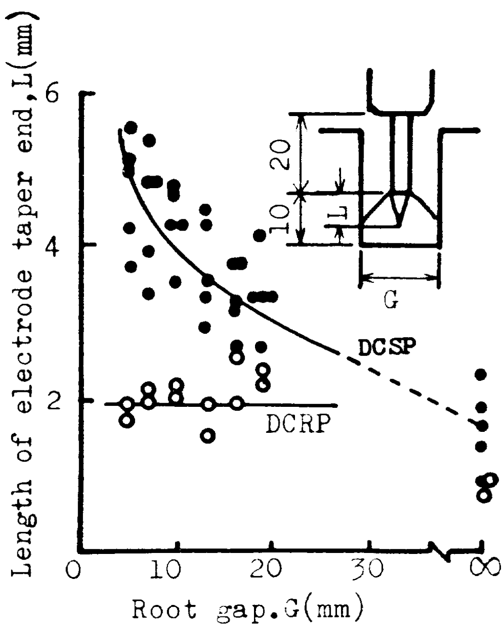


Fig. 9 Effect of root gap on length of electrode taper end

made a globular transfer, but the end of wire became sharper as the side faces came closer to each other and the diameter of transferring droplets became smaller. And the globular transfer changed to a spray transfer and the arc was stable. As the welding current became higher, this tendency was more distinguished, while under reverse polarity the transfer form was a spray type without an influence of distance between both side faces of grooves and an increased welding current.

4. Discussion on decrease of the electrode melting rate in the narrow gap welding of straight polarity

Generally, when the welding current is kept constant, it is recognized that the rate of melting of electrode wire is smaller in spray transfer than in globular transfer[6], and in the former, the heat quantity of the transferring droplets is larger than in the latter[7,8].

According to the results of the experiments under straight polarity, the transferring form of molten metals in a relatively wide groove is a globular transfer type, and it changes a spray transfer type as the groove becomes narrower as shown in Figure 6.

Therefore, a quantitative tendency is easily conjectured that the electrode melting rate decreases as a result of a larger input energy being consumed with a rising droplet temperature according as the grooves become narrower. In this discussion, the phenomenon of a continuous decrease in the electrode melting rate as the grooves become narrower even when the transferring form was changed to a spray transfer type, will be interpreted as follows;

1) The fact that the melting portion of wire end lengthens as the grooves becomes narrower in DCSP

The ignition of welding arc acts on the Principle of Minimum Voltage as well as that of general arcs, and it is apt to take place at a close location of electrode to the groove faces. Accordingly, the welding arc takes place initially at the root of groove. When the grooves become narrower and the arc voltage is high, the arc occurring areas of the wire end (cathode area) and of the groove faces (anode area) climb up together. Then the wire begins to be melted by heating positively also from the side face. Resultantly, the melting portion of wire end becomes longer as the grooves becomes narrower and also the arc extends laterally.

A downward electro-magnetic force acting upon the melting metal portion of wire end increases with a lateral extension of arc in narrow grooves as clarified from the calculation result of Dr. Nishiguchi and others[9]. It is considered that the wire end is apt to sharpen like a pencil tip. For these reasons, spray transfer of molten metal is promoted.

On the other hand, it is considered that the downward electro-magnetic force acting upon the melting metal portion of wire end increases and this force makes easy a downward transfer of the melting metal without delay, the electrode melting rate increasing because of the solid portion of the wire end being heated by arc directly. But according to the experimental results the melting rate decreases on the contrary. This apparently contradictory phenomenon comes from the fact that the variation of distributing density of heat source (cathod point) is not considered but attention is paid to only the downward electro-magnetic force taking place on the melting portion of wire end (the area is considered a part where in the cathode point moves about).

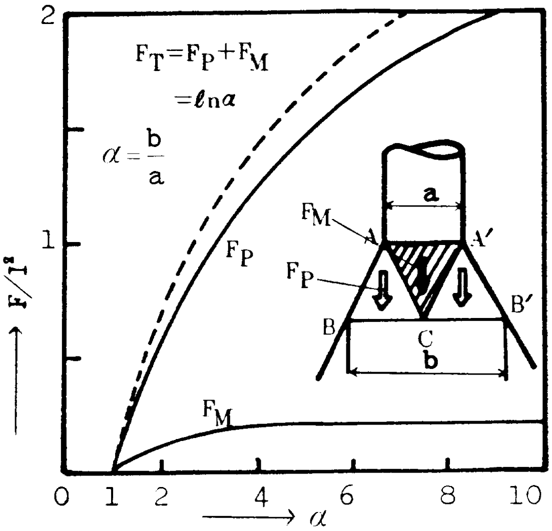


Fig. 10 Effect of taper index of current flowing pattern on electromagnetic forces around electrode tip[9]

Hereafter, the variation of electrode melting rate is discussed from the viewpoint of the melting heat efficiency.

2) The relation between the length of the melting portion of wire end and the electrode melting rate

Under straight polarity, the melting portion of wire end becomes longer and sharper and the arc is apt to take place from the side face of wire as the distance between both side faces of grooves becomes shorter. So the dispersion area of arc is widened at the wire end and the electrode melting rate becomes different from the case that the arc is centralized at one point.

Figure 11 shows a schematic drawing to predict the the relation between the area of dispersion zone and the electrode melting rate. Now, assuming that the electric input power remains constant, and that the cathode point of arc is relatively centralized at the wire end point (on the curve AB of Figure 11), the melting metal is placed in over-heated condition by the high current density. However, the wire comes gradually to be efficiently melted according as the cathod point of arc disperses to the proper area (on the curve BC of Figure 11); and the heat efficiency becomes highest at the point C, accordingly, the electrode melting rate per unit current value also reaches the maximum value[10]. Further, the dispersion of heat source becomes more extreme according as the dispersion area of cathode point extends wider (on the curve CD of Figure 11), accordingly

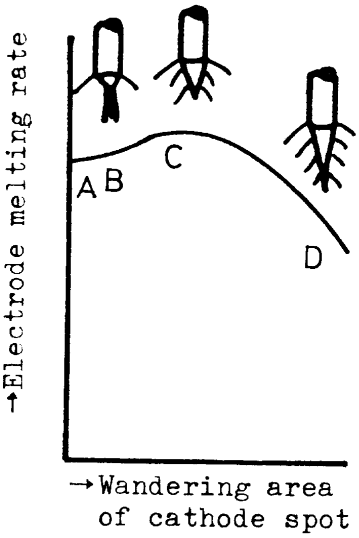


Fig. 11 Schematic explanation of the relation of melting rate and wandering area of cathode spot

the melting efficiency begins to decrease rapidly.

From these experimental results, it is seen that the length of melting portion of wire end L, substituted for the dispersion area of the cathode point of wire end, as arranged to have the relation of the electrode melting rate M_{RO}, will be indicated as shown in Figure 12, and it is equivalent to the curve CD in Figure 11.

That is, in order that the melting portion of wire end may become longer and the dispersion area of cathode point of arc may become wider as the distance between both side faces of groove becomes narrower, it seens, the heat efficiency contributing to melting of the electrode should decrease with a decreasing electrode melting rate.

5. Conclusions

The effects of groove width on the arc behavior and electrode melting characteristics have been observed and their causes have been discussed.

The behavior of reverse polarity MIG-arc is not affected by groove width, whereas the straight polarity MIG-arc comes to ignite directly at the side faces of groove as groove width becomes narrower. The arc extends laterally and the downward electromagnetic force acting upon the melted metal of wire end increases and the type of the droplet transfer changes to a spray transfer. And with it, the electrode melting rate decreases.

The reasons for the above mentioned phenomena are considered to be that an overdispersion of heat source contributing to melting the wire takes place, and accordingly the electrode melting rate decreases, so that the melting portion of wire end extends wider as both side faces of groove become narrower and the cathode point begins to disperse excessively.

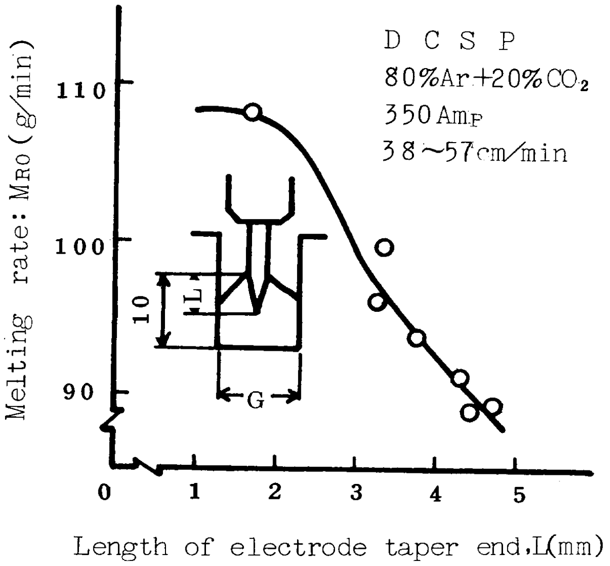


Fig. 12 Effect of electrode taper end length (L) on melting rate (M_{RO})

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