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Author(s)	Matsuda, Fukuhisa; Ushio, Masao; Sohno, Kazuo et al.
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Application of Fast Weaving to CO_2 Arc Welding (ReportI)†
– On Bead Appearance and Spattering Loss –

Fukuhisa MATSUDA* ,Masao USHIO** , Kazuo SOHNO*** and Shunji OSHIMA****

Abstract

An application of the weaving to bead-on-plate CO_2 arc welding is studied using a conventional weaving device which has the welding torch oscillate transversely to the welding direction like the pendulum motion in the range of 0 to 30 Hz in frequency and 0 to 8 mm in amplitude. Bead appearance and spattering loss are examined under various oscillation conditions and it is shown that there is optimum condition under which the smoothness of bead is improved and the spattering loss is reduced to 1/3 ~ 1/4 as compared with that in non weaving case. Most suitable conditions with respect to the bead appearance and spattering loss are in the region of oscillation of 5 to 15 Hz in frequency and 3 to 7 mm in amplitude in the case of middle current CO_2 arc welding.

The phenomena and the movement of molten metal during welding are observed using a high speed movie and the discussions concerning the mechanism for the reduction of spattering loss under the proper oscillating condition are described. The burried arc and stable movement in the pool is the reason to the improvement of the bead appearance and the reduction of spattering loss.

The change in the shape of fusion zone is discussed with an approximated calculation based on Rosenthal's heat conduction theory.

KEY WORDS: (Arc welding) (Weaving) (CO_2 welding) (Process conditions) (Spatter) (Weld pool)

1. Introduction

It is well known that weaving the arc has improved the quality of weld bead appearance and welded joint in usual manual arc welding process. In these days, the attempt to apply the weaving to various automatic welding procedures has been undertaken to improve the bead appearance, the mechanical properties of joints and the resistance to cracking and brittle fracture. Instead of conventional weaving technique which is to vibrate the welding torch, the new weaving methods are proposed for some welding processes such as the multiple electrodes submerged arc welding and the GTA welding, which are the ones of comparatively low oscillation of arc of 10 to 100 cycles/min in frequency by the use of alternating magnetic field, the twisted filler wire electrode and so on[3)–7)].

There are, however, scarcely any reports dealing with the welding arc phenomena or the movement of molten metal in the puddle during welding, especially under fast weaving condition as long as the authors know. In this paper, an application of the weaving to the bead-on-plate CO_2 arc welding is studied using a conventional weaving device which has the welding torch oscillate transversely to the welding direction like the pendulum motion in the range of 0 to 30 Hz in frequency and 0 to 8 mm in amplitude. Bead appearances and spattering losses are examined under the various oscillation conditions and it is shown that there is the optimum condition under which the smoothness of bead is improved and the spattering loss is reduced to 1/3 ~ 1/4 as compared with that in non weaving case. In addition, the arc phenomena and the movement of molten metal during welding are observed using a 16 mm high speed movie, and the discussions concerning the mechanism for the reduction of spattering loss under the optimum oscillating condition are described. The change in the shape of cross section of fusion zone is dicussed with the approximated calculation based on Rosenthal's heat conduction theory.

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* Professor
** Associate Professor
*** Graduate Student, Osaka University
**** Chief Engineer, Matsumoto Kikai Co. Ltd.

2. Experimetal Procedures

Chemical compositions of materials used in this investigation are shown in **Table 1**. The size of specimen is 300 mm in length, 150 mm in width and 10 mm in thickness. The diameter of the filler wire is 1.2 mm.

Table 1 Chemical compositions of materials used (wt%).

	C	Si	Mn	P	S	Fe
Base metal	<0.20	<0.35	0.60 ~1.20	<0.040	<0.040	Bal.
Filler wire	0.09	0.96	1.43	0.013	0.012	Bal.

Conventional bead-on-plate CO_2 arc welding is made using a commercial automatic welding machine. The welding speed applied is mainly 600 mm/min and a flow rate of CO_2 gas is 20 litters/min. The welding torch is held downwards separated by 15 mm above a plate and inclined backwards at an angle of 10 degrees from the vertical axis, which is illustrated in **Fig. 1**. The torch is fixed to the weaving arm which has enough length to bring the torch head an oscillatory motion in the horizontal direction.

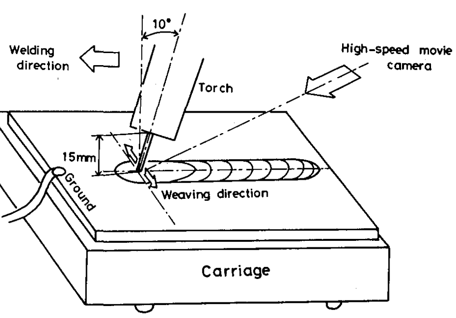


Fig. 1 Schematic view of weaving experiments.

A typical motion of the wire electrode under weaving is given in **Fig. 2**, which is obtained from analysis of high speed movies. The direction of oscillatory motion is adjusted to be transverse to the welding direction. The transverse displacement of the tip of wire could be approximated to a sinusoidal wave function.

The welding and oscillation conditions are listed in **Table 2**. The values of the welding current and voltage are settled in the region of "burried arc" near the transition condition between "open" and "burried" arc on operating characteristics, which is 27.5 volts and 300 amperes. The oscillation condition ranges from 0 to 30 Hz in frequency and from 0 to 8 mm in amplitude.

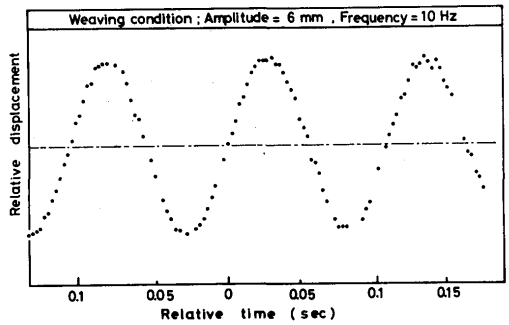


Fig. 2 Typical motion of wire electrode under weaving.

Table 2 Operating conditions.

Welding condition	
Polarity	D.C.R.P.
Current	295 ~ 300 A
Voltage	27.5 V
Travel speed	600 mm/min
Electrode extension	15 mm
Trailing angle	10°
Shield gas	CO_2
Gas flow rate	20 *l*/min
Welding condition	
Amplitude	0 ~ 8 mm
Frequency	0 ~ 30 Hz

In order to examine the effect of weaving on the spattering loss during welding, the following method is applied. The specimen and torch are covered by a large plate settled under the specimen and a hemi-spherical aluminum jar. After the welding of 160 mm in length, spattered materials are collected and the weights of them are measured. Since the spattering at the start stage of welding is extremely violent in any cases of weaving and undesirable to evaluate the effect of weaving on the spattering loss rate during welding, measured values of the total weight of spattered metal are corrected by reduction the averaged one at the starting stage from the total weight of spattered metal.

3. Experimental Results and Discussions

3-1. Effects of weaving on bead appearance and spateering loss

The change in the bead appearance corresponding to the change in weaving condition and the quality classification for the smoothness of the bead are shown in **Fig. 3**. The bead appearances are classified in four groups, from the first class, I, to the fourth one, IV, according to the sense of smoothness and regularity of the bead. It is apparent that there are optimum conditions in the frequency and amplitude of the oscillation, under which very smooth and regular bead is obtained. The optimum conditions range from 10 to 15 Hz in frequency and from 3 to 7 mm in amplitude. Some specimens are tested by the X-ray inspection after the welding under various weaving conditions. Any defects, blow hole and crack, could not be detected.

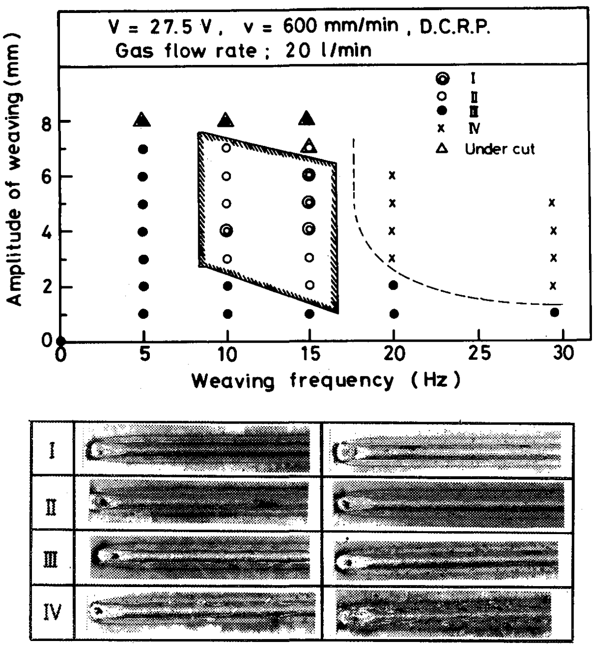


Fig. 3 The change in the bead appearances corresponding to the change in weaving condition and the classification for the smoothness and regularity of bead appearances the class I is of best appearance and the one in the IV class repesents irregular and unavailable bead.

In **Fig. 6 (a)** and **(b)**, current and voltage wave-forms of the welding arc are shown in cases of optimum and non weaving conditions. The application of weaving brings the increase of 10 ~ 20 amperes in averaged welding current without the change in feeding rate of the filler wire. Moreover, it is clearly shown that the reduction in the number of short-circuiting occurs by the application of the proper weaving. Generally the periodic short-circuitting associated with the dip transfer of the molten electrode whose duration is about 10^{-2} sec occurs under the non weaving usual CO_2 arc welding (the first type short-circuitting)[1]. But, under the proper weaving condition, the number of short-circutting decreases enormously and the other of short-circutting whose duration is below 10^{-3} sec remains. The welding arc does not disappear by this second type short-circutting. It is partially short-circuitted arc. The number of the second type one seemed to have no correlation with the bead appearance and spattering loss during welding.

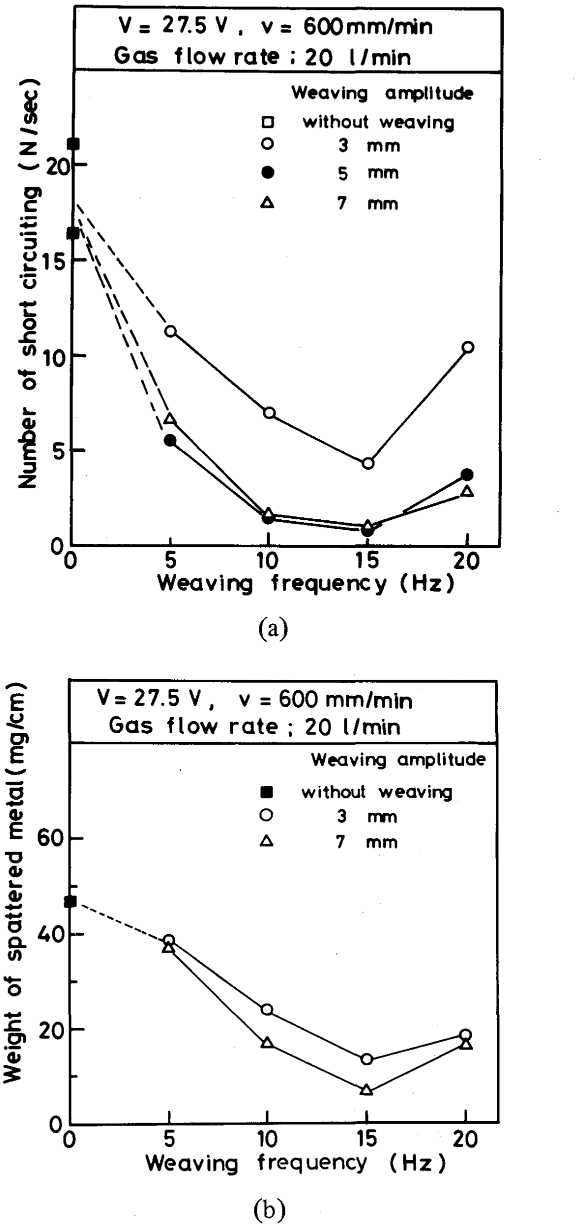


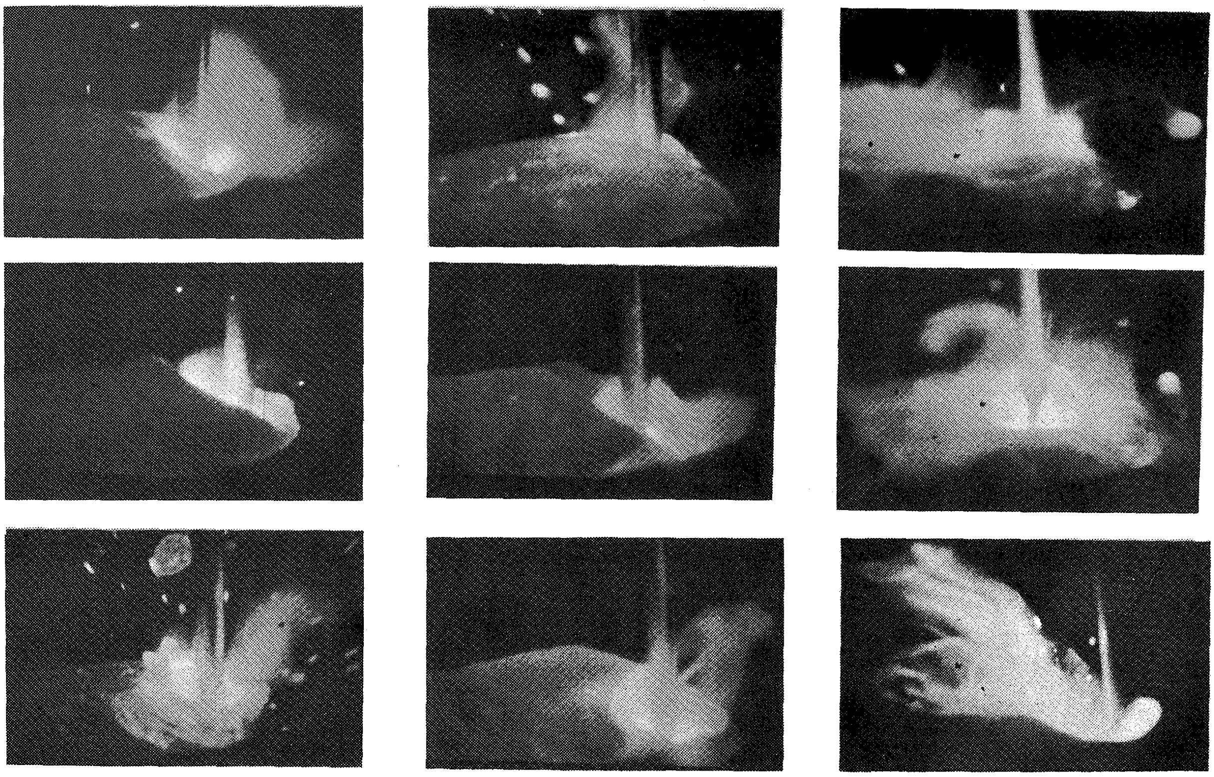
Fig. 4 (a) Averaged number of the first type short-circuiting of the arc.
(b) Weights of spattered metal per unit length of the weld in various cases of weaving.

Figure 4 (a) and (b) show the averaged number of the first type short-circutting of the arc and the weights of spattered metal per unit length of the weld, respectively, under the various conditions of weaving. It is evident that the spattering loss has a strong correlation with the number of the first type short-circutting. Besides, the oscillation condition of 15 Hz in frequency is most suitable to minimize the spattering loss and to improve the bead appearance. In this case the spattering loss is reduced to 1/3 ~ 1/4 as compared with that under the non weaving condition.

It is well known that there is a close relation between the number of short-circuitting and the spattering loss in the usual CO_2 arc welding under the middle current condition of welding. As for the relationship between the number of the first type short-circuitting and the spattering loss, the similar result was obtained in weaving CO_2 arc welding, too, in this study. It is proved that the optimum condition under which the occurrence of the first type short-circuitting is considerably few and spattering loss is much reduced, exists in the region of comparatively fast oscillation. This drastic change in the number of the first type short-circuitting and the spattering loss by the application of the proper weaving suggests the change in the arc phenomena and the transfer mode of molten electrode metal. It is discussed in the next section.

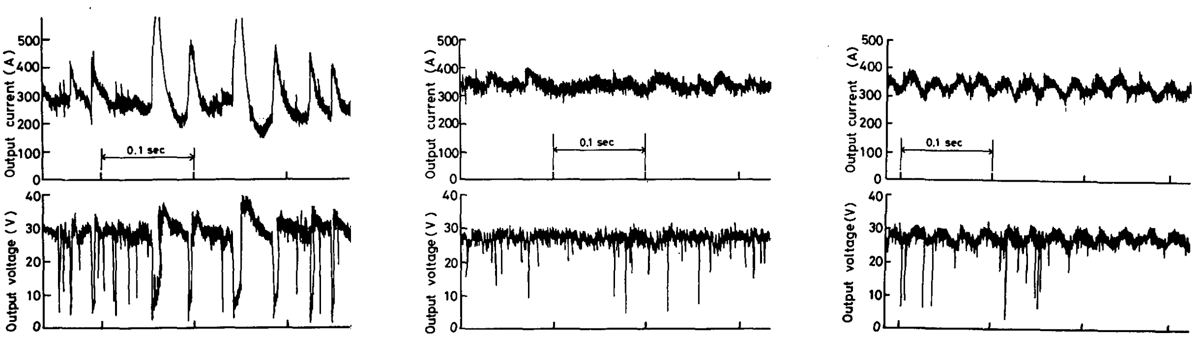
3-2. Observation of Welding Phenomena

The welding phenomena under the weaving and non weaving conditions are observed by the use of high speed motion picture photography. The two weaving conditions used are as follows, 5 mm in amplitude and 15 Hz in frequency and 7 mm and 20 Hz. **Figure 5** displays the sequential variation of the weld pool behavior in each weaving cases and Fig. 6 shows the time-variation of current and voltage of welding correspondingly.



(a) (b) (c)

Fig. 5 Typical photographs representing the weld pool behavior in cases of non weaving and two weaving conditions; (a) non weaving, (b) 5 mm, 15 Hz, (c) 7 mm, 20 Hz.



(a) non weaving (b) 5mm, 15Hz (c) 7mm, 20Hz

Fig. 6 Time-variation of current and voltage of the welding arc corresponding to the welding behaviors displayed in Fig. 5.

Non weaving welding produces a violent movement of the molten metal in the pool and an irregular fluttering of the pool surface. But this fluttering is not so effective to cause the first type short-circuitting irregularly. The arc behavior and transfer phenomena are considered as follows. The arc is constricted by the use of dissociable working gas and the arc roots on the wire electrode and pool surface are limited in the comparatively narrow region and therefore it prevents the arc from "climbing up" the electrode. The wire electrode which is fed continuously, is melted and becomes to shape a globule of the molten metal at the end of wire. Because of the formation of the arc roots in the limited region of the molten globule, the spray or streeming transfer which is associated with the formation of the tapered electrode tip caused by the dispersed heat input by the arc "climbed up" could not occur. So, the globule continues to grow until the molten electrode sticks into the pool accompanied with the disappearance of the welding arc. This is the first type short-circuitting. On the instant the globular metal is transfered into the weld pool. The short-circuitting causes the increase in current and it breaks the short-circuit by the explosion of the stuck wire electrode.

When using the weaving of 5 mm and 15 Hz, the flow of molten metal from the root area of the arc under the colum to the tail end of the pool appears to be more stable and gentle in comparison with the non weaving case. The arc is burning continuously and perfectly in the mode of "burried arc". The movement of the molten metal below the arc column is associated with the weaving movement of the wire electrode. The molten metal fills the gouged area near the front wall which was made by the arc when the arc is away from it and it is repeated by turns correspondingly to the pendulum-like movement of the arc as if seesaw motion.

In this situation, the arc is burning in the well in the pool. The arc roots on the wire electrode is considered to be dispersed in comparatively wide region, and the arc between the wire electrode and the side wall of the well too, could be burnt. It reduces the concentration of the heat input to the narrower region of the electrode tip effectively and promote the formation of the tapered electrode.

On the other hand, the first type short-circuitting doesn't occur in this case, which is shown in Fig. 6 (b). The transfer mode of the molten electrode metal is not the dip one. It is considered that the dispersion of the arc roots on the wire electrode changed the transfer mode.

In the case of weaving of 7 mm and 20 Hz, the number of short-circuitting increases. The travelling speed of weaving of the arc is too large to be accompanied with the swinging motion of the molten metal in the pool. The molten metal isn't able to fill sufficiently the area already gouged near the side edge of the front wall of the pool.

Therefore, the empty space around the wire electrode becomes larger and it changes the operating mode of the arc from "burried" to rather "open" arc. Fig. 6 (a), where the voltage waveform oscillates with the periodicity equal to twice as many as the weaving frequency, implys that only a slight change of arc length due to the movement of the molten metal in the pool exists. The metal transfer mode in this case is an intermediate one between those in "open" and "burried" arc. The increase in spattering loss seems to be attributable to the change in operating mode of the welding arc.

4. Weld Cross Sections

Macro appearances of weld cross-sections under several weaving conditions are shown in **Fig. 7**. Under the condition of weaving ranging between 5 to 30 Hz in frequency and 0 to 8 mm in amplitude, the shape of fused zone is strongly influenced by the amplitude of weaving rather than the frequency.

A brief calculation based on Rosenthal's heat conduction theory[8)] could well interpret these experimental shapes of penetrated region. Physical situation and coordinate system are illustrated in **Fig. 8**. The coordinate system (X, Y, Z) is a fixed rectangular coordinate system and the system (x, y, z) is the moving coordinate one with the same velocity as the welding speed.

Consider a point source which has a weaving movement on the plate. The time in which the heat source leaves from a position (X_1, Y_1) on the plate surface and returns to the same Y-position (X_2, Y_1) is short in comparison with the time for the heat diffusion from a point source to the range of extent of real arc heat source. Therefore, the heat input under the fast weaving condition which is above 5 Hz in frequency is roughly approximated to the dipersed point sources moving parallel to the X-axis with the same constant velocity.

Seven point sources are placed on the moving y-axis with the same separation. The segment on the y-axis, whose length is equal to the amplitude of the weaving, is divided to seven parts and each source are located on the center of those parts. The intensity of each source is distributed in proportion to the ratio of the time required to cross the each part during one period of weaving.

Using the quasi-stationary state heat conduction theory with moving coordinate system, the temperature distribution around heat source which is given in the following equation is calculated.

$$T(x,y,z) - T_0 = \sum_{i=1}^{7} \frac{Q_i}{2\pi\kappa\sqrt{x^2+(y-y_i)^2+z^2}}$$

$$\times \exp \frac{v}{2\alpha}\left(x - \sqrt{x^2+(y-y_i)^2+z^2}\right),$$

where, y_i : the position of i-th point heat source (cm),
Q_i : the intensity of i-th point heat source (cal/sec),
v : welding speed (cm/sec),
α : thermal diffusivity of the plate (cm^2/sec),
κ : thermal conductivity (cal/sec cm °C),

and the effective heat input is 0.65 of arc power.

The experimental results and the calculated ones are typically displayed in the bottom of Fig. 7. The qualitative agreement between these results suggests the validity in approximation introduced in the calculation on the shape of penetrated region of weld cross-section. The shape of fused zone is widely varied according to the weaving amplitude. These results suggest that the weaving is applicable to control the temperature field near the fusion boundary of the molten pool during welding.

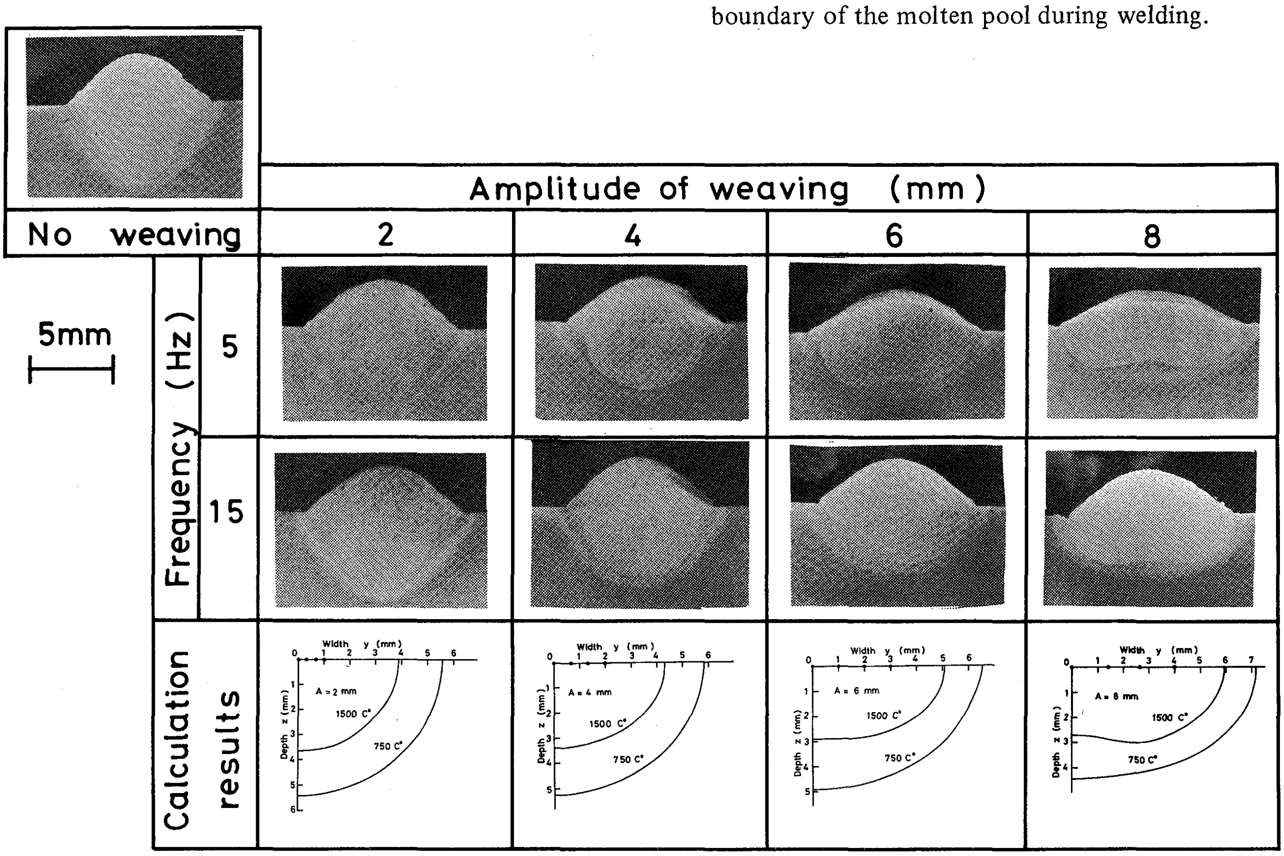


Fig. 7 Appearances of transverse cross-section of weld under several weaving conditions. Calculated isotherm line is based on the approximated one based on Rosenthal's heat conduction theory.

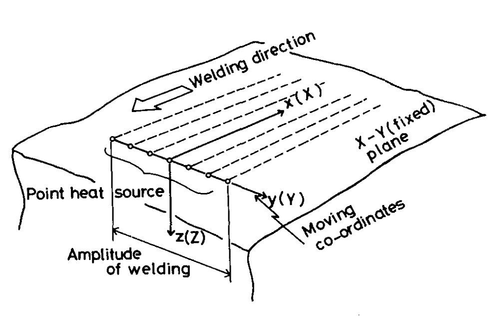


Fig. 8 Physical situation and coordinate system of calculation of temperature field for fast weaving.

5. Conclusions

The following conclusions were obtained as results of the investigation on the effects of weaving applied to CO_2 arc welding.

(1) By applying the weaving to CO_2 arc welding under proper conditions, the sound and smooth bead appearance is achieved.
The spattering loss could be reduced to about 1/3 ~ 1/4 in weight compared with usual non weaving CO_2 arc welding.

(2) Most suitable weaving conditions with respect to the bead appearance and spattering loss are in the region of oscillation of 5 to 15 Hz in frequency and 3 to 7 mm in amplitude in the case of middle current CO_2 arc welding.

(3) The burried arc and stable movement of the molten metal in the pool are realized under the proper weaving conditions. This is the reason why the bead appearance is improved and the spattering loss is reduced.

(4) An approximated calculation based on Rosenthal's heat conduction theory could interpret the change in the shape of penetrated region under various weaving conditions. This result suggests that this weaving is applicable to control the temperature field near the fusion boundary and in the pool during welding.

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