Investigation on Welding Arc Sound (Report I)†
– Effect of Welding Method and Welding Condition of Welding Arc Sound –

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Abstract

Investigation on the characteristics of welding arc sound has been made in oder to control the welding process. The sound wave, the sound pressure level and frequency spectrum etc. were measured, and the behavior of arc was observed by use of a high-speed motion camera.

Based on the examination, it was found that the welding arc sound has a good competence as the information signal to exhibit the welding process.

KEY WORDS: (Acoustics) (Arc Welding) (Process Parameters)

1. Introduction

In order to observe welding phenomena and control welding condition, it is necessary to select and detect an information signal which express exactly the welding process. Sometimes, it becomes very difficult to grasp the welding phenomena by means of usual methods, because a measurement of remarkable signal is interfered near the welding points by a high temperature, spattering, fuming, electromagnetic noise, etc. But, the sound signal of arc welding seems to provide an available information for the elucidation of welding arc phenomena.

Some of the welders have experientially remarked the welding arc sound as a criterion to exhibit the stability of arc welding[1]. While the advantages of use of the welding arc sound are expected, the details of the welding arc sound have not been published.

Therefore, we have, at first tried to make general characteristics of the welding arc sound clear. And then, the effect of welding methods and welding conditions on the welding arc sound were examined, and some interesting results were obtianed. Based on these results, an analysis of characteristics of the welding arc sound and mechanism of the occurrence of the welding arc sound that is correlated to the welding phenomena were proposed.

2. Experimental apparatus and method

2-1 Experimental apparatus

A schematic diagram of the apparatus and a system for measurements of an arc sound are depicted in **Fig. 1**. For

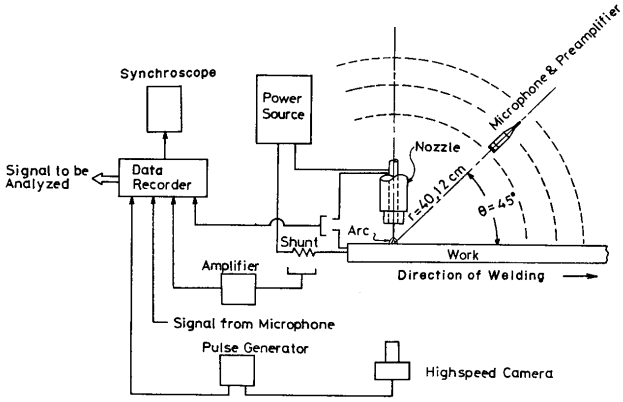

Fig. 1 Schematic diagram of experimental apparatus and measuring system.

these experiments, a power source of constant voltage characteristics is used in CO_2, MIG and CO_2 + Ar arc welding. On the other hand, a marketing power source of drooping characteristics and the transister controlled power source produced by authours are used in TIG arc

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welding. The welding arc sound is measured by means of a condenser microphon (RION, U-11 A) which is arranged as shown in Fig. 1. **Figure 2** shows a frequency response

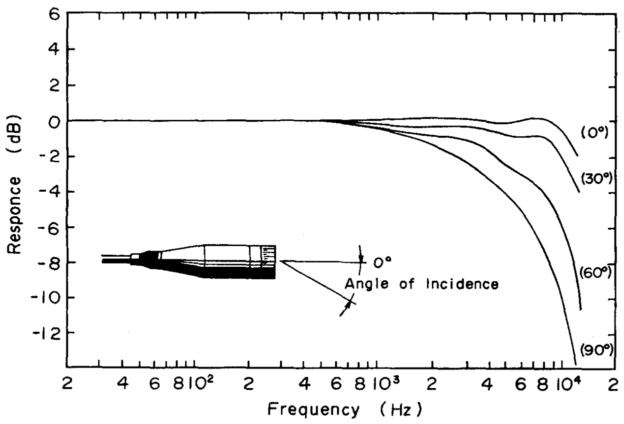


Fig. 2 Frequency response curve of condenser microphon.

curve of a condener microphon used in this examination. The welding arc sound is recorded on DR mode and an arc voltage and an arc current are also recorded on FM mode by use of a data recorder. In this case, a data recorder is synchronized with a high-speed motion camera.

2-2 Welding condition

Welding methods and conditions are described in **Table 1**. Through the experiments, the bead-on-plate

Table 1 Welding method and working condition.

Condition \ Method	CO_2 Arc Welding	MIG Arc Welding	TIG Arc Welding
Arc Current (A)	150 ~ 450	150 ~ 450	150 ~ 250
Arc Voltage (V)	Variable (1)	Variable	19
Welding Speed (cm/min)	20, 40, 60	20, 40, 60	0 (2), 20
Gas Flow Rate (l/min)	20, (0 ~ 25)	20, (0 ~ 25)	15
Extension (mm) / Arc Length (mm)	20, (15 ~ 40)	20	5
Torch Angle (°)	90	90	90
Polarity	R.P	R.P	R.P

(1) V = 0.032·I + 16 ± 1.5 (I < 300)
V = 0.060·I + 9 ± 2 (300 ≤ I ≤ 450)
(I ; Arc Current, V ; Arc Voltage)
(2) Water cooled copper plate

welding are carried out with a plate of mild steel (SM-41) and a water cooled copper. **Figure 3** shows the relation between the arc current and the wire feed speed in CO_2, MIG and CO_2 + Ar arc welding. In CO_2 arc welding, the range of suitable arc voltage is taken from the following equation as a temporary standard.

$$V = 0.032\,I + 16 \pm 1.5 \quad (I < 300)$$
$$V = 0.060\,I + 9 \pm 2.0 \quad (300 \leqslant I < 450)$$

where V is an arc voltage (V) and I is an arc current (A).

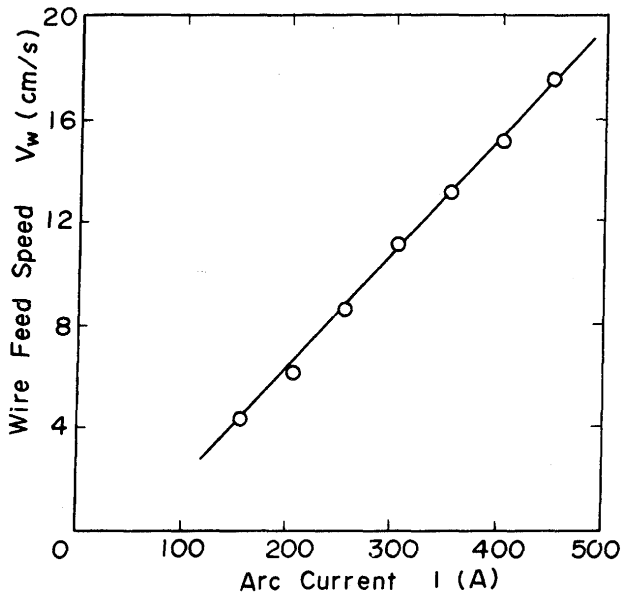


Fig. 3 Relation between arc current and wire feed speed.

2-3 Field of welding arc sound

It may be regarded that the source of welding arc sound is a point, because the distance (r) between the measurement point and the sound source is very great compared with the size of sound source. If the simple source of sound exists on the rigid wall of infinite size, the sound wave is emitted to the surrounding space as 1/2 spherical wave. In this case, it is well known that the sound pressure level (SPL) is expressed by the following equation (1).

$$SPL = PWL + 10\,log_{10}\,(\frac{Q}{4\pi r^2} + \frac{4}{R}) \text{ (dB)} \qquad (1)$$

Where PWL is power level (= 10 $\log_{10}$ W 10^{12} , W is acoustic power), Q is directivity factor (Q = 2, at 1/2 spherical wave), R is room constant (= S/(1 − $\bar{a}$), where $\bar{a}$ is mean sound absorption coefficient S is total surface area of room wall)

The relation between the distance from sound source (r) and SPL at PWL = 0 and R→∞ is shown in **Fig. 4**. The

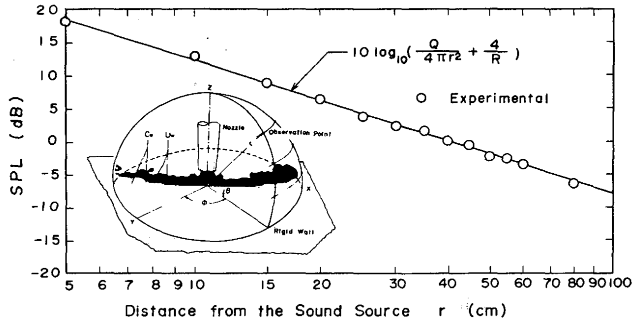


Fig. 4 Relation between distance from sound source (r) and SPL.

experimental results well agree with the values calculated from the equation (1) in the range of 5 ~ 100 (cm) of the distance between the measurement point and the sound source. However, this relation-ship changes slightly when the size of rigid wall, namely, the size of work piece, becomes small. We regard these results as reasonable, because the directivity factor (Q) decreases as the size of work piece becomes small. The room constant (R) by W.C. Sabine's formula is 188. C_w– and U_w– profiles shown in Fig. 4 mean the qualitative distribution about the concentration and the velocity of shielding gas respectively. It is considered that the propagation of sound may be affected by a kind of medium, a shape of a welding torch-nozzle and the likes However, it is possible to measure the welding arc sound with a good accuracy, except a special welding condition that reflects the sound intensively.

2.4 Analysis of welding arc sound

As the welding arc sound has many characteristics detailed examinations have been made of the sound wave, SPL on overall (O . A) and arbitrary band width, autocorrelation function of sound, the profile of frequency spectrum, etc.

When the simple source of sound exists on a rigid wall, the sound wave is emitted as 1/2 spherical wave which is described in the section 2.3. In this case, the relation between the distance and an arbitrary measurement point (x, y, z) is given by

$$r^2 = x^2 + y^2 + z^2 \qquad (2)$$

All the variations of spherical wave are determined by two elements, the time (t) and the distance (r). The sound pressure is shown as the function of time (t). An effective sound pressure is defined as

$$P_e = \sqrt{\frac{1}{T}\int_0^T p^2\,(t)\,dt} \qquad (3)$$

SPL is given by

$$SPL = 20\,\log_{10}\,P_e/P_{eo} \qquad \text{(dB)} \qquad (4)$$

Where P_{eo} is the standard value of effective sound pressure (= 2×10^{-5} N/m^2 = 2 x 10 μbar in atmosphere)

When the sound signal of welding arc follows a random process, autocorrelation function ϕ_{pp} (τ) is calculated from the following equation (5).

$$\phi_{pp}\,(\tau) = \frac{1}{T}\int_0^T p\,(t)\,p\,(t+\tau)\,dt \qquad (5)$$

Then, ϕ_{pp} (τ) is given by

$$\phi_{pp}\,(\tau) = \int_0^T \phi_{pp}\,(f)\,\exp\,(j2\pi f\tau)\,df \qquad (6)$$

The equation (7) is introduced from the Fourier transform of the equation (6)

$$\phi_{pp}\,(f) = \int_{-\infty}^{\infty} \phi_{pp}\,(\tau)\,\exp\,(-j2\pi f\tau)\,d\tau \qquad (7)$$

In order to analyse the sound signal of arc welding, the calculations are carried out by use of a digital Fourier transformer based on the equation (5) ~ (7). In this case, the higher harmonic which agrees with Nyquist frequency (f_N = 1/2$\Delta\tau$) is cut on account of the prevention of a error with an aliasing. In addition to that, the value of $\phi_{pp}(\tau)$ takes the average of $2^{13} \sim 2^{16}$ times of calculations. The results of frequency analysis based on this procedure have shown a good reproducibility, and the results are also confirmed by another type analyzer, such as the octave band, the 1/3 octave band and the geometrical band filter.

3. Experimental result and discussion

3-1 Welding arc sound

The typical patterns of output signals of an arc current, an arc voltage and a welding arc sound in three types of welding procedure are shown in **Fig. 5 -(1), (2), (3).** In

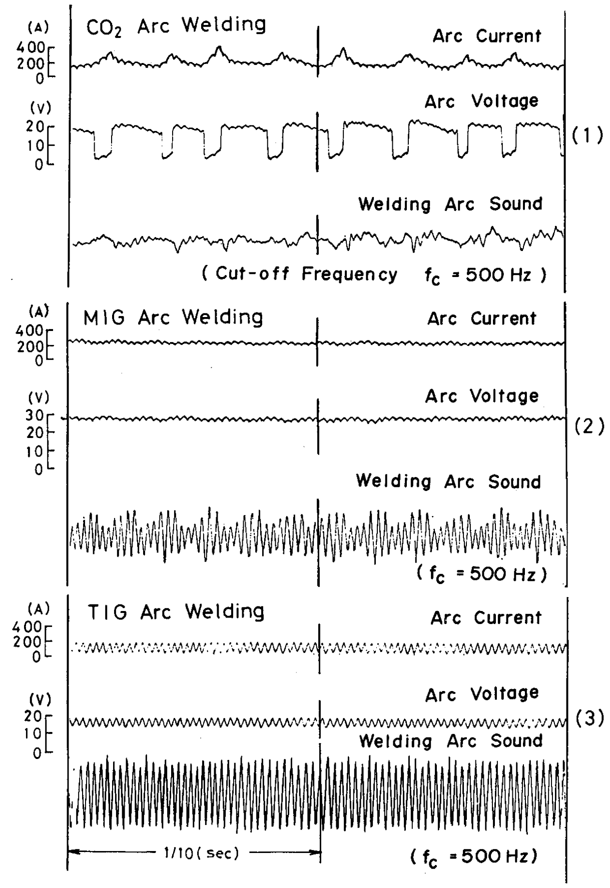


Fig. 5 Typical pattern of output signal of arc current, arc voltage and welding arc sound.

this case we have used a low-pass filter (cut off frequency: f_c = 500 Hz) in order to record the welding arc sound. The oscillogram shown in Fig. 5-(1) has been obtained under the condition of the stable and periodical short circuiting transfer in CO_2 arc welding. The sound waves are synchronized with the short eircuiting. Figure 5-(2) has been obtained under the condition of the spray transfer in MIG arc welding. Figure 5-(3) has shown the oscillogram by use of TIG arc welding of a marketing power source. The pattern of these oscillograms shown in Fig. 5 (2) and -(3) points out that the sound wave is depended on the ripple discharged from the welding power source.

Figure 6 shows the oscillogram which expaneded a time axis in Fig. 5-(1). Some parts of photographs of welding arc obtained by a high-speed motion camera (1000 frames/sec) are shown in **Photo. 1**. Instantaneous sound wave, lettering (A) and (B) in Fig. 6 is synchronized with an extinction (the lettering (a)) and a reignition (the lettering (b)) respectively. The photograph (4) and (11) in Photo. 1 correspond to the extinction and the reignition. The photograph (11) shows an explosive fusion of wire at the time of the reignition clearly. Though it has been considered from the point of (A) in the oscillogram that some explosion may be happened at the time of the extinction, and the explosive fusion could not be caught by the high-speed motion camera The relation between the distance (r) and the propagation time (T_i: time from (b) to (B) is shown in **Fig. 7**. The velocity of sound (r/T_i) obtained from Fig. 7 is about 1.2 Mach, and this value of 1.2 Mach means a shock wave. A reason for the emission of shock wave may be depended on the explosion on account of the rapid increase of current density of the wire. Characteristics of frequency range of the welding arc sound may be affected by the emission of shock wave as mentioned above.

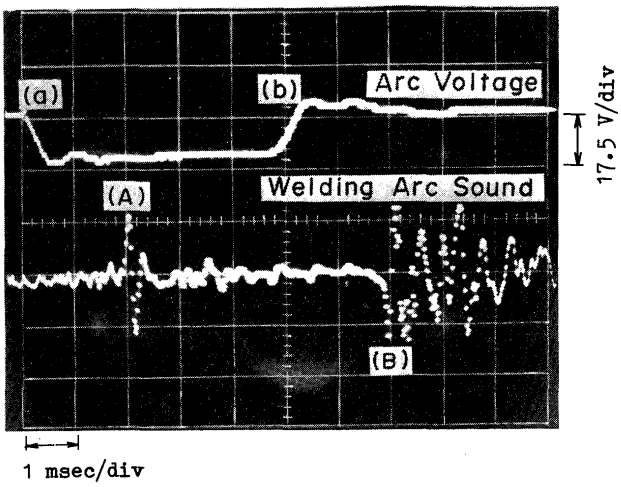


Fig. 6 Typical oscillogram of arc voltage and welding arc sound under short circuiting transfer in CO_2 arc welding.
(a) – (A): extinction, (b) -- (B): reignition

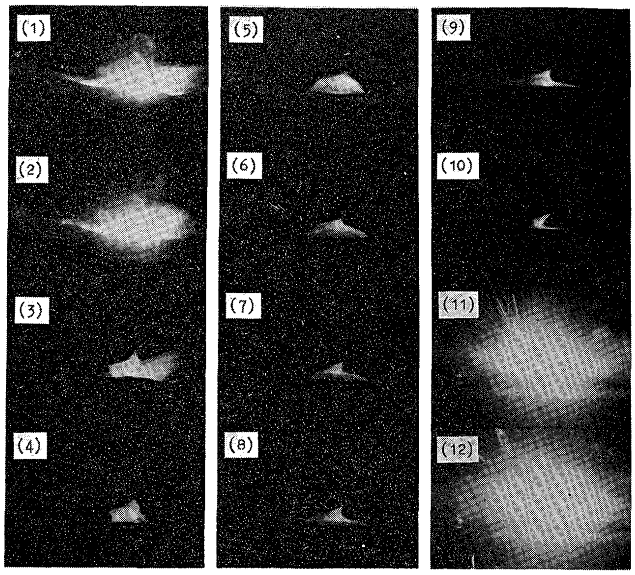


Photo. 1 High-speed motion photograph (1000 frames/sec) under short circuiting transfer in CO_2 arc welding. arc current 200 A, arc voltage 20 V, welding speed 20 cm/min (No. 4: extinction, No. 11: reignition)

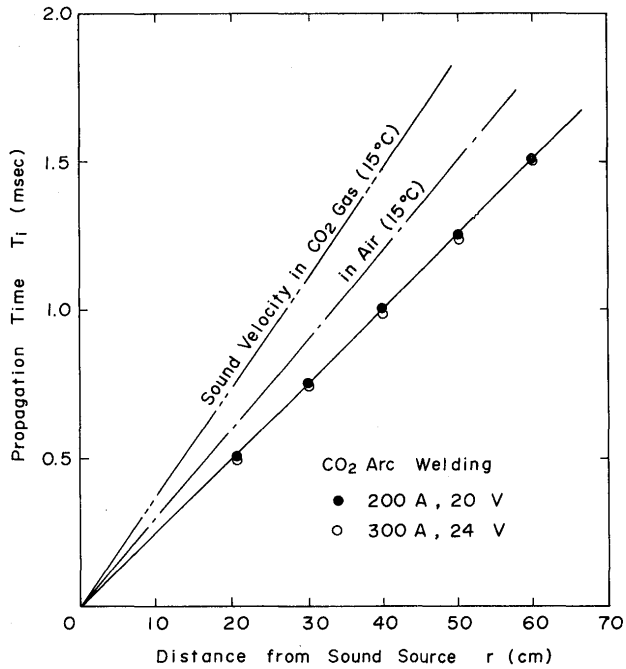


Fig. 7 Relation between distance from sound source (r) and propagation time (T_i).

3.2 Welding arc sound pressure

3.2.1 Effect of input power

An effect of input power (I · V) on SPL (O . A) in CO_2 and MIG arc welding is shown in **Fig. 8.** In this figure, the

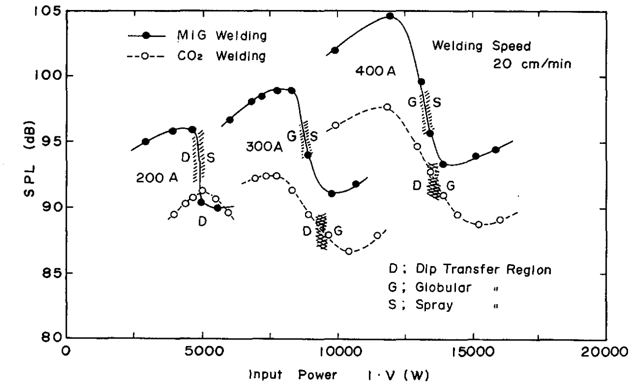


Fig. 8 Effect of input power (I·V) on SPL in CO_2 and MIG arc welding.

hatching zone exhibits the boundary for a particle transfer and D, G and S show a short circuiting transfer, globular transfer and spray transfer respectively. The relation between the input power and SPL is an "inverted S" type on CO_2 and MIG arc welding. When the arc voltage becomes appropriate to the welding arc current, SPL is stabilized and decreases The effect of arc voltage on SPL is remarkable in MIG arc welding compared with in CO_2 arc welding.

In TIG arc welding by use of a marketing power source SPL does not change in the range of 150 ~ 250 (A) of arc current at the constant voltage of 19 (V). When the perfect D.C power source, namely, a transister control type, is adopted, the welding arc sound is not almost emitted.

3.2.2 Effect of welding speed

An effect of the welding speed on SPL with various speed in CO_2 arc welding is shown in **Fig. 9.** As shown in

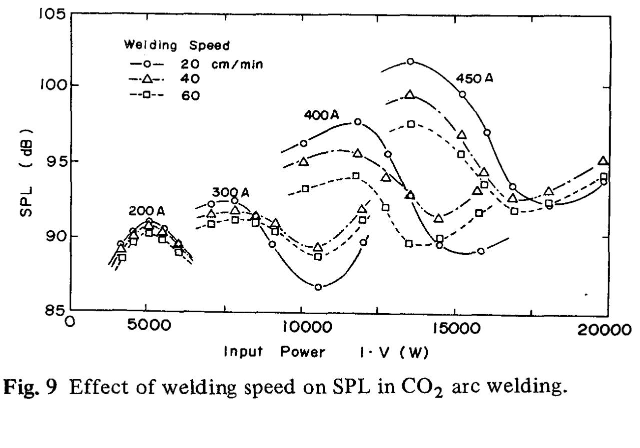
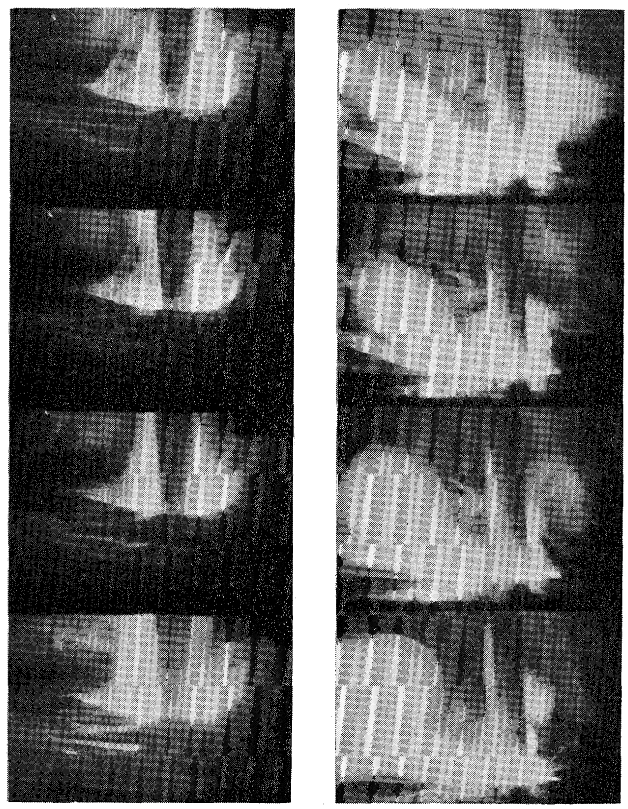


Fig. 9 Effect of welding speed on SPL in CO_2 arc welding.

this figure, the effect of the welding speed on SPL is very small under 200 (A) of arc current, but becomes considerably large above 300 (A). SPL at the welding speed of 20 (cm/min) decreased very quickly and crossed with SPL curve at the welding speed of 40 (cm/min) and 60 (cm/min). The reasons why SPL curves crossing are as follows: One is that the appropriate range of arc voltage becomes narrow, and the other is that the condition of droplets transfer becomes more stable, because the molten pool is digged deeply at the welding speed of 20 (cm/min) as shown in **Photo. 2-(A).**



(A) (B)

Photo. 2 High-speed motion photograph of molten pool (3000 frames/sec). welding speed (A): 20 cm/min, (B): 60 cm/min

3-2-2 Effect of shielding condition

It was already pointed out that the change of welding arc sound appears when the shielding gas is not enough[2). **Figure 10** shows an effect of gas flow rate (Q = 0 ~ 25 l/min) on SPL. SPL becomes constant when the shielding gas is not supplied even if an arc current increases. SPL increases with the increase of gas flow rate up to 15 (l/min), and then it becomes constant.

However, SPL slightly decreases under the condition of 200 (A) – 20 (V) in CO_2 arc welding.

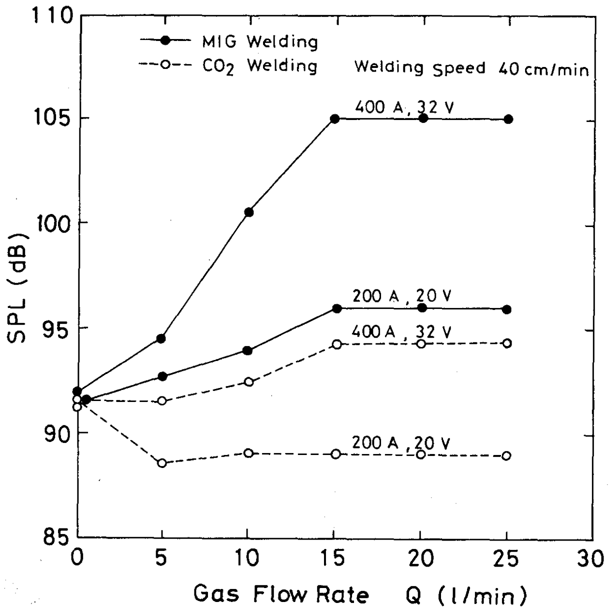


Fig. 10 Effect of gas flow rate on SPL in CO_2 and MIG arc welding.

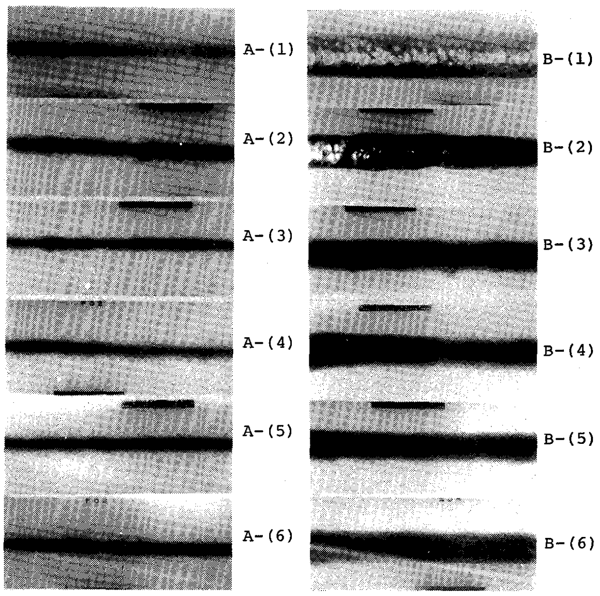


Photo. 3 X-ray photograph of weld bead in CO_2 arc welding.
A: 200 A, 200 V, B: 400 A, 32 V
(1) Q = 0 l/min.
(2) Q = 5 l/min.
(3) Q = 10 l/min.
(4) Q = 15 l/min.
(5) Q = 20 l/min.
(6) Q = 25 l/min.

Photograph 3 shows the X-ray photographs of the weld bead in CO_2 arc welding when the shielding gas flow rate changes between 0 (*l*/min) and 25 (*l*/min) under the conditions of 200 (A) – 20 (V) and 400 (A) – 32 (V). It has been found from these photographs that a good condition of gas shielding is obtained above 10 ~ 15 (*l*/min). The plateau range of shielding gas flow rate in SPL agrees with the range of the good conditions based on the X-ray photographs. These agreements mean that the welding arc sound may become a good information signal in order to know a welding process.

3.2.4 Effect of wire extension

An effect of the wire extension (H) on SPL in CO_2 arc welding is shown in **Fig 11**. When the wire extension is

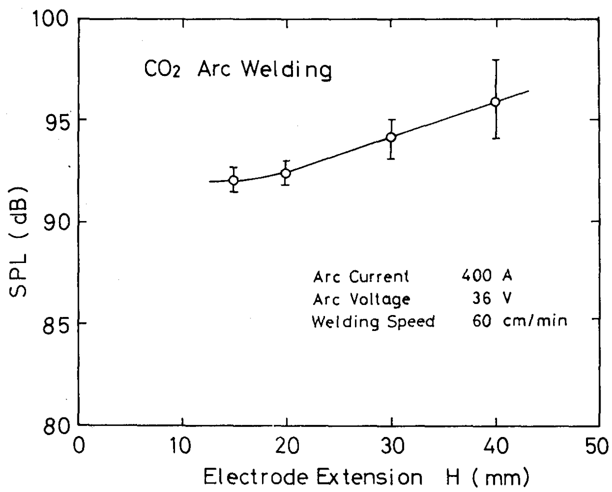


Fig. 11 Effect of wire extension on SPL in CO_2 arc welding.

large, the droplets easily secede from the wire for the preheating effect. However, when the wire extension becomes too large, the welding arc sound becomes unstable and large and a shape of weld bead meanders. If the wire extension is kept in a suitable length, generally in the range of 10 ~ 20 (mm), the welding arc sound becomes stable and small.

3.3 Frequency characteristic of welding arc sound

Figure 12 shows an effect of frequency spectrum of welding arc sound ($f_p - f_c$ = 100 ~ 8980 Hz). A unique frequency spectrum of welding arc sound is emitted according to the welding method. As shown in Fig. 12 (1), (2), a very wide band frequency spectrum has been obtained in CO_2 and MIG arc welding. The simple frequency spectrum shown in Fig. 12-(3) expresses that the sound in TIG arc welding is nearly pure sound.

A unique frequency (f_R) which agrees with the ripple frequency of power source is found in the each spectrum. An intensity of f_R increases with the increase of arc current and voltage. The periodic time for the contraction and the expansion of arc column, which is observed by a high-speed motion camera, agrees with the ripple

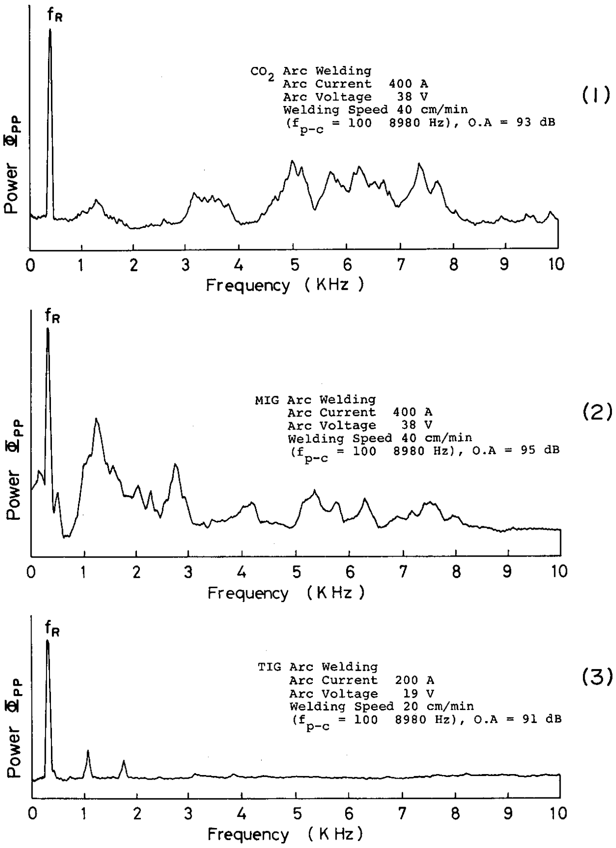


Fig. 12 Frequency spectrum of welding arc sound.

frequency (f_R).

Figure 13 shows the spectrum at the range of low frequency in CO_2 arc welding (f_c = 250 Hz) Peaks of lettering f_D and f_G are identified with the short circuit frequency and the secession frequency of droplets observed by an oscillograph and high-speed motion camera

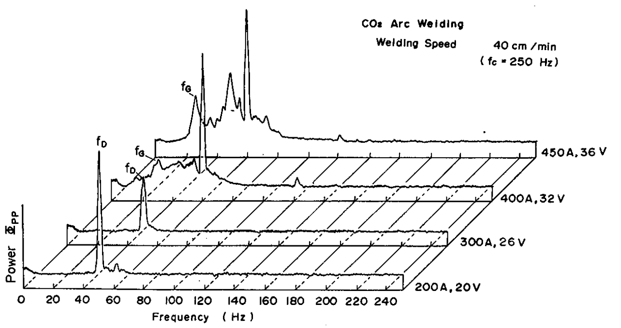


Fig. 13 Frequency spectrum of welding arc sound at low range.

4. Conclusion

In this paper, we have made the characteristics of welding arc sound clear in the various welding methods

The results obtained are summerized as follows:

(1) Welding arc sound has a good competence as the information signal to express the welding process.

(2) Welding arc sound emits a unique frequency spectrum according to the welding methods, and the spectrum has a very wide band frequency in CO_2, MIG and CO_2 + Ar arc welding. Otherwise, the spectrum of TIG arc welding has a simple frequency state that means nearly pure sound.

(3) The instantaneous sound pressure synchronized with the extinction and the reignition of arc is very strong, and it has a characteristic of the shock wave's propagation.

(4) Welding arc sound is effected by an input power welding speed, gas flow rate, kind of the gas, wire extension and others.

(5) Welding arc sound provides the informations about the contraction and the expansion of arc column, the behavior of the molten pool, and the droplets transfer.

Acknowledgement

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