Image Processing for On-Line Detection of Welding Process (Report III)†
–Improvement of Image Quality by Incorporation of Spectrum of Arc–

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Abstract

It is possible to improve the visual information, which is obtained from the arc welding process, by incorporation of wave-length spectrum.

In this paper, the spectrum of welding arc and molten pool is measured with a grating monochrometer. This measurement indicates that CO_2 arc, Ar arc and molten pool have their peculiar spectrum respectively.

The images of the arc welding process are improved and the configuration of the molten pool is relatively emphasized by selecting the image pickup device and the optical filter on the basis of the characteristics of the spectrum.

KEY WORDS: (Measurement) (Radiation) (Television) (CO_2 Welding) (MIG Welding) (GTA Welding) (Molten Pool) (Automatic Control)

1. Introduction

It had been previously reported that the visual information obtained from the part where the arc welding process is in progress, provides a great deal of significant information for the automation of welding process.[1, 2] The system in which information is picked up by an image pickup device and processed with an auxiliary processing unit or a digital processor to extract useful information had also been already reported.[3, 4]

A method of elevating the value of the obtained visual information by incorporating the characteristics of arc wavelength spectrum, is reported in this paper. Monitoring the molten pool with an image pickup device while the arc welding process is in progress would obviously produce the information effective for evaluating the welding process. Although the molten pool itself is luminous, the radiation intensity is considerably lower within the region of visible light, as compared with luminance emitted by arc, causing difficulties in monitoring with an image pickup tube in many cases.

In view of the above, a method was experimented in which the monitoring of molten pool was attempted through utilization of the difference in the wavelength spectra between the arc and molten pool by means of an S_i vidicon image pickup tube, which senses the near infrared ray, and various optical filters.[5] This report, however, failed to specify the actual values of measurement of wavelength spectrum of the arc light, simply referring to the data of manual arc welding measured in the past.

This study proposes to demonstrate the improvement of image quality for facilitating the detection procedure with the relatively emphasized image of molten pool achieved by carrying out grating-monochrometric measurement of spectrum of four kinds of gas shield arc and by selective application of image pickup tube and optical filter, based on the results of above mentioned measurement of spectra of gas shield arc combined with the results obtained by the measurement of spectra of molten pool simultaneously made.

2. Characteristics of Spectra of Arc Light and Molten Pool

2.1 Images of arc and molten pool in various wavelength

Prior to make the measurement of spectra, the arc and molten pool were photographed, using various interference filters. Examples of images obtained are shown in **Fig. 1**. They were laterally photographed. The film used and the value of transmitted wavelength of light through the filter are noted on respective photographs. The molten pool becomes more discernible as the value of wavelength becomes longer, as demonstrated especially in the photograph (a) taken with an infrared film of sensitivity upto 900 nm using SC74 filter that transmits only the light having the wavelength above 740 nm; in which the molten pool is distinctly visualized. In order to quantitatively evaluate the above, the arc light was then measured by spectrometry.

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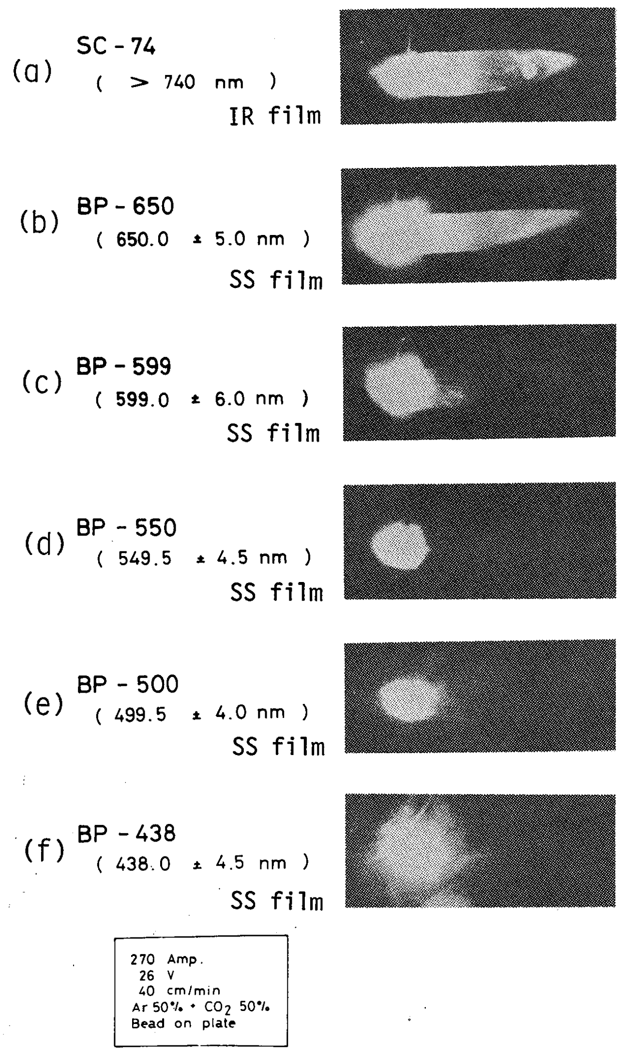


Fig. 1 Images of arc and molten pool in various wavelength.

2.2 Measurement of spectra of arc light and molten pool

The measurement of spectra of arc light was made with the arrangement as shown in **Fig. 2**. The spectrometer used was the 0.25 MI Ebert type grating monochrometer, model JE-25E (Nippon Jarrel Ash Co., Ltd., Japan) which is known to have the measuring range of 0 - 940nm with a resolving power of 0.5 nm through a slit of 100 μm width. The photomultiplier tube used was R406 side-on type (Hamamatsu Television Co., Ltd., Japan) having a sensitivity peak at approximately 750 nm, capable of sensing the light in the wavelength region between 400 and 1,100 nm.

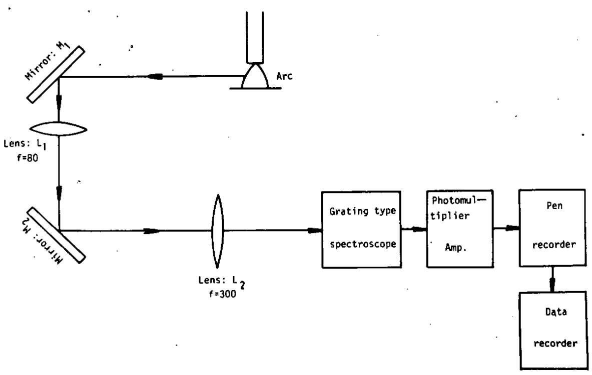


Fig. 2 Schematic arrangement for measurement of spectra.

The arc under investigation comprised CO_2 arc, Ar (MIG and TIG) arc and Ar + CO_2 (50%) arc. The electrode wire used for MIG arc, CO_2 arc and Ar + CO_2 arc was MG-50, ϕ = 1.6 mm (Kobe Steel Co., Ltd., Japan) and a rod of W + ThO_2 (1%) was used as the electrode for TIG arc. Two kinds of nozzles of copper and ceramic, were used for TIG arc. The plates of SS-41 were used for all kinds of arcs as the test piece. The chemical compositions of the test piece and the electrode wire are shown in **Table 1**. For experimenting all the arcs, the measurement was made with positioning just under the electrode where the maximum brightness was obtained. The measurement of the radiation from the molten pool was made in two method, i.e., the one in which the arc light was intercepted by a slit (100 μm wide) and the other in which the radiation from the molten pool was measured within a short time immediately after extinction of arc, were compared. The corrections were made for the influence of leakage arc light in the former case and the error caused by lowering of temperature due to cooling in the latter. The amplified output of photomultiplier tube was recorded with a data recorder. Reproducing the spectrometric data of wavelength that was converted in a time-serial signal on the magnetic tape, the measured range of 450-940 nm was divided into 490 equal sections of 1 nm each, and 256 samples from each section were digitlized with A-D converter and averaged to determine the mean value as the representative value of each section. Each representative value was corrected following the characteristics of spectral sensitivity of photomultiplier tube R406. In view of the changing in arc generation point of CO_2 arc and Ar + CO_2 arc and also of the time fluctuation in the quantity of light passing through the slit of a spectrometer, the mean value, $S_n(\lambda)$, of n sets of experimental spectrometric data which satisfies the under-mentioned equation for the arbitrary wavelength λ within the measured range,

Table 1 Chemical compositions of wire and workpiece.

Materials	Elements (%)				
	C	Mn	Si	P	S
S M-4 1	0.15	0.44	0.31	0.013	0.041
M G-5 0	0.08	1.10	0.42	0.013	0.014

was calculated. The above value was determined to represent the time average of the spectra.

$$|S_n(\lambda) - S_{n-1}(\lambda)| < \epsilon \quad \ldots\ldots\ldots\ldots (1)$$

Wherein ϵ is the limit of allowable error. The sufficient result was obtained for $n = 5$. Stillness in MIG and TIG arc generation produced satisfactorily reproducible data, not requiring the averaging procedures.

2.3 Results of measurement of spectra

Figures 3, 4, 5 and **6** show the results of measurement of spectra of arc light; Fig. 3 for CO_2 arc, Fig. 4 for Ar + CO_2 arc, Fig. 5 for MIG arc and Fig. 6 for TIG arc. While the component at the short wavelength side of the visual region has greater relative intensity than that at the long wavelength side and the near infrared region in Figs. 3 and 4, several peaks of line spectrum arc observed in the region of 700-900 nm wavelength in Figs. 5 and 6. The profiles of the peaks within the region of 700-900 nm in Figs. 5 and 6, which show the spectral pattern of Ar arc, are seen well correspond with the same region of characteristic spectrum of Ar[6] arc shown in **Fig. 7. Figures 8 (a), (b)** and **(c)** show the characteristic spectra of Fe, Mn, C[6] which are main compositions of the wire and the test piece, used in the measurement, as are shown in Table 1. The element Si, which is another main composition, has no remarkable characteristic spectrum in the region of 450-600 nm. The results of the spectrum analyses shown in Figs. 3, 4 and 5 correspond partially with the characteristic spectrum of Fe (line a – 1 in Fig. 8 (a)) in the neighbouring region of 500 nm, but have no remarkable correlation to that of Mn and C. The peak which appears near by 600 nm in Figs. 3, 4, 5 and 6 corresponds to the line

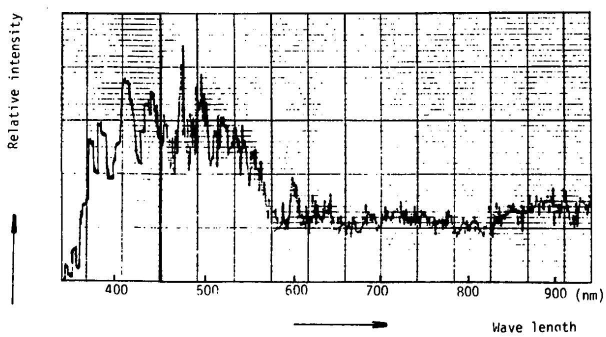


Fig. 3 Spectrum of CO_2 arc.

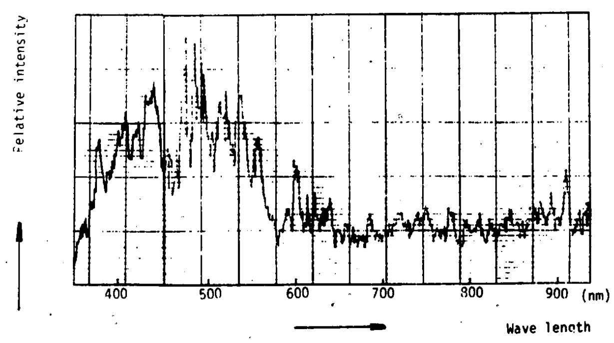


Fig. 4 Spectrum of Ar + CO_2 arc.

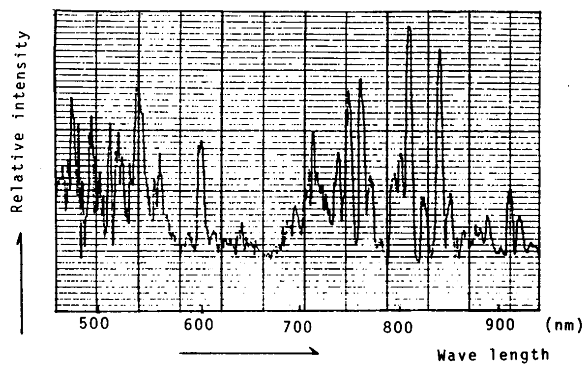


Fig. 5 Spectrum of MIG arc.

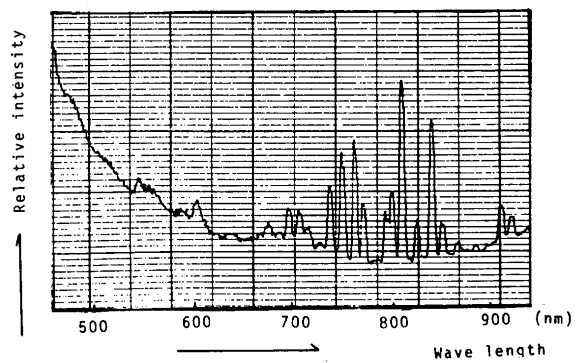


Fig. 6 Spectrum of TIG arc.

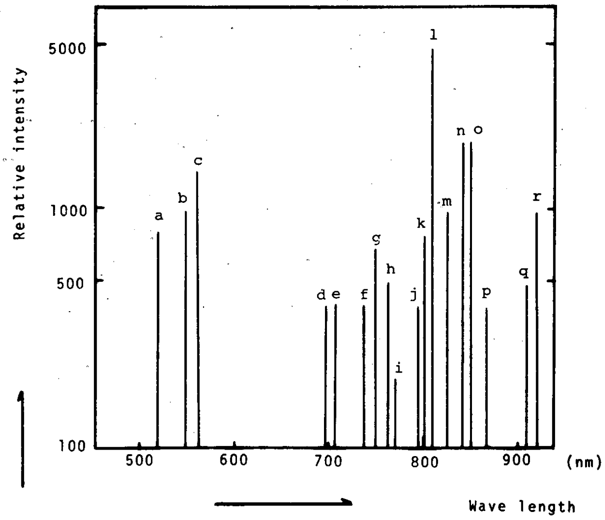
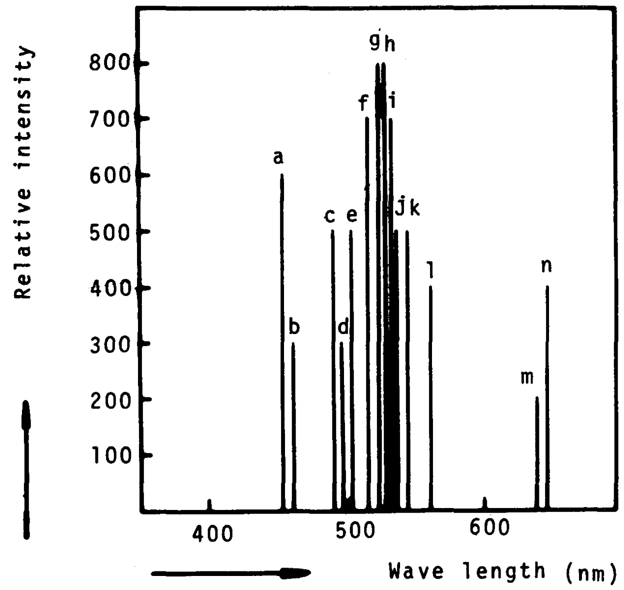
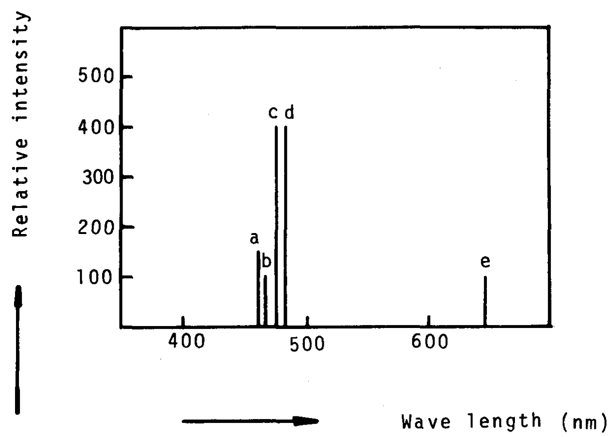


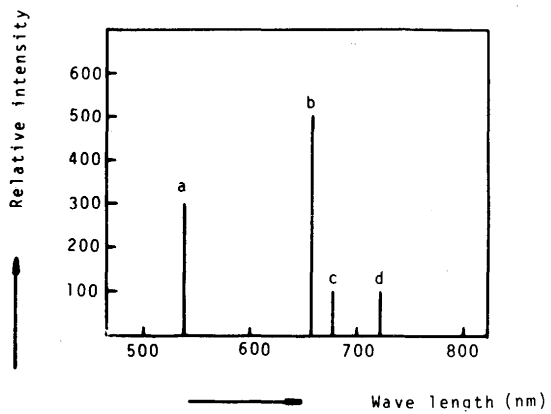
Fig. 7 Characteristic spectrum of Ar.



(a) Characteristic spectrum of Fe.



(b) Characteristic spectrum of Mn.

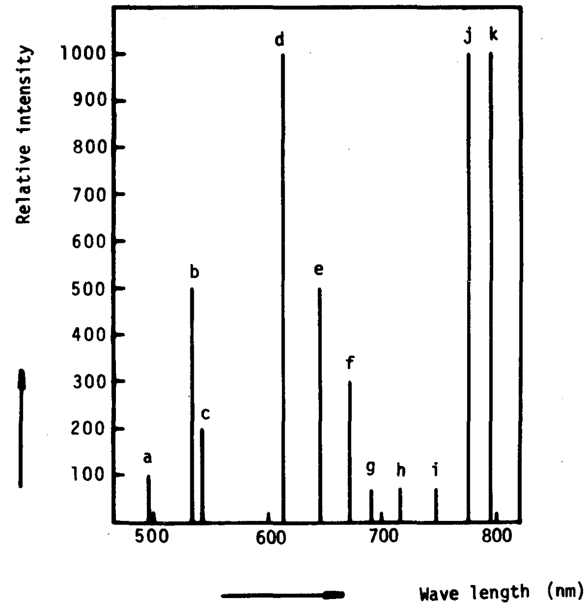


(c) Characteristic spectrum of C.

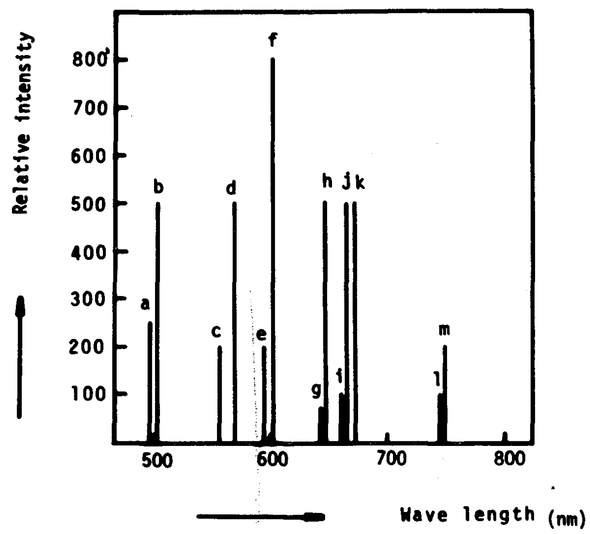
Fig. 8 Characteristic spectra.

spectrum of d in **Fig. 9 (a)** or f in **Fig. 9 (b)**, which are the characteristic spectrum of O and N respectively. The influence of these two elements on the spectral profile is due to mixing of air in the shield gas for welding arc. **Figure 10 (a)** is the continuous spectrum of radiation from the molten pool, showing the increase of intensity over the infrared region. When it is compared with the curves shown in **Fig. 10 (b)** calculated from the Wien's radiation law for black body expressed by **Eq. 2**,

$$I(\lambda) = \frac{C_1}{\lambda^5} e^{-C_2/\lambda T} \qquad \cdots\cdots (2)$$

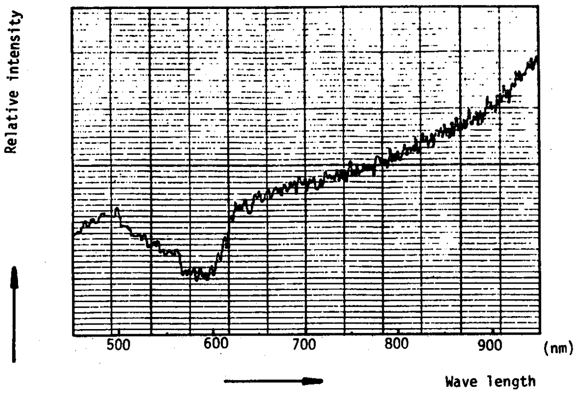


(a) Characteristic spectrum of O.

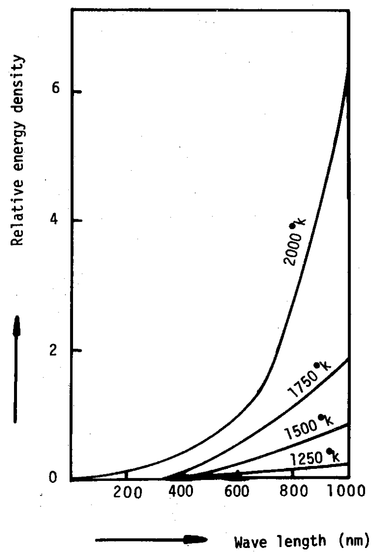


(b) Characteristic spectrum of N.

Fig. 9 Characteristic spectra.



(a) Spectrum of radiation from molten pool.



(b) Spectrum of blackbody radiation.

Fig. 10 Comparison of radiation spectrum.

(wherein C_1 and C_2 represent the constants and T, the absolute temperature.)

it is seen to tend to well correspond with each other. We can easily understand from Figs. 3, 4 and 10 (a) about the dimmed effect of arc light and the emphasized effect of molten pool as seen, for instance, in the image of infrared region in Fig. 1 (a) as compared with Figs. 1 (b) - (f).

3. Improvement of Image Quality with Optical Filter

The abovementioned results suggest the possibility of obtaining the relatively emphasized image of the molten pool for CO_2 and Ar + CO_2 arcs if an optical filter that transmits only the wavelength over 600-700 nm is attached to an image pickup tube that has sensitivity to this wavelength region. **Figure 11** shows the relative values of spectral sensitivity of Sb_2S_3 vidicon which is most com-

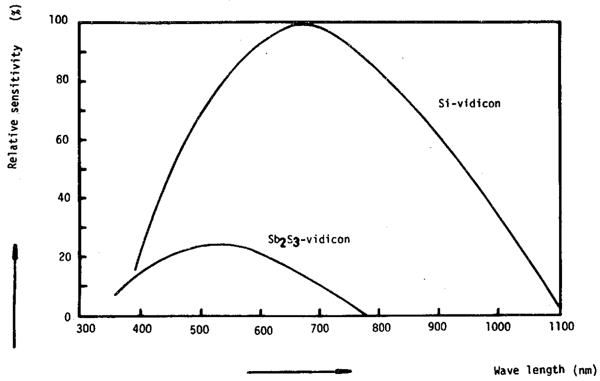
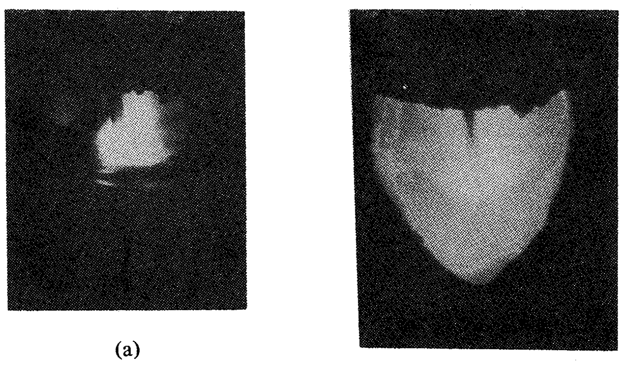


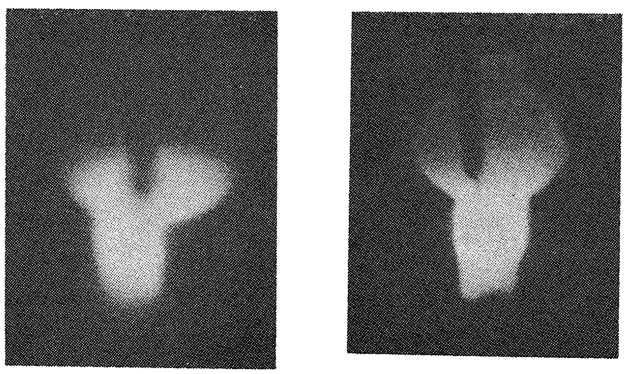
Fig. 11 Spectral sensitivity of pickup tubes.

monly used and Si vidicon which has sensitivity of near infrared region. The use of a suitable filter even for Sb_2S_3 vidicon that has sensitivity upto approximately 800 nm can emphasize the image of molten pool for CO_2 arc. This was achieved as shown in **Fig. 12** in the fillet welding of CO_2 arc using Sb_2S_3 vidicon: **(a)** the image filtered through ND filter that has a property of flat dim-



(a) (b)

Fig. 12 Images obtained during fillet welding of CO_2 arc.
(a) Image with ND filter attached Sb_2S_3 vidicon.
(b) Image with SC74 filter attached Sb_2S_3 vidicon.



(a) (b)

Fig. 13 Images obtained during square groove welding of CO_2 arc.
(a) Image with ND filter attached Si vidicon.
(b) Image with IR90 filter attached Si vidicon.

ming effect over the region of visual and near infrared and **(b)** the image filtered through SC74 filter (aforementioned). The difference between them is evident. However, the clearer image of the molten pool can be obtained by detection of infrared image with an Si vidicon. **Figure13** is an example substantiating the above, **(b)** being the image obtained by attaching an Si vidicon with IR90 filter which transmits the light of longer wavelength than 900 nm for square groove welding of CO_2 arc. This permitted posterior view of the molten pool.

On the other hand, in the case of Ar arc, a bandpass filter (inferference filter) that avoids the peaks of the characteristic spectrum of Ar in the near infrared region is advisable as exemplified in **Fig. 14** by MIG arc welding using Si vidicon with **(a)** ND filter, **(b)** SC74 filter and **(c)** band-pass filter of 880 ± 10 nm. Although only the arc is visible in (a), the considerably clear image of molten pool is observed in (c).

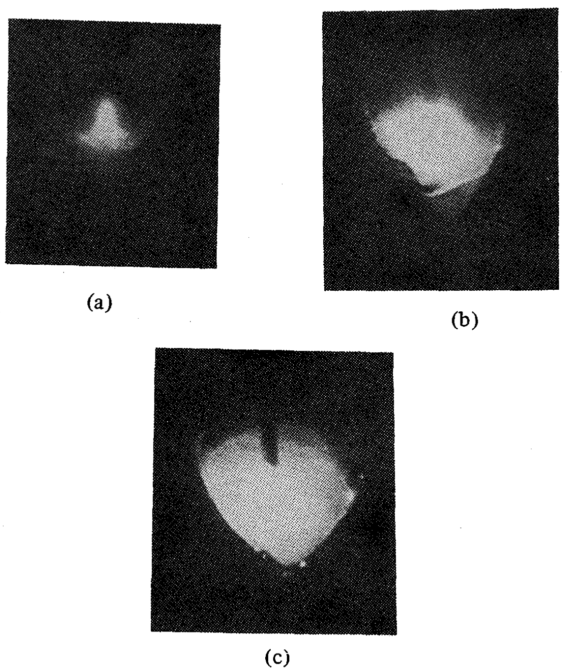


Fig. 14 Images obtained during fillet welding of Ar MIG arc.
(a) Image with ND filter attached Si vidicon.
(b) Image with IR90 filter attached Si vidicon.
(c) Image with BF880 filter attached Si vidicon.

4. Conclusion

This report can be summarized as follows:

(a) As a result of the spectrometric measurement of four kinds of arc and radiation from the molten pool, the differential characteristic profiles of spectrum were obtained.

(b) The selective combination of an image pickup tube and optical filter in accordance with the above measurement results permitted emphasizing of the image of molten pool and improved the image quality for the purpose of welding process automation.

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