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TEMPERATURE MEASUREMENT BY UV THERMAL RADIATION

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Abstract: The accurate measurement of temperature is very important to achieve high quality products in materials processing such as arc welding and thermal cutting. The IR(infrared) radiation thermometer has been applied to these processing, because it requires no physical contact with an object. Generally, the radiation thermometry leads to noticeable error in measuring temperature of molten pool under the welding where the emissivity is unknown. In the present paper, the molten pool temperature measurement by UV(ultra violet) thermal radiation has been discussed. In the experiment, stainless steel have been melted with TIG(tungsten inert gas)-arc, and the temperature distribution of molten pool has been measured with an UV sensor system and IR sensor.
Keywords: UV, Radiation Thermometry, Welding.

1. INTRODUCTION

The radiation thermometry is useful in measuring temperature without physical contact but it was reported in previous papers[1,2)] that the IR radiation thermometry leads to noticeable error in measuring temperature under materials processing such as welding and thermal cutting, where the emissivity is unknown in almost every case. Kraus[3)] measured temperature of weld pool by using emissivity data which were obtained by reflecting a focused laser beam off a weld pool at several locations but the temperature was measured only within weld pool because the emissivity varies with metal oxides. In the case of measuring temperature under GTA welding, it is necessary to shutoff the welding arc because the arc light interferes with the measurement. Besides, the effect of radiation from an electrode on the measurement was reported by Farson et al.[4)]. To prevent these effects Giedt et al.[5)] instantaneously moved the electrode from measuring point. In the present paper, to avoid the above difficulty, a feasibility study has been conducted to determine if UV thermal radiation from an object can be used for an accurate temperature measurement of the object.

2. UV RADIATION THERMOMETRY

In the radiation thermometry, the thermal energy radiated by an object is measured to determine the temperature of the object. The energy radiated by an object, i.e. the spectral radiance (L), can be expressed by the following relation according to Planck's law of black body radiation under the assumption that the object is black body.(see Fig.1)

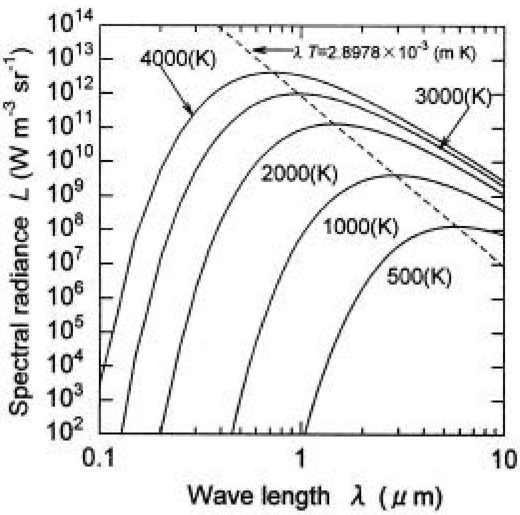


Fig.1 Spectral radiance of blackbody.

$$L(l,T)=\frac{2c_1}{l^5}\cdot\frac{1}{\exp(c_2/lT)-1} \quad (1)$$

where: c_1 = 5.9548 10^{-17}[W m^2] , c_2 = 0.014388[m K] , λ: wave length , T: temperature[K]

Since a normal object is not considered to be a black body, the luminance temperature measured with a radiation thermometer differs from the true temperature. That is to say, the relationship between the true temperature T[K] and the luminance temperature S [K] is expressed as follows,

$$L(l,S) = e \cdot L(l,T) \quad (\ :\text{emissivity.}) \tag{2}$$

$$S = \frac{c_2}{l} \cdot \frac{1}{\ln[\{\exp(c_2 / lT) - 1\}/e + 1]} \tag{3}$$

Where the emissivity is known, the true temperature can be easily determined by using Eqs.(1) and (2). But in actual materials processing, it is very difficult to estimate accurately the emissivity of the object, because the value depends on the surface state and temperature[6]. Figure 2 shows the example of change in emissivities with temperature[6]. Accordingly, one of the important problem in radiation thermometry is to develop an emissivity-free method (method for reducing emissivity effects[6]), taking account of industrial application of radiation thermometry. One of the way to the emissivity-free method is to reduce the wavelength for the thermometry[7, 8] . Figure 3 shows the

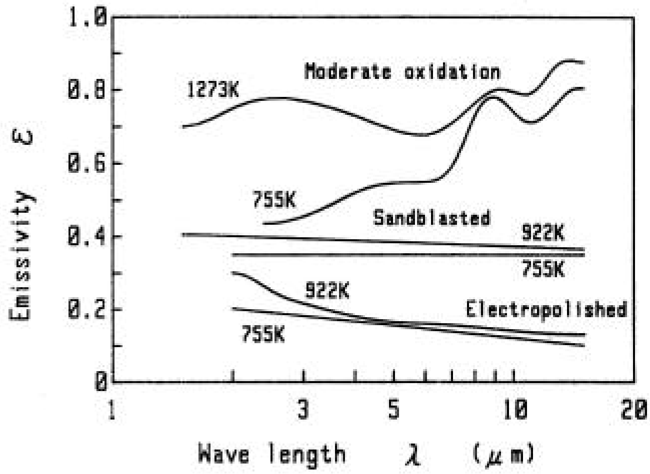
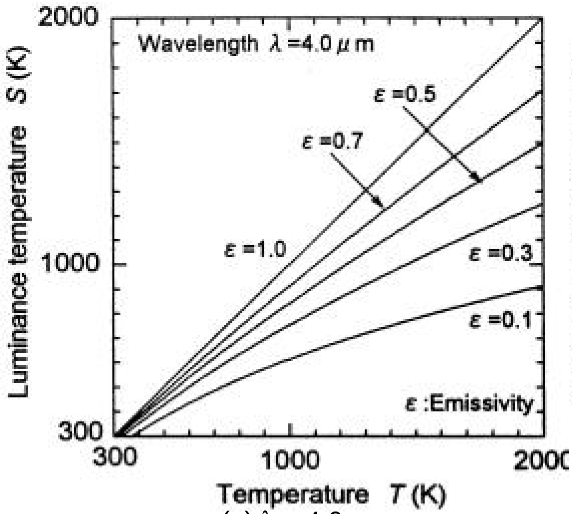
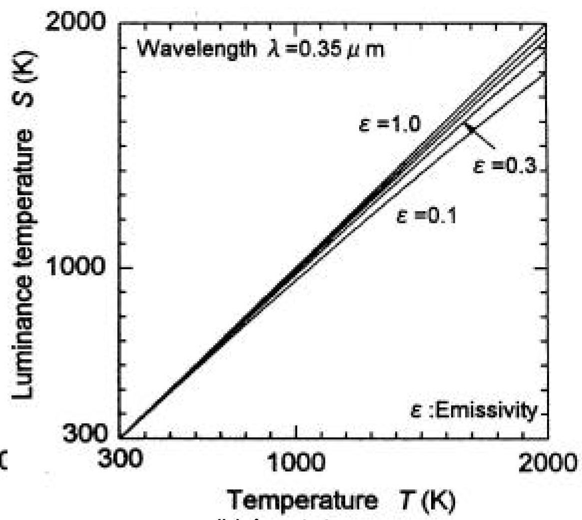


Fig.2 Spectral emissivities of Inconel



(a) λ = 4.0μm



(b) λ = 0.35μm

Fig.3 Relation between temperature and luminance temperature.

emissivity effect on the radiation thermometry, (a) is for IR range(λ=4.0μm) and (b) is for UV range(λ=0.35μm). Figure 3 suggests that the influence of the emissivity on the luminance temperature is reduced and the luminance temperature approaches to the true temperature in the UV radiation thermometry. But figure 1 show that the spectral radiance of UV is so weak that it is very difficult to measure it ; accordingly it is necessary for the sensitivity of the measurement system to be high.

3. TEMPERATURE MEASUREMENT OF WELD POOL

As shown in figure 4, the UV sensor consists of a CCD camera and an image intensifier, and UV reflection mirrors (shown in figure 5) and grass filters (U-340x2, U-350x1) have been used in the system to detect UV radiation(0.35μm). A trial blackbody furnace was used for calibration of this system. The IR sensor consists of a CCD camera and an interference filter (0.96μm).

The experimental setup used to measure weld pool temperature is shown in figure 6. Stainless steel

on a water cooled copper have been melted with TIG(tungsten inert gas)-arc, and the temperature distribution of molten pool has been measured with an UV sensor system and IR sensor after arc off.
Figure 7 shows the thermal image of stainless steel weld pool by UV sensor (a) and by IR sensor (b)

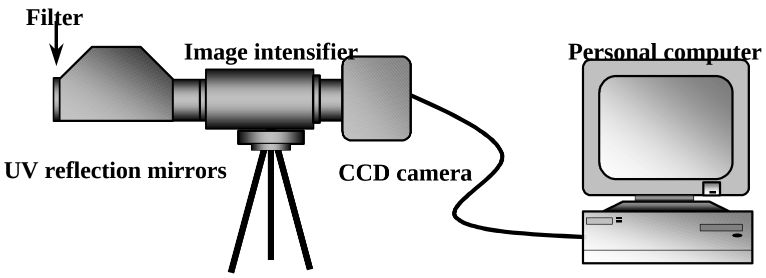


Fig.4 UV image system used in the present work.

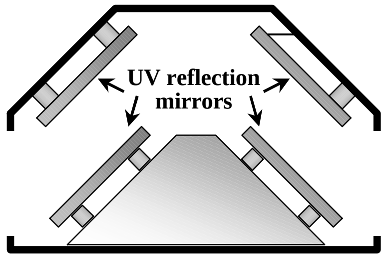


Fig.5 Arrangement of UV reflection mirrors.

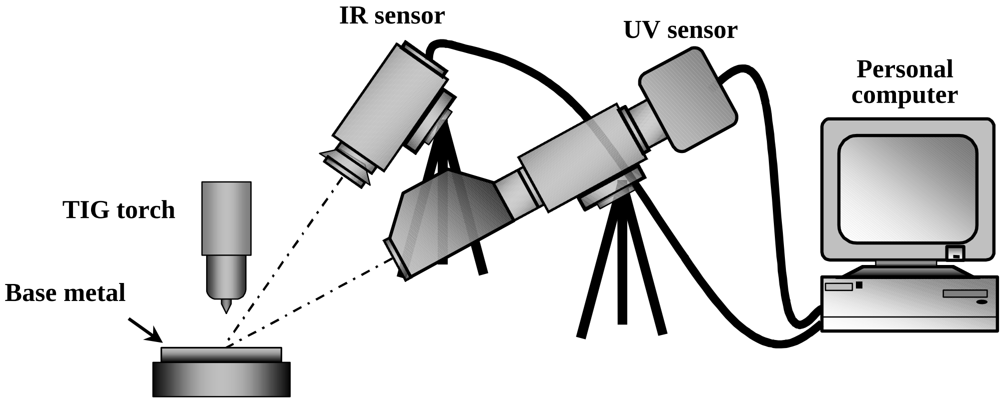
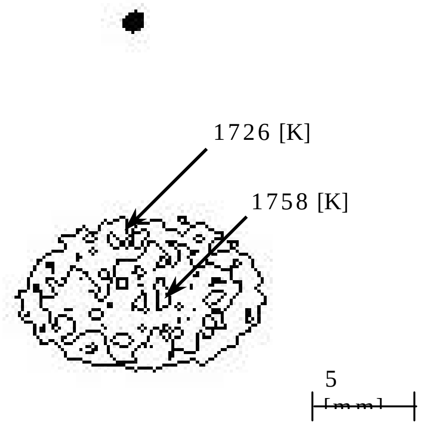
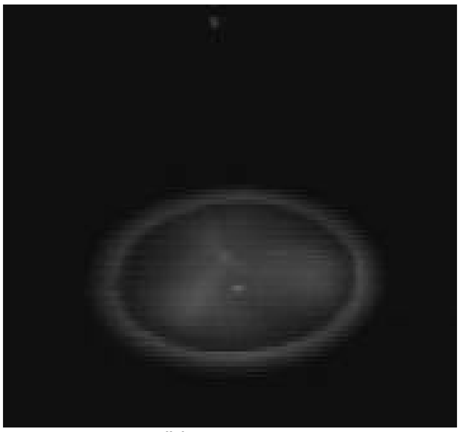


Fig.6 Experiment of weld pool temperature measurement.



(a) UV sensor

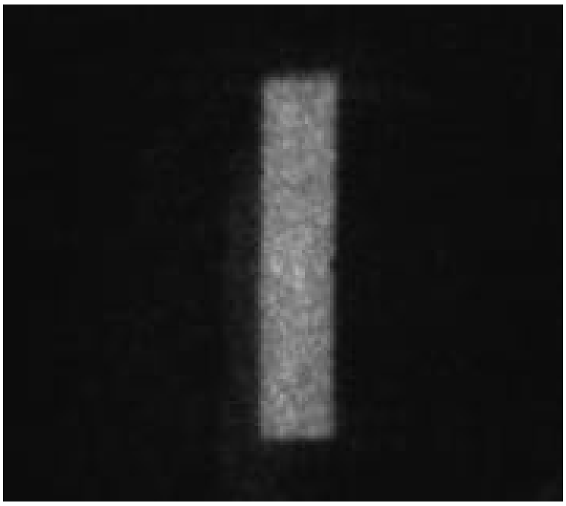


(b) IR sensor

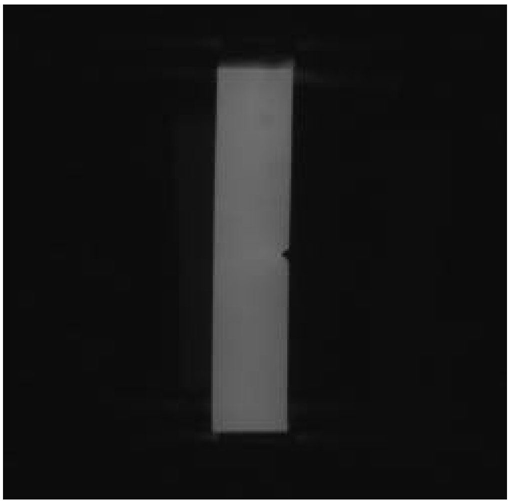
Fig.7 Thermal image of pool surface with TIG.
(SUS304, I = 150[A])

(at 1/15[s] after extinction of arc).
Figure (a), derived from the UV thermal image, shows the luminance temperature distribution on the molten pool surface of stainless steel. At the edge of molten pool, the measured value of luminance temperature is about 1700[K], and the temperature is nearly equal to the melting point of the material. As shown in the figure (b), high luminance zone is observed on the edge of molten pool, where the emissivity is high due to the oxidization. It is clear that the IR thermal image is quite different from the true temperature field. Figure 8 shows the thermal image of tungsten ribbon lamp (2530.9[K]) by the

UV sensor with image intensifier (a) and without image intensifier (b). As shown in figure 1 the spectral radiance of UV is so weak that an image intensifier is used to oscillate the radiance in this measurement system. But the thermal image with image intensifier has many noises, while the thermal image without image intensifier does not have noises. The figure suggests that if temperature of an object to be measured is higher, this measurement system can achieve a thermal image more accurately.



(a) With image intensifier



(b) Without image intensifier

Fig.8 Thermal image of tungsten ribbon lamp.

4. CONCLUSION

A feasibility study has been conducted to determine if UV thermal radiation from an object can be used for an accurate temperature measurement of the object. In the experiment, the weld pool surface temperature has been measured by using a UV sensor system and a satisfactory result has been obtained. Accordingly, the UV method, proposed in this work, offers a powerful means of accurate temperature measurement for thermal materials processing.

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