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The influence of electrochemical reactions induced by an external circuit on submerged arc weld metal

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Based on electrical conductivity of molten slag, a new method of applying direct current external circuit between slag and pool to control inclusions and improve weld bead appearance was designed and tested. The results show that the effect of the external circuit can effectively reduce the size of inclusions in weld metal. As the cathode of the electric field, a W–(2 wt%)Ce electrode inserted into molten slag induces electrochemical reactions and results in the reduction of sulfide inclusions in weld metal. Moreover electron emission of W–Ce electrode improves arc characteristic and makes an improved weld bead appearance.

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1. Introduction

The molten flux layer in submerged arc welding (SAW) is actually an ionic electrolyte. In general, thermochemical reactions occurring at the interface of the slag with the molten metal tend to be dominated. However, electrochemical reactions would result from the ionic conduction of current through the molten slag layer. This has now been realized in deoxidation of liquid steel by applying the external circuit to induce electrochemical reactions at the final stage of steelmaking. Work by Li et al. has indicated that the total oxygen content in liquid steel could be removed to the order of 10^{-5} wt% with the external circuit [1]. It has also been reported that the amount of dissolved oxygen in liquid copper could be decreased to the order of 10^{-6} wt% by the same way [2]. Indacochea et al. indicated that there is an electrochemical effect at the slag/metal interface during SAW [3], but as the welding current is carried largely by the submerged arc and only limited portion through the molten slag layer, the electrochemical reaction is insignificant generally [4]. Polar et al. and Kim, et al. suggested with experiments the mechanism of oxygen pickup caused by electrochemical reactions in SAW [5,6]. Based on the detailed research works on electrochemical reactions occurring in droplet metal of SAW [7], and aiming at obtaining finely dispersed oxide inclusions in weld metal, Li et al. have explored a new method of applying the external circuit between molten slag and pool during welding to induce electrochemical reactions, and control the movement of O, S elements in pool. The size and distribution of inclusions have been studied in relation to the nucleation of acicular ferrite; however there have been few reports on a controlling technique of inclusions during weld pool solidification. The present letter reports the preliminary results of applying the external circuit to control inclusions and hence the influence on weld bead.

2. Experimental procedure

The experimental method is illustrated in Fig. 1. A direct current power supply of 30 V/50 A was used to apply voltage or current across the slag layer. One output terminal of the power was connected to the electrode inserted into molten slag and another to the back of the weldment (Fig. 1(a)). The electrode of W–(2 wt%)Ce which was insulated with consumable wire electrode was seated on torch of automatic submerged arc welding machine (Fig. 1(b)). During welding, the W–Ce electrode was being inserted inside the molten slag rigidly (but not being inserted into weld metal pool) behind the arc to supply slag–metal voltage. The filler metal of 4 mm diameter H10Mn2 (AWS A5.17 F7A2-EH14) wire with SJ101 (AWS SFA-5.17F7A4-EH14) agglomerated flux was used for experiments. Several bead-on-plate welds were made on 16 mm thick Q235 (ASTM A283-D) steel plates using direct current reverse polarity (DCRP) at 30–32 V. The wire speed was adjusted to maintain the current 550–600 A and the travel speed was 32 cm/min. In order to evaluate arc stability in different cases, as described previously in the literature [8], the arc voltage was sampled by a signal analyzer to obtain probability-arc voltage curves during welding. Transverse sections of the weld were polished and examined under the DM4000M optical microscope

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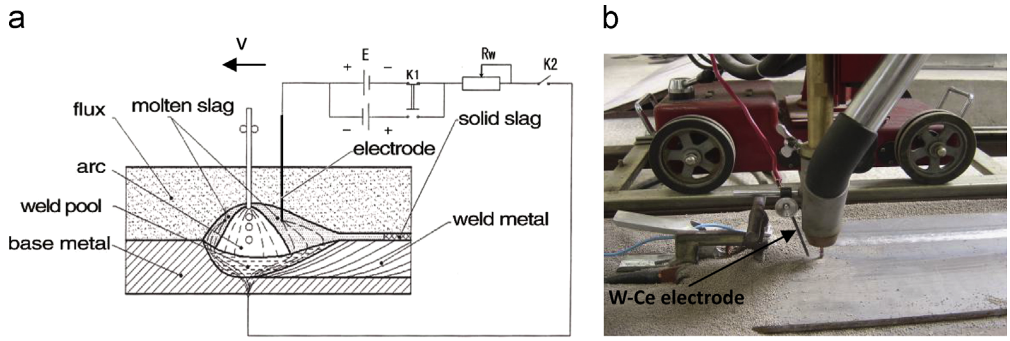

Fig. 1. Experimental arrangement with (a) schematic diagram of applying external circuit to submerged arc welding and (b) photograph of W–Ce electrode seated on torch.

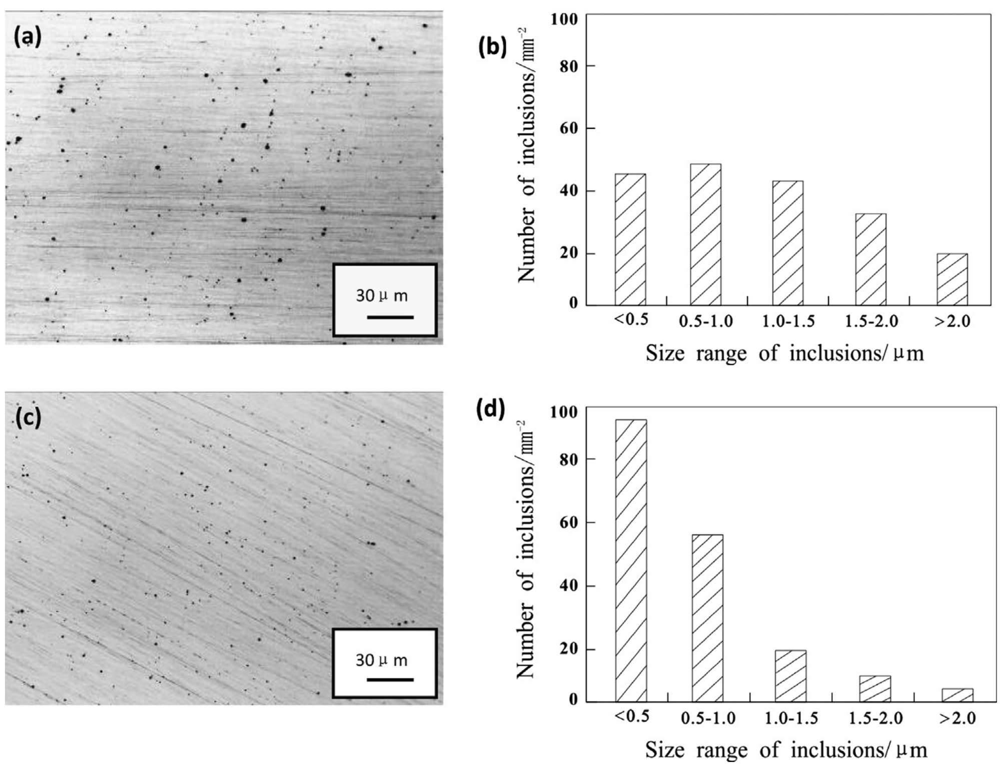

Fig. 2. Micrographs and distribution of inclusions in weld metal. (a) (b) Weld without external circuit. (c), (d) Weld with external circuit (10–12 V).

to characterize the size and distribution of the inclusions. The microstructure characteristic of inclusions in weld was observed by the JSM-6360LV scanning electron microscope (SEM) equipped with an energy dispersive spectroscope (EDS).

3. Results and discussion

The morphology of inclusions in weld metal. Fig. 2(a) and (b) shows the optical micrograph and size distribution of inclusions in weld metal without external circuit whereas Fig. 2(c) and (d) with external circuit respectively. It can be seen that inclusions in weld metal appear much smaller by applying the external circuit. This indicates that an external electric field exerts certain actions on size of inclusions. The external electric field is likely to be capable of controlling the growth of inclusions during weld pool solidification. In a traditional SAW process, microsegregation during weld pool solidification leads to significant enrichment of oxygen and deoxidants in the interdendritic liquid. The growth and dissolution of inclusions largely depend on the fluid velocity and temperature fields in the weld pool [9]. As evidence of experiments in the case of Fig. 2(c) and (d), when an external voltage of 10–12 V was applied between slag and pool, the corresponding current of 7–8 A could be measured but no current with external voltage decreased to zero. It concluded that external voltage drove both ionic and electronic charge carries transfer toward certain directions. The earlier work on thermodynamic calculation of molten slag during SAW has been carried out by the author, and it revealed that thermodynamic equilibrium would be established between molecules and ions [10]. Several studies have discussed the ionic and electronic conductions in slag melts and the general agreement is that the ionic conduction plays a significant role with applying external voltage [11]. Therefore, instead of thermodynamic equilibrium, the contribution of external voltage to the dissolution of inclusions would be expected for non-equilibrium due to ionic conduction. This is helpful for dissociation of oxide and sulfide into ions at rear of the molten pool. Meanwhile, the movement of positive and negative ionic charge carries behind the arc is also beneficial to achieve the uniform distribution of inclusions and reduce the growth rate of large size inclusions from segregation.