Technical Note: Surface Tension of 304 Stainless Steel under Welding Conditions

Influence of shielding gases is evaluated

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Introduction

Although the surface tension of liquid metal plays an important role in weld bead formation during welding, very little surface tension data on commercial alloys are available. Furthermore, none of the prior measurements were conducted under conditions simulating arc welding. This note evaluates the surface tension of 304 stainless steel, measured under arc welding conditions. The results also show the influence of shielding gas mixture on surface tension. This is a part of an effort conducted by the Welding Research and Engineering Group at The University of Tennessee to evaluate the weldability of stainless steels.

Experimental Procedure

The drop weight method was used in this determination. The end of a 304 stainless steel rod was melted with a low current, plasma arc welding torch to produce the drop. The surface of the rod was polished and cleaned with acetone prior to drop melting.

The 304 stainless rod composition is:

C-0.060	P-0.021	Si-0.50
Mo-0.14	Co-0.08	N_2-0.078
Mn-1.64	S-0.004	Cr-18.40
Cu-0.14	Al-0.010	Ni-8.09

Pure argon shielding gas and combinations Ar + 10% H_2, Ar + 10% N_2 and Ar + 10% Freon 12® were used in the experiments. The addition of H_2 was employed because H_2 is a common addition to Ar when welding the austenitic stainless steels in high speed welding. Likewise, N_2 is sometimes employed as a backing gas in austenitic stainless welding and as such is incorporated in the shielding atmosphere. Freon 12® was used because of prior experiments which showed effects that may have been related to surface tension changes. Oxidizing gas additions (CO_2, O_2) were not employed because of possible detrimental effects on the tungsten electrode. Other gas mixtures, such as He, He + H_2 and He + Ar, can also be evaluated in further work with the technique. The arc current was maintained at 20 A during drop formation. The detached drops were collected and weighed for calculation. The material density was taken to be 7.5 g · cm^{-3} from the work of Ahmad and Murr (Ref. 2).

When a liquid drop detaches from the end of the rod, the following relation holds (since the plasma torch was aligned perpendicular to the melted rod, the arc force played a negligible role in drop detachment):

$$\gamma = (M_o g/r)F$$

where γ is the surface tension, M_o is the weight of the drop, g is the gravitational constant, r is the radius of the rod, and F is an empirically derived correction factor. F is a single-valued function of $r/(M_o/P_2)^{1/3}$, where P_2 is the drop density. The tabulated correction factors obtained by Lando and Oakley (Ref. 1) were used in this determination.

Results and Discussion

The results are summarized in Table 1. The value of surface tension for each gas mixture is the average of four measurements. The accuracy of results is within ±4%.

The surface tension measured in pure Ar is 1169 erg · cm^{-2}. This is in close agreement with the results measured in earlier work (Ref. 2) using the sessile drop method under high frequency heating in Ar. The data indicates that the surface tension data for 304 stainless steel measured under other experimental conditions are also valid under welding conditions. The addition of H_2 to the shielding gas increases the surface tension of 304 stainless steel by 10%. This is believed to be caused by the reducing effect of hydrogen, which decreases the concentration of oxygen on the drop surface.

The nitrogen addition decreases the surface tension slightly. The addition of Freon 12® produces a 7% decrease in surface tension compared to pure argon.

Data on the effects of different shielding gases on the surface tension of many weld metals, as well as the effect of weld metal composition on surface tension with singular shielding gas, is important for the analysis of bead shape and penetration effects in welds. These data will be important for weld modeling studies, and thus further measurements should be conducted to provide a proper database for fundamental weld evaluations.

References

1. Lando, J. L., and Oakley, H. T. 1967. Tabulated correction factors for the drop-weight-volume determination of surface and interfacial tensions. *Journal of Colloid and Interface Science* 25:526–530.

2. Ahmad, U. M., and Murr, L. E. 1976. Surface free energy of nickel and stainless steel at temperatures above the melting point. *Journal of Materials Science* 11:224–230.

Table 1

Gas Mixture	M_o(g)	r(cm)	$r/(M_o P_2)^{1/3}$	F	γ(erg · cm^{-2})
Ar	0.850	0.158	0.326	0.2211	1169
Ar + 10% H_2	0.942	0.158	0.315	0.2192	1280
Ar + 10% N_2	0.835	0.158	0.328	0.2215	1147
Ar + 10% Freon 12®	0.784	0.158	0.335	0.2226	1082

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