A Statistical Analysis Applied to Arc Melting Tungsten-Base Alloys

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Consumable-electrode arc melting has become a popular process for melting a wide variety of steels, titanium alloys, and metals for nuclear applications. Currently, it is also being applied to the refractory metals: tungsten, tantalum, molybdenum, and columbium, and their alloys.

The arc melting or arc casting of tungsten is a potentially important process. However, it is quite difficult to obtain good final ingot quality with this melting technique. Among the factors that influence the ingot quality are steep thermal gradients, grain size and orientation, ingot surface quality, and alloy homogeneity.

A number of studies are currently in progress to improve tungsten ingot quality by optimizing and developing more consistent melting practices. Complicating these programs, however, is the fact that little is known about the relationship between the several variables that define this combined melting and casting operation. Clearly, an understanding of the relationship between the variables would be of value, as it would provide the necessary tool for a closely controlled, systematic investigation to determine what factors predominantly influence the melting process and, more importantly, the resultant ingot quality.

Obviously, if such a relationship could be developed for arc melting of tungsten, similar relationships could be developed for other metals.

Analysis of data

To establish a relationship between the melting variables for tungsten, data were obtained from a review of current arc-melting practices presently applied at seven different arc-melting facilities.[1-8] Generally, the review was limited to dc, straight-polarity melting methods. As shown in Table I, a moderately broad range of values was obtained for each variable considered important to process.

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Table I. Summary of Consumable-Electrode Vacuum Arc-Melting Variables

Variable	Range of Values Encountered
Alloy composition, wt % W	92-100
Electrode properties	
Density, % of theoretical,	70-100
Diam., in., D_e	0.75-2.25
Ingot properties	
Wt, lb	7-84
Diam., in., D_i	2.50-5.00
Melting conditions	
Current, amp	2700-8000
Voltage	22-36
Input power, kw, P	87-247
Melting rate, lb/min, R	0.25-2.47
Vacuum, microns Hg	0.02-50

These data were then analyzed by a semiempirical method to establish the relationship between the arc-melting variables.

As a first approximation, the most reasonable and convenient choice for a correlation among the arc-melting variables seemed to be one of input power (volts x amps) vs. melting rate (lb per min). However, the resultant degree of correlation obtained from these data was generally poor. As measured by the rank-order correlation coefficient[9], the degree of correlation was found to be 0.65. Values for the rank order correlation coefficient may range from 0 to 1, with 0 representing no correlation and 1 representing an ideal correlation.

Next, using this correlation coefficient as a guide, a new parameter was devised that included allowances for the ingot and electrode cross-sectional areas and the electrode density. Essentially, this was accomplished by evaluating various empirically formulated products of melting rate, electrode density, and ingot and electrode cross-sectional area with respect to their ability to correlate with input power.

At first, in these empirical formulations, only the influence of the cross-sectional areas was considered. The correlation coefficients resulting from this initial effort for various weighting factors ranged from 0.813 to 0.857.

In attempting to obtain an even higher degree of correlation, a series of calculations was performed to evaluate the significance of the electrode density. The correlation coefficient obtained using this new parameter was 0.888.

Finally, using the optimum adjusted melting-rate parameter, the five basic arc-melting variable were related according to the formula:

$$P = 10R\rho(0.8D_e^2 + 0.2D_i^2) + 100,$$

where P is input power, R is melting rate, ρ is electrode density, D_e is the diameter of the electrode, and D_i is the diameter of the ingot.

Conclusions

From the above relation, it is apparent that input power is directly related to melting rate, electrode density, and a weighted sum of the ingot and electrode cross-sectional areas. Also, since the data used in the analysis were obtained from seven different melting facilities, it can be concluded that existing differences between melting practices and furnace designs have little or no effect on the correlation among the variables of several sources. A higher degree of correlation, however, might have resulted if sufficient data had been available from a single source and a single alloy composition.

The general significance of the development of this relationship by semiempirical analytic means may be summarized as follows:

1) A known relationship among the arc-melting variables will aid current efforts to optimize tungsten-base alloy arc-melting practice.

2) With arc-melting practices optimized, use of the relationship would contribute to consistency among these practices and hence to quality control in the production of tungsten-base alloy ingots.

3) The arc-melting process for other metals might also be defined by a relationship similar to the one that has been developed for tungsten.

References

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