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The Thermal Conductivity of AISI 304L Stainless Steel

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A compilation and critical analysis of the thermal conductivity (λ) of AISI 304 stainless steel (SS) between 100 and 1707 K has been given in the literature. The author represented his "recommended" values of λ by an inflection in the λ versus temperature relationship between 300 and 500 K. Because a physical mechanism had not been identified that would produce such a temperature dependence in λ of 304 SS, interest was generated in the possible existence of an as yet undiscovered phenomenon that might cause such an inflection. Consequently, experimental verification of the inflection was sought. The present paper presents recent measurements of λ, the electrical resistivity, and the absolute Seebeck coefficient of 304L SS from 300 to 1000 K and of the thermal diffusivity (α) from 297 to 423 K. The λ values computed from the α measurements were within $\pm 1.6\%$ of the directly measured λ. An inflection was not observed in the temperature dependence of λ between 300 and 500 K. After careful evaluation and because a physical mechanism still has not been identified which would produce such an inflection, the authors conclude that the inflection in the λ vs T relationship reported in the literature was caused by the data analysis technique.

KEY WORDS: electrical resistivity; Seebeck coefficient; thermal conductivity; thermal diffusivity; 304 stainless steel.

1. INTRODUCTION

In 1983, Bogaard [1] presented a paper on the thermal conductivity (λ) of AISI 304 stainless steel (SS) between 100 and 1707 K. His paper was a compilation and critical analysis of the values of λ that had been published

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to that time and included 20 sets of data from 15 references. Two sets of λ data "indicated quite a flat slope from 300 to 500 K," and four λ data sets "indicated rather low values" in this temperature range [1]. To reflect these data, his "recommended" values of λ have an inflection in the λ versus temperature (T) relationship between 300 and 500 K. This representation was in contrast to the previous compilation of Chu and Ho [2], which showed no such inflection. Consequently, interest was generated in the possible existence of an as yet undiscovered phenomenon that might cause such an inflection. (See, for example, Klemens and Williams [3] for a theoretical discussion of the λ of 304L SS.) Thus, experimental verification of the inflection was sought.

This paper presents measurements of λ, the electrical resistivity (ρ), the Seebeck coefficient (S), and the thermal diffusivity (α) of 304L SS. The behavior of these quantities over the 300 to 500 K temperature range was investigated extensively, and analyses were performed to determine if an inflection in λ exists in this temperature region.

2. EXPERIMENTAL APPARATUSES

Two apparatuses were used to measure four transport properties of well-characterized specimens of 304L SS. The Oak Ridge National Laboratory (ORNL) high-temperature-longitudinal (HTL) apparatus [4] has been used to measure λ, ρ, and S of numerous materials between 300 and 1000 K. These materials include the National Institute of Science and Technology's (NIST) stainless steel SRM 735 [5]; HTL and NIST λ data for SRM 735 agreed to within the experimental uncertainty band of $\pm 3\%$ at 300 K and $\pm 5\%$ at 1000 K computed by NIST [6]. The Springfields Laboratory's flash laser apparatus was used to measure α [7]. The experimental uncertainties for these two apparatuses are given in Table I.

Table I. Experimental Uncertainties of Measured Properties

Property	Uncertainty
λ	$\pm 1.5\%$, (300–700 K)
	$\pm 3.0\%$, (700–1000 K)
ρ	$\pm 0.4\%$
S	$\pm 0.14\ \mu V \cdot K^{-1}$
α	$\pm 2.0\%$

3. SPECIMENS

Specimens were fabricated from a hot rolled plate of AISI 304L SS manufactured by Jessop Steel Company, Washington, PA. The plate was given the solution anneal typical of this type product [8]. Table II lists the chemical composition of the plate as determined by the manufacturer, and compositions typical [8] for the steel are listed for comparison. The microstructure of the steel revealed a grain size of 40 μm, about 5 to 10% ferrite phase, and numerous annealing twins.

The HTL specimen was a cylinder 10.2 mm in diameter and 77.8 mm in length. The Springfields Laboratory specimen was a disk 10.0 mm in diameter and 1.285 mm in thickness.

4. RESULTS, DISCUSSION, AND CONCLUSIONS

Table III lists the physical properties of 304L SS measured at ORNL and the values of λ calculated from the measurements of α obtained at Springfields. For the calculations of λ from α, a density of 7.873 $g \cdot cm^{-3}$, measured at Springfields Laboratory and corrected for thermal expansion using a coefficient of 12×10^{-6} K^{-1}, and the specific heat (C_p) function listed in Table III were used. The data were fit by the method of least squares to obtain the second-order polynomials listed in Table III. As shown in Fig. 1, the ORNL values of λ were within ± 0.9% of the least-squares equation; the λ values calculated from the Springfields Laboratory α data were within ± 1.6% of this equation.

Figure 2 is a plot of the λ of 304 SS between 300 and 700 K from the compilation of Bogaard [1], from the earlier compilation of Chu and Ho [2], and from the ORNL least-squares equation. Note the significant difference in slope of Bogaard's compilation in this temperature region.

Table II. Chemical Composition of 304L SS

Element	Specimen (wt%)	Typical steel (wt%)[a]
Cr	18.10	18–20
Ni	9.20	8–12
Mn	1.81	2.0
Si	0.41	1.0
S	0.008	0.03
P	0.025	0.045
C	0.022	0.03 max.

[a] From Ref. 8. Balance is iron (Fe).

Table III. Measured Properties of 304L SS

T (K)	λ $(W \cdot m^{-1} \cdot K^{-1})$	ρ $(\mu\Omega \cdot cm)$[a]	S $(\mu V \cdot K^{-1})$[b]	α $(cm^2 \cdot s^{-1})$
		ORNL[c]		
333.7	14.92	74.83	−1.40	
354.9	15.27	76.46	−1.51	
380.1	15.62	78.39	−1.78	
380.3	15.77	78.62	−1.66	
402.4	16.16	80.10	−1.90	
423.1	16.63	81.69	−2.10	
450.4	17.04	83.79	−2.31	
450.5	17.06	83.84	−2.19	
474.8	17.42	85.50	−2.41	
476.1	17.58	85.77	−2.49	
573.1	18.99	92.17	−3.03	
673.2	20.46	98.17	−3.40	
975.3	24.33	112.29	−3.66	
		Springfields		
297.2	14.25[d]			0.0375
300.2	14.04			0.0370
303.2	14.53			0.0382
305.2	14.33			0.0377
308.2	14.40			0.0378
313.2	14.54			0.0381
339.2	15.07			0.0391
347.2	15.10			0.0391
355.2	15.08			0.0390
366.2	15.39			0.0395
373.2	15.61			0.0400
398.2	16.00			0.0406
423.2	16.53			0.0416

[a] Corrected for thermal expansion.
[b] Absolute Seebeck coefficient.
[c] $\lambda = 7.9318 + 0.023051\,T - 6.4166 \times 10^{-6}\,T^2$ (λ in $W \cdot m^{-1} \cdot K^{-1}$). $\rho = 43.869 + 0.10443\,T - 3.5154 \times 10^{-5}\,T^2$ (ρ in $\mu\Omega \cdot cm$). $S = 2.527 - 0.01434\,T + 8.202 \times 10^{-6}\,T^2$ (S in $\mu V \cdot K^{-1}$). $C_p = 0.4267 + 1.700 \times 10^{-4}\,T + 5.200 \times 10^{-8}\,T^2$ (C_p in $J \cdot g^{-1} \cdot K^{-1}$). $\alpha = 3.0246 \times 10^{-2} + 1.9016 \times 10^{-5}\,T + 1.7244 \times 10^{-8}\,T^2$ (α in $cm^2 \cdot s^{-1}$).
[d] Values calculated from α measurements.

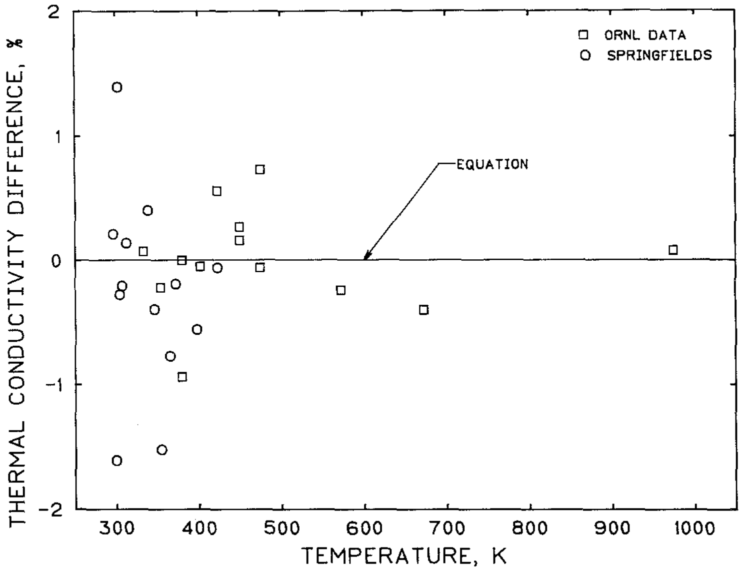

Fig. 1. Difference in percentage as a function of temperature between the ORNL least-squares equation for the λ of 304L SS (Table III) and the ORNL λ measurements and the λ calculated from the Springfields Laboratory α measurements.

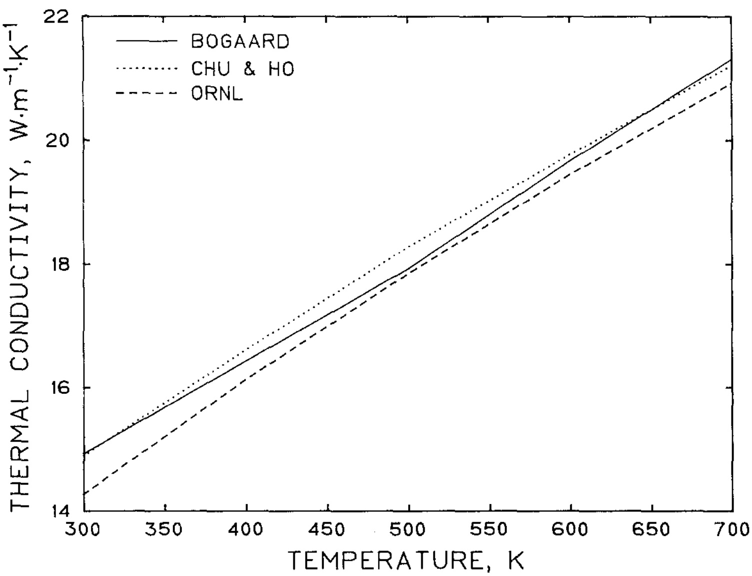

Fig. 2. Thermal conductivity of 304L SS between 300 and 700 K from the compilations of Bogaard [1] and Chu and Ho [2] and the ORNL least-squares equation (Table III).

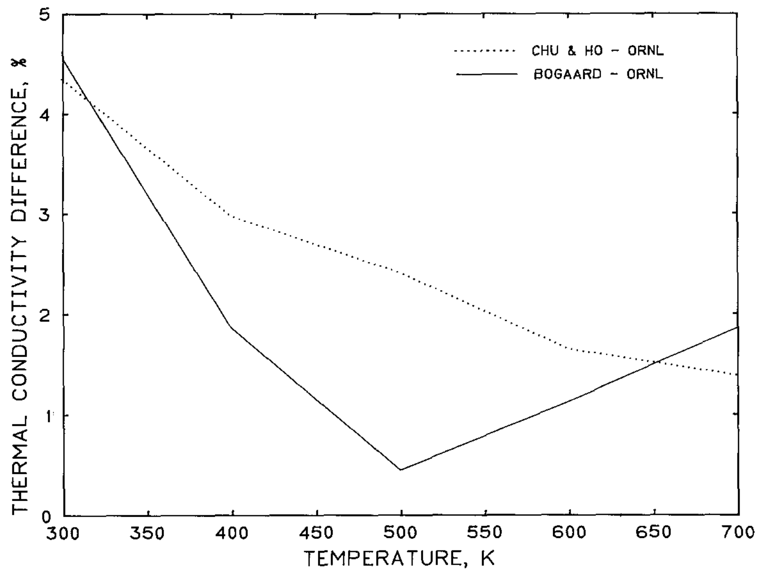

Fig. 3. Difference in percentage from 300 to 700 K between the least-squares equation for λ of 304L SS listed in Table III and the compilations of Bogaard [1] and Chu and Ho [2].

This slope difference is better illustrated in Fig. 3, which depicts the percentage difference between the two compilations and the least-squares equation for the ORNL data.

In retrospect, the difference between the authors' measurements and Bogaard's compilation is less than the experimental errors involved in obtaining the λ data. The point of interest, therefore, is not the magnitude of the difference but, rather, the implication from Bogaard's compilation that an inflection exists in the λ of 304 SS between 300 and 500 K and that an as yet unknown phenomenon might exist to explain this inflection in the λ of 304 SS.

To investigate this point further, the data were plotted on expanded graphs, but an inflection could not be identified visually. Because second-order polynomials such as those in Table III do not have inflections, the ORNL λ data between 333 and 673 K were fit by the method of least squares to a third-order polynomial in T. The resulting inflection point was at 886 K, which was outside the temperature range of the λ data used in the fit and outside the range of interest. The variance of the λ data points about the second- and third-order equations were essentially the same, so the data are represented equally well (statistically) by a polynomial of either order. Thus, we conclude that the precision of the data does not support the existence of an inflection in the λ versus T relationship between 300 and 500 K.

Upon close examination, it appears that the inflection resulted from Bogaard's procedure of data analysis. Specifically, Bogaard attempted to join the low-temperature λ data sets to the high-temperature λ data sets using a smooth curve, "Generally, the recommended curve was drawn such that the deviations of the literature data scattered symmetrically" [1] about the smooth curve.

In conclusion, the authors of the present paper find such an inflection in λ to be without theoretical or experimental justification.

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REFERENCES

1. R. H. Bogaard, in *Thermal Conductivity 18, Proc. 18th Int. Conf. Therm. Conduct.* (Plenum Press, New York, 1985), pp. 175–185.
2. T. K. Chu and C. Y. Ho, in *Thermal Conductivity 15, Proc. 15th Int. Conf. Therm. Conduct.* (Plenum Press, New York, 1978), pp. 79–104.
3. P. G. Klemens and R. K. Williams, *Int. Met. Rev.* **31**:197 (1986).
4. J. P. Moore, R. S. Graves, and D. L. McElroy, ORNL-4986 (Oak Ridge National Laboratory, Oak Ridge, TN, 1974).
5. J. G. Hust and P. J. Giarratano, NBS Special Publication 260-46 (U.S. Department of Commerce, National Bureau of Standards, Washington, D.C., 1975).
6. R. S. Graves, J. P. Moore, and R. K. Williams, in *Thermal Conductivity 16, Proc. 16th Int. Conf. Therm. Conduct.* (Plenum Press, New York, 1983), pp. 343–349.
7. K. E. Gilchrist and J. E. Brocklehurst, Atom No. 240 (Springfields Nuclear Power Development Laboratories, Salwick, Preston, UK, 1976), pp. 257–267.
8. *Metals Handbook, Vol. 3* (American Society for Metals, Metals Park, OH, 1980), p. 5.