circulating pump. The secondary constant-temperature bath served merely to provide coolant for the primary bath. The primary bath maintained a constant temperature within the limits of ±0.18 deg F.

The temperature wave at $x = 0$ was provided by intermittently heating the oil as it was pumped from the primary constant-temperature bath. The temperature of the oil was increased about 10 F by the cyclic heater 6, which was controlled by the timing switch.

OPERATION

The operating procedure was simple. After the vacuum pump had been in operation for a period of over 1 hr, the other components were turned on at approximately 15-min intervals as follows: Bath controls and circulating pumps, timer for cyclic heater, amplifiers, and then the recording milliammeters. Wave shapes were recorded for only six to twelve of the 105-sec cycles.

RESULTS

It was possible to make a complete thermal-diffusivity determination in a period of 1 hr. Repeated measurements could be made in a period of 45 min. The maximum probable error of these measurements was ±6.8 per cent. The principal source of error was involved in the harmonic analysis of the time-temperature data. The greatest experimental difficulty was associated with the maintenance of a steady flow of constant-temperature oil from the primary bath. Considerable time and labor were required to analyze the data.

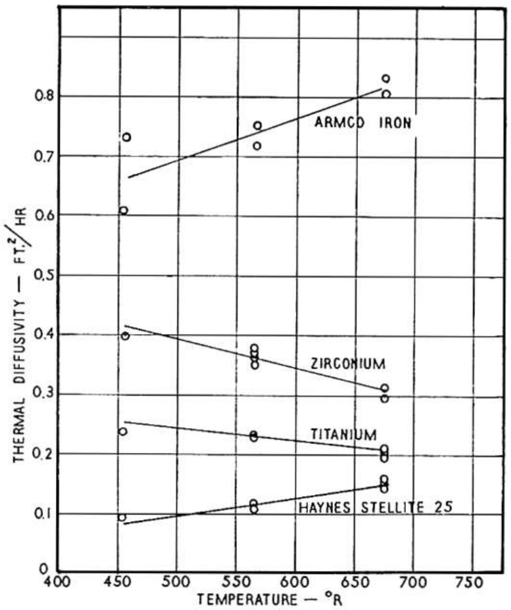

FIG. 3 THERMAL DIFFUSIVITY OF ARMCO IRON, ZIRCONIUM, TITANIUM, AND HAYNES STELLITE NO. 25

Specimens of Armco iron, titanium, zirconium, and Haynes Stellite No. 25 were tested at 456, 564, and 672 R. The calculated values of the thermal diffusivities are shown in Fig. 3.

CONCLUSIONS AND DISCUSSION

A periodic heat-flow method can be used to make determinations of the thermal diffusivities of metals with an accuracy of about 5 per cent. The experimental data can be obtained in a period of 1 hr after the specimen has attained the mean temperature level at which the experiments are to be made. The necessary apparatus is complex and expensive and the detailed analysis of the data is difficult. The method is not sufficiently accurate to study the influence of temperature gradient or mechanical strain on thermal conductivity.

The work recently reported by Sidles and Danielson (12) confirms these conclusions. Sidles developed a new modification of this method and he measured diffusivities at temperatures to above 1000 F. He estimated his measurements to be within ca 0.25 per cent at 32 F and within ca 10 per cent at 400 F.

Starr (9) claimed a very high accuracy of ±0.06 per cent. However, he tested only one brass rod the conductivity of which was known to within ca ± 5 per cent.

The Forbes bar method remains as the most promising technique for obtaining reliable values of thermal diffusivities at high temperatures in a short interval of time. The experimental determinations can be made in a period of 10 min after the specimen has attained the mean temperature level. Since an accuracy of better than 1 per cent can be obtained, the Forbes bar method can be used to study conductivity-temperature gradient or conductivity-strain relations.

ACKNOWLEDGMENT

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Discussion

G. C. DANIELSON,[6] P. H. SIDLES,[6] AND G. J. PEARSON.[6] The purpose of the investigation reported in this paper was to evaluate experimentally the periodic heat-flow method of determining the thermal diffusivity of metals. The conclusions were that this method was inferior to the Forbes bar method from the standpoint of accuracy and the rapidity with which data could be obtained and that the Forbes method is to be preferred for studying thermal conductivity versus temperature gradient or thermal conductivity versus strain. We would like to discuss these conclusions.

Both the Forbes bar and the periodic heat-flow methods re-

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quire an equilibrium condition before data can be taken. The time required to attain this equilibrium is long compared with that required to actually take the necessary data. Therefore the total time required for one thermal-conductivity determination is essentially the same for each of the two methods.

To the best of our knowledge, no Forbes bar technique has been used to measure thermal conductivity at high temperatures with an accuracy of better than 1 per cent as was stated by the authors. Hall[7] concludes his discussion of the Forbes method with a quote from a paper by Stewart to the effect that Angström's method (a periodic heat-flow method) should be adopted in preference to the Forbes method. Hogan and Sawyer[8] in a recent study using the Forbes bar technique fail to indicate any accuracy for their measurements, stating only that the assumptions made in deriving the theory would cause an error of less than 1 per cent for the samples they measured.

When one considers that periodic heat-flow methods permit the necessary data for a thermal-conductivity determination to be obtained simultaneously from a single sample while Forbes bar methods require either separate experiments on the same bar or simultaneous experiments on different bars, one concludes that the periodic heat-flow technique is inherently more accurate. It has been our experience that this conclusion is correct.

As was pointed out in a recent report by Sidles and Danielson,[9] experiments of the periodic heat-flow type which required two separate experiments for one determination of thermal diffusivity were definitely inferior to the technique developed by the writers and described in that report[9] in which all necessary data were obtained simultaneously on a single sample. It should be pointed out that the large errors reported at 400 C were not caused by inherent difficulty with the method but by the decreased stability of the sample at that temperature.

In view of the results of previous studies of thermal conductivity versus strain it is quite evident that accuracies of considerably better than 1 per cent are required for studies of this type. Bridgman,[10] in a study of seven different metals, found effects of tension on thermal conductivity ranging from about 0.39 per cent for a 2050 kg/cm^2 load in Fe to 0.015 per cent for a 770 kg/cm^2 load in Pd.

We would like to point out that neither the periodic heat flow nor the Forbes bar method seems to be well adapted for studying relations of thermal conductivity versus strain. The difficulty inherent in both methods is that each requires an equilibrium condition which would be altered by straining the sample. Measurements of the afterstrain conductivity can be made only after waiting for this equilibrium condition to prevail. During this period of time, annealing will take place, thus partially erasing the effect on conductivity caused by the strain. A suitable method for measurements of this type should be free from this difficulty.

We would like to propose that a technique similar to the moving heat-source method of Rosenthal and Ambrosio[11] might be useful for measurements of this type. A sensitive amplifier-recorder system and very small heat pulses would be used. A determination of the before-strain conductivity would be made and the sample allowed to return to equilibrium with the ambient temperature. The sample would then be strained and the heat source immediately moved along the sample to measure the afterstrain conductivity. The distinction between this proposed technique and both the Forbes bar and the periodic heat-flow technique is that here only a temperature equilibrium is required and that this equilibrium would not be altered by straining the sample as would a temperature-gradient equilibrium or a periodic heat-pulse equilibrium.

AUTHORS' CLOSURE

The authors thank Messrs. Danielson, Sidles, and Pearson for their logical and unusually well-informed discussion. In view of the broader experience of this group, the authors wish only to clarify their stand on the Forbes method of determining thermal diffusivity.

If experimental error is the criterion, a method requiring one experiment, such as the authors used, is superior to the Forbes method, which requires two experiments, only when the total error of the two experiments is greater than the error from the single experiment. It was the authors' experience that the maximum theoretical error in their experiments (6.8 per cent) was considerably greater than could be expected for similar Forbes method experiments. This finding, plus the simpler apparatus required for the Forbes method, provides the basis for the authors' recommendation.

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