N-155 and S-816 would have topped the list by a wide margin, and yet after several hours of vibration, they shifted to the bottom of the list.

Fig. 9 shows the results of similar tests at 1350 F. It will be noted that N-155 retains its characteristic high initial damping and rapid drop. S-816 shows a much less rapid drop, being in the order of 2 to 1 in 100 hr with no evidence of becoming flat. Fig. 10 begins to show the same trends at 1500 F, but because of the more or less early failure of the bars, long-time results were not available. The points enclosed in large circles indicate the time of failure of the bar but not the pressure at failure. Those points, which are off scale to the left, indicate the initial pressure and should be plotted approximately one log-cycle further to the left (0.01 hr).

Summary

Tests on four gas-turbine-bucket materials have been conducted at elevated temperatures which involved the measurement of the pressure required to vibrate specimens in a pneumatically driven fatigue machine. The pressure is assumed to be a qualitative measure of the internal damping of the material.

It was found that at a peak stress of 40,000 psi, the nickel and cobalt-base alloys showed a minimum damping near 800 F and a sharp rise between 1350 F and 1500 F. The two iron-base alloys had a maximum damping between 800 F and 1200 F, a slight dip at 1350 F, and a sharp rise at 1500 F.

Two of the materials indicated excessively high damping at 1200 F and above at stresses below their fatigue limit. This high value, however, became rapidly smaller as vibration was continued, to the extent that they finally showed the lowest values of the four materials. This means that damping data obtained by more orthodox means in short times may, in some cases, be greatly in error if used in choosing materials for gas-turbine buckets. It appears that this could be a rather important factor in those designs where internal damping of the buckets is believed to be a major factor in limiting vibration.

In closing, it should be emphasized that these results are based on a minimum of data and are therefore subject to some revision as more data are accumulated. Probably the largest single source of error is the fact that a number of successive tests were made on a single bar, and the results themselves indicate that past history may have a marked effect on behavior.

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Discussion

R. O. Fehr.[4] The author reports that the damping of materials varies with temperature, and shows a minimum value at 800 F. Tests previously conducted and reported[5] by us have shown similar results. Those investigations showed, on some materials, an increase in damping with temperature increases above room temperature. Further increase of temperature led to a reduction in damping. For example, the lowest damping was found for 13 per cent Cr-iron at approximately 900 F, for N 153 at approximately 1050 F, and for S 495 at approximately 1050 F, all for a stress of 30,000 psi.

H. F. Moore.[6] The author has presented an interesting summary of some preliminary results of damping tests of several high-temperature-resisting metals under repeated cycles of stress. While, as the author freely states, these results are not yet sufficient in number, or range of tests, to serve as a basis for quantitative values, the author is to be thanked for giving publicity to preliminary results in this field about which so much is yet to be learned. His use of a fatigue machine driven by compressed air in studying damping effects offers promise of usefulness in the study of change of damping, and his use of the variation of pressure as the tests proceed is worthy of critical study.

To this discusser the further detailed study of the phenomenon of damping seems to be another approach to the search for an experimental test which may possibly serve to locate the very early stages of the spreading fatigue crack, and thus to serve to shorten the long time necessary to find limiting stresses for oft-stressed machine parts. It would seem worth trying to study the change of wave form of the damping curve after various lengths of time and different numbers of cycles of vibration, as well as to note the change of pressure.

In the investigation of the effect of repeated stress at high temperatures, it may well be remembered that in such tests creep as well as repeated stress affects the results, and the study of creep occurring in any tests, especially tests which take a long time to carry out, may yield some valuable information. Again, the author is to be thanked for giving us a somewhat unusual viewpoint from which to study the behavior of metals under internal friction, especially metals at high temperatures.

Author's Closure

Work done since this paper was submitted and still continuing gives further support to the results reported. Comparisons now being made between damping curves and pressure values indicate a fairly linear relationship between pressure divided by stress and the logarithmic decrement. However, as expected, the machine damping is fairly high, being about 0.7 per cent at low stresses, down to 0.4 per cent at high stresses. By subtracting the machine damping quite reasonable values of damping have been obtained in the few cases where a direct comparison has been made to more orthodox damping tests. Due to the high machine damping it is obvious that very low internal-damping values cannot be accurately obtained.

The author wishes to thank the discussers for their consideration. The suggestions of Mr. Moore are being given careful thought and appear worthy of incorporation in our program.

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[5] "Measurement of the Damping of Engineering Materials During Flexural Vibration at Elevated Temperatures," by Carl Schabtach and R. O. Fehr, *Journal of Applied Mechanics*, Trans. ASME, vol. 66, 1944, p. A-86.

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