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CAVITATION DAMAGE IN LIQUID METALS

(Potassium Studies)

by

S. L. Rudy, A. Thiruvengadam

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prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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HYDRONAUTICS, incorporated
research in hydrodynamics

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TECHNICAL PROGRESS REPORT 607-3
For the Period
1 November to 31 December 1966

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I. ABSTRACT

Cavitation damage data are presented showing the rate of volume loss as a function of test duration for TZC, Cb-132M, and T-111, in liquid potassium at 600°F. The effect of potassium temperature from 400 - 1200°F on the steady-state zone rate of damage for each of the above metals is also given. 316 stainless steel and TZC exhibit peak rates of damage at 600°F whereas, Cb-132M and T-111 peak damage rates occur at 800°F.

Selected mechanical data at elevated temperatures, are given for the metals tested.

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II. INTRODUCTION

A continuing series of experiments are being performed in high temperature liquid potassium using a controlled environment test facility described in Reference 1. This is the third technical progress report describing additional experiments performed in this facility which complete the first phase of the test program. The effect of testing time on the cavitation damage rates of TZC, Cb-132M, and T-111 at a potassium temperature of 600°F were obtained through steady state where two heat treated conditions of an alloy were tested, the heat treated condition which exhibited the greatest resistance to damage was used for the following tests.

These same specimens in steady state condition were tested as preselected potassium temperatures between 400 and 1300°F to determine the effect of temperature on the cavitation damage rate, and secondly to find the temperature at which peak damage occurs.

III. EXPERIMENTAL RESULTS AND DISCUSSION

TZC Alloy

Cavitation damage testing of stress relieved TZC specimens* to steady state at a potassium temperature of 600°F was achieved in 6 to 7 hours. The rate of volume loss with increasing test time for the TZC specimens is shown in Figure 1. The peak rate of volume loss, as well as the steady state rate, for stress relieved TZC is lower than that for Recrystallized TZC** as can be seen from Figure 8. The very noticably chipped rock appearance of recrystallized TZC is in sharp contrast to the more regular, slightly "grainy" appearance of the cavitated surface of the stress relieved TZC specimens. For the determination of the effect of potassium temperature on the damage rate of TZC, the stress relieved specimens were chosen since they exhibited greater resistance to damage than the recrystallized form. Figure 2 shows the rate of damage as a function of temperature. TZC exhibited a peak rate of damage at a potassium temperature of 600°F as was previously found true for 316 stainless steel (Reference 2).

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* Heat treatment: Stress relieved at 2200°F for 1/2 hour (V.C.) (Vacuum Cooled).

** Heat treatment: Recrystallized at 3400°F for 1 hour (V.C.)

Cb-132M

The next metal tested in the series was stress relieved* and recrystallized** Cb-132M. The rate of volume loss with increasing testing time was continued at a potassium temperature of 600°F until steady state was reached. The stress relieved condition required 7-1/2 to 8-1/2 hours (Figure 3), where the recrystallized form reached steady state in only 6 to 7 hours (Figure 4). Stress relieved Cb-132M exhibited both a lower peak rate of volume loss and lower steady state rate, than did the recrystallized form. Damage patterns of both stress relieved and recrystallized Cb-132M were nearly identical. Both showed a regular, slightly grainy, eroded appearance somewhat similar to that observed previously in ductile metals such as stainless steel. Stress relieved Cb-132M was selected for further testing at varying potassium temperatures, since this condition exhibited the greatest damage resistance. Stress relieved Cb-132M specimens, in steady state, were tested at the preselected potassium temperatures between 400 and 1300°F to determine the effect of liquid temperature on the rate of volume loss. A peak rate of damage occurred at 800°F (Figure 5), whereas the two previous metals tested, 316 stainless steel and TZC, displayed a peak rate of damage at 600°F (Figure 2).

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* Heat treatment: Stress relieved 1 hour at 2200°F, (V.C.)

** Heat treatment: Recrystallized 1 hour at 2700°F, (V.C.)

T-111

The rate of volume loss with increasing testing time for T-111 in the stress relieved condition*, was obtained at a potassium temperature of 600°F. Steady state condition was achieved in 7 to 8 hours; (see Figure 6). A regular, silvery, matte finish, was observed on the eroded surface of the T-111 specimens, very similar to that obtained on 316 stainless steel (Reference 2).

These steady state specimens were then run at the preselected liquid potassium temperatures to determine the effect of liquid temperature on the rate of volume loss for T-111. A peak rate of damage occurred at 800°F. Figure 7 shows the rate of damage as a function of temperature. One point of major interest is the behavior of the damage rate for T-111 above 1000°F. When the same T-111 specimens, previously tested at temperatures from 400 to 1000°F, were tested in 1200°F liquid potassium, the observed rate of volume loss was consistently 5 times the rate noted at 1000°F.

The potassium in which the 1200°F tests were conducted was the same batch that had been used for the previous T-111 temperature series. However the 1000°F and 1200°F tests were run on two consecutive days. Sometime during the night of this test period there was a brief power interruption which stopped the vacuum pump. (It is standard practice to continue evacuation of the drybox chamber during the night after testing is completed). Due to

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* Heat treatment: Stress relieved 1 hour at 2000°F, (V.C.)

the particular electrical hookup, (for safety) the vacuum pump does not normally restart when the power is reapplied unless the relay is manually tripped. The stopping of the vacuum pump allowed the box to back fill slowly with air (through the vacuum pump) and by morning the dry box chamber was found to be at atmospheric pressure. Even though the box chamber was filled with air, the retort was still sealed from the chamber and vacuum system which is normal practice. Standard clean up conditions were begun by evacuation of the chamber for 2 hours, back filling, with pure argon, and leaving it for 20 minutes at atmospheric pressure. After this, the box was again evacuated to a pressure of 10 millitorr and then once more back filled with fresh argon. A routine oxygen and moisture check showed that the levels were well below 15 ppm. in the dry box chamber.

The potassium that was in the retort was heated to 600°F. A sample was withdrawn from the retort, and no discoloration or foreign material was observed. With this observation of the liquid metal and the fact that the retort was sealed it was decided that the potassium was not contaminated and could be used for the remaining tests. When the rate of damage of T-111 at 1200°F was unusually high as compared to previously obtained rates, a recheck test series was run. The steady state specimens were retested at 600°F to determine whether they would exhibit the same steady state rate of volume loss obtained previously. This recheck test series yielded consistent rates of volume loss which were only 1/3 of those observed before. It is known that T-111 is very sensitive to oxygen at elevated temperatures.

The potassium was sampled in the standard manner and dumped. The cause for this reduced damage is not known, however the potassium sample will be analyzed for oxygen contamination during the next period. A new batch of pure potassium was transferred to the retort, which was heated to 1000°F for 1 hour, then cooled to 600°F and dumped. This procedure is standard to assure complete absorption of oxides in the clean liquid metal which may have been left from a previously suspected contaminated batch of potassium. Having completed the retort cleaning, a new batch of high purity potassium was transferred to the retort and heated to 600°F. Using this potassium, a new stress relieved T-111 specimen (no. 16) was tested until it reached steady state. The rate of volume loss with time correlated well with the previous T-111 specimens as shown on Figure 6. The rate of volume loss at 1000°F for this new specimen was nearly the same as for the other specimens.

Since these data were fairly representative of previously obtained values we proceeded with the 1200°F tests. At 1200°F, the first test point, of 15 minute duration, showed a rate of volume loss of only 1/3 the rate obtained at 1000°F, and an order of magnitude less than that obtained with the previous specimens (nos. 14 and 15). (Figure 7). A second 15 minute test showed that the rate of volume loss had increased to approximately the same as that exhibited by the two previous T-111 specimens. All other successive tests yielded the same high results. Reasons for this phenomenon are not yet clear and further analysis will be attempted in the final report.

A comparison of the cavitation damage resistance of 316 stainless steel, TZC, Cb-132M and T-111 in liquid potassium is shown in Figure 8. Although peak damage rates occur at varying times for each alloy tested, the general trend of damage rate as a function of time is the same.

An early investigation showed that the cavitation damage rate of 316 stainless steel in liquid sodium was highly dependent on the temperature; (Reference 3). Also, 100-A Titanium was shown to have the property of cavitation damage rate dependence upon liquid sodium temperature, (Reference 4). All of the alloys tested so far in this current series, 316 stainless steel, TZC, Cb-132M and T-111, in liquid potassium exhibit this same cavitation damage rate dependence upon liquid temperature. It is interesting to note that 316 stainless steel and TZC show a decided peak rate of damage at a liquid temperature of 600°F, whereas Cb-132M and T-111 exhibit this same type of damage rate peak at a liquid temperature of 800°F. These results are shown in Figure 9. A possible explanation of these peaking trends may be obtained by considering the interaction of the mechanical properties of these alloys and liquid properties of the potassium over the temperature range under consideration. Such analyses will be attempted in the final report.

Mechanical Properties of Alloys Tested

Pertinent mechanical properties of 316 stainless steel, TZC, Cb-132M and T-111 are presented in Figures 10 through 13. Through use of the data from these figures, the estimated strain energy

(Reference 5) of each metal was computed for temperatures of interest. The estimated strain energies of these metals at elevated temperatures are presented in Figure 14.

Potassium Purity Analysis

Potassium oxygen analysis sampling is being continued according to schedule, with oxide impurities being kept below the specified 50 ppm limit. Table 1 gives the results of two more random oxygen analyses.

IV. CONCLUSIONS

Cavitation damage resistance of TZC alloy in potassium up to 1000°F is better than 316 stainless steel, T-111, or Cb-132M. Above 1000°F, 316 stainless steel is slightly more resistant to damage than TZC, T-111, or Cb-132M.

V. FUTURE WORK

We plan to install a secondary seal system on the retort nozzle for conducting the pressure cavitation studies in liquid potassium. These tests will be conducted on 316 stainless steel and TZC at 4 potassium temperatures between 400 and 1300°F and at 12 retort pressure levels between 2 and 40 psia. On completion of these studies, a final report will be prepared incorporating the analysis of these results.

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TABLE 1

Oxide Impurity Levels in Liquid Potassium

Sample No.	Time Taken	Date Taken	Time Potassium was held in retort	Box O_2 (ppm)	Box H_2O (ppm)	Potassium Temp. °F	Oxygen Impurity ppm*
12	4 PM	12/9/66	7 days	56.0	0.4	400	7
13	4:30 PM	12/22/66	13 days	1.0	0.2	400	7

* Unamalgamated residue calculated as oxygen from K_2O.

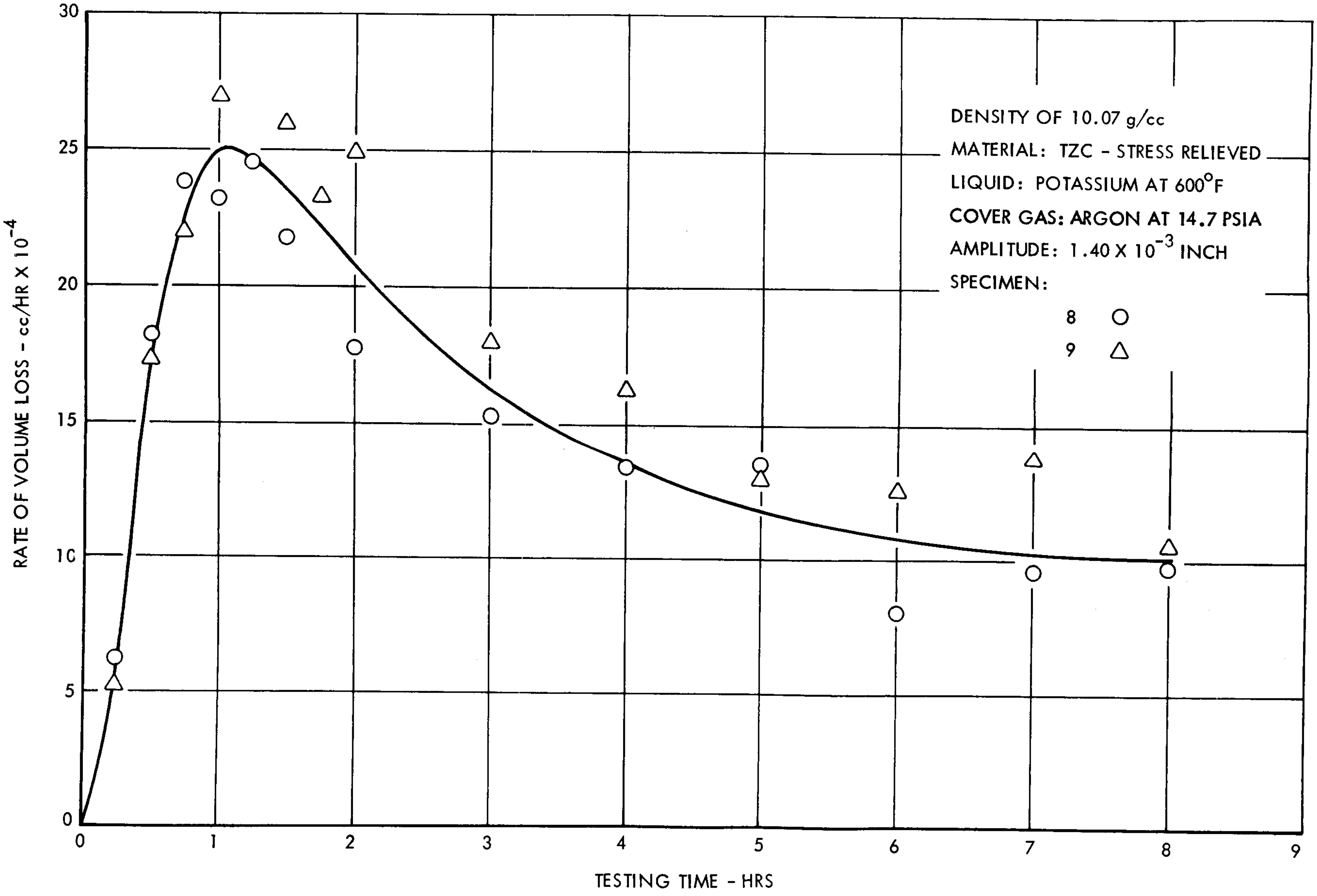

FIGURE 1 - EFFECT OF TESTING TIME ON THE CAVITATION DAMAGE RATE OF TZC IN LIQUID POTASSIUM

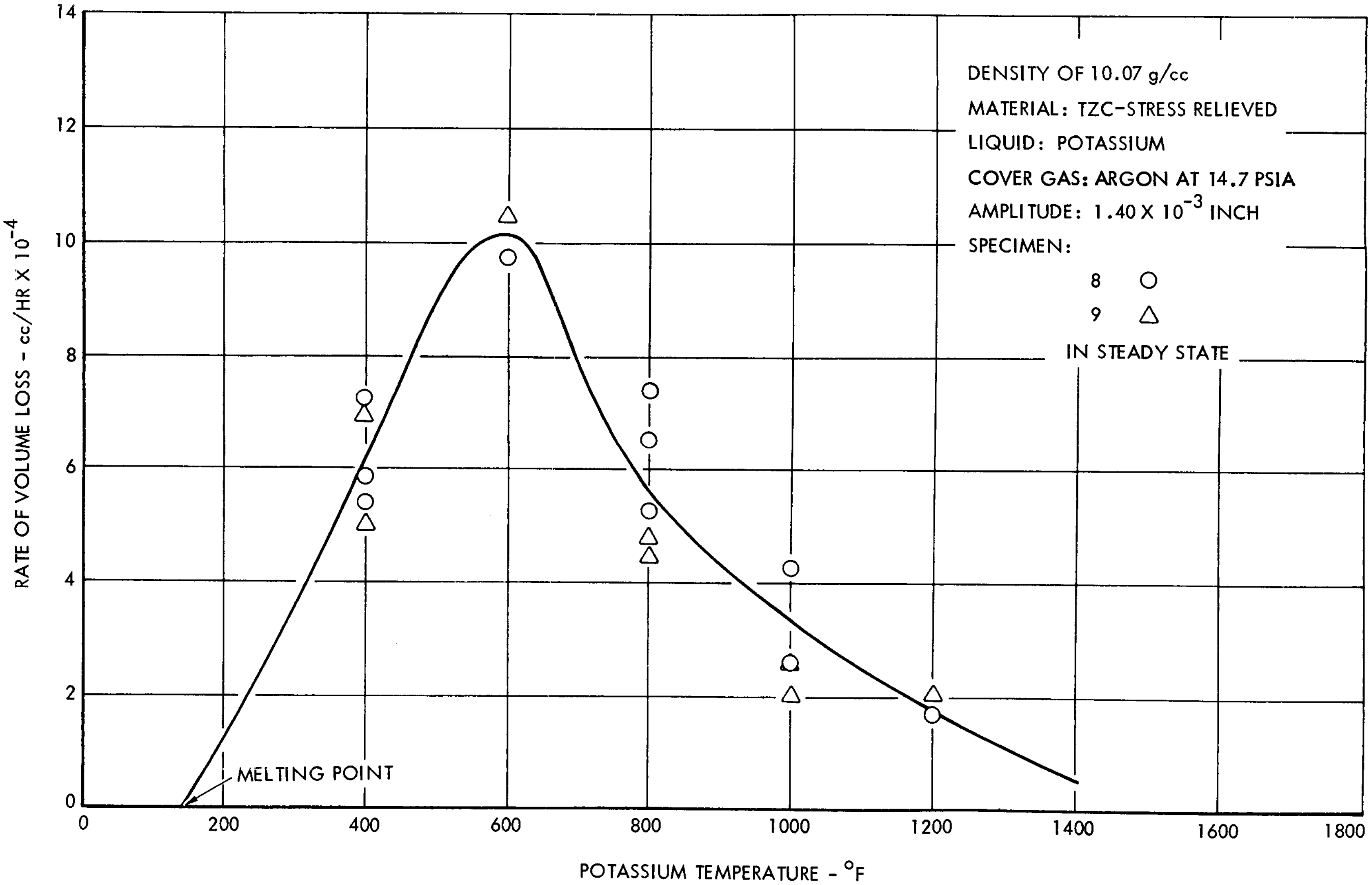

FIGURE 2 - EFFECT OF TEMPERATURE ON THE CAVITATION DAMAGE RATE OF TZC IN LIQUID POTASSIUM

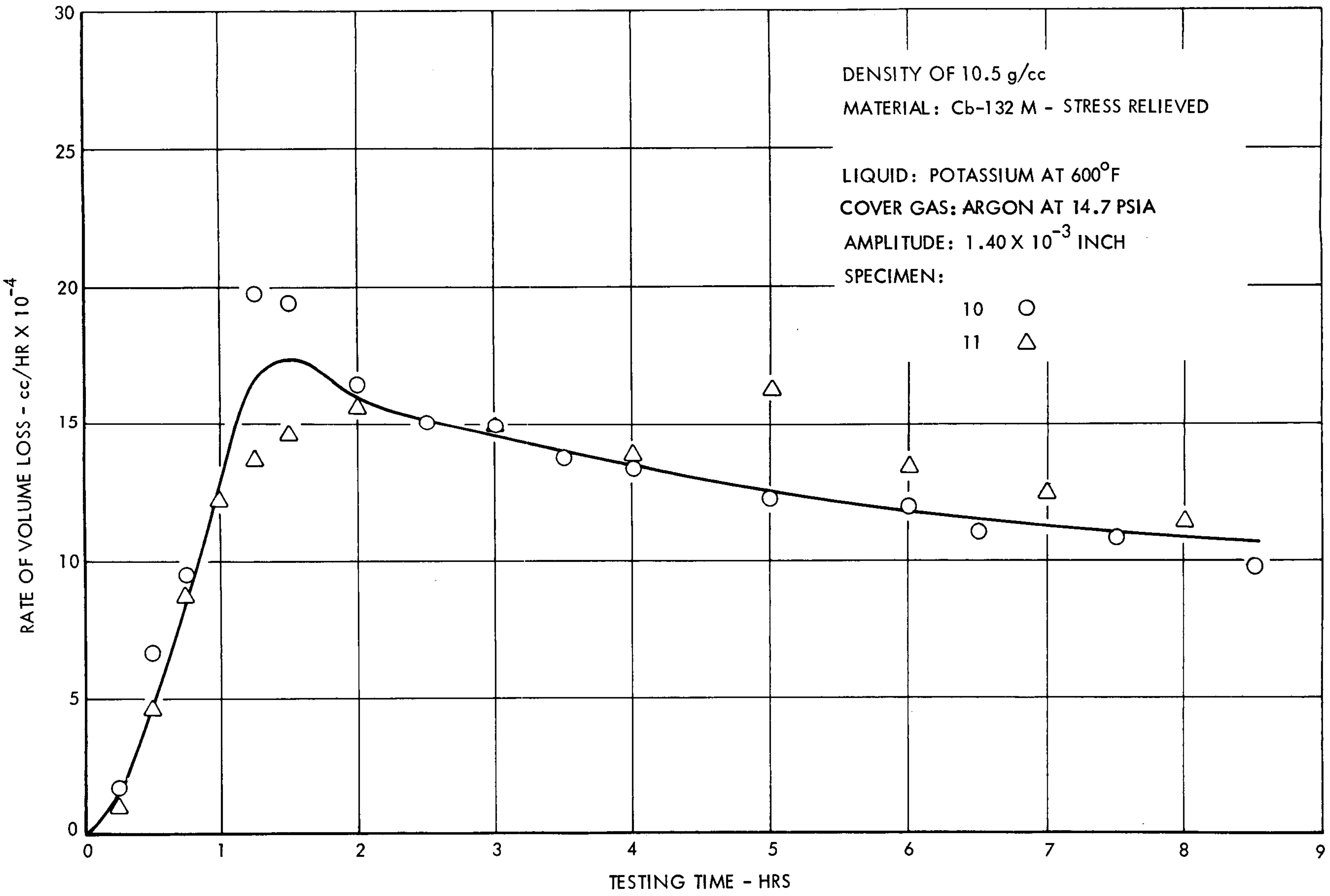

FIGURE 3 - EFFECT OF TESTING TIME ON THE CAVITATION DAMAGE RATE OF CB-132 M IN LIQUID POTASSIUM

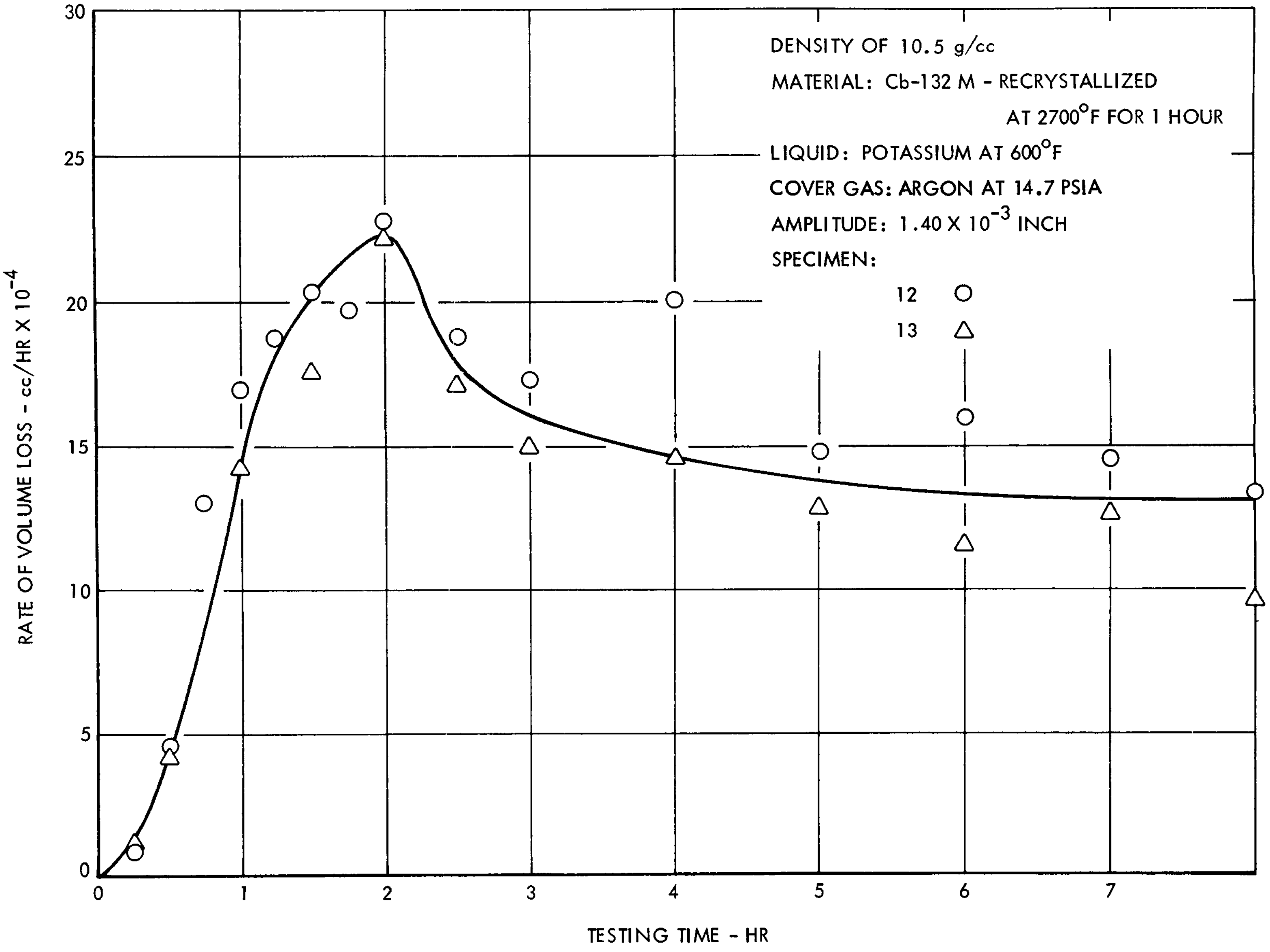

FIGURE 4 - EFFECT OF TESTING TIME ON THE CAVITATION DAMAGE RATE OF CB-132 M IN LIQUID POTASSIUM

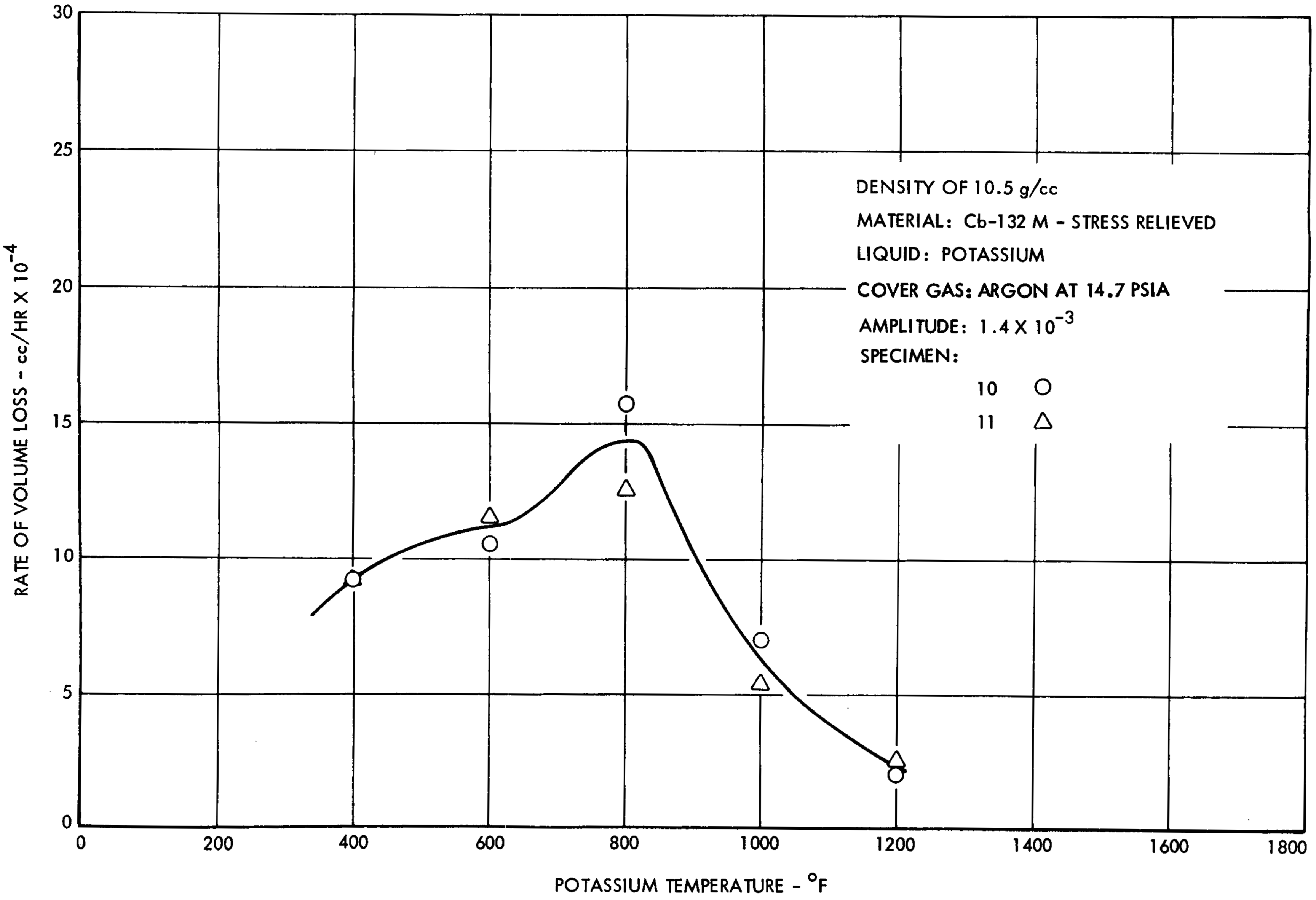

FIGURE 5 - EFFECT OF TEMPERATURE ON THE CAVITATION DAMAGE RATE OF CB-132 M IN LIQUID POTASSIUM

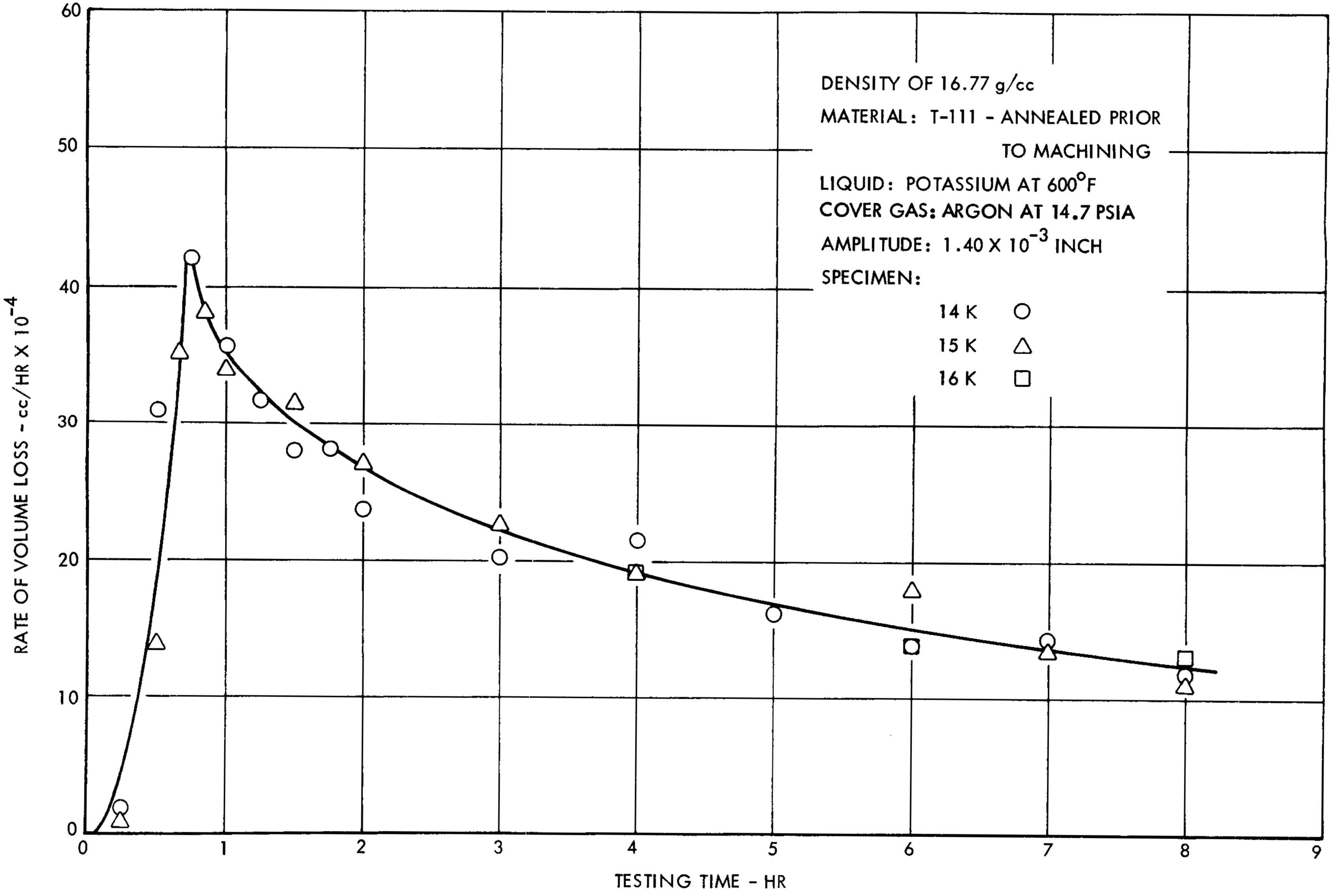

FIGURE 6 - EFFECT OF TESTING TIME ON THE CAVITATION DAMAGE RATE OF T-111 IN LIQUID POTASSIUM

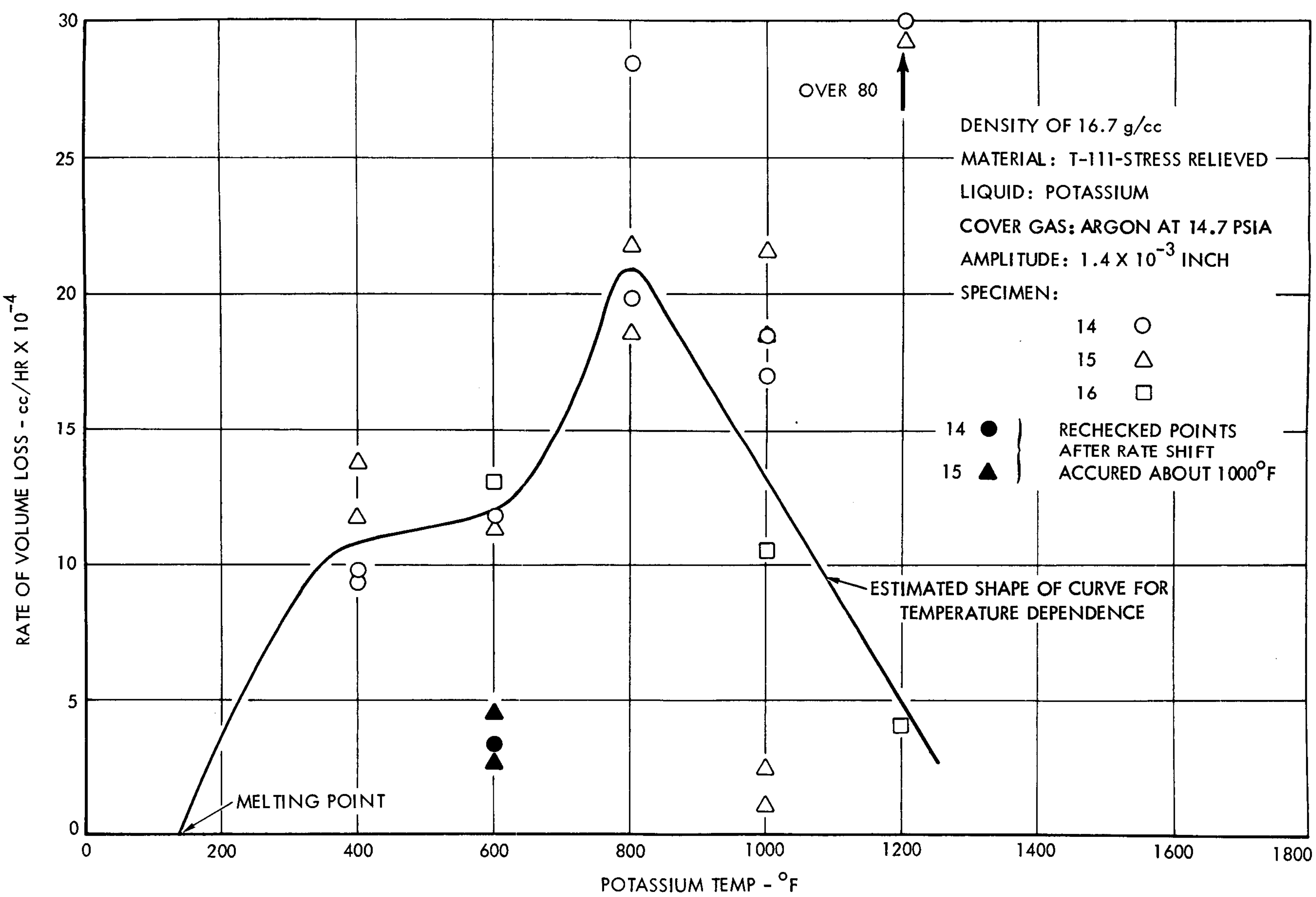

FIGURE 7 - EFFECT OF TEMPERATURE ON THE CAVITATION DAMAGE RATE OF T-111 IN LIQUID POTASSIUM

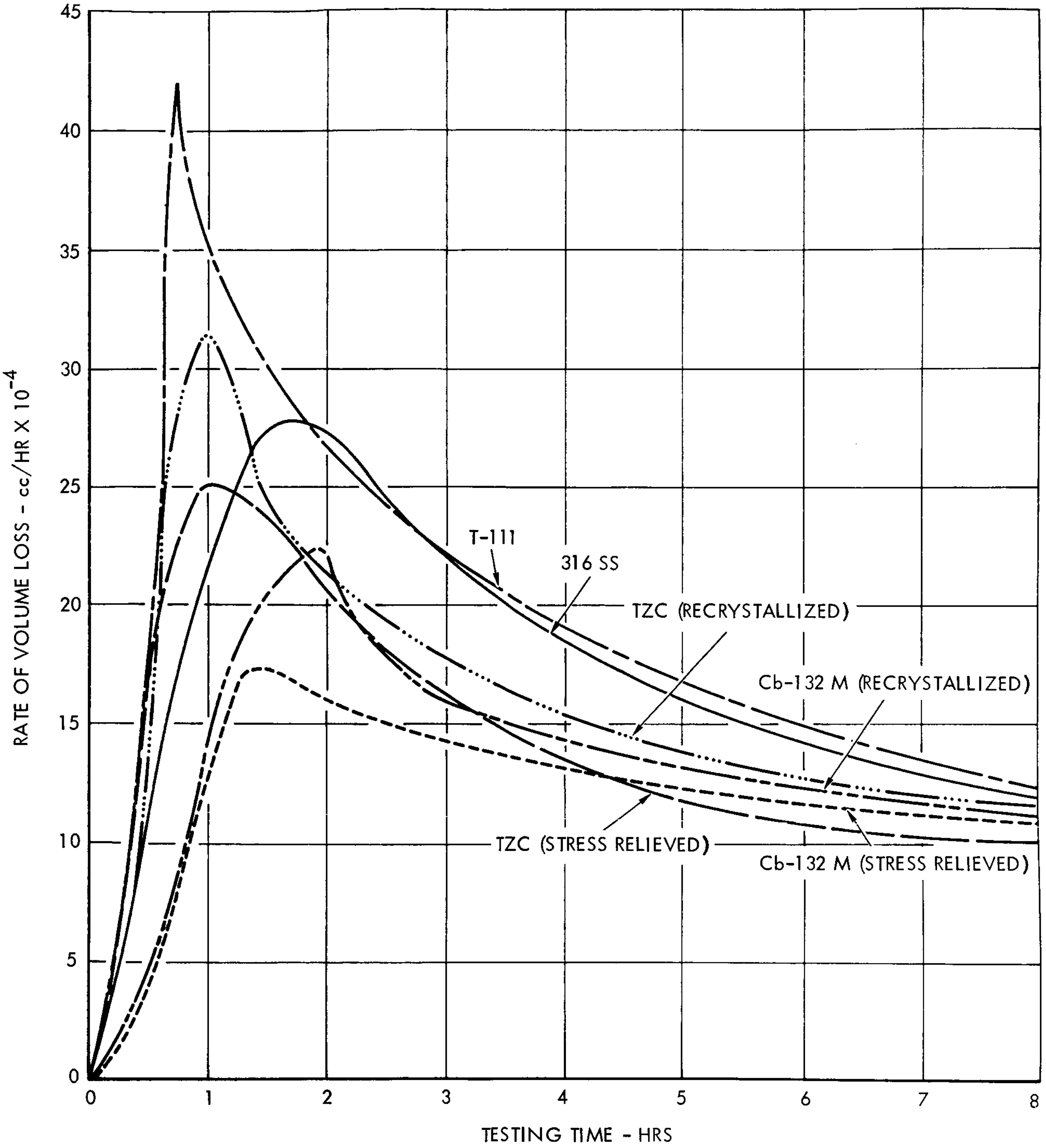

FIGURE 8 - COMPARATIVE CAVITATION DAMAGE RESISTANCE OF REFRACTORY ALLOYS IN HIGH TEMPERATURE LIQUID POTASSIUM

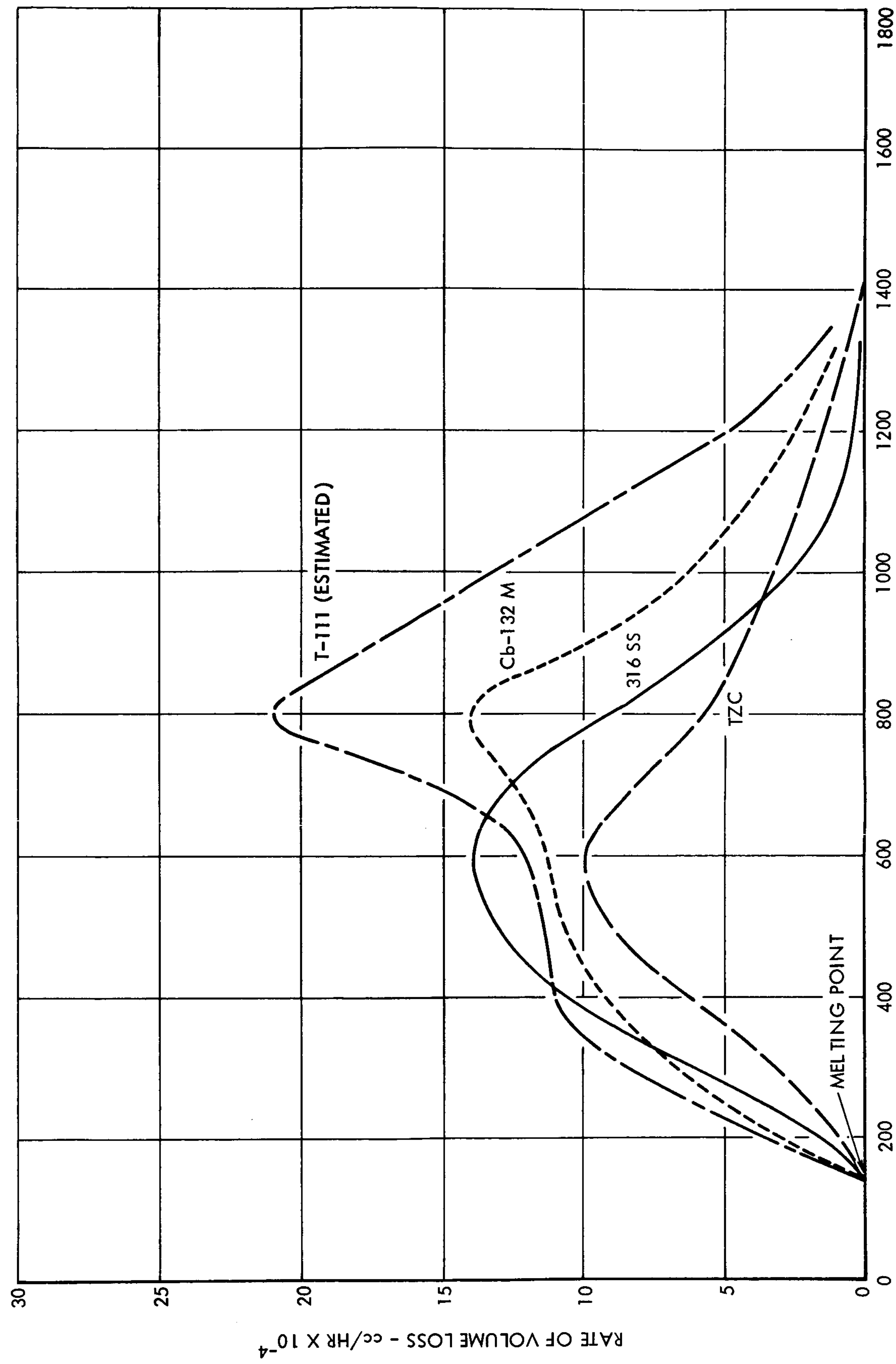

FIGURE 9 - COMPARISON OF THE EFFECT OF TEMPERATURE ON THE CAVITATION DAMAGE RATE OF REFRACTORY ALLOYS IN LIQUID POTASSIUM

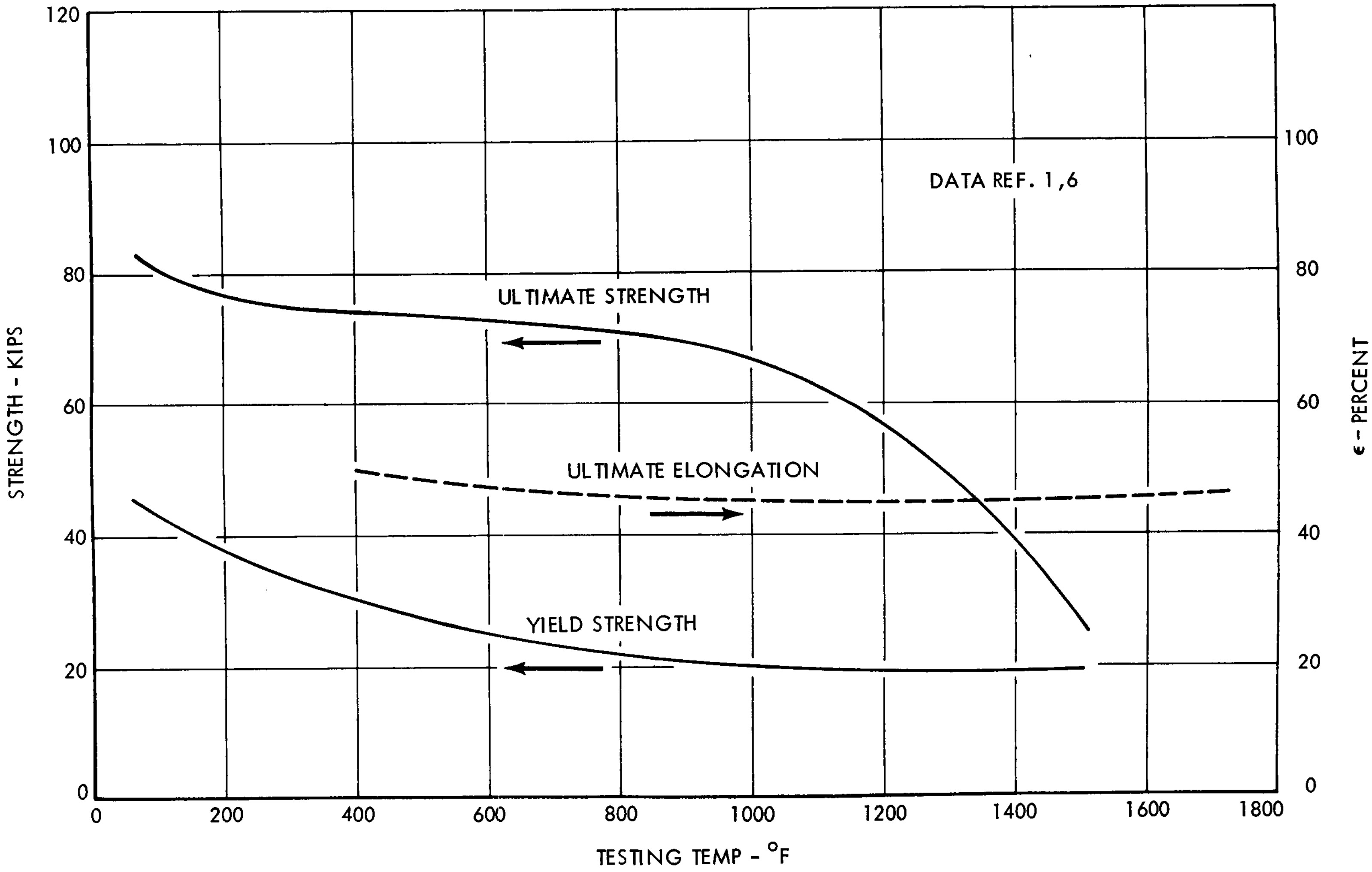

FIGURE 10 - SELECTED MECHANICAL PROPERTIES OF 316 STAINLESS STEEL AT ELEVATED TEMPERATURES

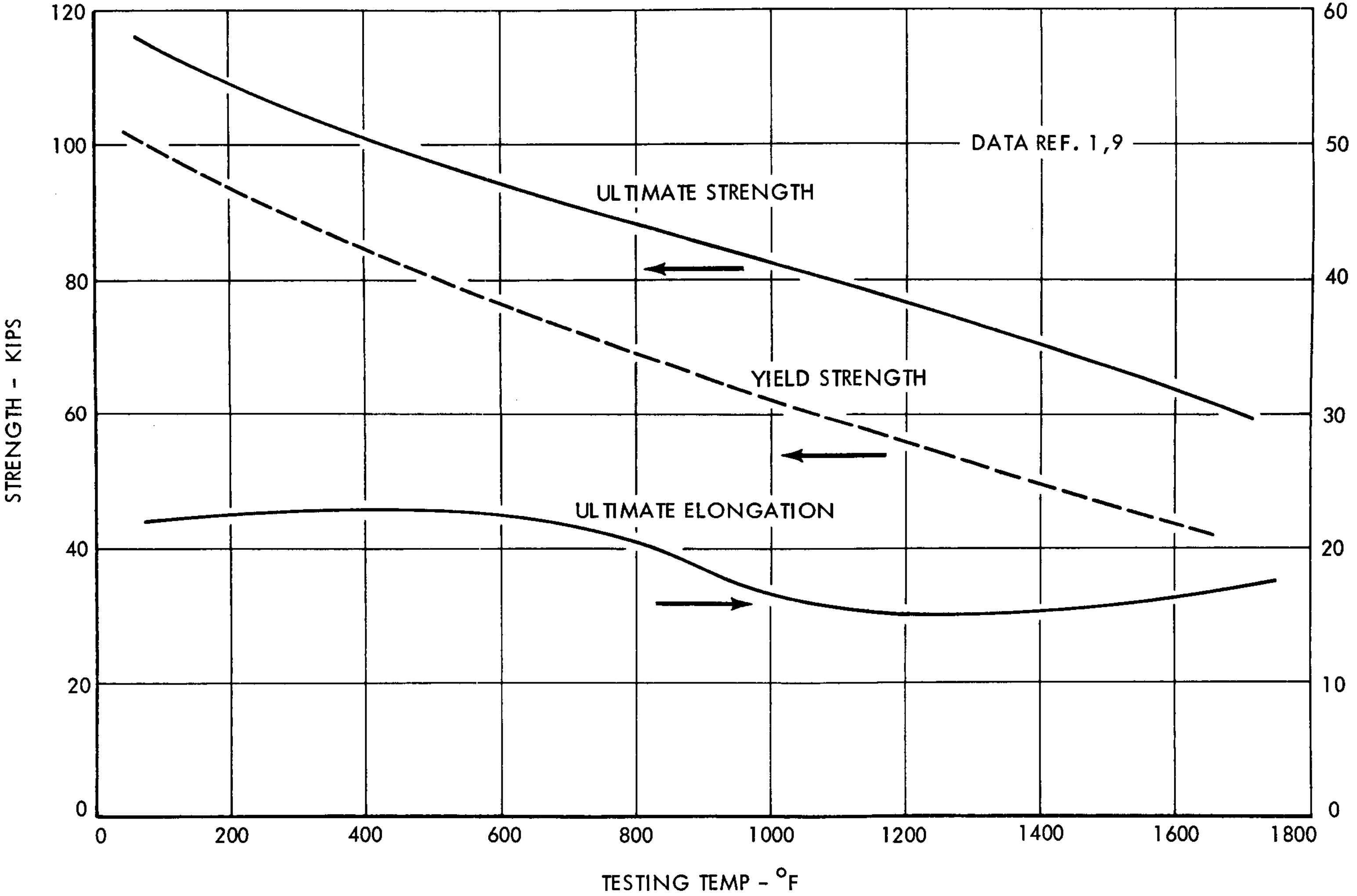

FIGURE 11 - SELECTED MECHANICAL PROPERTIES OF TZC AT ELEVATED TEMPERATURES

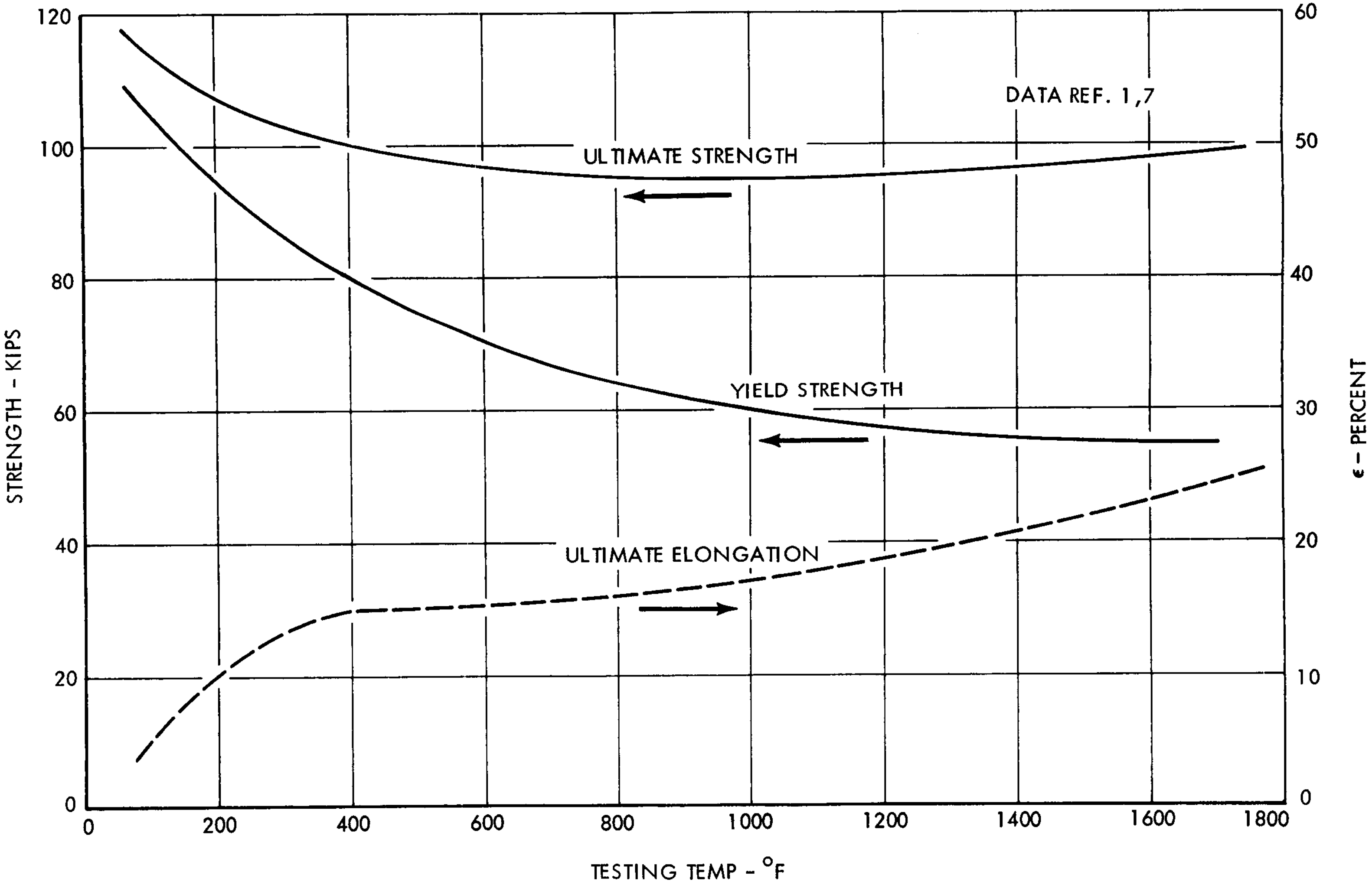

FIGURE 12 - SELECTED MECHANICAL PROPERTIES OF CB-132 M AT ELEVATED TEMPERATURES

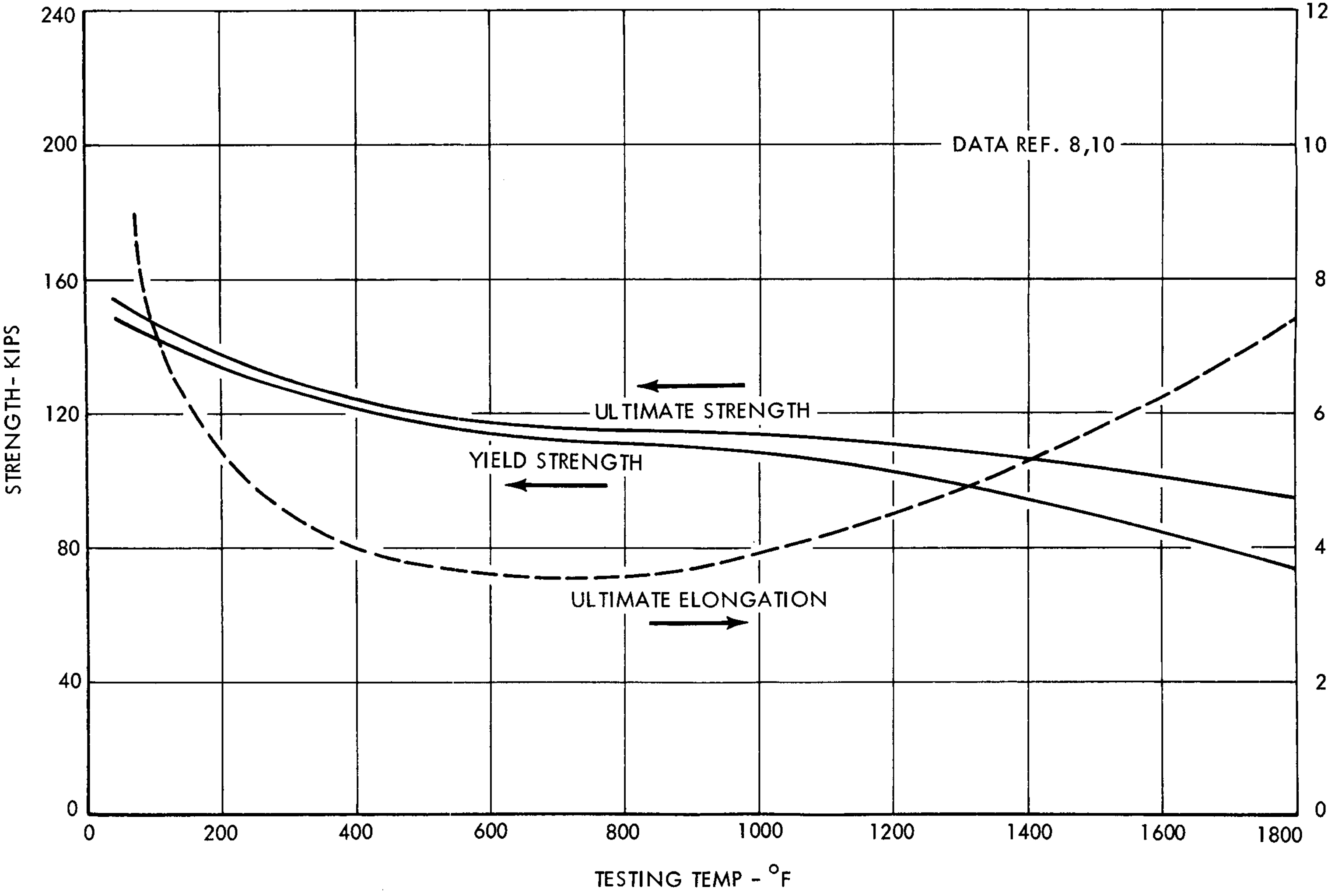

FIGURE 13 - SELECTED MECHANICAL PROPERTIES OF T-111 AT ELEVATED TEMPERATURES

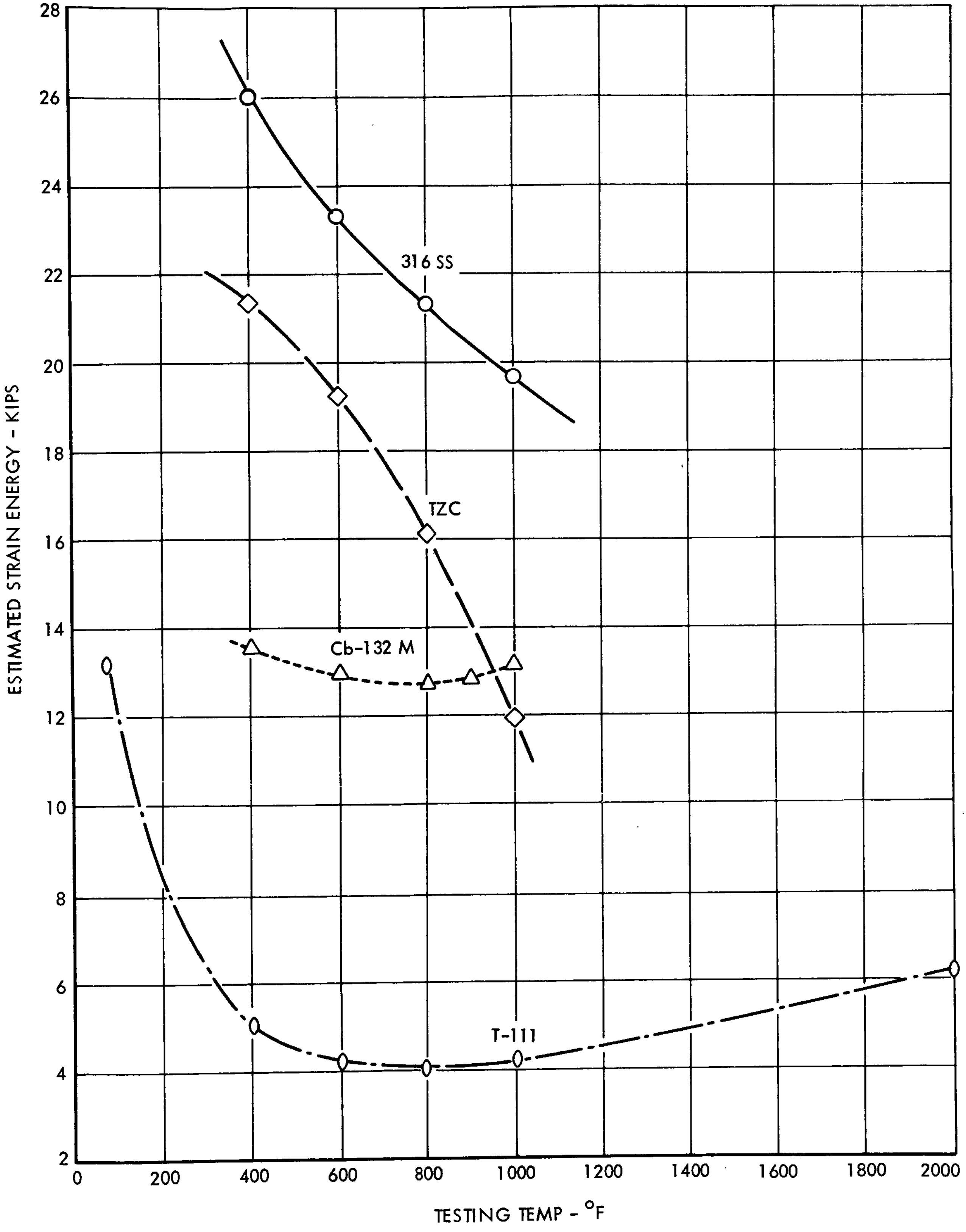

FIGURE 14 - EFFECT OF TEMPERATURE ON THE ESTIMATED STRAIN ENERGY OF 4 REFRACTORY ALLOYS