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# CAVITATION DAMAGE IN LIQUID METALS

by

A. Thiruvengadam, H. S. Preiser and S. L. Rudy

prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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## HYDRONAUTICS, incorporated

research in hydrodynamics

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# TECHNICAL PROGRESS REPORT 467-2
For the Period
1 January - 31 March 1965

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## I. ABSTRACT

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Progress for the period 1 January 1965 to 31 March 1965 is reported herein. The significant result achieved during this period is the determination of the effect of temperature on the rate of cavitation damage of 316 stainless steel in pure liquid sodium at temperatures up to 1500°F. The intensity of cavitation damage was estimated for each temperature using the rate of damage obtained from these experiments and published strain energy values. The intensity is found to be very much less at higher temperatures. The intensity of damage at 1000°F is about a tenth of the intensity at 400°F; at 1500°F the intensity of damage is about a thousandth of that at 400°F.

author

## II. INTRODUCTION

An understanding of the mechanism of cavitation damage in high temperature liquid metals such as sodium and potassium would greatly aid the designer of equipment and systems using these liquid metals. With this motivation, a series of systematic experiments are being performed at HYDRONAUTICS, Incorporated with the help of a controlled environment test facility described in detail in References 1 and 4. This is the second technical progress report describing additional experiments performed in this facility. The most significant among these experiments deals with the effect of the temperature of the liquid sodium on the cavitation damage rate of 316 stainless steel. There was an earlier attempt to obtain similar data using eutectic NaK up to 1000°F which showed that the cavitation damage on 316 stainless steel was strongly dependent on the temperature, Reference 2. These tests were reported to be inconclusive because of the lack of control of "sound factors". However, the general trend was that the damage was much lower at higher temperatures in conformity with the observations made in common liquids such as water, Reference 3.

More recently, 100A titanium was tested in liquid sodium up to 1000°F and again the results showed reduction in damage rate at higher temperatures, Reference 4. However, these experiments also proved to be less valuable in the sense that the oxide impurity in the liquid sodium was not known. Because of the limitations of the earlier purge type dry box (atmosphere displaced by pressurized argon without benefit of vacuum pump-down), the oxide levels were believed to be near saturation values for each of the test temperatures. These considerations, among others, led to the design of an improved facility in which sodium purity could be maintained around 30 ppm of oxygen over a test duration of 8 hours. It was decided to test 316 stainless steel in low oxide sodium among other tests planned. The results of this phase experiments are presented in this report.

## III. RESULTS AND DISCUSSION

### Effect of Testing Time.

It has been established that the rate of cavitation damage is time dependent, Reference 4. The initial run of experiments on 316 stainless steel, Reference 1, aimed at obtaining the relationship between the rate of weight loss and the test time in 1000°F sodium, showed that the intensity at this temperature was so low that only a few surface indentations could be observed up to 25 hours of testing. There was no observable weight loss. For this reason, the damage rate versus time relationship was obtained at 400°F sodium and the results are shown in Figure 1. The steady state was reached in approximately 5 to 6 hours.

### Effect of Temperature of Sodium.

Using a 316 stainless steel specimen that had reached the steady state zone as shown in Figure 1, a series of experiments was conducted over a range of temperatures between 300°F to 1500°F at 100°F intervals in order to determine the variation of the rate of cavitation damage with the temperature of the sodium.

The duration of each test run was one hour. The damage rate was determined from one one-hour experiment for each reading. A minimum of three readings were taken at each temperature in order to check the reproducibility of the data. The precautions for obtaining high purity sodium as described in Reference 1 were maintained throughout these experiments. The results are shown in Figure 2. The rate of weight loss at $1500^{\circ}F$ is of the order of a hundredth of a milligram per hour as compared to 16 mg/hour at $400^{\circ}F$.

An understanding of this experimental result involves the knowledge of how the material properties as well as the liquid properties change as the temperature varies. One of the properties of the material that is known to control the energy absorbing capacity of the material in fracture due to cavitation damage is the strain energy of the metal, Reference 4. The strain energy is given by the area under the stress-strain diagram. Unfortunately, the stress-strain data are not available for the high temperatures of interest in these experiments. However, the values of yield strength, ultimate strength and ultimate elongation are available for each temperature, and using these data, the strain energy was estimated from the following approximate relationship.

$$S_e = \frac{(Y + T)\epsilon}{2} \qquad [1]$$

where

$S_e$ is the strain energy

Y is the yield strength

T is the ultimate strength

$\epsilon$ is the ultimate elongation

The variation of strain energy with temperature for 316 stainless steel was computed from data given in Reference 5 and is shown in Figure 3.

The intensity of cavitation damage is defined as the power absorbed by the material per unit area and is given by

$$I = \frac{\Delta w \; S_e}{\rho A_e \; t} \qquad [2]$$

where

I is the intensity of cavitation damage

$\Delta w$ is the weight loss

t is the test duration

$S_e$ is the strain energy of the metal

$\rho$ is the density of the metal

$A_e$ is the area eroded

The intensity of cavitation damage was estimated using the weight loss data shown in Figure 2 and the strain energy values shown in Figure 3 for various temperatures (see Table I). Figure 4 shows the effect of temperature of liquid sodium on the intensity of cavitation damage. In order to obtain a relative idea of the order of magnitude of the decrease in intensity at higher temperatures, the relative intensity with respect to the intensity at $400^{\circ}F$ is plotted in Figure 5 as a function of temperature. It is interesting to note that the relative intensity of cavitation damage at $1500^{\circ}F$ is of the order of $10^{-3}$. This result is to be expected from the fact that the vapor pressure increases from an order of $10^{-7}$ atmosphere at $400^{\circ}F$ to nearly one atmosphere at $1500^{\circ}F$, Reference 6. From the designers' point of view, this result is useful since it gives him a rough idea of how the damage rate varies with temperature, when the material and cavitation conditions remain constant.

## IV. CONCLUSIONS

The following conclusions may be drawn from the data obtained thus far.

1. The relative intensity of cavitation damage at $1500^{\circ}F$ with respect to that at $400^{\circ}F$ is of the order of $10^{-3}$.

2. The relative intensity at $1000^{\circ}F$ relative to $400^{\circ}F$ is of the order of $10^{-1}$.

## V. WORK TO BE ACCOMPLISHED DURING NEXT REPORTING PERIOD

During the next reporting period it is planned to complete the cavitation damage experiments on TZM, T-222 Stellite 6B and CB-132M at 400, 1000 and 1500$^{\circ}$F and compare their cavitation damage resistance.

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5. "Steels for Elevated Temperature Service," United States Steel, Pittsburgh, Pennsylvania, P. 46, 1961.

6. Jackson, C. D., Editor, Liquid Metals Handbook, Sodium-NaK Supplement, 3rd Edition, TID 5277, Government Printing Office, Washington, D. C., P. 31, July 1955.

TABLE I

Intensity of Cavitation Damage as a Function of Temperature in Liquid Sodium and 316 Stainless Steel

$$I = W . S_e \times 2.9 \times 10^{-6} \frac{\text{Watts}}{\text{Meter}^2} ; \quad W - \text{mgs/hour}; \quad S_e - \text{psi.}$$

| Temp. | Weight Loss* mg/hour | Strain Energy psi x $10^{-3}$ | Intensity watts/meter$^2$ | $\frac{I_T}{I_{400}}$ |
|---|---|---|---|---|
| 300 | 13 | 29.0 | 1.10 | 0.88 |
| 400 | 16 | 27.0 | 1.25 | 1.0 |
| 500 | 6 | 25.0 | 0.44 | .35 |
| 600 | 3 | 23.5 | 0.20 | .16 |
| 700 | 6 | 23.0 | 0.40 | .32 |
| 800 | 6 | 22.0 | 0.38 | .30 |
| 900 | 4 | 21.0 | 0.24 | .19 |
| 1000 | 2 | 20.0 | 0.12 | $.96 \times 10^{-1}$ |
| 1100 | 0.70 | 19.0 | 0.04 | $.32 \times 10^{-1}$ |
| 1200 | 0.25 | 16.5 | 0.012 | $.96 \times 10^{-2}$ |
| 1300 | 0.70 | 13.5 | 0.027 | $.22 \times 10^{-1}$ |
| 1400 | 0.50 | 11.5 | 0.017 | $.14 \times 10^{-1}$ |
| 1500 | 0.01 | 10.0 | 0.003 | $.24 \times 10^{-2}$ |

* Average of three readings.

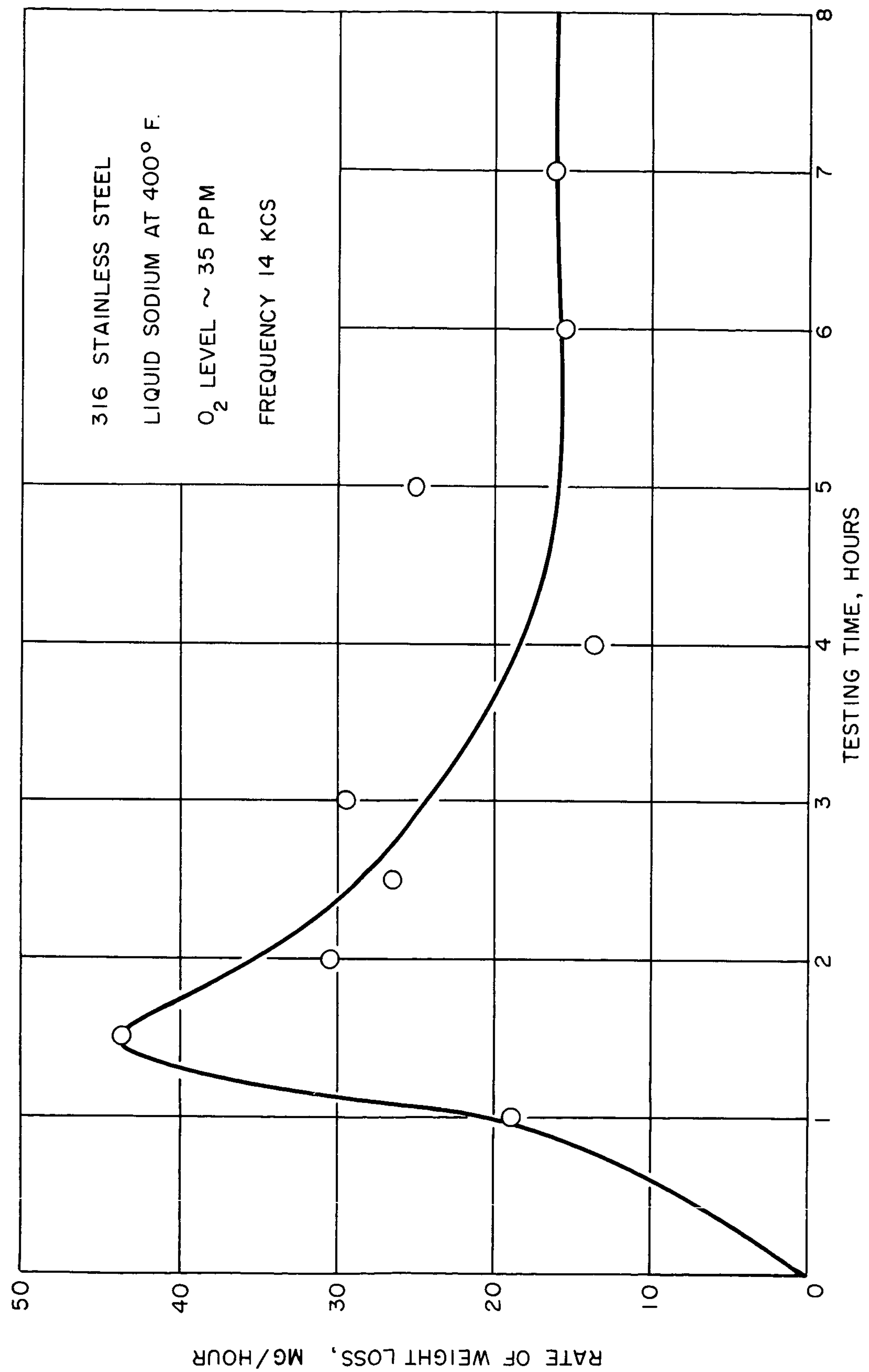


FIGURE 1– EFFECT OF TESTING TIME ON CAVITATION DAMAGE RATE IN 400° F., LIQUID SODIUM

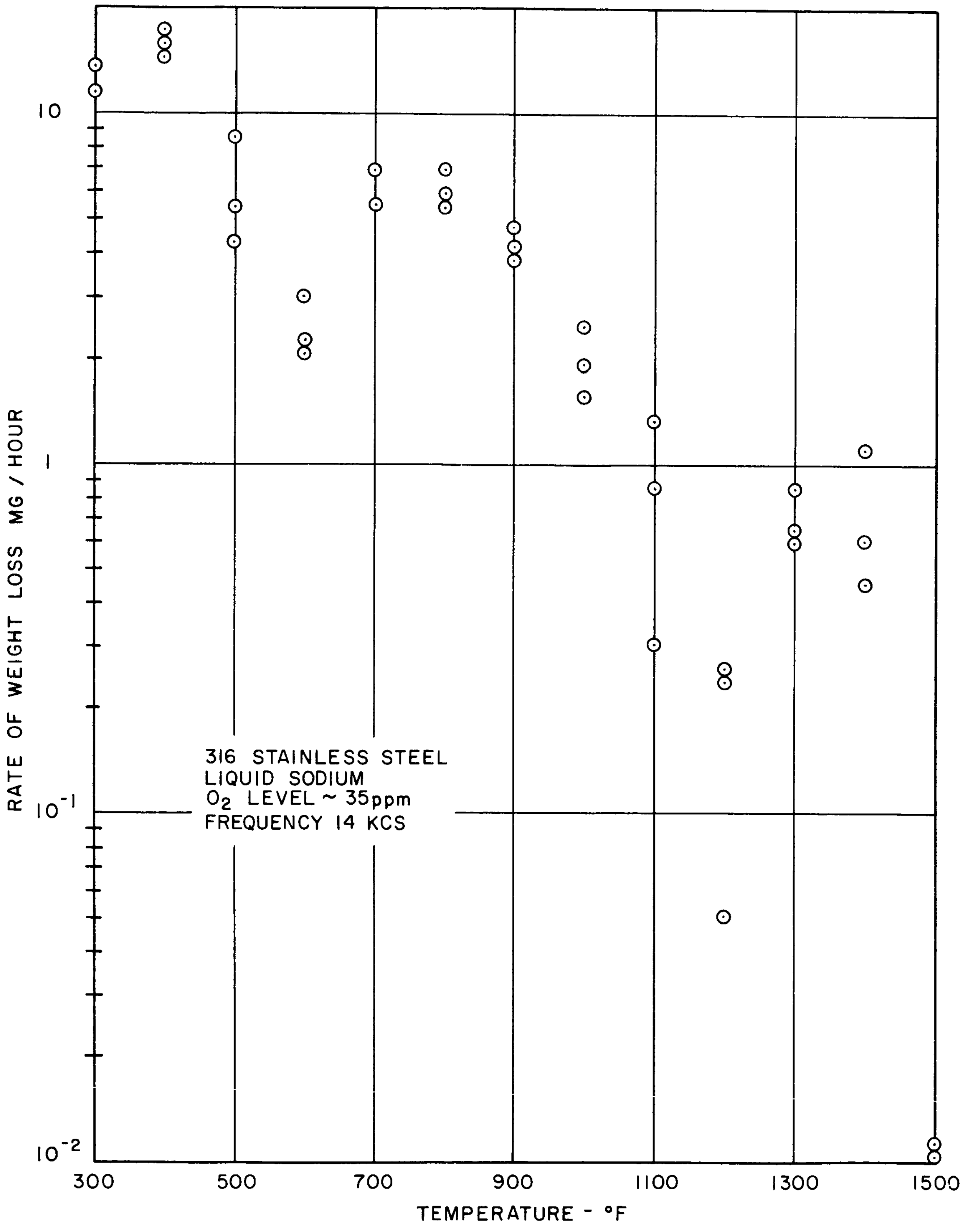


FIGURE 2 - EFFECT OF TEMPERATURE ON THE CAVITATION DAMAGE RATE OF 316 STAINLESS STEEL IN PURE LIQUID SODIUM

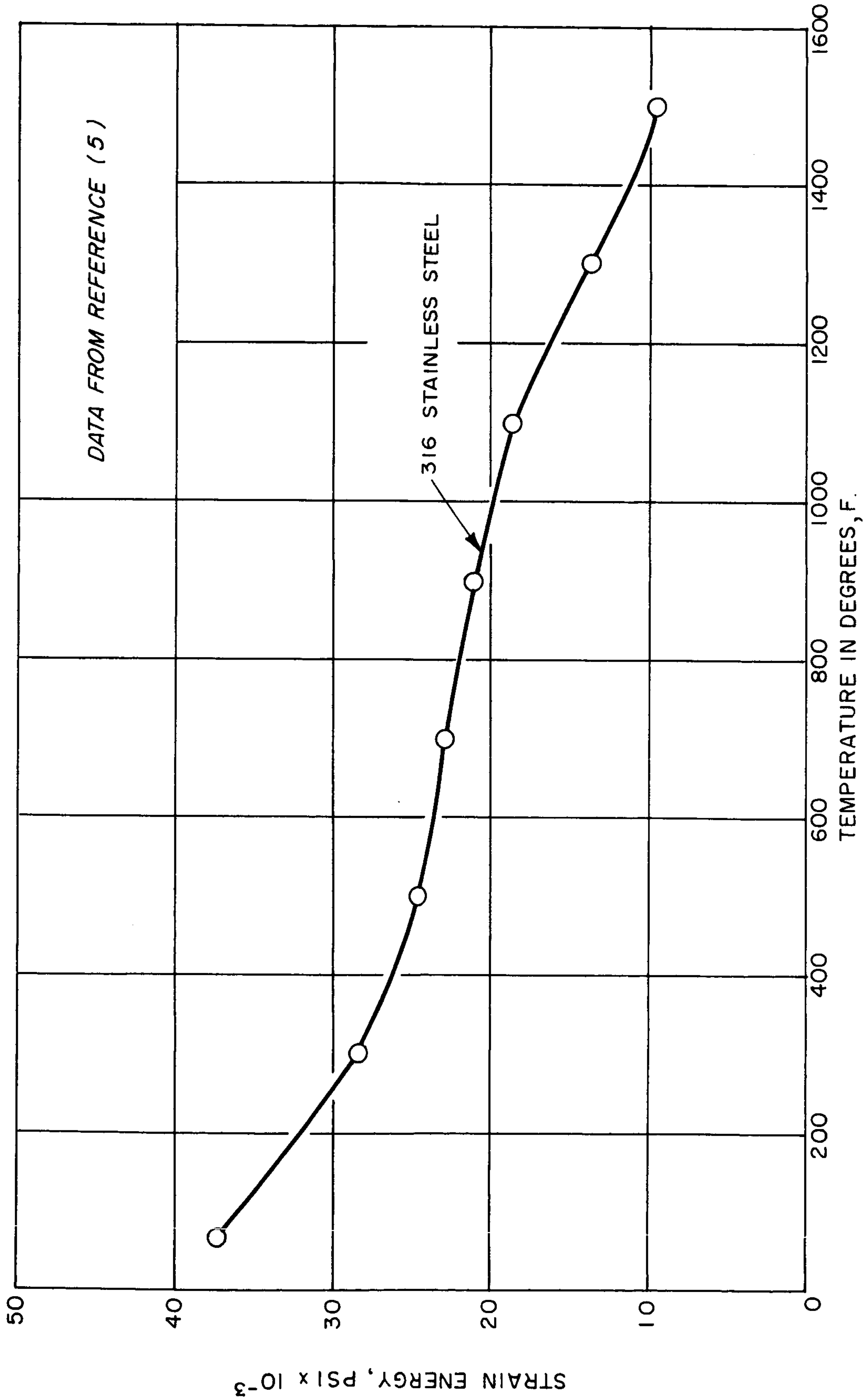


FIGURE 3- EFFECT OF TEMPERATURE ON STRAIN ENERGY

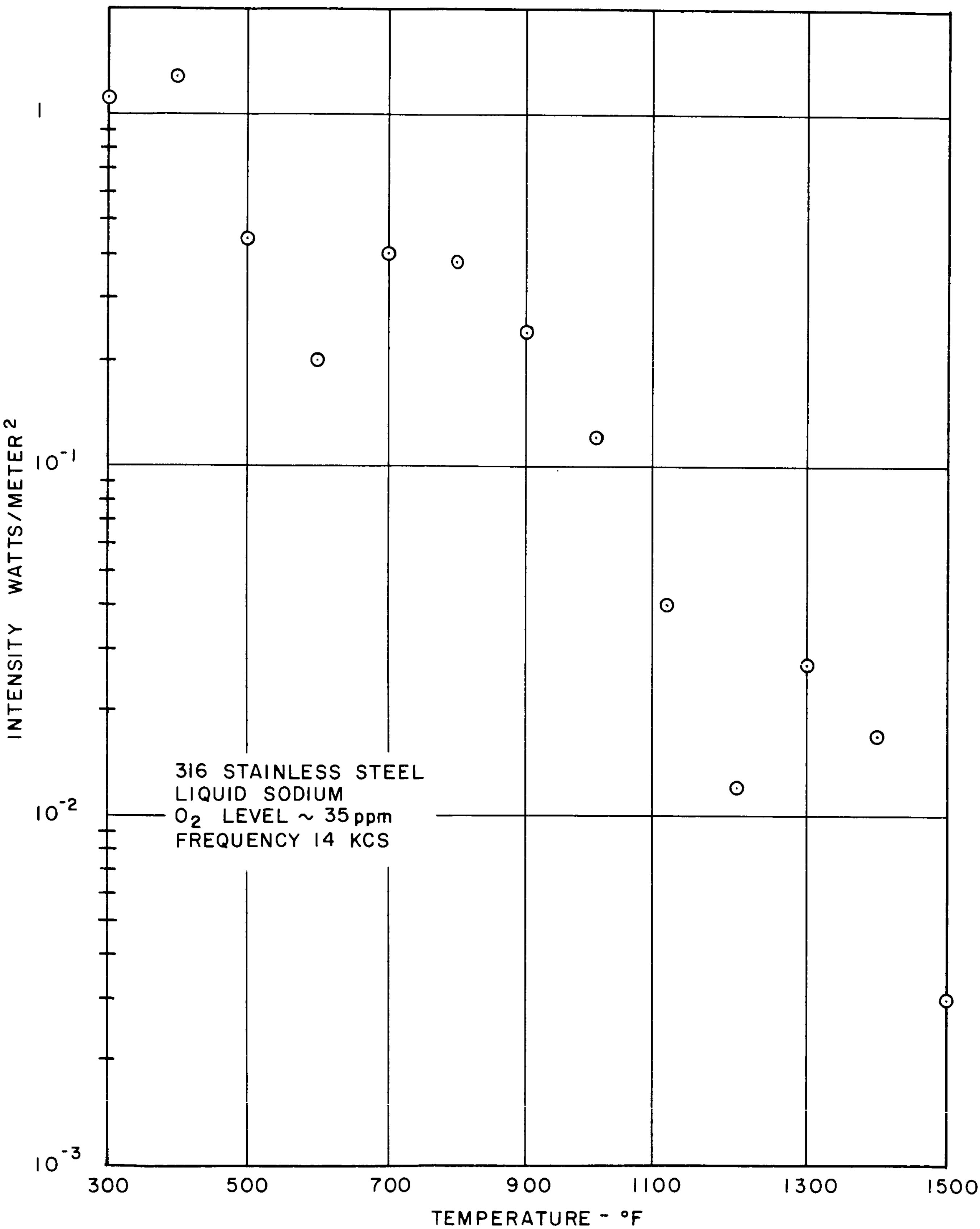


FIGURE 4 - EFFECT OF TEMPERATURE ON THE INTENSITY OF CAVITATION DAMAGE IN LIQUID SODIUM

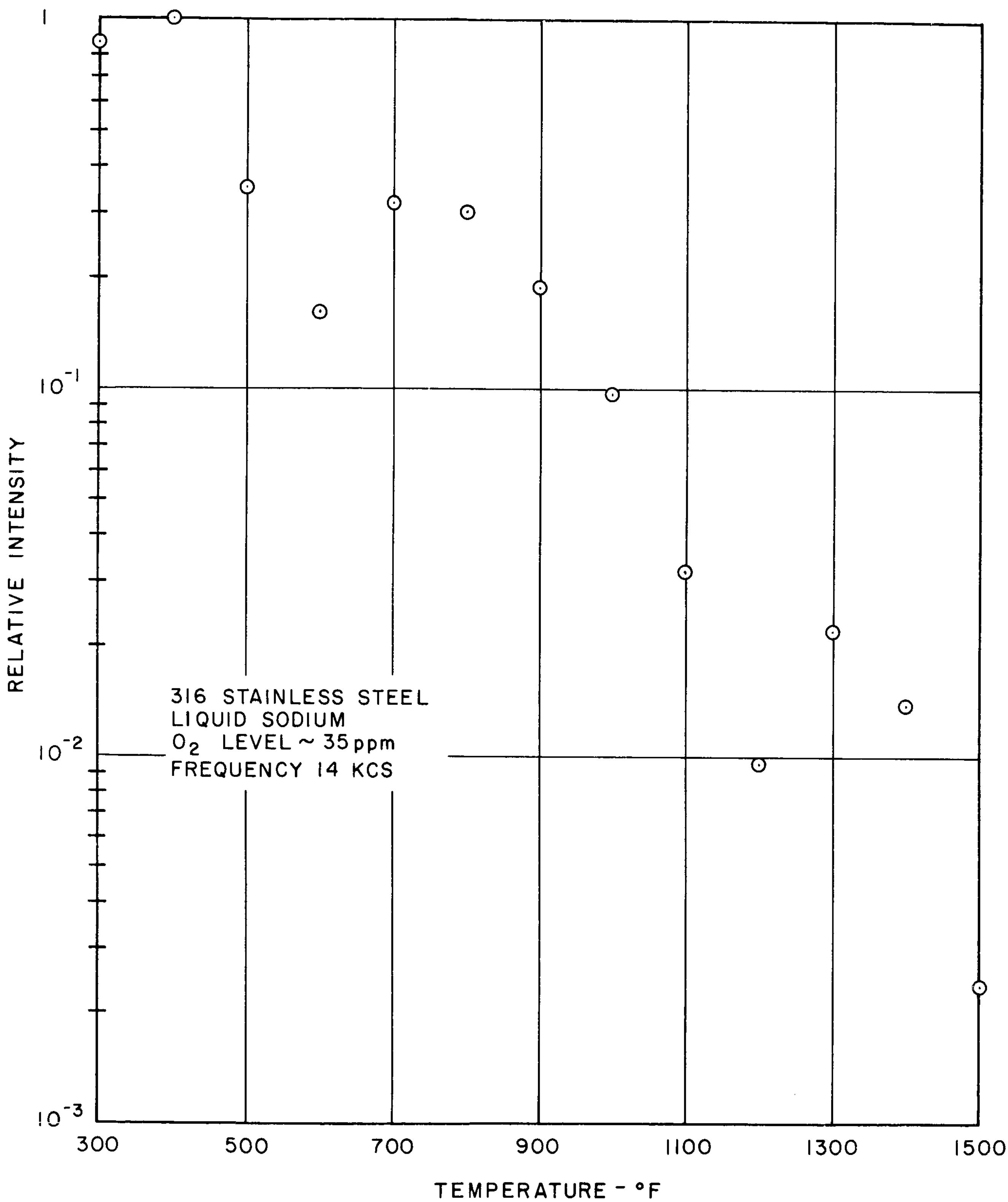


FIGURE 5 - EFFECT OF TEMPERATURE ON THE RELATIVE INTENSITY OF CAVITATION DAMAGE IN LIQUID SODIUM

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