THE UNIVERSITY OF MICHIGAN

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Report No. 01357-2-I

APPLIED STRESS AND CAVITATION DAMAGE

(Submitted for 1969 ASME Cavitation Forum)

by

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Financial Support Provided by:

National Science Foundation

Grant No. GK-1889

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March 1969

INTRODUCTION

Much effort has been expended for many years in attempting to correlate cavitation damage rates with material properties. In cases where the material-fluid combination is such that corrosion effects would be small, the pertinent material properties are usually considered to be the conventional mechanical properties. Since these properties are partially functions of each other, some degree of correlation can generally be obtained in terms of any of them, though correlations are more successful in terms of some properties than of others. Nevertheless, there are numerous test results for particular materials and applications which deviate very substantially from any best-fit curves generated for a comprehensive data set.[1, e.g.] One of the reasons for such variations may be the differing stress fields existing in cavitated components prior to test. Such stress fields originate either from externally applied stress, which is typical in any operating structure, or "built-in" stresses due to varying degrees of cold-work incurred during fabrication processes, due to operating loads in the structure, or from the prior cavitation attack itself. This paper reports a study of the effects of applied external loads on cavitation damage rates for a variety of materials. Since the surface stress regime existing at the point of bubble implosion is a resultant of the prior stress regime and that induced by the bubble, it would be supposed that the resultant failure would be affected by the prior stress regime.

PREVIOUS WORK

The first previous work to our knowledge on the relations between applied prestress and cavitation damage was done in this laboratory[2, 3] several years ago using cavitating mercury in a venturi. Type 304 stainless steel ribbons were held under tension across the venturi diffuser in the region where the cavitation bubbles collapsed. It was found that cavitation damage rates increased under tensile prestress by about 8%, and also that the ultimate strength of the specimens (broken in a tensile machine) was reduced by a given cavitation volume loss more when the damage had occurred under tension than otherwise. The yield strength was similarly affected for small tensions, though larger tensions induced cold work which obviated partially the effect of the cavitation damage.

More recently Shalnev, et. al.[4] studied the effects of pretension on cavitation damage using an aluminum alloy similar to Type 3003-0. His tests were conducted in a vibratory facility by positioning the stressed specimens in close proximity to the tip of the cavitating horn. He found that damage rates were almost doubled for moderate tensile loads (~2000 psi). Stresses to 6000 psi had little additional effect. The yield stress of his material was 10,700 psi.

PRESENT STUDY

Our present study used an arrangement much like that of Shalnev[4]. However, provision was made for both compressive and tensile prestress. The flat specimens (Fig. 1) are held close (24 mils) and parallel to the lower face of the vibrating horn (nominally 20 kHz, 2 mil unit) by a hydraulic ram capable of applying either tension or compression. The entire arrangement is contained in an open tank with fluid level slightly above (1 1/2") the tip of the horn. Previous tests which we made with non-stressed specimens in this arrangement showed that damage rates were strongly dependent on clearance,[5] (maintained constant in the present tests), but are highly reproducible and comparable to those obtained in the conventional arrangement. Distilled water was used in the present test with approximately saturated air content. Water temperature was 73 $^{\circ}$F and pH 7.5. Further details of the test are given elsewhere[6, 7].

OFHC Copper, 3003-0 aluminum (similar to Shalnev alloy), SAE 660 bronze, 65/35 brass, 304 stainless steel, 1020 carbon steel, and tooling plate magnesium alloy were tested, each under zero load, and tensile and compressive prestress equal to 0. 75 yield strength. In a single case (copper) 1. 5 yield was used. With both aluminum and copper the effects of rolling direction as compared to prestress direction were tested. After cavitation, the effect of a given volume of cavitation damage upon the yield and tensile strength of copper and aluminum cavitated specimens was measured in a standard tensile breaking test and compared to specimens cavitated under zero load.

The most apparent result of all these tests is that the effect s differ widely in both direction and magnitude depending upon specific materials, even for this simple uniaxial prestress condition. There is an overall trend, however, indicating increased damage rate with materials cavitated under pre-tensile loads and a damage decrease for pre-compression. Ten separate test conditions were involved (differing in material, proportionate stress magnitude, or specimen orientation with respect to rolling direction). For each of these, zero, compressive, and tensile loads were tested. At least two specimens were tested for each of the 30 conditions, sometimes more, so that a total of 138 specimens were used. The averaged and extreme results are shown in Table 1-A for the uniform rate portion of the test and in Table I-B for the early portion where the rate is increasing before a uniform rate is attained. The full test results are given elsewhere [6, 7] and Fig. 2 is a weight loss time curve for magnesium alloy, showing typical results for this type of test. Table I shows two significant results:

1. The maximum effect observed on the uniform damage rate does not exceed 20%, while in the initial test period the effects

are much larger (56% max.). This is consistent with much cavitation damage test experience wherein the largest variations are often encountered in the early portion of a test.

2. The average effect in the uniform rate portion of the test is that compression slightly reduces damage while tension increases it to a somewhat greater extent. In the early ("incubation") period the mean effects are the same (compression decreasing damage and tension increasing it).

The effect of a given volume of cavitation damage upon the strength properties of the cavitation specimens (Fig. 1 shows a specimen damaged to the extent required for the breaking test) has been reported[6, 7] in the form of a ratio of percent change of tensile or yield strength to percent change in cross-sectional area as computed directly from MDP (Mean depth of penetration = volume loss divided by damaged area). If the material removed by cavitation were in a layer of uniform thickness with no penetration below the nominal depth of the layer, then a given percent reduction in area computed on this basis should produce an equal percent reduction in strength properties. If the ratio is greater than unity, the effect of cavitation damage on the strength of the damaged member is proportionately greater than the nominal area reduction. If the ratio is negative, the cavitation damage has actually strengthened the member, presumably through cold work effects. This was actually observed in two cases for aluminum. However, typical results show ratios somewhat greater than unity, 2.15 for the yield strength of copper with zero load being the largest.

The largest effects were found for zero load, as opposed to our previous tests with mercury [2,3] where these were found under tension. In the present tests there is little difference between the effect of tension and compression. In general, it appears that countering mechanisms are involved. Clearly the non-uniform distribution of the cavitation volume removal should weaken the specimen by a larger proportion than the nominal area reduction. If in addition microcracks penetrate below the cavitation pits, as we have here observed,[6] the strength reduction should be larger. However, at the same time, cavitation work-hardening of the surface material, depending upon the material, may more than counter the effects of uneven distribution in volume loss.

CONCLUSIONS

These tests show that the effects of externally applied stress upon cavitation damage can be quite substantial, particularly (though not exclusively) in the early part of the test. Since these tests were limited to uniaxial applied loads, it may be that two or three dimensional applied stress patterns will show even more dramatic effects.

The measurements of the effect on specimen gross strength properties of a given volume removal by cavitation as compared to the nominal area reduction[6, 7] should allow at least an engineering estimate of this effect for different materials and for damage incurred under different conditions of prestress, as would apply in most operating machines.

ACKNOWLEDGEMENTS

The Financial support for this investigation was furnished by the National Science Foundation, Grant No. GK 1889, Project 01357.

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TABLE I - AVERAGE AND EXTREME DAMAGE RATES

A. Rates Measured in Linear Portion of Curve

	Percent Change Compression *	Percent Change Tension **
Maximum Positive	+4.5	+16.9
Maximum Negative	-13.8	-2.4
Algebraic Average	-1.5	+5.8

B. Initial Rate Effects

	Percent Change Compression *	Percent Change Tension **
Maximum Positive	+56.4	+53.7
Maximum Negative	-51.8	-53.4
Algebraic Average	-4.2	+1.16

* $\frac{\text{Compressive Weight Loss} - \text{Zero Load Weight Loss}}{\text{Zero Load Weight Loss}} \times 100$

** Comparable to definition above for tensile weight loss.

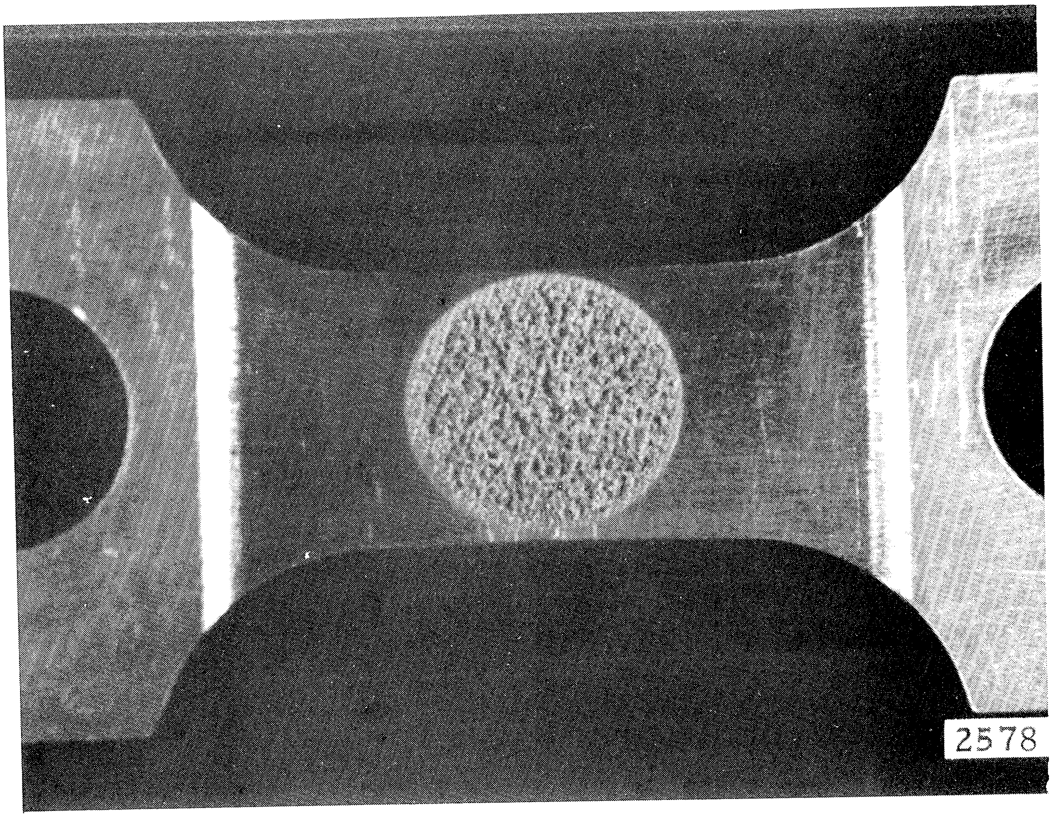

Fig. 1. Photograph of Damaged Specimen for Stress-Strain Test

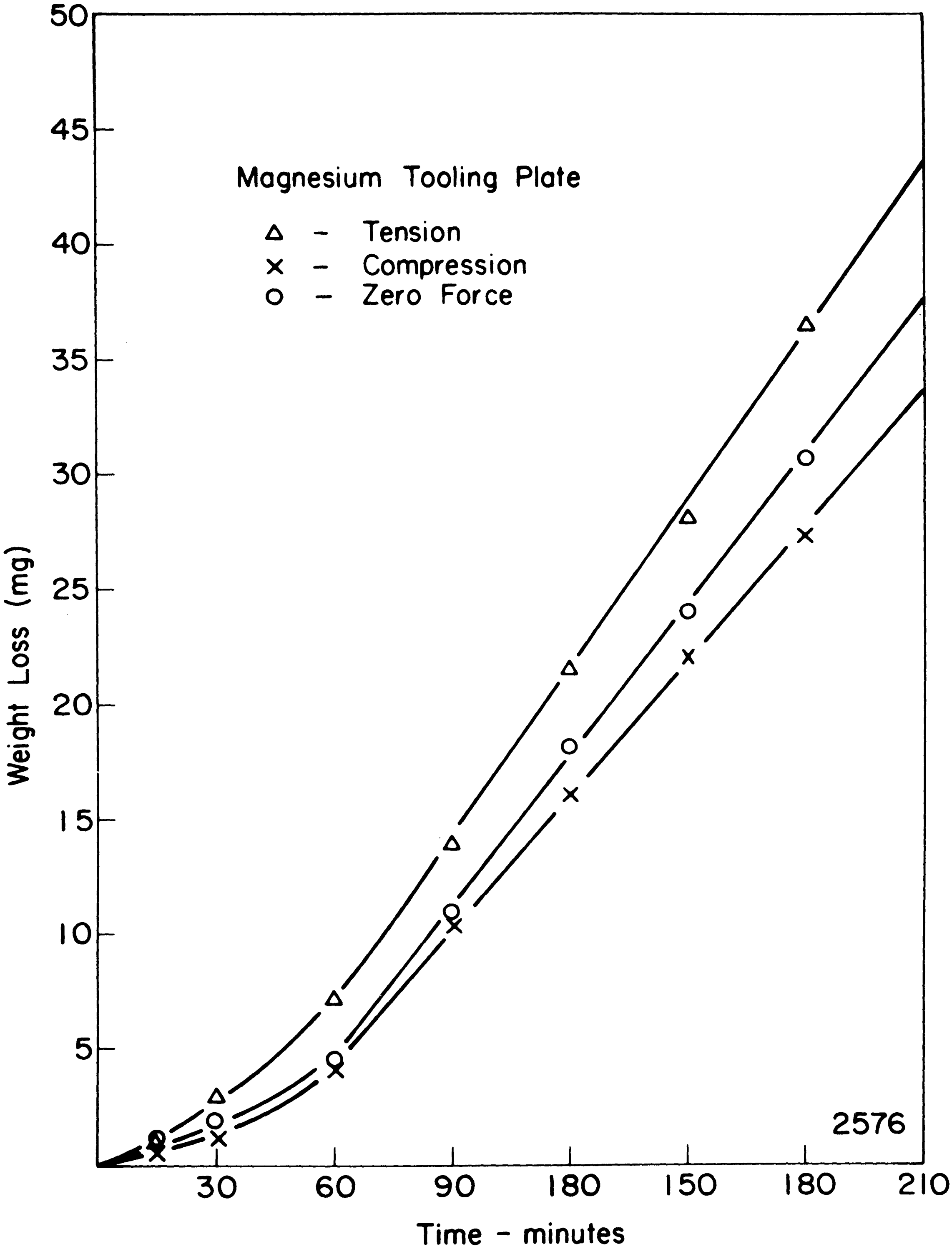

Fig. 2. Weight Loss versus Duration for Magnesium Tooling Plate