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CAVITATION-EROSION CHARACTERISTICS OF PROPELLOR BRONZE AND MONEL IN WATER AT 55°F

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ABSTRACT

A continuation of the cavitation resistance study of selected materials in water at $55^{o}F$ has been conducted. The tests were performed in the Nuclear Engineering Department of the University of Michigan on Monel and a propellor bronze, using an ultrasonic vibratory facility with a frequency of 20kHz and a double amplitude of approximately two mils.

The Monel was found to be less resistant to corrosion attack, under these conditions and fluid environment, than was the propellor bronze. The appearance of damage in its initial phases is similar for the two materials, although the propellor bronze shows a lower rate of damage after sustained testing.

A ranking of these materials and those tested previously for Worthington gives the following ordering in terms of decending cavitation erosion resistance; K801, propellor bronze, Monel, Coke Flour, SAE 660 and Fluorosint.

The mechanical properties of the materials are compared with predicting equations for average MDP rate and show that yield stress and tensile strength are the most useful parameters for prediction of relative cavitation resistance of these materials.

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I. INTRODUCTION

The overall investigation for Worthington Corporation which has been pursued using the Ultrasonic Vibratory Facility in the Nuclear Engineering Department at The University of Michigan has been divided into a number of separate investigations or phases. The present report completes "Phase I", an investigation of the cavitation erosion resistance of a number of selected materials in water at 55°F.

A previous report[1] included data for four materials, SAE 660(a.), Fluorosint(b.), Coke Flour(c.), and Kennametal 801(d.). The present report includes some mechanical property data for these materials, which has become available after publication of the earlier report[1] as well as a comparison of the two presently evaluated materials, Monel(e.) and propellor bronze(f.), with the tested materials.

The Ultrasonic Vibratory Facility was previously described[1] along with the experimental procedure used in this laboratory for the evaluation of the cavitation erosion resistance of materials. Some of the data previously reported[1] is included here also for convenience, since it is pertinent to the evaluation of these materials as a group.

II. EXPERIMENTAL RESULTS

The experimental results are displayed as cumulative weight loss versus test duration in Fig. 1 and as cumulative MDP (mean depth of penetration), in Fig. 2. In addition to the damage versus

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a.) High-Lead Tin Bronze, Alloy 3B (83% cu, 7% Sn, 7% Pb, 3% Zn)
b.) A Filled TFE Fluorocarbonresin
c.) 25% Coke Flour Filled Feflon
d.) "Kennametal K801", Tungsten Carbide, Ni Binder
e.) "K" Monel (66% Ni, 29% Cu, 3% Al)
f.) Nickel Aluminum Bronze (SAE 701C; ASTM B-150 Alloy 2) (10% Al, 5% Ni, 2.5% Fe, 1% Mn)

time curves for Monel and propellor bronze, the curves for SAE 660 and K801 are also shown. The expressions used for the calculation of MDP from weight loss for all the materials are shown in Table 1.

TABLE 1

Mean Depth of Penetration Relations

Material	Density	Relationship
Monel	8.31 gm/cc	MDP(mils) = 0.0312W/mg.
Propellor Bronze	7.42 gm/cc	MDP(mils) = 0.0349W/mg.
SAE 660	8.93 gm/cc	MDP(mils) = 0.029W/mg.
K801	14.8 gm/cc	MDP(mils) = 0.0175W/mg.
Coke Flour	2.4 gm/cc	MDP(mils) = 0.108W/mg.
Fluorosint	2.4 gm/cc	MDP(mils) = 0.108W/mg.

The cumulative damage versus test duration curves (Fig. 2) indicate that the Monel is not as cavitation-resistant as is the propellor bronze. However, it is very much better than the SAE 660 and Coke Flour, the latter of which is not shown on the graph but was about comparable to SAE 660. Thus, both of the present materials are more cavitation-resistant than all of the other materials tested in this program except for K801.

The very early portions of the tests do not show as great a rate of damage as the later portions. The early portion of both the Monel and propellor bronze data are non-linear, although quite similar. After approximately five hours of testing both materials attain an approximately constant damage rate, which is considerably greater than the rate prior to that point. The uniform rate for the propeller bronze is considerably less than that for Monel. The damage previously found[1] for the K801 is much more extensive in the early part of the test than is that of either Monel or propellor bronze, but the constant rate which it approaches at a later time is considerably less than that for Monel or propellor bronze. Table 2 lists the rates of damage for all of the materials calculated from the uniform portion of the damage versus time curve. In Table 2 the materials have also been ranked according to their cavitation erosion resistance. The K801 being the most resistant was given a ranking of 100%. On the basis of the ratio of the damage rate for K801 to that of each of the other materials, the materials listed in decending order of resistance are; K801, propellor bronze, Monel, Coke Flour, SAE 660 and Fluorosint. The ratio for propellor bronze is approximately 29% and that for Monel is 19%. The worst material, Flourosint is then only 0.5%. However, note that Coke Flour is substantially better than SAE 660 brass.

Photographs of the damaged surface of each of the present specimens are shown in Fig. 3 along with photographs of those previously tested, i.e., SAE 660, Coke Flour, and K801. The damage pattern of the propellor bronze and the Monel is considerably different from that of the Coke Flour and the SAE 660. The SAE 660 surface shows the characteristic furrowed pattern typical of materials tested in this type of system in low density fluids such as water[2,3], whereas Monel, propellor bronze and K801 show an apparently more uniform surface damage. Our present opinion, however, is that if the tests were to continue so that the total volume loss of these materials approached that of the SAE 660, the characteristic non-uniform damage pattern might then become discernable.

TABLE 2.

Cavitation Erosion Rate of Materials in Water at 55°F.

Material	Rate	Ranking
K801	0.0111 mil/hr	100
Propellor Bronze	0.0379 mil/hr	29
Monel	0.0586 mil/hr	19
Coke Flour	0.209 mil/hr	5
SAE 660	0.428 mil/hr	3
Fluorosint	2.27 mil/hr	0.5

III. MECHANICAL PROPERTIES

Stress-strain curves and hardness tests have been performed where possible for all these materials. The various mechanical properties were then calculated and are shown in Table 3. The mechanical property data for the K801 is not complete because of a lack of necessary test material. The data which is given for this material (Table 3) was obtained from the published literature. The diamond pyramid hardness test was not adequate in the case of Coke Flour and Fluorosint, which are elastomeric in nature and do not lend themselves readily to this type of test. In these materials, the indentor does not leave a permanent indentation.

In previous tests in this laboratory[2,3], a number of predicting equations were determined which relate the various mechanical properties to the average rate of material attrition. These correlating equations were obtained using a least mean squares stepwise regression analysis of The University of Michigan IBM 7090 computer. From this work, which is comprised about 60 fluid-material-temperature combinations, the statistically best of the equations, which are pertinent to the

TABLE 3

Room Temperature Mechanical Property Data

Material	Monel	Propellor Bronze	SAE 660	K801	Coke Flour	Fluorosint
Hardness (DPH 1.1kg load)	391	304.5	117.5	739	*	*
Tensile Strength, psi	157 200	111 800	44 613	300 000	1512	398
0.1% Yield Strength	95 000	69 000	23 000	*	920	325
0.2% Yield Strength	115 000	79 000	25 200	*	1010	360
Elongation, %	22.0	20.5	21.96	*	69.16	1.40
% Reduction in Area	45.0	33.5	16.95	*	37.83	0
Elastic Modulus, psi	26.3×10^6	14.67×10^6	16×10^6	89×10^6	1.3×10^5	2.12×10^5
Ultimate Resilience, psi	470.3	426.1	62.3	502	8.8	0.376

* This data is not available

tests in water are shown in Table 4.

Two sets of equations are given for the tensile strength and hardness whereas only one equation each is shown for the ultimate resilience and the yield strength. Equations (a) are those equations obtained in this facility[2,3]. All types of materials have been considered ranging from soft brasses to hard cermits and carbide materials, as well as similar materials with different states of heat treatment. Equations (b) are those obtained using data from materials which were amenable to test in both water and mercury[2]. These would include materials such as steels, and refractory alloys. The equations have been corrected to account for differences in test temperature. The correlations are based on data obtained in tests at 95°F so that a correction must be applied such that comparison can be made with the present tests which were run at 55°F. A previous test in this laboratory[2,3] indicates that the higher temperature data should be multiplied by a factor of 0.511 to make it comparable to the present tests.

Using the equations of Table 4, the data of this investigation, as well as the data of the previous report[1], have been compared with the bulk of the tests which have been run in water in this laboratory. Curves representing each of the predicting equations have been plotted separately (Fig. 4, 5, 6 and 7). For the Worthington tests, the relations involving yield stress and tensile stress are most consistent with the data.

IV. SUMMARY AND CONCLUSIONS

The cavitation resistance of Monel and propellor bronze in a vibratory damage test have been measured. In addition, these materials have been ranked with the other materials tested in this phase of the Worthington program.

TABLE 4

Single Property Correlations - Water

Property	Relation	CD**
Tensile Strength, (TS)	a.) $AMR^* = K_1(-1.570+6.84x10^2(TS)^{-1/2})$	0.851
	b.) $AMR = K_1(0.006+8.38x10^3(TS)^{-1})$	0.953
Hardness, (H)	a.) $AMR = K_1(-0.267+16.62(H)^{-1/2})$	0.754
(DPH -1.1 kg load)	b.) $AMR = K_1(0.184-4.26x10^{-9}(H)^3)$	0.934
Ultimate Resilience, (UR)	a.) $AMR = K_1(0.591+8.504(UR)^{-1/2})$	0.673
Yield Strength, (YS)	b.) $AMR = K_1(0.011+27.95(YS)^{-1/2})$	0.922

NOTES

* Average Mean Depth of penetration rate.

** Coefficient of Determination

1) Equations (a) are correlations from all the water data run in this facility (including brasses, etc.).

2) Equations (b) are correlations of water data from steels and refractory alloys run in this facility[2].

3) K_1 = 0.511 = Temperature correction effect, since the correlations were based on tests at 95°F and present tests were run at 55°F.

The propellor bronze showed a somewhat lower cavitation damage rate than Monel on the basis of the entire test period. There was, however, an initial period of the test in which the damage rates were non-linear during which the damage rates of both Monel and propellor bronze were approximately equal. After about five hours the rate of damage of both materials increased considerably and became constant. The Monel then showed a somewhat greater rate of damage than did the propellor bronze.

The data obtained on the Monel and propellor bronze were compared with that from the materials run previously. The Monel and propellor bronze were considerably more cavitation erosion resistant than the SAE 660, Coke Flour, or Fluorosint, but not as resistant as K801. A ranking of these materials in decending order of cavitation damage resistance gives; K801, propellor bronze, Monel, Coke Flour, SAE 660 and Fluorosint.

Inspection of the damaged surfaces of the present specimens indicates that they have not yet reached that point in the test at which the material removed is sufficient to substantially change the "flow geometry", thereby causing the furrow type of damage pattern which was exhibited by the SAE 660, as well as numerous other materials tested in low density fluids as water[2] in facilities of this type.

Some of the pertinent mechanical properties of the materials which were studied, in this phase of the investigation, have been measured and the damage data compared with previously generated predicting equations based on these properties. For this particular data, the best correlations with the predicting equations are obtained with tensile stress and yield stress.

BIBLIOGRAPHY

1. Kemppainen, D. J., and Hammitt, F. G., "Cavitation-Erosion Characteristics of Selected Materials in Water at 55^{o}F," Technical Report #08153-1-T, Nuclear Engineering Department, University of Michigan, July 1966.

2. Garcia, R. "Comprehensive Cavitation Damage Data for Water and Various Liquid Metals Including Correlations with Material and Fluid Properties," Ph.D. Thesis,Department of Nuclear Engineering, The University of Michigan, August 1966; also available as ORA Technical Report No. 05031-6-T, The University of Michigan.

3. Garcia, R., and Hammitt, F. G., "Cavitation Damage and Correlations with Material and Fluid Properties", ASME Paper No. 67-FE-10, to be published *ASME Trans., J. Basic Engr.*, also available as Internal Report No. 05031-11I, Nuclear Engineering Department, University of Michigan, September 1966.

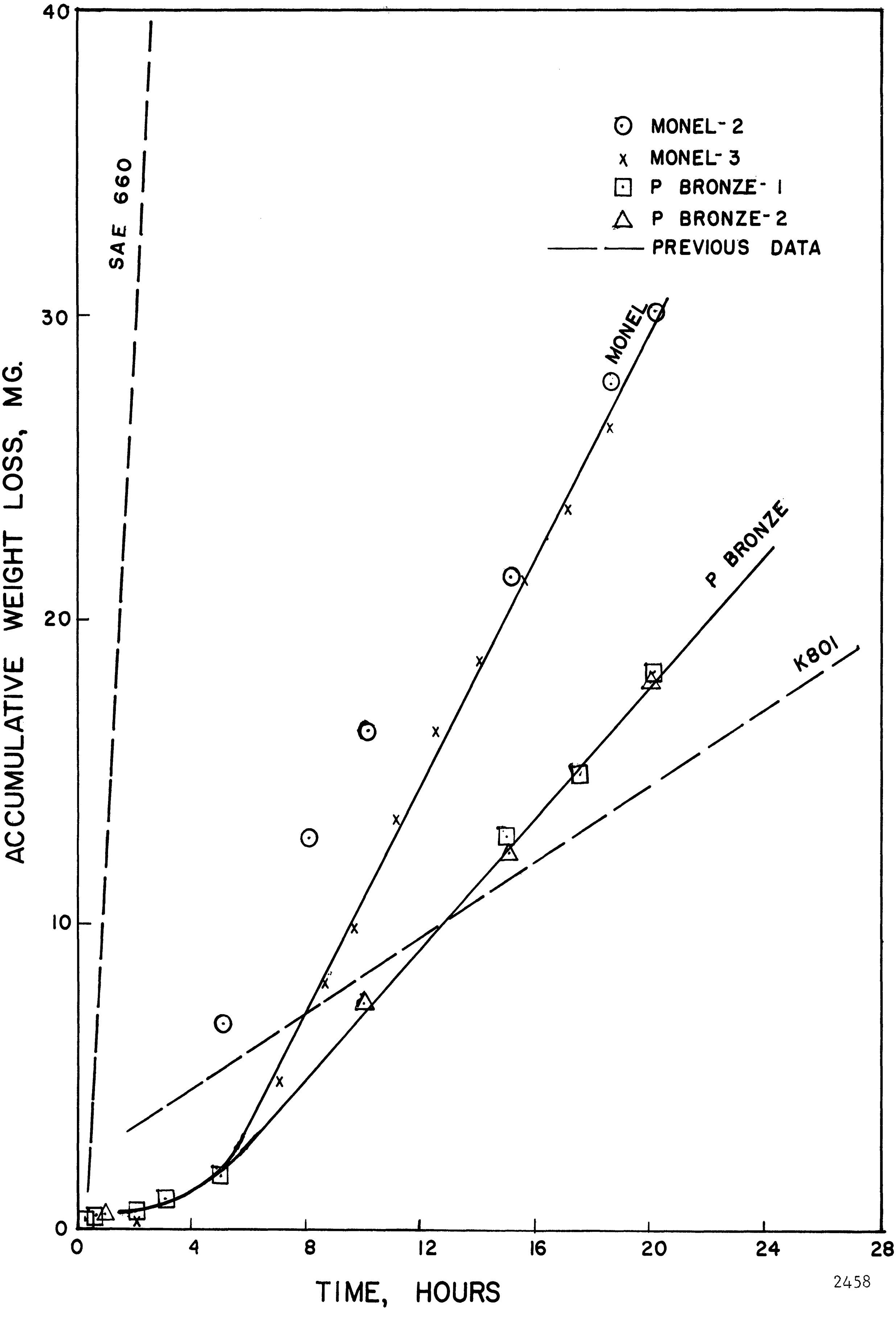


Fig. 1.--Cumulative Weight Loss versus Duration.

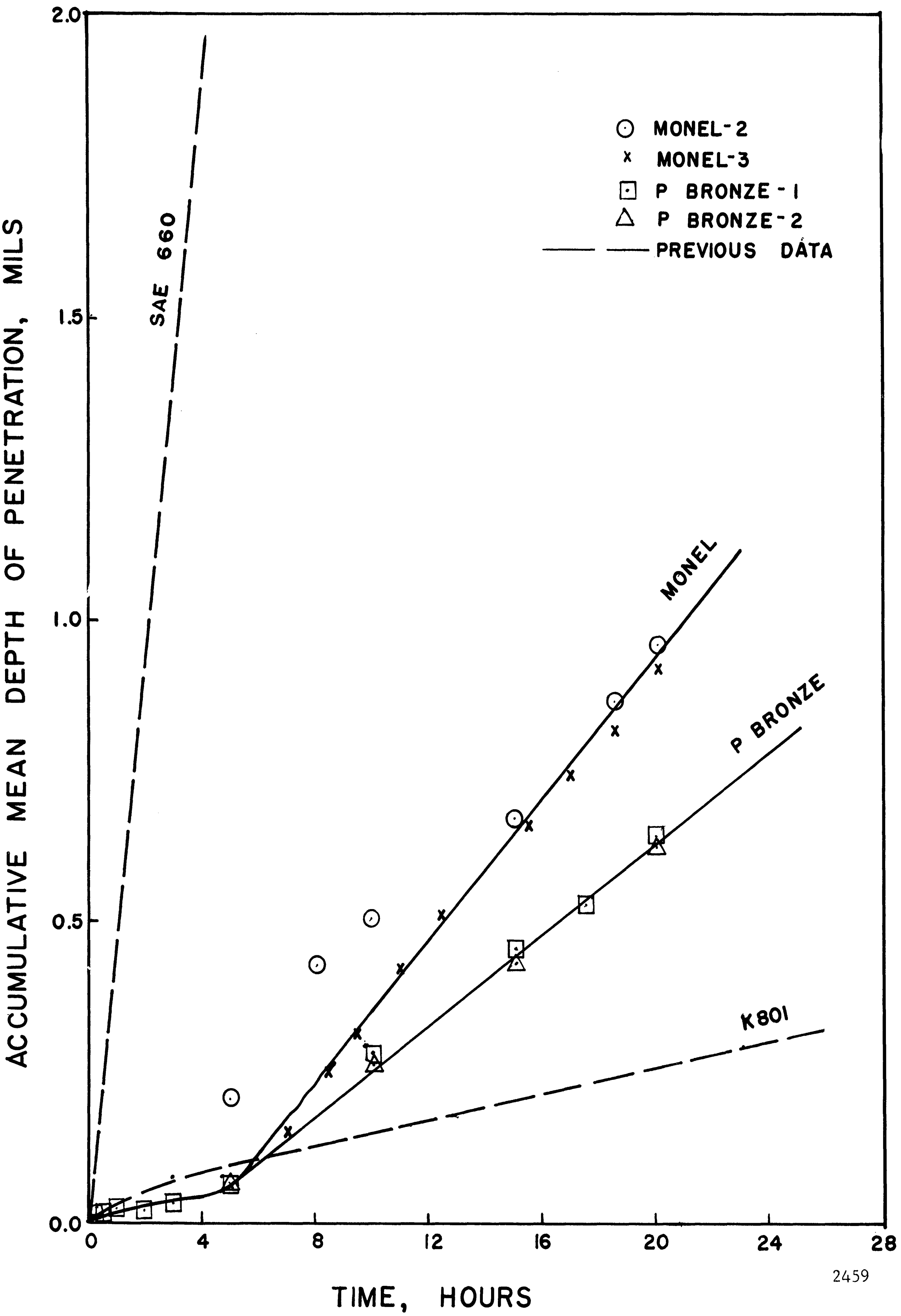
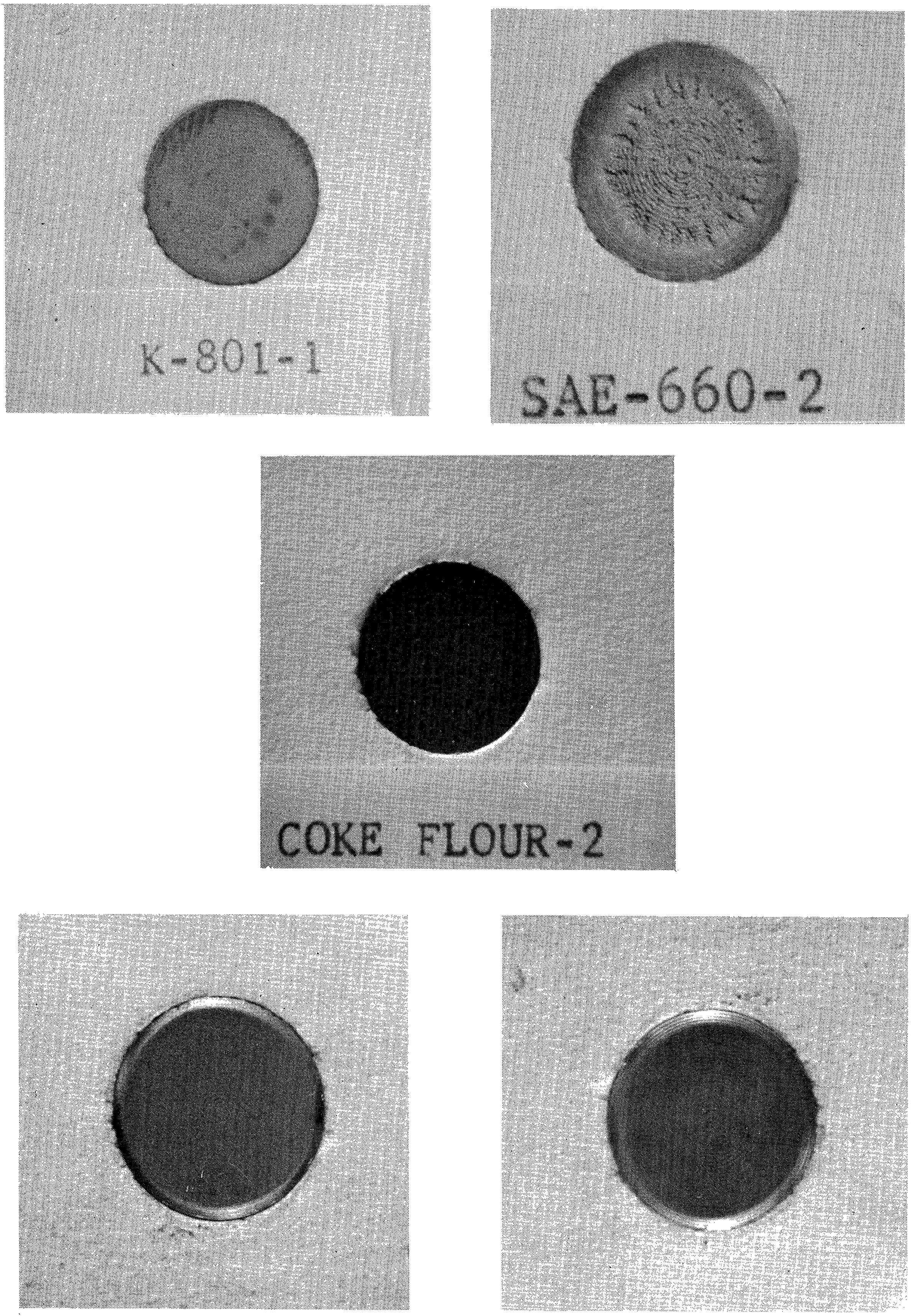


Fig. 2--Cumulative MDP versus Duration.



MONEL **PROPELLOR BRONZE** 2460

Fig. 3--Specimen Surface Structure after Completion.

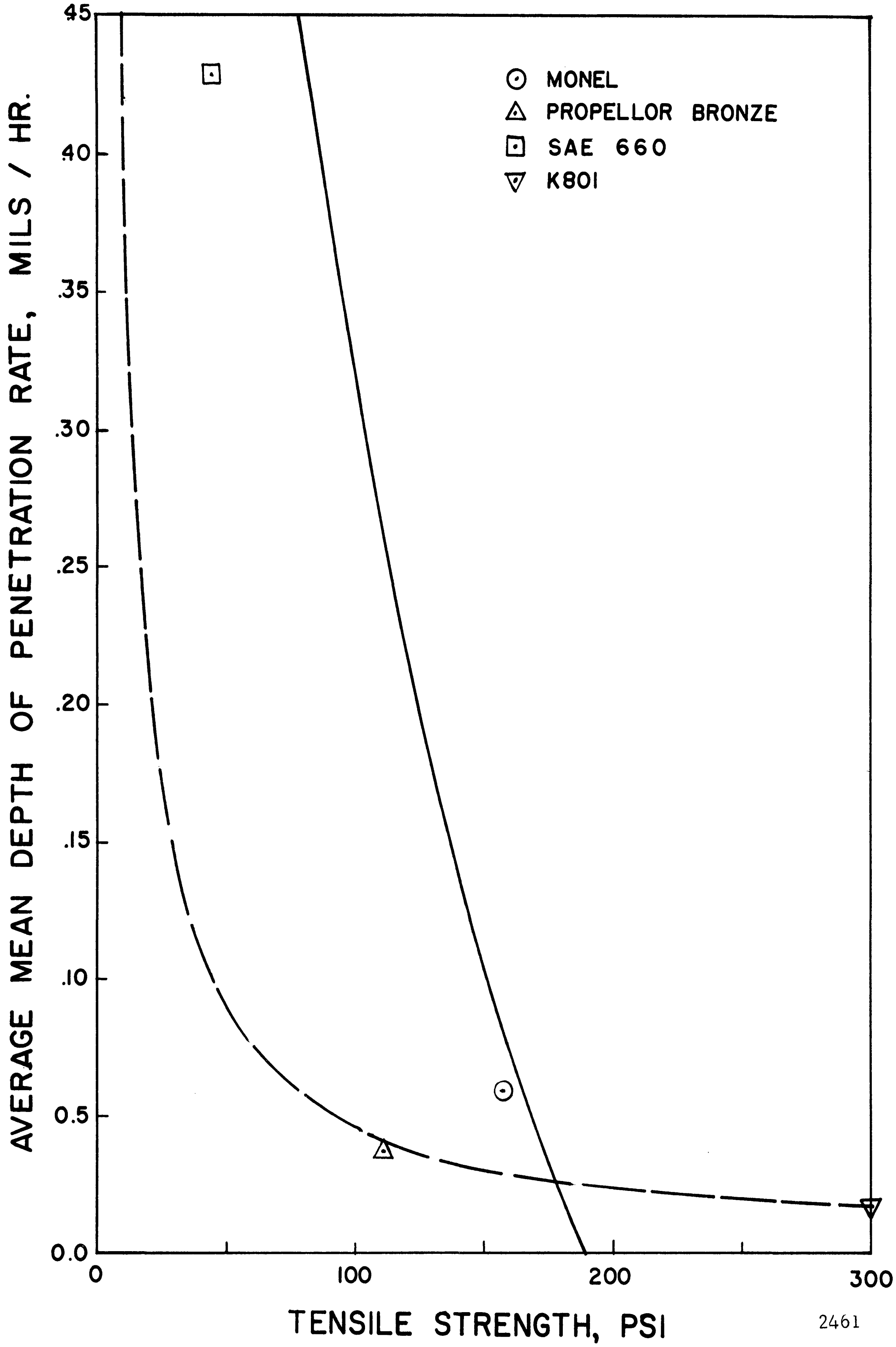


Fig. 4--Comparison of Predicted and Experimental Average MDP Rate versus Tensile Strength.

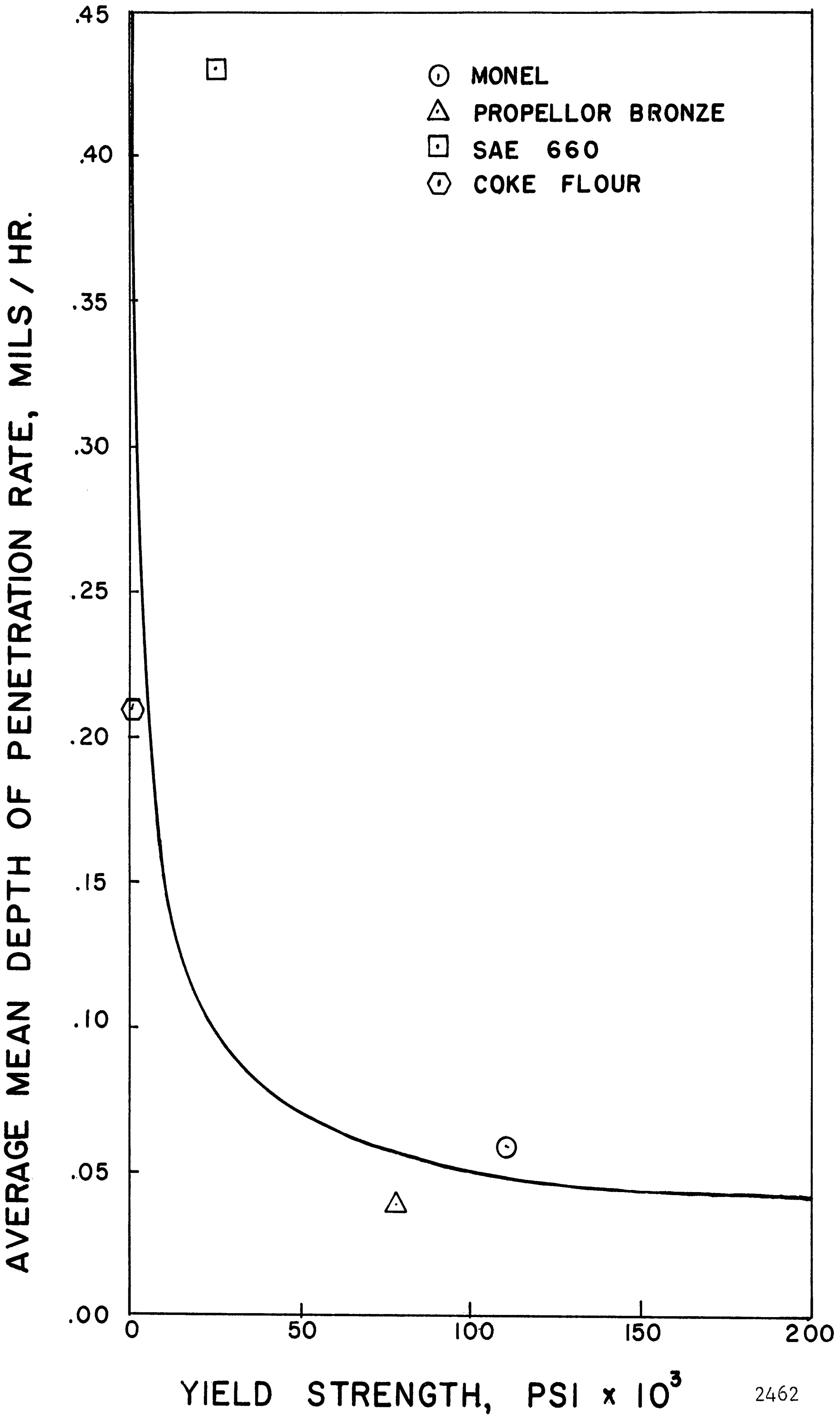
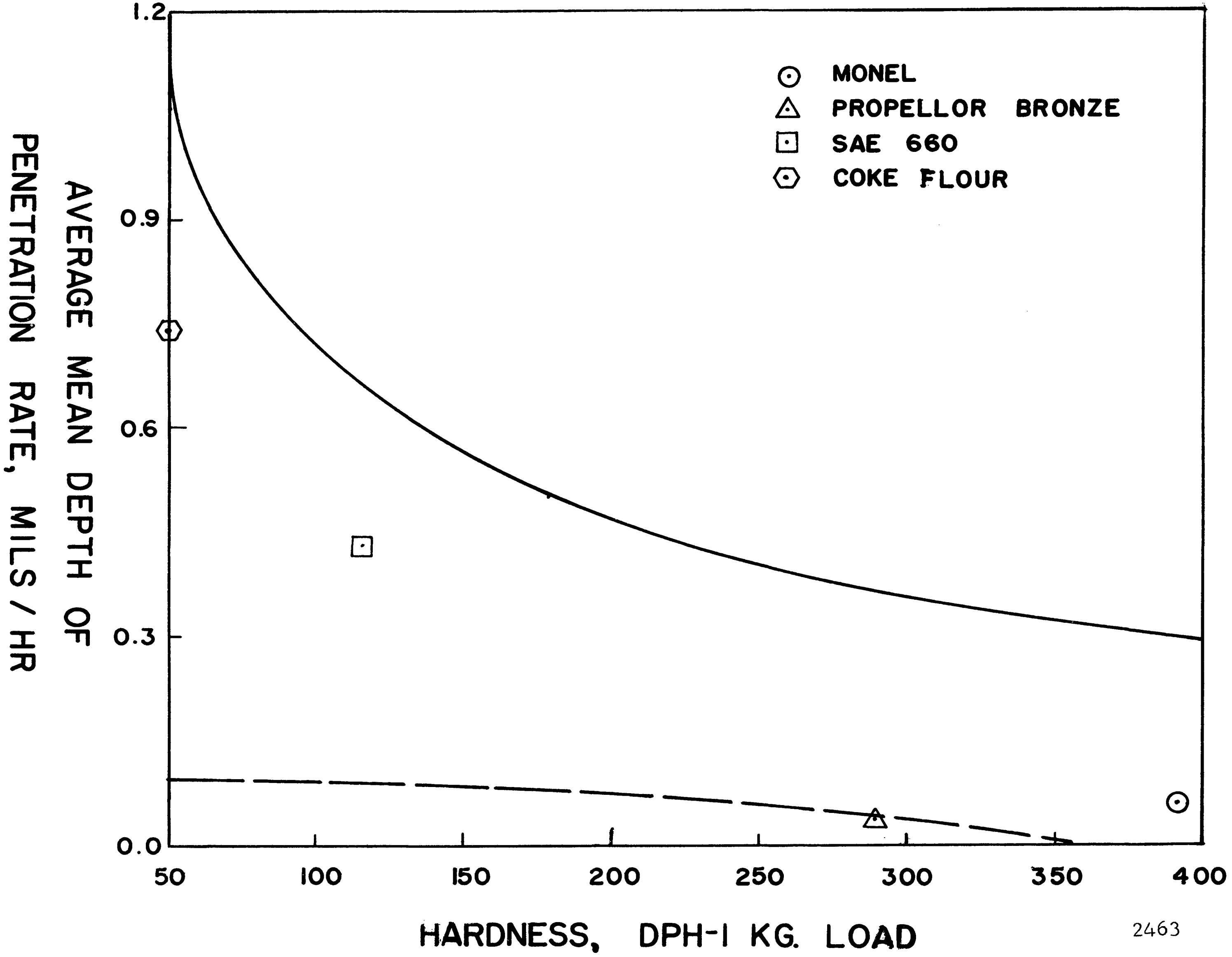
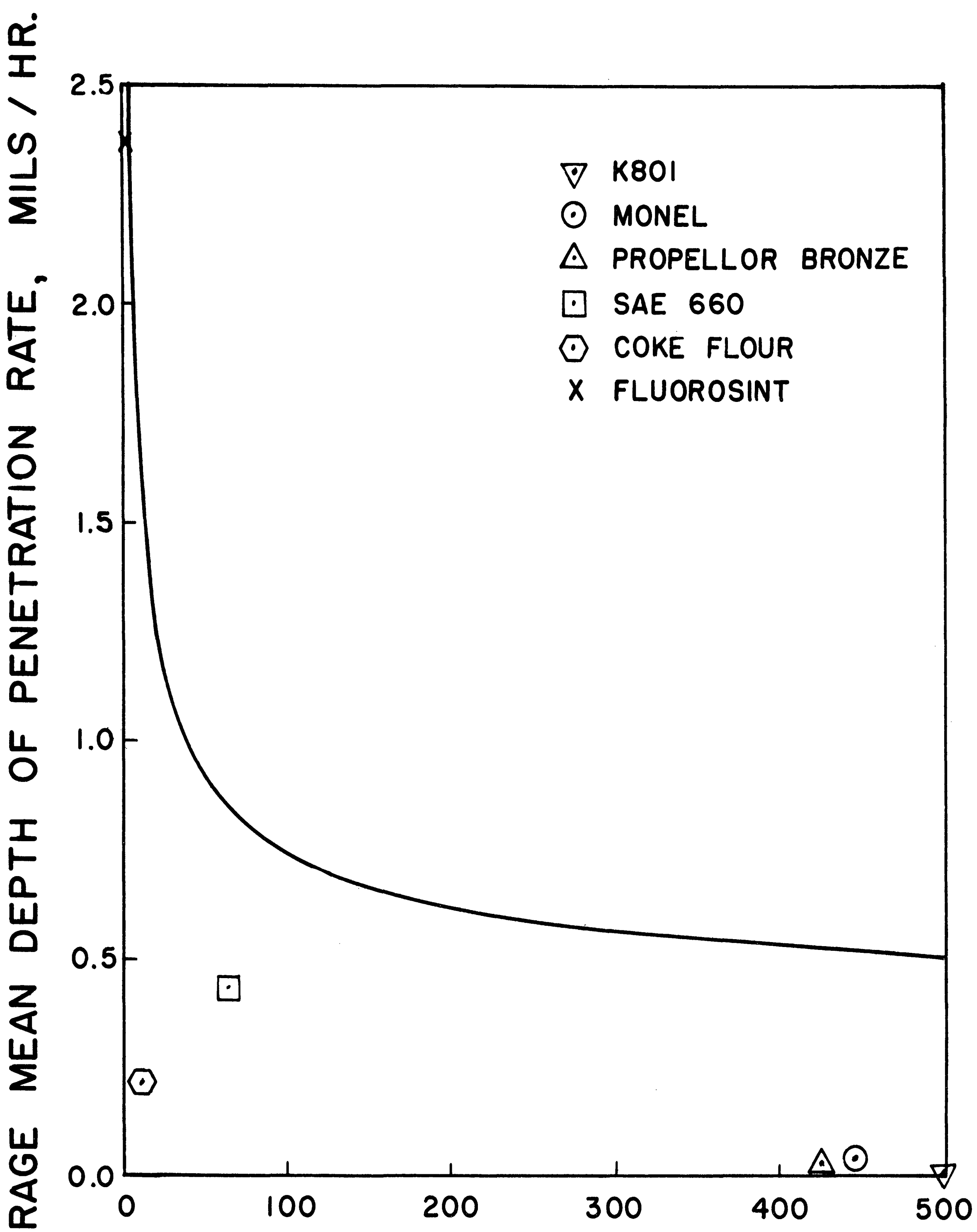


Fig. 5--Comparison of Predicted and Experimental Average MDP Rate versus Yield Stress.



Comparison of Predicted and Experimental Average MDP Rate versus Hardness.



Comparison of Predicted and Experimental
Average MDP Rate versus Ultimate Resilience