THE UNIVERSITY OF MICHIGAN
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Final Report

AN INVESTIGATION OF THE EFFECTS OF SUPERIMPOSED ULTRASONIC VIBRATIONS ON THE DRAWING OF ALUMINUM WIRE

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UMRI Project 2729

under contract with:

ALUMINUM COMPANY OF AMERICA
NEW KENSINGTON, PENNSYLVANIA

administered by:

THE UNIVERSITY OF MICHIGAN RESEARCH INSTITUTE ANN ARBOR

December 1959

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I. INTRODUCTION

The purpose of this investigation has been to determine if superimposed ultrasonic vibrations would result in improvements in the process of drawing aluminum wire. It was felt that these improvements could be made principally in the surface finish, because of previous experience in applying ultrasonic vibrations to metal cutting and grinding operations. In each of these areas it has been observed in the course of experiments at The University of Michigan that frictional forces at the interface between the cutting edge and the workpiece were reduced when the tool or the work was subjected to vibrations in the range from 10 kcps to 30 kcps. Improved surface finish was also observed in each case. Hence it was expected that in drawing aluminum wire there should be some improvement in the work surface due to a lowering of the frictional forces between the wire and die surfaces. Some of the surface conditions which might conceivably be improved by a reduction in friction are: galling, spalling, checking, and luster.

An additional effect that has been noted in steel wire[1] is that of the effect of superimposed high-frequency vibrations on the yield and tensile strengths of aluminum. Such an effect should be advantageous, since if the drawing forces can be reduced, there should be a corresponding reduction in frictional forces.

A part of the investigation involved efforts to examine the friction and wear characteristics of the type of aluminum used in wire products by the use of the automatic cycling friction-wear machine of the type developed for Alcoa under a previous contract. Once the wear characteristics of two unvibrated parts were determined, it was planned to apply vibrations to one of the rubbing surfaces or to the solution in which the two surfaces were immersed during the tests. These tests are incomplete as yet but will be finished as student research projects and reported by letter at a future date.

[1]G. E. Nevill, Jr., and F. R. Brotzen, "Effect of Vibrations on the Static Yield Strength of Low Carbon Steel," Proc. ASTM, 57, 75 (1957).

II. EXPERIMENTAL PROCEDURE

The work not involving the use of the friction-wear machine consisted of two phases:

(1) an investigation of the effects of high-frequency vibrations on the tensile and yield stress of aluminum wire, and
(2) a comparison of the axial forces involved in drawing wire through vibrating and nonvibrating dies.

In all the tests involving the application of high-frequency vibrations, the means for producing them were the same. They consisted of a 1.6-kilowatt high-frequency electronic generator and a magnetostriction transducer coupled to an exponentially tapered solid metal horn.

The electronic generator covered a frequency range of from 5 to 30 kcps. The magnetostriction transducer was operated at its resonant frequency, or at the remnant frequency of the combination of the transducer with whatever was attached to it. This was about 12.5 kcps for the tests on yield strength, and about 15 kcps for the drawing tests.

A. EFFECT OF HIGH-FREQUENCY VIBRATIONS IN THE YIELD AND TENSILE STRENGTHS

In Fig. 1 is shown a photograph of the apparatus used to perform the experiments to determine the effect of vibrations on the yield and tensile strengt

The magnetostriction transducer was a Sheffield-Cavitron type which is normally supplied with their 500-watt ultrasonic drilling equipment. Attachment of the test wire into the end of the tapered horn was accomplished by inserting the wire into a hollow 1/4 -20 cap screw set into the horn. The wire was prevented from pulling out of the screw by cold-heading it after the screw was slipped onto the wire. This method of attachment was found to be the most successful solution of what had turned out to be a difficult problem. The difficulty lay in the fact that the intense vibrations would cause the wire to pull out of an ordinary clamping device. Soldering was tried but the soldered joint was rapidly fatigued.

The same method of attaching the wire was used at the other end of the specimen.

Total elongation was measured by means of a differential transformer and a two-channel Sanborn recorder. The elongation was sensed by two forked probes which rested on the cap screws at either end of the test specimen. Between the two probes were two rods. One rod was attached to the core of the differential transformer; the other was attached to the slug which moved concentrically in

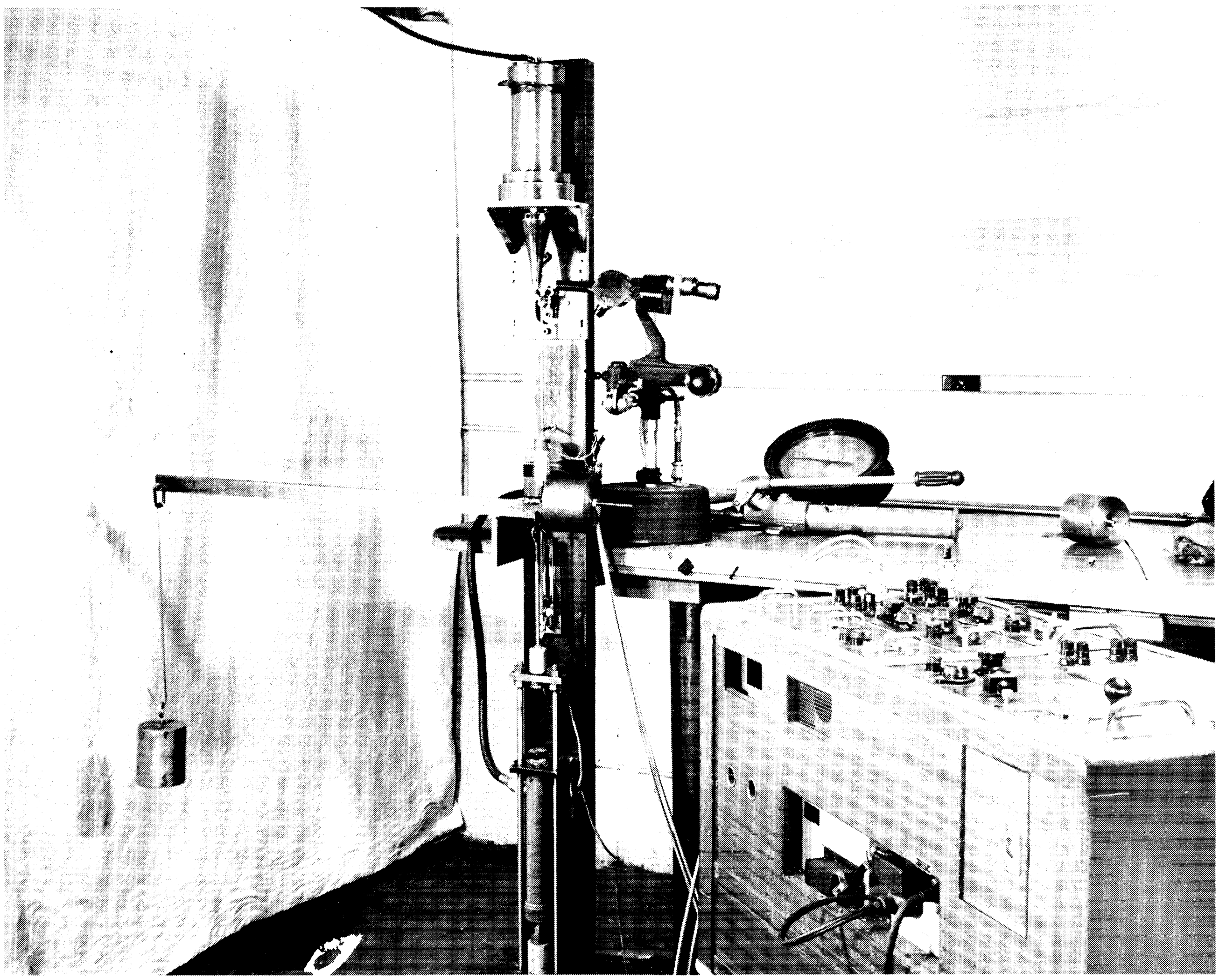

Fig. 1. Photograph of apparatus used for determining the effect of high-frequency vibrations on the yield and tensile strengths of aluminum. The ultrasonic transducer for vibrating the wire is shown at the top of the picture. A microscope for observing the amplitude of the vibrations is focused on the tip of the transducer. At the bottom of the test stand is the hydraulic loading system. The dead weight loading system (lever and weights) for calibrating the dynamometer is shown in the center of the picture. In use, it is taken out, and the test wire placed between the transducer and the dynamometer which can be seen mounted in the top end of the hydraulic loading system. To the right of the apparatus is the Sanborn recorder used for the force and elongation measurements.

and out of the core as the length of the wire changed. The whole sensing system was spring-loaded to maintain good contact with the cap screws.

At the bottom end of the test wire was a steel cylinder 3 in. in diameter and 3 in. long. This served two purposes. The first was to provide a vibration node at the end of the wire in order to improve the vibrational characteristics of the system. The second purpose was to prevent the heat generated in the test specimen due to the vibrations from affecting the force dynamometer attached directly below it. The temperature rise of the test wire was less than 25°F, but this was sufficient to cause considerable drift in the strain gage bridge circuit used in the dynamometer.

The dynamometer itself was a simple steel bar 4 in. long and 3/4 in. square. Four SR-4 strain gages were mounted on its sides so as to measure the elastic strain in the bar, which was in turn proportional to the applied load. One channel of the Sanborn recorder was used for the elongation measurements and the other for recording the load on the wire. Calibration of the dynamometer was accomplished by the use of dead weights hanging on its lower end.

Data were obtained for the total elongation of the wire as a function of load for the vibrated and nonvibrated cases for 1100 SO aluminum wire 0.149 in. in diameter.

B. WIRE-DRAWING TESTS

Since a conventional wire-drawing machine was not available, a horizontal broach (Cincinnati, Model 2A, 5 hp) was adapted for the desired tests. Figure 2 shows a photograph of the modified machine, the electronic generator, and the force measuring equipment used in the tests. The broaching tool was removed and the dynamometer used in the tension tests was attached to the end of the ram. The magnetostriction transducer with a wire-drawing die brazed on the tip of the metal horn was placed at the position where the broaching workpiece was originally located.

The direction of vibration of the die was perpendicular to the axis of the wire in the above arrangement.

Several tests were made in which the direction of vibration of the die was parallel to the axis of the wire. To do this, a cantilever system was used as shown in Fig. 3.

Because of the mass of the die and other loading factors, the best response of the transducer in the wire drawing operations was at a frequency of about 13 kcps. In future work this could just as well be some higher frequency above the range of audibility.

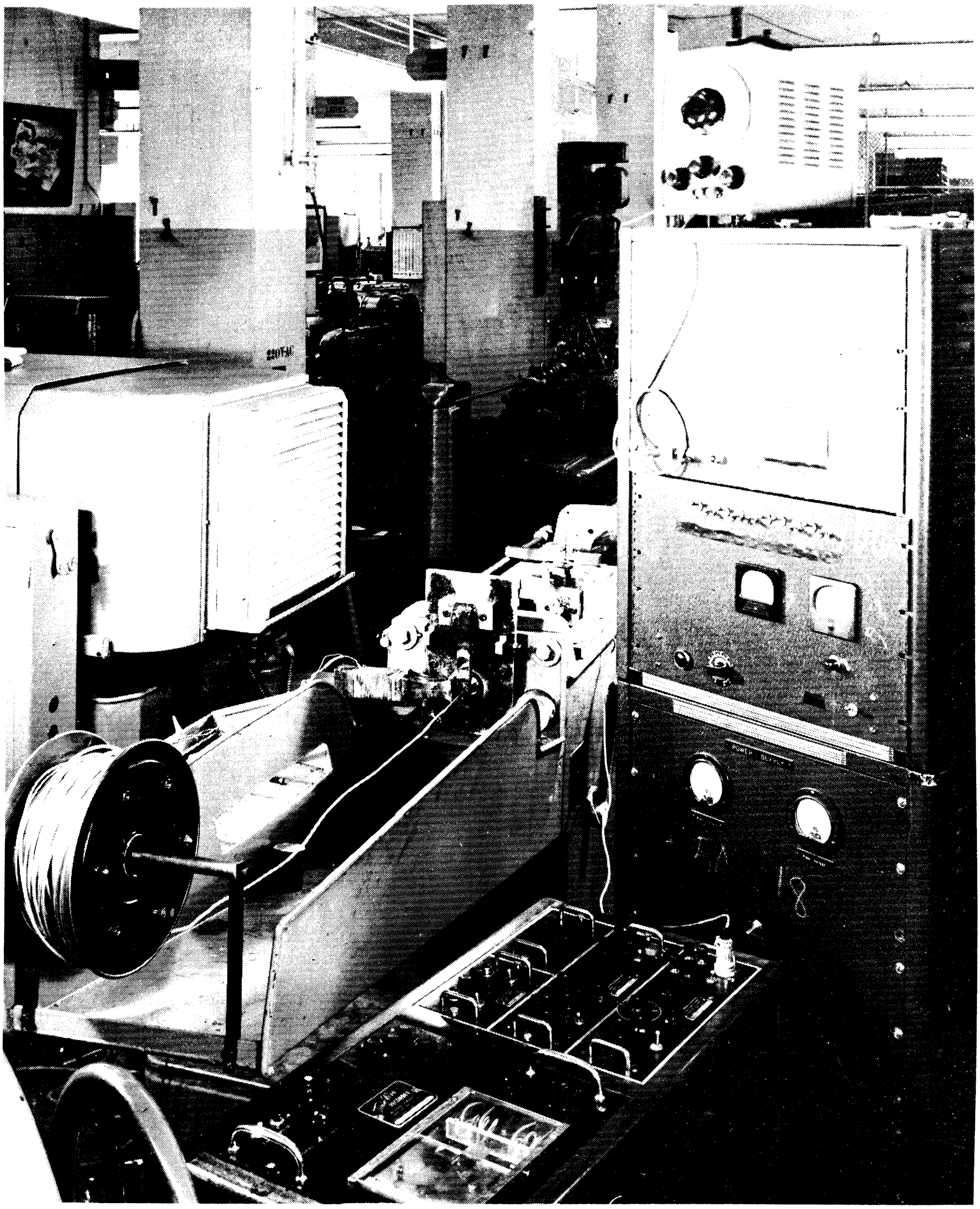

Fig. 2. Equipment used for the wire-drawing tests. Aluminum wire is pulled through the die mounted in the horizontal broaching machine. The ultrasonic transducer is in a horizontal position and extends to the left of the die. In such a position it vibrates the die in a direction perpendicular to the wire axis. The Sanborn recorder used for force measurements is in the lower part of the picture, and the electronic generator of the high-frequency current for the transducer is directly behind the recorder.

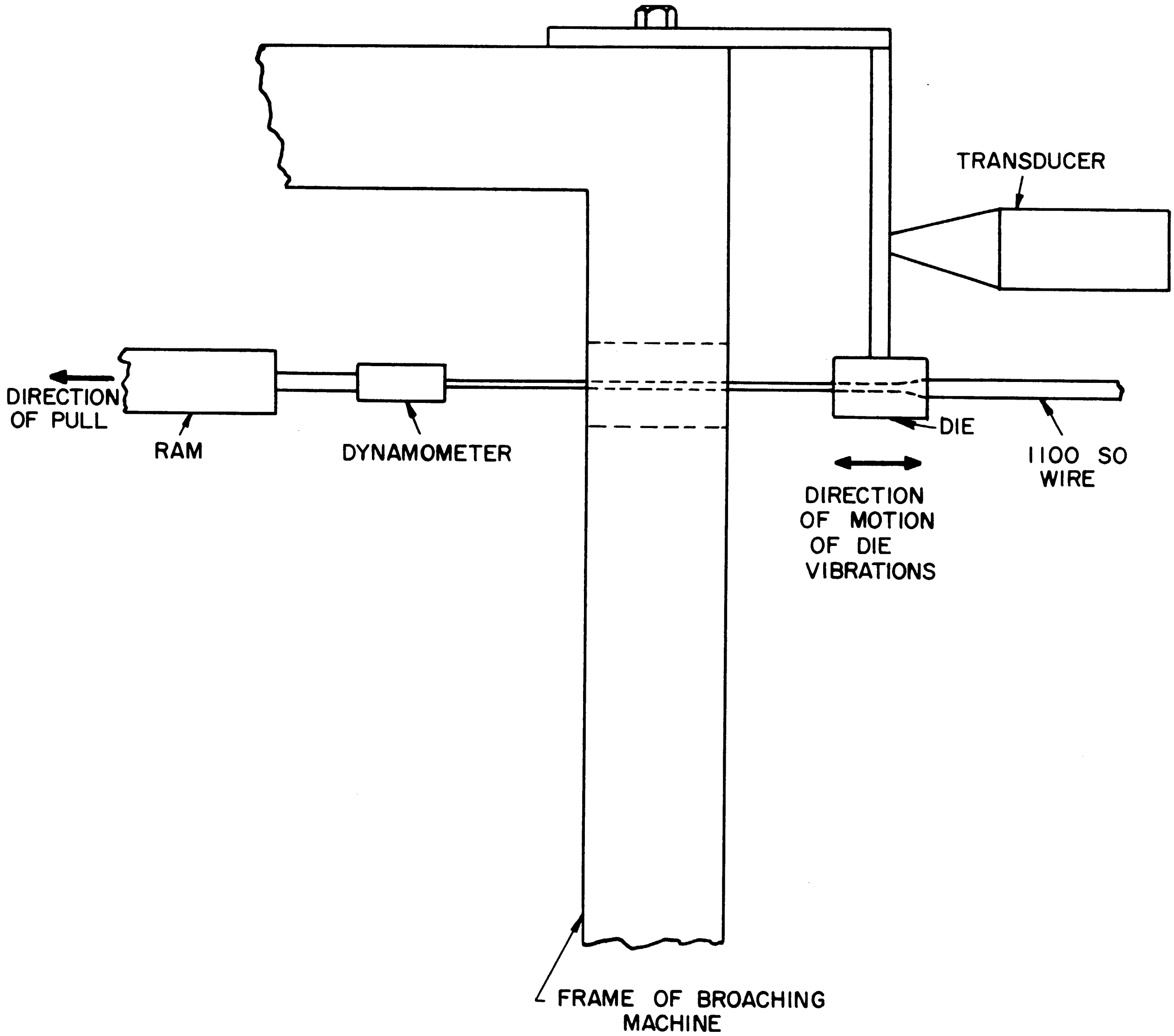

Fig. 3. The arrangement of the transducer, die, and wire for applying vibrations parallel to the wire axis.

III. RESULTS

A. EFFECT OF HIGH-FREQUENCY VIBRATIONS ON THE YIELD AND TENSILE STRENGTHS OF 1100 SO ALUMINUM WIRE

Figure 4 shows a plot of the stress vs. strain data for the vibrated and the nonvibrated cases. It can be seen that the superimposed high-frequency vibrations reduce the yield and tensile strengths of the 1100 SO aluminum. This is in accord with the results reported in Ref. 1. The amount of the reduction corresponds approximately to the peak stress level of the superimposed vibration. For a typical condition, the peak amplitude of vibration of the wire was approximately .0004 in. The observed reduction in yield stress for this condition was 1300 psi. If a value of 10×10^6 psi is used for Young's modulus of aluminum, then the stress in the wire for an amplitude of .0002 in. is:

$$\text{Stress} = \frac{10 \times 10^6}{.0002}$$

$$= 500 \text{ psi}$$

As might be expected, the amount of the reduction of yield and tensile stresses depended on how hard the transducer was driven.

Table I shows the results of the loading tests on a single specimen in which the load was removed as soon as yielding was observed. The specimen was then loaded, but this time with ultrasonic vibrations superimposed upon the static stress. Loading was again stopped when the yield stress was reached. As is to be expected, strain-hardening raises the yield stress, and each time vibrations are applied, the yield stress is lowered.

An additional experiment was performed in which the direction of vibration was at right angles to the axis of the wire. No reduction in the tensile or yield stresses was noted.

B. THE EFFECT OF HIGH-FREQUENCY VIBRATIONS ON THE FORCE NECESSARY TO DRAW 1100 SO WIRE THROUGH A DIE

Table II shows the reduction in the forces that were obtained as a result of vibrating the die in a wire-drawing experiment. The reduction of area was about 15%. Drawing speeds are also shown in the table. Table III shows the percentage reductions in drawing forces obtained with various lubricants as a result of applying vibrations. It is apparent that the superimposed vibrations reduce the drawing forces.

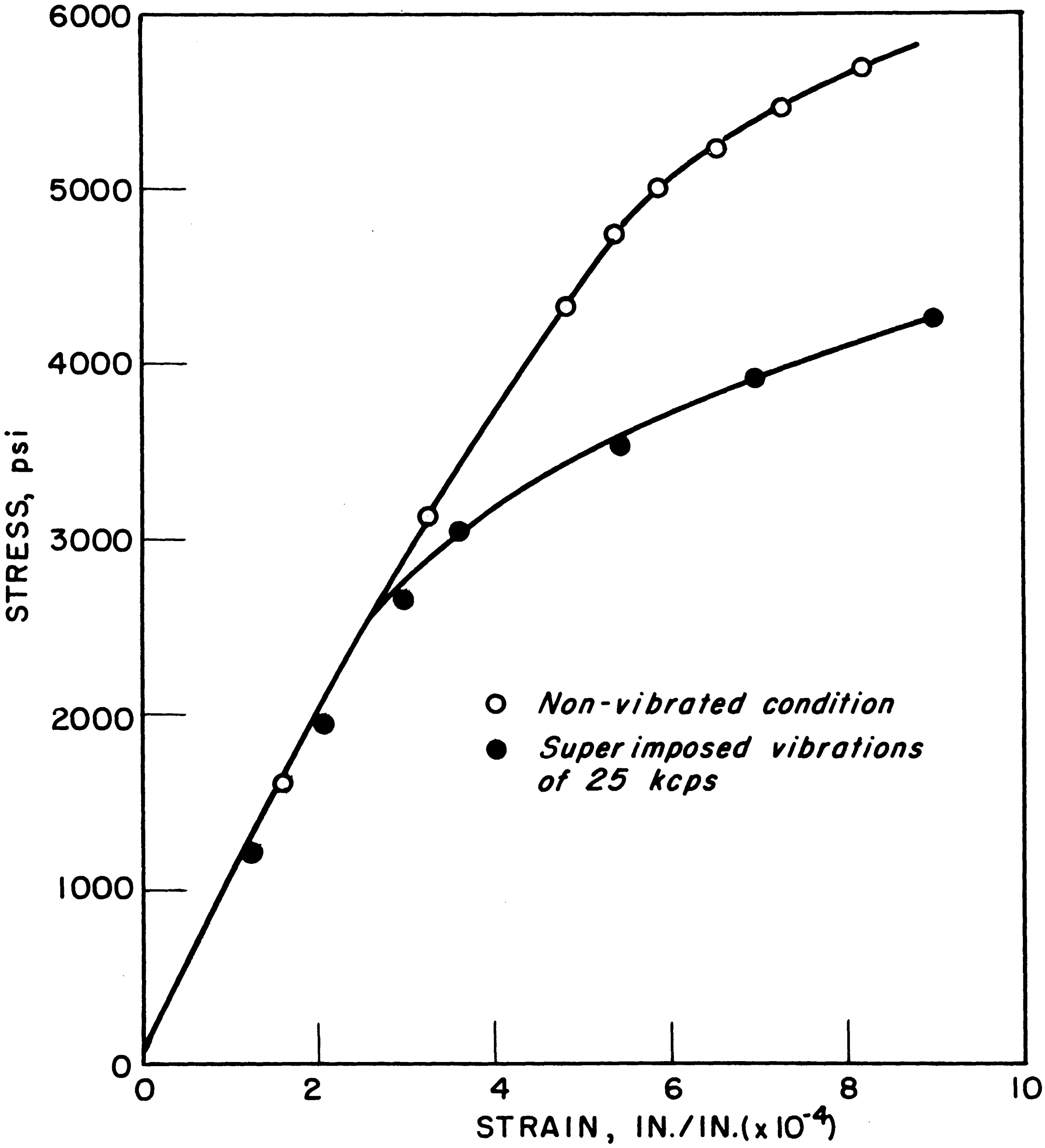

Fig. 4. Stress-strain plots are shown for 1100 SO aluminum for the cases when the wire is vibrated and when it is not vibrated.

TABLE I

REDUCTION IN YIELD STRESS OF 1100 SO ALUMINUM
BY THE APPLICATION OF ULTRASONIC VIBRATIONS

All the tests were made on the same specimen. After each nonvibrated test a vibrated test was performed. The yield stresses increase due to work-hardening of the metal.

Yield Stress, psi	
Nonvibrated	Vibrated
4650	3000
4750	3050
6200	5300
8000	5600

TABLE II

FORCES REQUIRED TO DRAW 1100 SO ANNEALED ALUMINUM WIRE
FOR NONVIBRATED AND VIBRATED CONDITIONS

Mineral oil was used as a lubricant and the reduction in area was about 15%. The frequency of vibration was 16 kcps.

Drawing Force, lb		Percent Reduction in Force	Drawing Speed, ft/min
Nonvibrated Die	Vibrated Die		
81	58	29	7.0
71	56	21	13
64	54	17	17

TABLE III

PERCENTAGE REDUCTIONS IN DRAWING FORCES OBTAINED WITH VARIOUS LUBRICANTS AS A RESULT OF APPLYING VIBRATIONS

Type of Lubricant	% Reduction in Drawing Force When Vibrations Are Applied to the Die
No. 4 machine oil	26
Mineral oil	29
Light lapping oil	18
No. 6 machine oil	18

C. SURFACE FINISH

No observations were made on the effect of vibrations on surface finish because the dies that were used were not sufficiently smooth themselves, and soon became scratched and worn. This prevented a good comparison of the surface finish for the vibrated and nonvibrated cases.

IV. DISCUSSION OF RESULTS

The principal conclusion from the experiments is that there is a trend in the right direction such that on a full-scale operation at normal drawing speeds and with good dies it might be expected that the superimposed vibrations will yield beneficial results. This is based primarily on the fact that the drawing forces were reduced, and that this must come from a reduction in friction. Inasmuch as the effect was observed for any direction of vibration of the die with respect to the wire, it is probable that the reduction in drawing force is not due primarily to a reduction in the yield strength of the aluminum, although this possibly is a factor. With more precision in the measurement of vibrational amplitude it could undoubtedly be determined.

The energy required to draw a wire through a die is used up in overcoming the friction between the die surfaces and the wire and in plastically deforming the wire. Because of the transverse method of vibration of the die, namely, with all parts having the same velocity, no appreciable vibrational compressive or tensile stresses were exerted across the wire. That is, the body forces probably were small. Therefore, the principal effect must have been due to the remaining source of energy dissipation, friction at the wire and die surfaces.

With friction being reduced, localized heating should be less, and there should be a consequent reduction in surface residual stress.

V. RECOMMENDATIONS FOR FUTURE WORK

Future investigations should be done with standard dies, wire sizes, and speeds. It would be desirable to try vibrating the die in one of its basic modes, preferably a radial mode, instead of merely working against the initial forces of the wire.