
Masters Theses

Student Theses and Dissertations

1957

Internal friction in manganese copper alloys

William Paul Dixon

Follow this and additional works at: https://scholarsmine.mst.edu/masters_theses



Part of the [Physics Commons](#)

Department:

Recommended Citation

Dixon, William Paul, "Internal friction in manganese copper alloys" (1957). *Masters Theses*. 2559.
https://scholarsmine.mst.edu/masters_theses/2559

This thesis is brought to you by Scholars' Mine, a service of the Missouri S&T Library and Learning Resources. This work is protected by U. S. Copyright Law. Unauthorized use including reproduction for redistribution requires the permission of the copyright holder. For more information, please contact scholarsmine@mst.edu.

INTERNAL FRICTION
IN
MANGANESE COPPER ALLOYS

by

William Paul Dixon

A
THESIS

submitted to the faculty of the
SCHOOL OF MINES AND METALLURGY OF THE UNIVERSITY OF MISSOURI
in partial fulfillment of the work required for the

Degree of
MASTER OF SCIENCE, PHYSICS MAJOR

Rolla, Missouri

1957

91233

Approved by-

Harold O. Fuller

Professor of Physics

ACKNOWLEDGEMENT

The writer wishes to express appreciation to those in the Bureau of Mines who have created this research opportunity and have provided the equipment for carrying it out. Among those who have made the work possible are Robert W. Geehan, Chief, Division of Mineral Technology; J. A. Rowland, Chief, Branch of Metallurgy; James W. Jensen, Supervisor, Physics of Metals Unit; Dr. Harold Q Fuller, Chairman, Department of Physics, Missouri School of Mines.

Mr. Jensen supervised the work, making suggestions about the design of new equipment and the modifications of the old. His greatest help was through many informal discussions of the physics of manganese-copper alloys.

The metallography was done under the direction of Mr. Paul Barnard, metallographer.

CONTENTS

	Page
Acknowledgement	ii
Illustrations	iv
Tables	v
Introduction	1
Processes associated with internal friction	3
Summary of previous work on Manganese-Copper alloys	8
Modified Ke pendulum	13
Preparation of wire specimens	21
Results	24
Conclusions	38
Bibliography	42
Vita	45

ILLUSTRATIONS

Figure	Page
1. Phase diagram of Manganese-Copper	12
2. Ke pendulum	14
3. Cold chamber	17
4. Recording system	20
5. Strain dependence of internal friction	26
6. Internal friction in specimen A-3	27
7. Internal friction in specimen A-14	30
8. Internal friction in specimen A-15	31
9. Internal friction in specimen A-15b	32
10. Internal friction in specimen A-19	34
11. Internal friction in specimen A-19b	35
12. Decay of internal friction	36

TABLES

Table	Page
1. Structure change in Manganese-Copper	9
2. Solution treatment	25
3. Aging	25

INTRODUCTION

The study of the physical properties of the manganese-copper alloys is an intriguing one. These alloys show promise of usefulness in instances in which high internal friction is needed to reduce the noise and vibrational stresses at resonant frequencies of a part of a machine. The purpose of this study has been to learn more about the internal friction of manganese-copper alloys as a function of temperature, stress amplitude, frequency, time, and past history of the specimen. From this information the mechanism for absorption of vibrational energy is proposed, or at least some progress has been made toward its determination.

The capacity of a vibrating solid to convert mechanical energy into heat, even when isolated from surroundings, is commonly manifested by a loss of amplitude of a freely vibrating body^{18/}. The processes in the material which absorb vibrational energy are caused by internal friction. A perfectly elastic material would sustain a mode of vibration forever.

There are several ways in which a metal may differ from an elastic material: it may undergo plastic flow or creep, behave non-elastically, or behave anelastically. These are types of deformation without fracture. Creep is a deformation which continues to increase as long as the stress is applied. Strain is proportional to stress in a non-elastic material and there is a partial recovery after the stress is removed. Zener^{28/} defines anelasticity as "that property of solids in virtue of which stress and strain are not single valued functions of one another in

that low stress range in which no permanent set occurs and in which the relation of stress to strain is still linear." This means that a step force produces an immediate displacement but that there is a time delay in reaching the steady state or maximum displacement.

Common methods of measuring internal friction include the measurement of the decay rate or logarithmic decrement of a free mode of vibration which may be torsional, transverse, or longitudinal, although the decay of a torsional mode is probably the most often applied^{1 9 20 30/}. The angle between stress and strain in a driven torsional mode of vibration is a measure of the internal friction^{17/}.

The apparatus used in this study was a modified Ke^{13/} torsion pendulum. The logarithmic decrements of free modes of vibration were measured over a range of temperatures for each specimen.

PROCESSES ASSOCIATED WITH INTERNAL FRICTION

An early theory of internal friction by Zener^{29/} was that stress inhomogeneities give rise to fluctuations in temperature, and hence to local heat currents. These heat currents are concurrent with a rise in entropy which in turn was associated with thermoelastic internal friction. Zener thought that internal friction due to cold-work was a special example of thermoelastic internal friction. He pointed out that it has a maximum value at a frequency of the order of magnitude of the ratio of the thermal diffusion constant to the square of the mean linear dimension of the inhomogeneities in stress.

Zener^{28/} describes in mathematical terms the characteristics of a model which he called a standard linear solid. The differential equation for the model is equation 1,

$$F + T_y \cdot dF/dt = M_r(y + T_f \cdot dy/dt). \quad (1)$$

F is the stress, y is the strain, M_r is the relaxed modulus of elasticity, T_y is the characteristic time for stress relaxation at constant strain, and T_f is the time for strain relaxation at constant stress. The solution for stress as a function of time at constant strain may be found from equation 2,

$$F(t) = M_r y_0 + (F_0 - M_r y_0) e^{-t/T_y}. \quad (2)$$

The solution for strain as a function of time at constant stress is expressed in equation 3,

$$y(t) = F_0/M_r + (y_0 - F_0/M_r) e^{-t/T_f}. \quad (3)$$

If equation 1 is integrated with respect to time over a period so short that no relaxation takes place the integral is

$$T_y \cdot dF = M_r T_f \cdot dy. \quad (4)$$

and

$$M_u = dF/dy = M_r T_f / T_y. \quad (5)$$

M_u is assumed to be the elastic modulus over a time so short that relaxation cannot take place.

Reed^{21/} describes internal friction as "a property of matter in virtue of which organized energy of imperfectly elastic stress is rendered irrecoverable, or unavailable for mechanical work." Reed found the internal friction of well annealed single crystals to be, in general, considerably less than that of corresponding polycrystalline materials, and that the decrements of unannealed crystals may be as large as those of polycrystalline specimens.

It has been observed that atoms of solute in a solid solution may diffuse through the lattice to nuclei of precipitate or grains of precipitate and become trapped. The grain grows as more atoms are trapped on it. This removal of atoms from solid solution may absorb energy and contribute to internal friction. The solute may be either metallic or nonmetallic atoms. The diffusion of an atom from one lattice point to another or to an interstitial position is dependent on temperature and on the frequency of mechanical vibration. The diffusion rate is a maximum when the period of vibration is near the mean atomic jump time. The position of the internal friction peak will also depend on the concentration of solute^{7 8 10 14 26/}.

If plots of internal friction versus $1/T$ at frequencies w_1 and w_2 can be superimposed by a simple shift of axis, the relaxation time is

of the order $e^{-H/RT}$. H , the activation energy in calories per mole, may be calculated from equation 6,

$$H = R \ln(w_2/w_1)/(1/T_1 - 1/T_2). \quad (6)$$

R is the gas constant, and T_1 and T_2 are absolute temperatures of the respective internal friction peaks for w_1 and w_2 .

Ke^{13 16/} observed that grain boundary viscosity is an important source of internal friction. He also found that the addition of alloying elements, either metallic or nonmetallic, affects the magnitude of the internal friction peak, and that the addition of an alloying element also causes a second peak which is produced by grain boundary relaxation. Pearson and Rotherham^{19/} found that the activation energy for grain boundary relaxation is not the same as that for volume self-diffusion. Wenig and Machlin^{25/} calculated the activation energy for grain boundary relaxation from equation 7,

$$H = R \ln(GS_2/GS_1)/(1/T_1 - 1/T_2), \quad (7)$$

where T_1 and T_2 are the absolute temperatures of the respective internal friction peaks measured at the same frequency for grain sizes GS_1 and GS_2 . The value for the activation energy computed from this equation agreed with the value computed from equation 6.

Ke¹⁵ found that the internal friction caused by cold-work increases with the amount of cold-work to which the specimen is subjected before and after recrystallization, and that internal friction decreases with annealing at successively higher temperatures until a stable value is reached. Ke also found that an increase in precipitated impurity content increased internal friction.

In certain aluminum-copper alloys Ke^{11/} observed a stress dependence of internal friction which he called anomalous internal friction. At a given temperature it first increased, then decreased, with an increase in stress amplitude. At each stress amplitude there was an optimum temperature of measurement at which this internal friction was maximum.

Ke noted that his observations of internal friction in both monocrystalline and polycrystalline specimens of metals were consistent with the concept that internal friction is caused by the presence of dislocations within the crystals of the specimen. All models used for interpretation demonstrated an interaction between solute atoms and dislocations in which solute atoms are trapped by dislocations and conversely dislocations are immobilized by solute atoms.

In the theory of dislocations proposed by Cottrell^{5/} there are described process of interaction between dislocations and between dislocations and other irregularities in the crystal which absorb energy. Two sources of internal stress in a crystal which may interact with dislocations and absorb energy are particles of precipitate and crystal boundaries. The stresses resulting from distortion can be relieved by migration of large solute atoms to the region where the lattice is expanded and small solute atoms to the compressed region, but the strains remain.

Cottrell stated, furthermore, that external shear stress may produce dislocations of opposite sign in pairs. Dislocations of opposite sign attract and their movement together will result in mutual annihilation if they are on the same slip plane; therefore, under external shear stress

they must acquire an activation energy sufficient to separate them at least the critical distance. At less than the critical distance for unstable equilibrium the external stress will not hold the dislocations apart. The activation energy, H , per unit thickness, is expressed in the equation

$$H = \left[\frac{G\lambda^2}{2\pi(1-\nu)} \right] \left[\log(R/r_0) - 2 \right], \quad (8)$$

where G is the modulus of elasticity, λ is the dislocation strength in centimeters, ν is Poisson's ratio, r_0 is of the order of $6 \cdot 10^{-8}$ centimeters, and R is the distance of displacement. Thus the production of dislocations in pairs can be a mechanism for internal friction.

SUMMARY OF PREVIOUS WORK ON MANGANESE-COPPER ALLOYS

Seifert^{23/} and Worrell^{23 27/} in studying the structure and internal friction of manganese-copper alloys, measured the logarithmic decrement of a transverse mode of vibration at 700 cycles per second. A peak in internal friction for a specimen quenched from 925° C. was observed at -7°C. Annealing at 625° C. for 72 to 144 hours greatly reduced this peak. They associated the high internal friction of this 88 percent manganese-12 percent copper alloy with stress relaxation of the twins in the gamma phase, a solid solution of copper and manganese.

Since internal friction of manganese-copper alloys has been associated with structure, a knowledge of the structure is essential. Basinski and Christian^{2/} investigated the structure of manganese-copper as a function of temperature and percent composition of each element. The structure of the gamma solid solution is face-centered cubic at high temperatures, but as the temperature is lowered the structure changes to tetragonal. The temperature for the structure change for four compositions of manganese-copper is given in Table 1.

Basinski and Christian reported that the temperature of the structure change is dependent on the composition and the grain size. Not all of a grain changes structure at once, but the change takes place in twinned bands which on a polished surface were tilted at an angle of 2° 5'. As the temperature is lowered new bands form until the entire grain has changed structure, as in a martensitic change. The change is reversible, but thermal cycling in the tetragonal region causes some plastic deformation. The twins form instantaneously; the c/a ratio change of a grain

TABLE I

The Temperature Ranges for the Complete Structure Transformation from Cubic to Tetragonal of Solution-Treated Manganese-Copper Alloys.

Composition pct. by wt.		Temperature Range of Structure Change
<u>Mn</u>	<u>Cu</u>	
88	12	110° C. to 150° C.
85	15	55° C. to 90° C.
80	20	-10° C. to 15° C.
75	25	-70° C. to -50° C.

is non-homogeneous. The mechanism for the structure change is a double shear on (110) planes at a 60-degree angle. No internal friction measurements were reported by them.

Basinski and Christian stated that the change in manganese-copper copper was like a martensitic transformation. This type of transformation is described by Cohen^{3/} as "a characteristically insuppressible change in structure" in which "no atomic diffusion is required; instead, portions of the parent crystal undergo a process of sudden shear to generate plates of the martensite product. The transformation does not proceed by growth of existing plates but by sudden formation of new ones which spring 'full-born' into existence as the temperature is lowered."

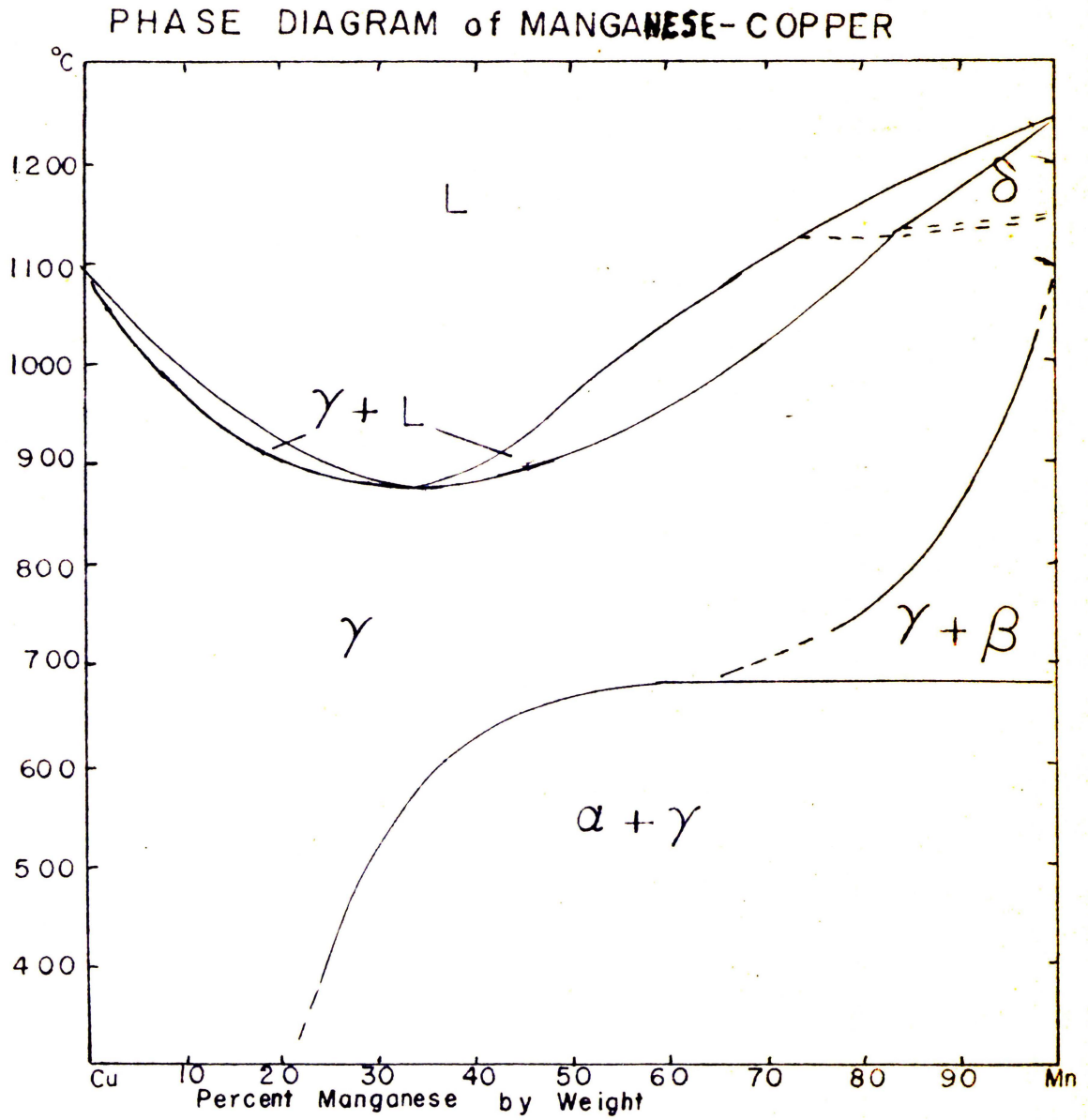
Rowland, Armantrout, and Walsh^{22/} have shown that the alloys with high damping capacity which are most suitable for structural or machine components contain from 60 percent to 80 percent manganese. They also found that solution-treated alloys of less than 78 percent manganese have cubic structure and low damping capacity at room temperature, whereas those of greater than 78 percent manganese have tetragonal structure and high damping capacity at room temperature. Aging solution-treated alloys at 375° C. to 450° C. results in gradual nucleation and subsequent growth of alpha manganese; in the case of alloys of less than 78 percent manganese it results in a change from cubic to tetragonal structure as well as greatly increased damping capacity.

Sickafus^{24/} investigated the internal friction of 75 percent manganese-25 percent copper and 85 percent manganese-15 percent copper alloys as a function of temperature over a range from room temperature to 225° C.

The alloys were first solution-treated, and the internal friction as a function of temperature was measured in a torsion pendulum. The same specimens were later aged in the temperature region for precipitation of alpha manganese and the measurement of internal friction repeated. Sickafus made the following observations: The solution-treated 75 percent manganese alloy had low damping capacity throughout the temperature range. Aging the sample at 400° C. increased the damping capacity at room temperature, but at some higher temperature, which depended on aging time and aging temperature, the damping capacity dropped to a low value. On the other hand, the damping capacity of the solution-treated 85 percent alloy dropped to a low level at a temperature above 85° C. Aging the specimen shifted the upper limit of the high damping-capacity region to 145° C. In all specimens which exhibited high damping capacity there occurred a decay of damping capacity at constant temperature over a given period of time. The rapid increase in internal friction was concurrent with a decrease in dynamic rigidity in all specimens except one for which an internal friction peak was observed at 220° C.

Darling^{6/} suggested a mechanism for internal friction of manganese-copper alloys, employing a twin interface which is extremely sensitive to the precise position of atoms in its immediate vicinity. Movement of the twin interface is promoted by a low shear stress in a direction perpendicular to the direction of the stress, and will relax the stress completely if the twinned crystals are large enough. The atomic movement required to move the twin interface in manganese-copper alloys has been found to be exceptionally small and to decrease with an increase in manganese content.

FIGURE 1



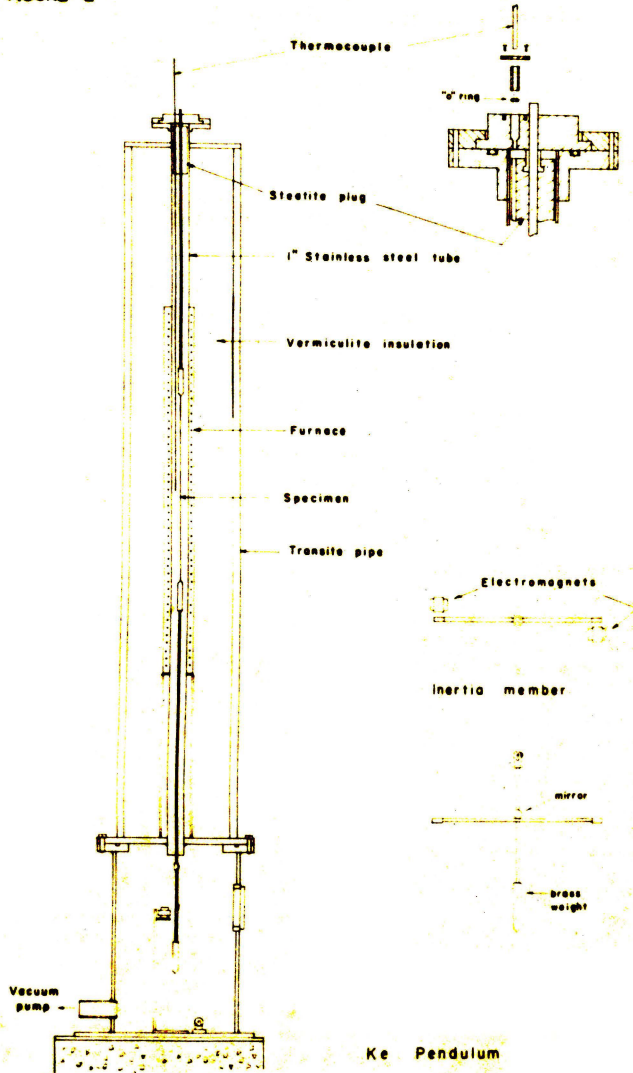
from Thesis by Sickafus²⁴

MODIFIED KE PENDULUM

The Ke pendulum consisted of a wire with an attached inertia member suspended vertically in a vacuum chamber as in Figure 2. The suspension was made in four parts, the top section of which was a 1/8-inch-diameter steel rod with a brass flange on the upper end and a pin vise for holding the specimen on the lower end. The second section, the specimen, was a 12-inch manganese-copper wire of 0.030-inch diameter. The third section consisted of another steel rod with a pin vise on the upper end and a square notch in the lower end to fit the drawing-instrument type of connection on the inertia member. The last section, the inertia member, was cross-shaped with a mirror on the vertical member and small iron weights on the ends of the arms. A pair of electro-magnets was attached to the walls of the vacuum chamber near the ends of the arms of the cross. A torque was applied to the pendulum by the force on the iron in the inertia member of the magnetic field produced by electrical pulses through the electro-magnet windings. The pulses were produced by manually tapping the switch.

The vacuum chamber for the pendulum, which was designed by Sickafus^{24/}, was in two parts; an 8-inch-diameter cylindrical section mounted with the axis of the cylinder vertical on a concrete block, and a removable furnace which fit on top of the large cylinder. The over-all length of the furnace assembly was 4 feet. It was constructed of a 1-inch-diameter stainless steel specimen tube, 3 cylindrical electric heating elements, insulation, a 2-1/2-inch-diameter brass flange at the top, and an 11-inch-diameter steel flange at the lower end. The electric heating elements were placed

FIGURE 2



from Thesis by Sickfus 24

around the center of the tube and balanced by adjusting the potential across each to produce a uniform temperature in a region slightly longer than the specimen. The insulation was a 6-inch-diameter section of transite pipe filled with vermiculite.

"O-ring" seals were made in the flanges joining the furnace section and the large chamber and flanges joining the upper specimen holder and specimen tube. There was also an "O-ring" seal in the hole through the upper specimen-holder flange for a 1/8-inch-diameter thermocouple rod. The pressure was reduced to a range 50 microns to 200 microns to reduce the effect of air friction. Cottell and Entwistle⁴ found that the air friction was greatest near atmospheric pressure and that it was negligible below 100 microns.

The observation window in the large chamber was made by cementing with shellac and latex a 3/8-inch-thick glass plate over a 3/4-inch by 3-inch opening.

The furnace was capable of producing temperatures up to 500° C. and was regulated with a Brown potentiometer controller, which by the on-off method controlled the furnace temperature within ± 0.5 degrees C.

Sickafus in his investigations assembled the specimen in the pin vises in a horizontal position and lowered the three upper parts of the pendulum assembly as one unit into the furnace. The furnace was balanced on a weight and pulley system and was raised from the lower chamber to attach the inertia member. With the pendulum complete the furnace was lowered in place and bolted to the large chamber. However, in this investigation the entire pendulum was assembled in a vertical position, and the three

upper parts were lowered into the furnace as the assembly progressed. The inertia member was attached either by the same procedure Sickafus used or through a port in the side of the large chamber.

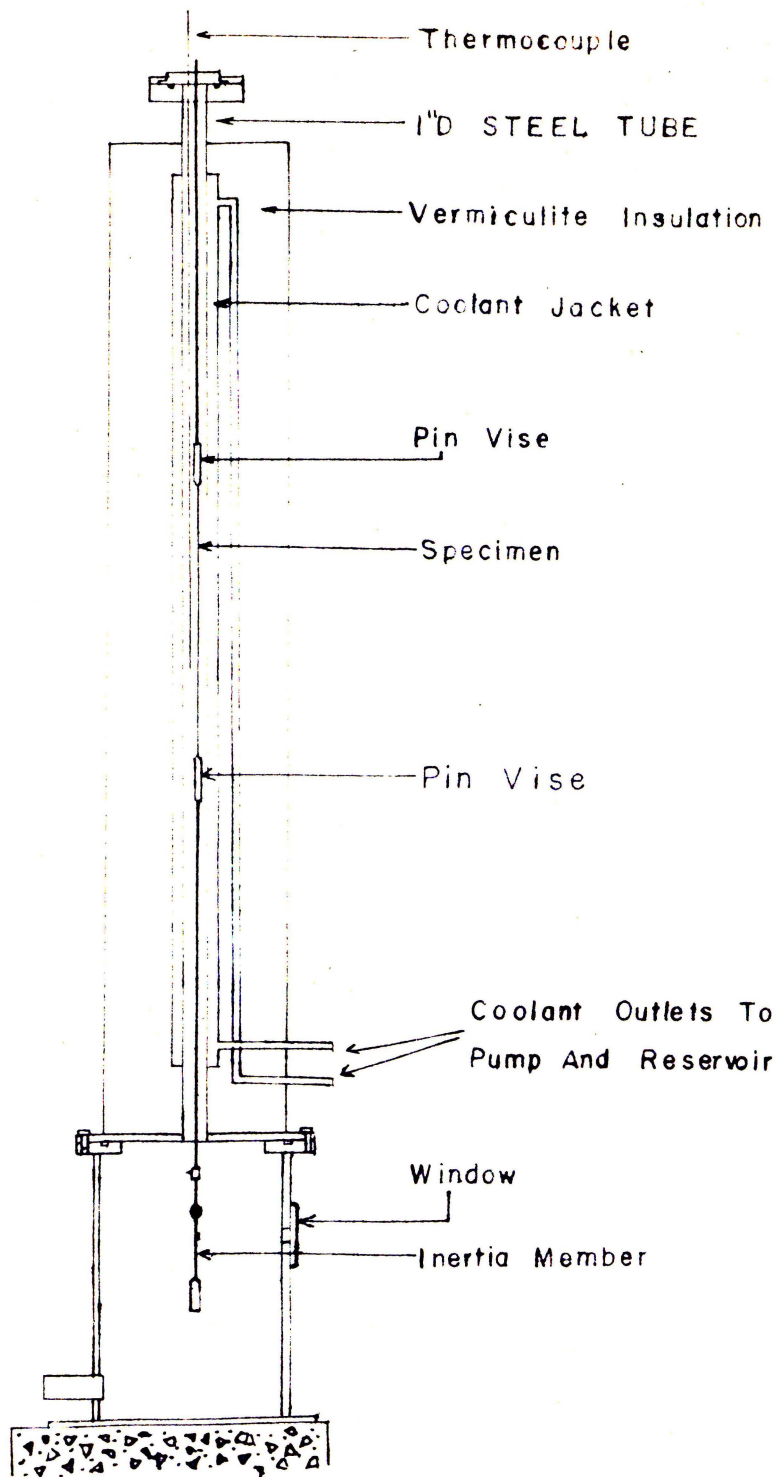
Modifications of Sickafus' design as shown in Figure 3 included a cold chamber to replace the furnace and extend the temperature range below room temperature, and a six-inch-diameter port in the side of the large chamber for access to the inertia member without the raising of the furnace.

A coolant was circulated around the specimen tube of the cold chamber inside a jacket of 1-1/2-inch-diameter pipe 36 inches long and coaxial with the 1-inch-diameter specimen tube. The cold chamber was insulated with a steel jacket seven inches in diameter and 46 inches long filled with vermiculite and sealed to prevent moisture from condensing in the insulation.

Alcohol was chosen for a coolant when the pendulum was operated at reduced temperatures and was pumped from a reservoir through the pendulum cold chamber by a centrifugal pump. A small amount of water in the alcohol caused no difficulties. Initially the alcohol was cooled by dropping chipped dry ice into the reservoir, but this method was unsatisfactory because the slight reduction of pressure in the intake of the pump caused evolution of the carbon dioxide, which was soluble in the alcohol. The pump filled with gas instead of fluid and the flow of fluid stopped. At slow speeds the pump would not work at all, but at high speeds, maintained for short intervals, enough cold alcohol could be circulated to reduce the pendulum temperature to a minimum of -10° C. to -30° C.

KE PENDULUM
COLD CHAMBER

FIGURE 3



A heat exchanger was made from a section of 1-1/2-inch-diameter brass pipe. The closed end of the pipe was submerged to a depth of about 2 inches in the coolant reservoir, and the pipe filled with chipped dry ice over which about 80 ml of alcohol was poured. When the return stream of coolant from the cold chamber was directed over the submerged end of the heat exchanger in the reservoir, the temperature range of the pendulum was extended to -24° C. It is possible to obtain lower temperatures with this system by simply increasing the size and surface area of the heat exchanger.

A modification which was abandoned was a system for circulating air over dry ice through the pendulum chamber. This system operated down to -25° C. but it had several serious disadvantages: Air friction was greater than the internal friction of a low damping-capacity alloy; condensation froze on the inside of the system on humid days; the ice film increased the apparent internal friction and caused erroneous temperature measurements; a desiccant was effective in preventing icing only when the relative humidity was low. The results from the ice-free runs, however, were correlated with later runs at reduced pressures in the fluid-cooled system.

The frequency of the pendulum was known to be a function of the diameter and the length of the wire specimen, the dynamic modulus of the alloy, and the inertia of the pendulum; the frequency of the original Sickafus pendulum was approximately 6 cycles per second. In tests of frequency dependence of internal friction a reduction of frequency to about 1 cycle per second was obtained by means of another inertia member. At the same time the tensile stress on the specimen was increased

from 132 lb/in² to 220 lb/in². Since the internal friction measurements were made from the decay of the torsional mode of vibration, and the tensional and torsional stresses were of the same order of magnitude, it was desired to keep the tensile stress low.

In the recording system a beam of light was focused on a mirror on the oscillation pendulum. The reflected light beam passed through the observation window to a 6-inch-square translucent screen which was 60 inches from the pendulum. A continuous trace of the light spot on the screen was recorded by a 35 mm flowing-film camera. Figure 4 is a sketch of the recording system.

The maximum angle of deflection recorded by the camera was 1.2 degrees, or a strain of $5.2 \cdot 10^{-5}$ for a 12-inch length of 0.030-inch-diameter wire. The logarithmic decrement was calculated from the film over a range from 10 to 80 cycles at 3 or more strain amplitudes from 1.2 degrees to 0.2 degrees. If A_n is the distance on a projection of the film from maximum to minimum of the trace of 1 cycle, and A_{n+m} is the distance from maximum to minimum of the trace m cycles later then

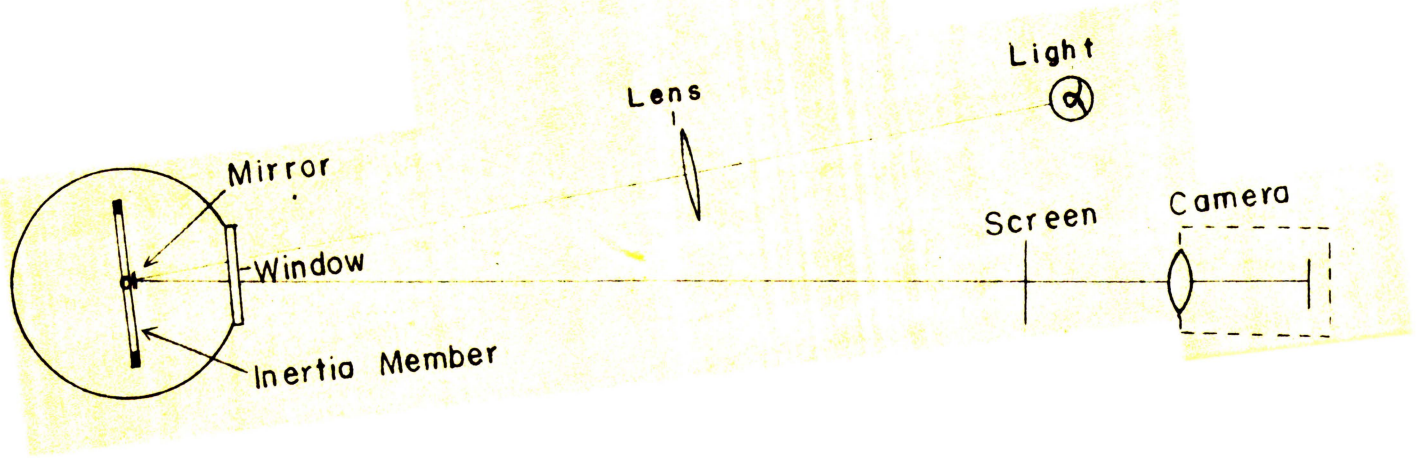
$$A_n/A_{n+m} = e^{m\delta},$$

$$\delta = \log \text{dec} = \ln(A_n/A_{n+m})/m,$$

$$\phi = \text{internal friction} = \delta/\pi.$$

RECORDING SYSTEM

FIGURE 4



PREPARATION OF WIRE SPECIMENS

The wires for the Ke pendulum specimens were drawn from manganese-copper ingots which were cast under an inert atmosphere and under controlled conditions. These controlled processes reduced but did not eliminate dirt and other foreign inclusions. The 0.030-inch-diameter wires as drawn were in a cold-worked condition. The cold-work was removed by heat treatment.

The wire was first inspected under a microscope for flaws and a 15-inch section which was free of visible flaws was selected for heat treatment. To remove the effects of cold-work the alloy was heated to the recrystallization temperature long enough for the growth of a new grain structure. This is a temperature below the melting point at which the manganese and copper atoms occupy random positions in a face-centered cubic lattice. This structure, known as the gamma solid solution, may be frozen by quenching to a temperature below that for precipitation of manganese^{8/}. The temperature for solution treatment of each alloy may be determined from the phase diagram, Figure 1.

A modification of the heat treatment procedure had to be made because the available conventional furnaces provided no means of holding the specimen straight so that it would not require straightening and cold-working after solution treatment. The wire was suspended with a weight attached to the lower end in a vertical pyrex tube and heated by passing an electric current of 10 to 14 amperes through it. It was then quenched by dropping it into vacuum pump oil that filled the lower end of the tube.

A copper wire hook was clamped to each end of the specimen with a 1/4-inch section of 0.030-inch copper tubing. The upper hook was placed in the loop of a 0.010-inch diameter iron wire fuse, and the lower hook held the weight. Sliding electrical contacts were made on the hooks, and at the end of the heating period the wire was dropped by blowing the fuse. The drop time for the weight to the bottom of the oil was about 7 seconds. When another section of wire was added between the specimen and the weight to suspend the weight near the bottom of the oil, the specimen dropped faster and a more uniform quench was possible. The time from melting of the fuse to submersion of the top of the specimen in the oil was 2 to 3 seconds.

Several attempts were made to measure the temperature of the wire in the range 700° C. to 1000° C. with an optical pyrometer, the lower limit of which was about 1000° C. Direct measurement of the temperature of the wire by a thermocouple was not possible, for the air around the specimen was cooler than the specimen and the cavity necessary to insert a very small thermocouple into the specimen would reduce the conductivity and create a hot spot.

A method of comparison of the color of the tip of a heated thermocouple with the color of the hot specimen was developed to measure the temperature of the specimen. The thermocouple was placed inside a helical heating element with the tip in a position visible between the turns of the heater. The helix, about 1/4-inch long, was made of 0.020-inch-diameter nichrome wire and had an inside diameter of about 0.035 inch and a pitch of about 0.040 inch. The diameter was just large enough for passage of the

tip of the platinum vs. platinum-13 percent rhodium thermocouple. As the thermocouple was heated to the desired temperature the specimen was heated until the colors of the thermocouple and specimen matched. Matching of colors was accomplished by holding the thermocouple in line of sight with the specimen, either between specimen and observer or beyond the specimen. It was not possible to put the thermocouple inside the tube, for the heat from the thermocouple heater would cause a hot spot on the specimen. There was a perceptible change in color for a 5° C. change in temperature at 900° C. Since the temperature of the thermocouple was always lower than that of the heater, observation of the color of the thermocouple was important.

To prevent excessive oxidation of the solution-treated specimens and to reduce the possibility of distilling off manganese, the heat treatment was done under a positive pressure of dried helium. The grade-A helium was passed through a CaCl_2 filled drying tube and a furnace filled with titanium shavings at 850° C.

Aging was done in the pendulum furnace under a positive pressure of helium. The furnace chamber was evacuated to 200 microns and filled with helium. A 75 percent manganese specimen, A-15b, was aged 1-1/4 hours at 445° C. with a total time of 3 hours above 350° C. A 70 percent manganese specimen, A-19b, was aged 1 hour at 440° C. with a total time of 3 hours above 350° C. Both specimens were removed from the furnace while hot and were air cooled.

RESULTS

In an introductory experiment on a specimen of aged 85 percent manganese alloy used by Sickafus in his experiments and tested under the same conditions he used, a curve for internal friction as a function of temperature was established which compared closely with that set up in the previous work. It was found that internal friction was relatively high below 145° C. and low above that temperature, and that decay in internal friction occurred at constant temperature over a given period of time.

Table 2 lists specimens that were solution treated in this investigation. Table 3 lists the specimens from Table 2 that were aged to precipitate alpha manganese.

Specimen A-3 was heated to the temperature for gamma solid solution to remove the effects of cold-work and cooled slowly through the temperature ranges for precipitation of beta manganese and alpha manganese. The structure was reported by the metallographer to be that for the gamma solid solution with a large amount of manganese precipitate. From X-ray diffraction it was found that the structure of the gamma solid solution was tetragonal and the precipitate was alpha manganese. The internal friction curve, Figure 6, dropped steeply from 0.0067 at -20° C. to less than 0.0005 at 100° C. Internal friction in the range of high values was dependent on strain amplitude, frequency, and the rate of change in temperature. The internal friction of A-3 as a function of strain amplitude is plotted for three temperatures

Table 2 - Solution Treatment

Specimen Number	Composition pct. by wt.		Solution treatment		
	Mn	Cu	Temperature Deg. C.	Time	Cooling
A-3	85	15	950*	5 min.	furnace cooled
A-14	85	15	1000*	5 min.	oil quench
A-15	75	25	885**	5 min.	oil quench
A-19	70	30	920**	5 min.	oil quench

* The temperature was measured with an optical pyrometer.

** The temperature was measured by the color matching method described in the section on preparation of specimens.

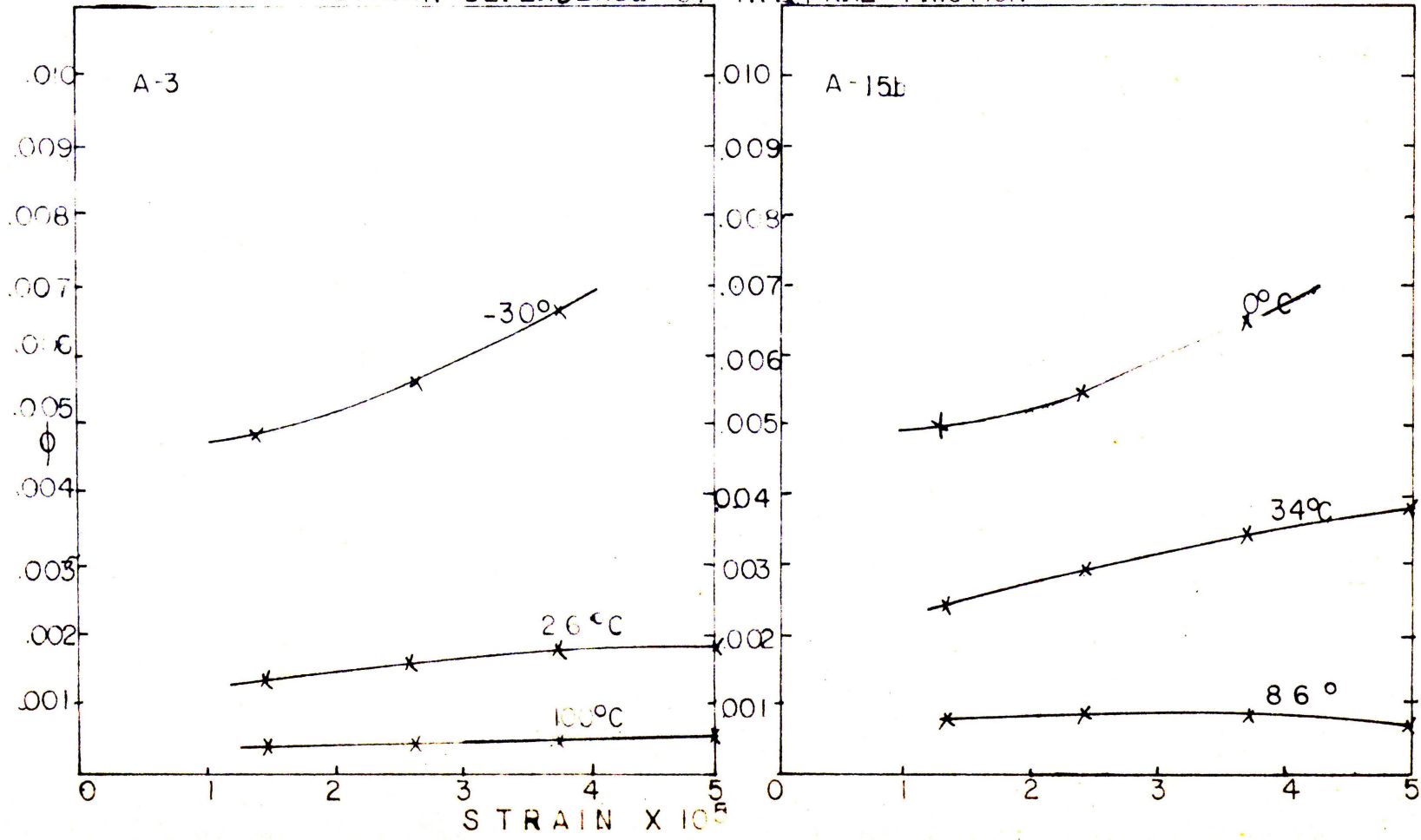
Table 3 - Aging

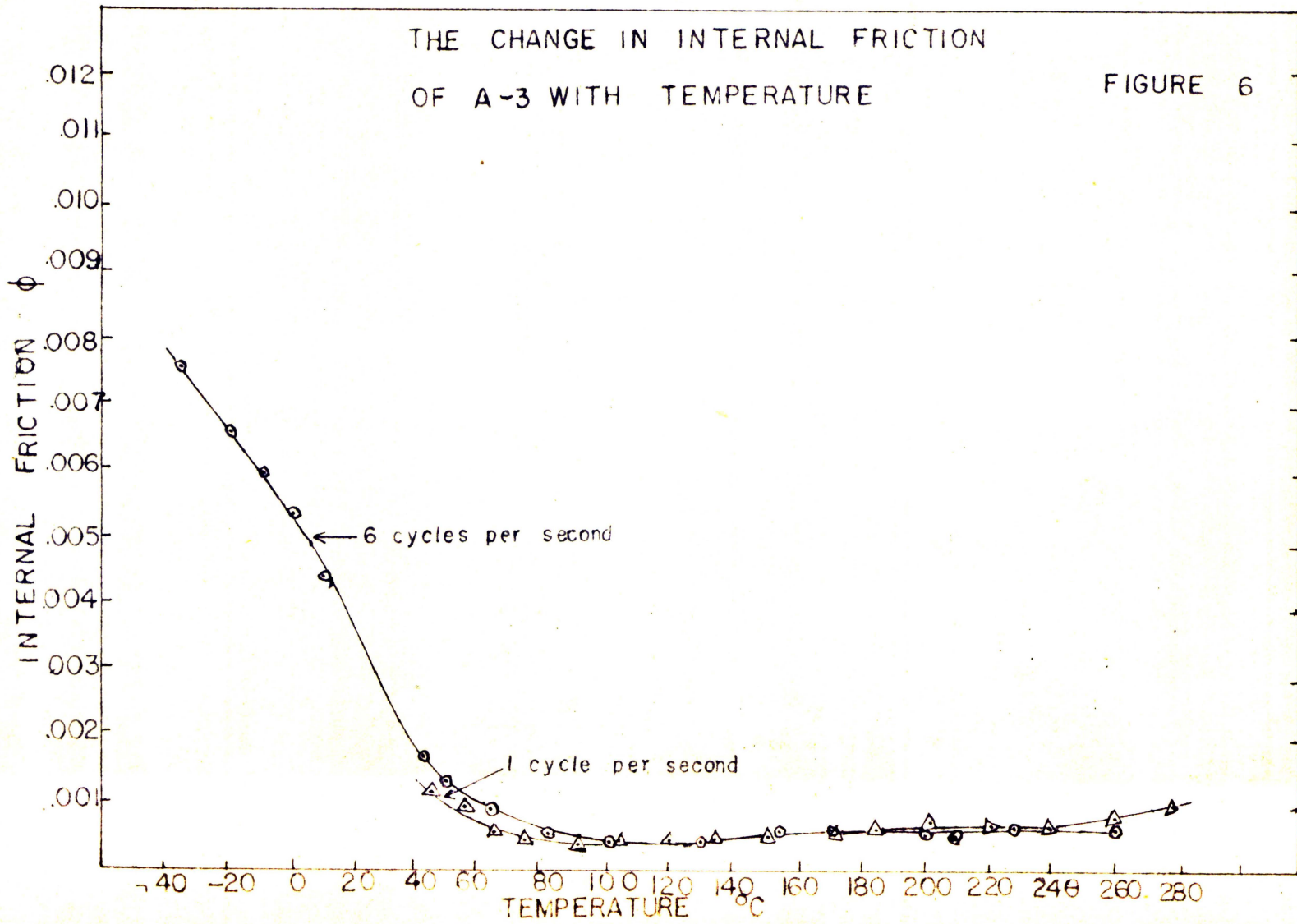
Specimen Number*	Aging Temperature	Aging Time	Total time above 350° C.
A-15b	445° C.	1 1/4 hour	3 hours
A-19b	440° C.	1 hour	3 hours

* The letter b was added to the specimen number from Table 2 to indicate additional heat treatment of the specimen.

FIGURE 5

STRAIN DEPENDENCE OF INTERNAL FRICTION



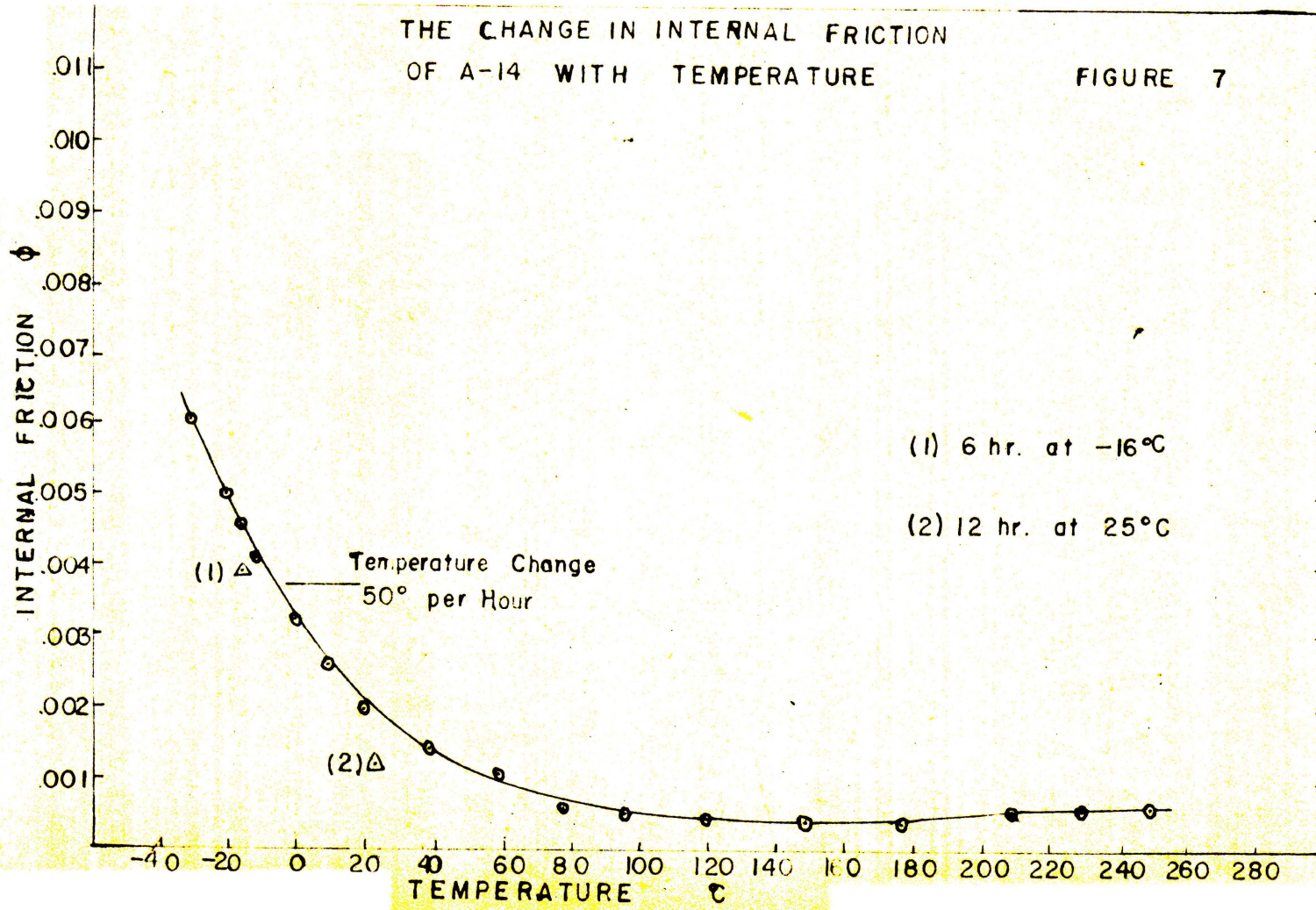


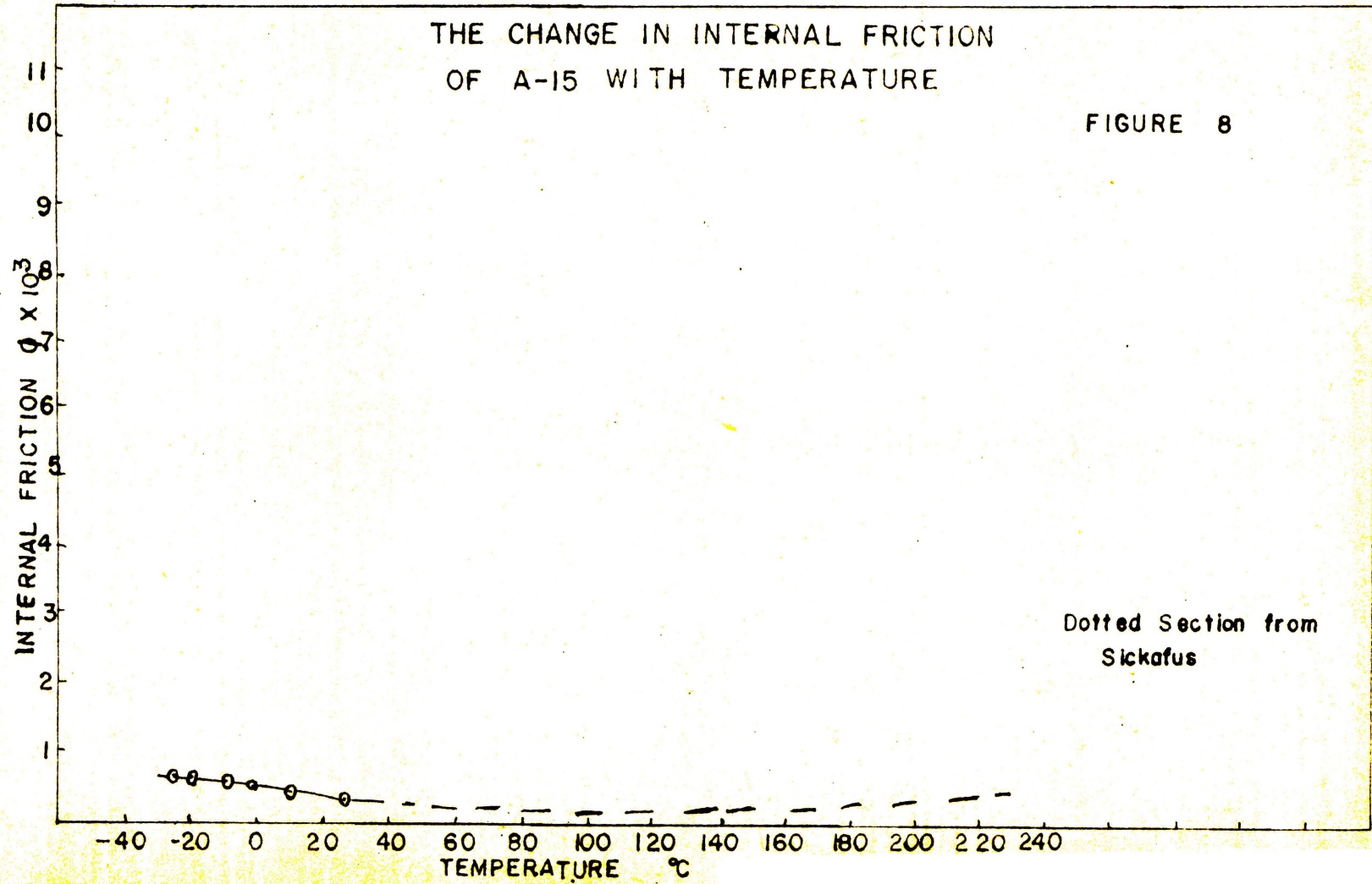
in Figure 5. Internal friction was not strain dependent at higher temperatures where the structure was cubic; it increased more with an increase in strain at successively lower temperatures where the structure was tetragonal. Internal friction as a function of temperature at the frequencies 6 cycle per second and 1 cycle per second is plotted in Figure 6. The internal friction of a specimen maintained at room temperature dropped from approximately 0.0028 to 0.0013 during 16 hours. There was a similar decay of internal friction at any temperature in the high internal friction region, but the original high values were reproducible.

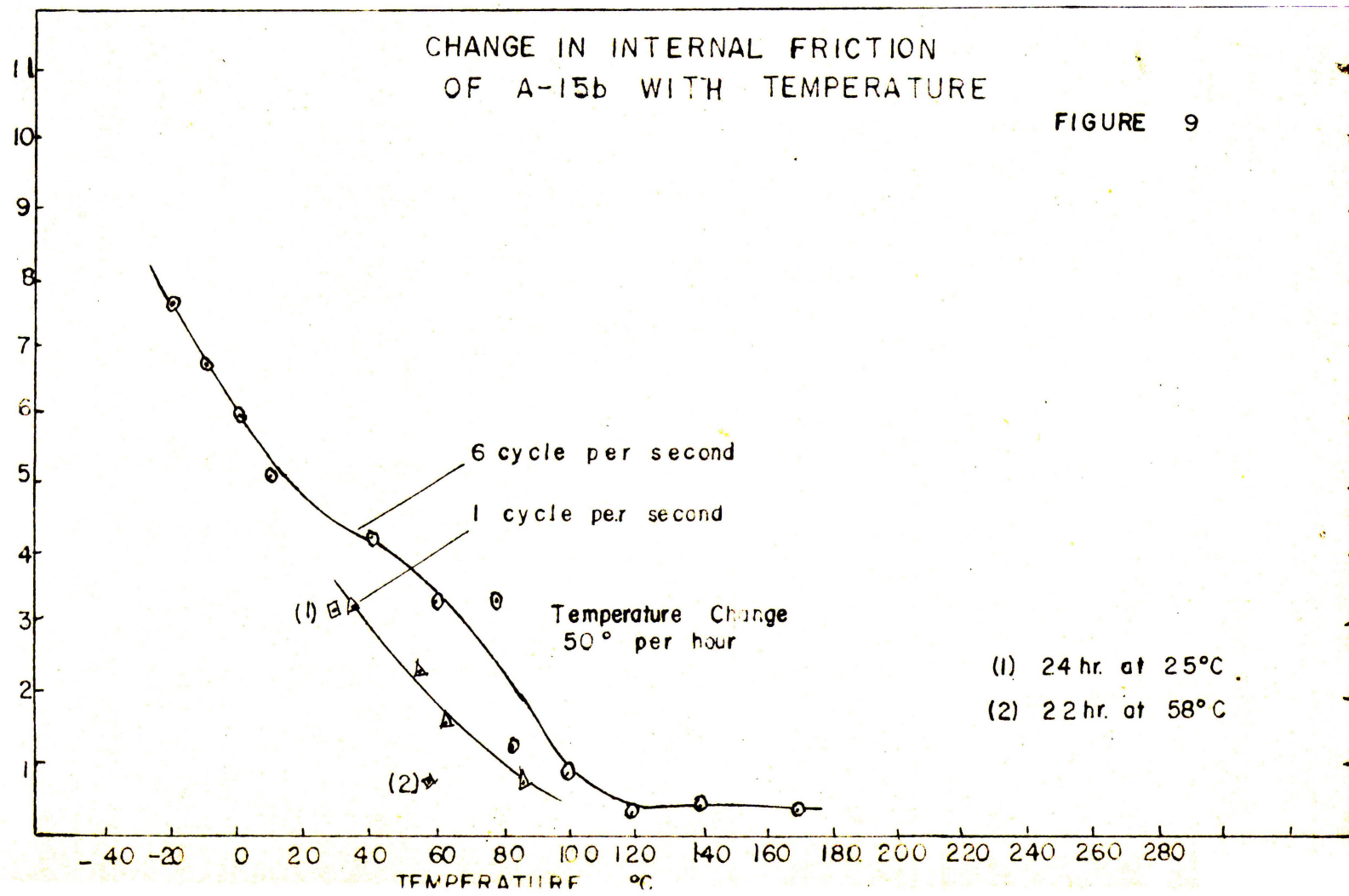
Specimen A-14 was heated to the temperature for gamma solid solution and quenched in oil. The structure was reported to be that for the gamma solid solution with a small amount of manganese precipitate. The structure of the precipitate was identified by X-ray diffraction as that of alpha manganese. Figure 7 is a plot of internal friction of A-14 as a function of temperature with a temperature change of approximately 50° C. per hour. The internal friction was high at low temperatures and low above 100° C. The measurements were made with a frequency of about 6 cycles per second. Internal friction is plotted in Figure 12 as a function of time at $-16 \pm 1^\circ$ C. for 6 hours. After 1 hour it was constant.

Specimen A-15 was a solution treated at 885° C. for 5 minutes and oil quenched. There was no evidence of manganese precipitate in the metallograph. The structure of a solution-treated 75 percent manganese alloy was cubic at room temperature, and the magnitude of internal friction was low. The internal friction is plotted as a

function of temperature from -24° C. to 27° C. in Figure 8. (The dashed section is the curve Sickafus obtained from another solution-treated 75 percent manganese alloy.) Specimen A-15 was aged as indicated in Table 3, and the designation was changed to A-15b. There was a marked change in the internal friction characteristics. Figure 9 is a plot of internal friction as a function of temperature at the frequencies 6 cycles per second and 1 cycle per second. The internal friction of A-15b was dependent on the temperature, the rate of change in temperature, the strain amplitude, and the frequency of vibration. The internal friction at room temperature was higher than that for the 85 percent manganese specimens, but it dropped to a low value above 120° C. It is plotted in Figure 12 as a function of time at $58 \pm 0.5^{\circ}$ C. for 22 hours. The internal friction dropped rapidly for the first 3 hours and continued to drop slowly for the rest of the period. Plots of the strain dependence of internal friction at three temperatures are shown in Figure 5. At lower temperatures there was a greater increase in internal friction with an increase in strain amplitude. Specimen A-19 was solution-treated at 920° C. and quenched in oil. The structure was cubic and there was no evidence of manganese precipitate. The internal friction was plotted as a function of temperature from -24° C. to 27° C. in Figure 10; it was very low. The specimen was aged as indicated in Table 3 and designated A-19b. The internal friction after aging was much greater than before, and it was greater in this aged 70 percent manganese alloy than in the aged 75 percent manganese alloy.



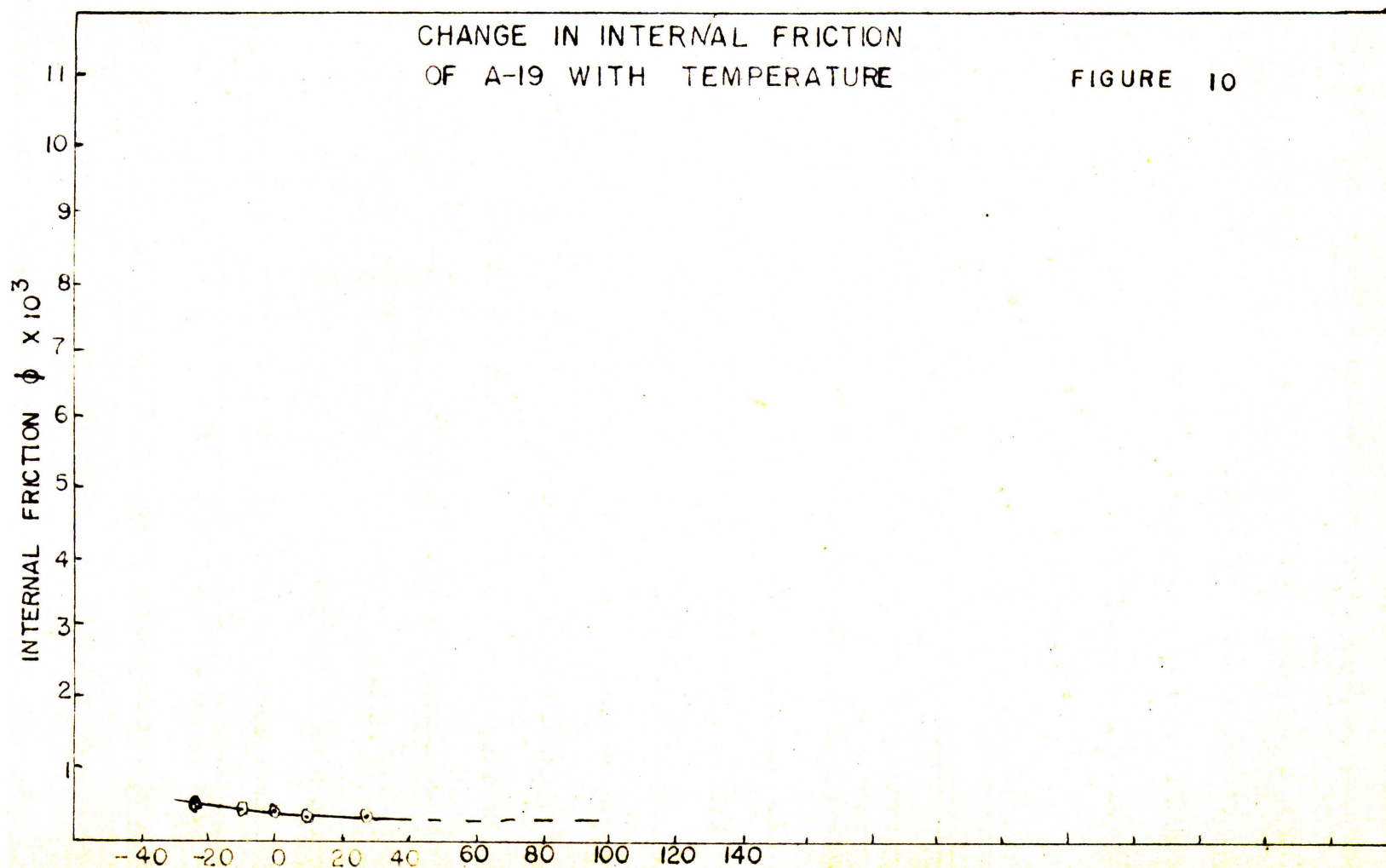




The probable reason for greater magnitude of internal friction in A-19b than in A-15b is that A-15b was aged too long for a maximum value of internal friction. The internal friction of A-19b was dependent on the temperature, the rate of change in temperature, the strain amplitude, and the frequency of vibration. Internal friction is shown in Figure 11 at the frequencies 6 cycles per second and 1 cycle per second. It dropped from very high values at -20° C. to 0.0005 at 130° C. with a temperature change of about 50° C. per hour.

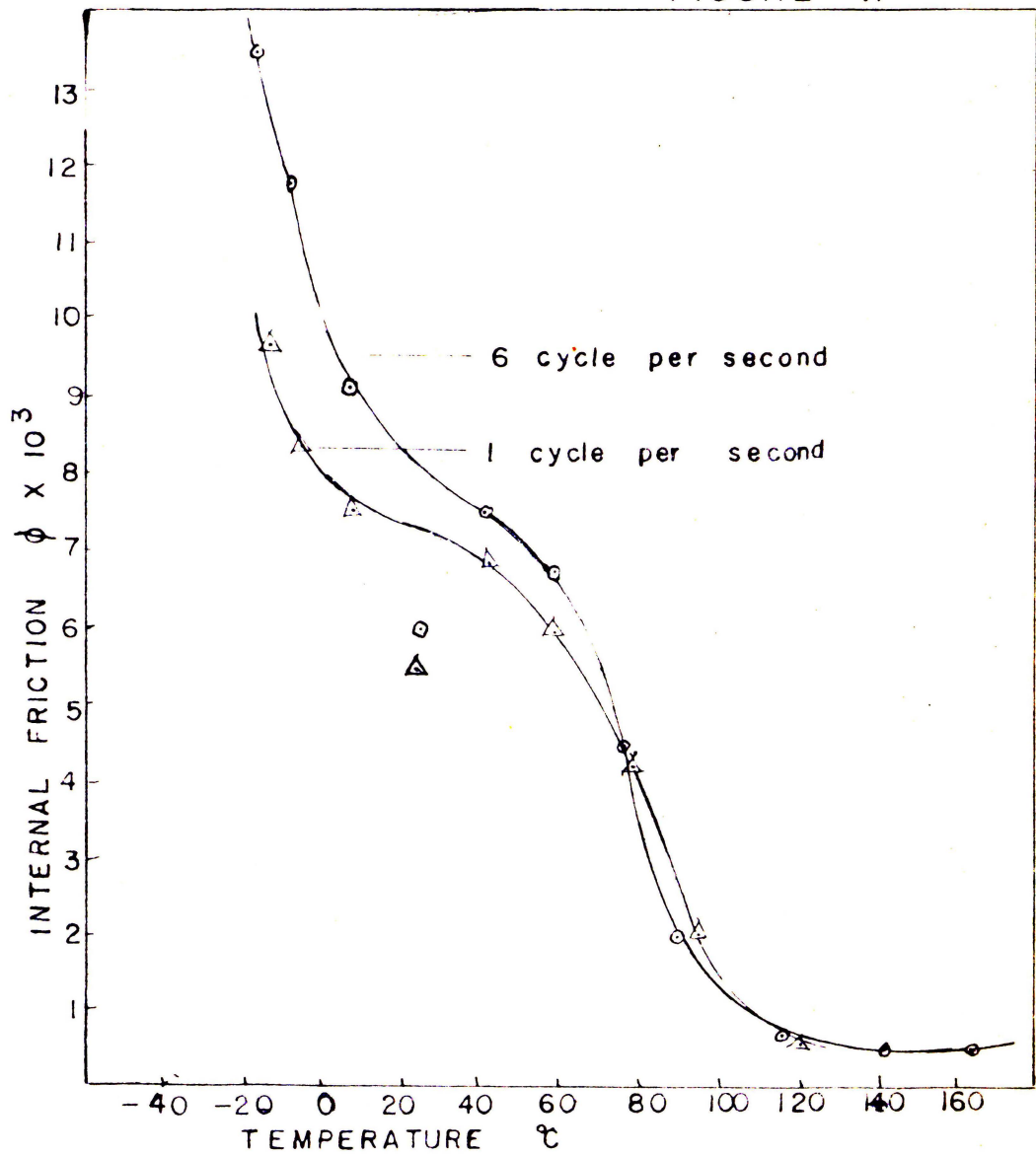
In all specimens with high internal friction the internal friction decreased with a rise in temperature in the temperature range -24° C. to 120° C. After having been held at constant temperature for several hours internal friction increased and then decreased as the temperature was increased. This type of peak was caused by a dependence of internal friction in manganese-copper alloys on the rate of change of temperature.

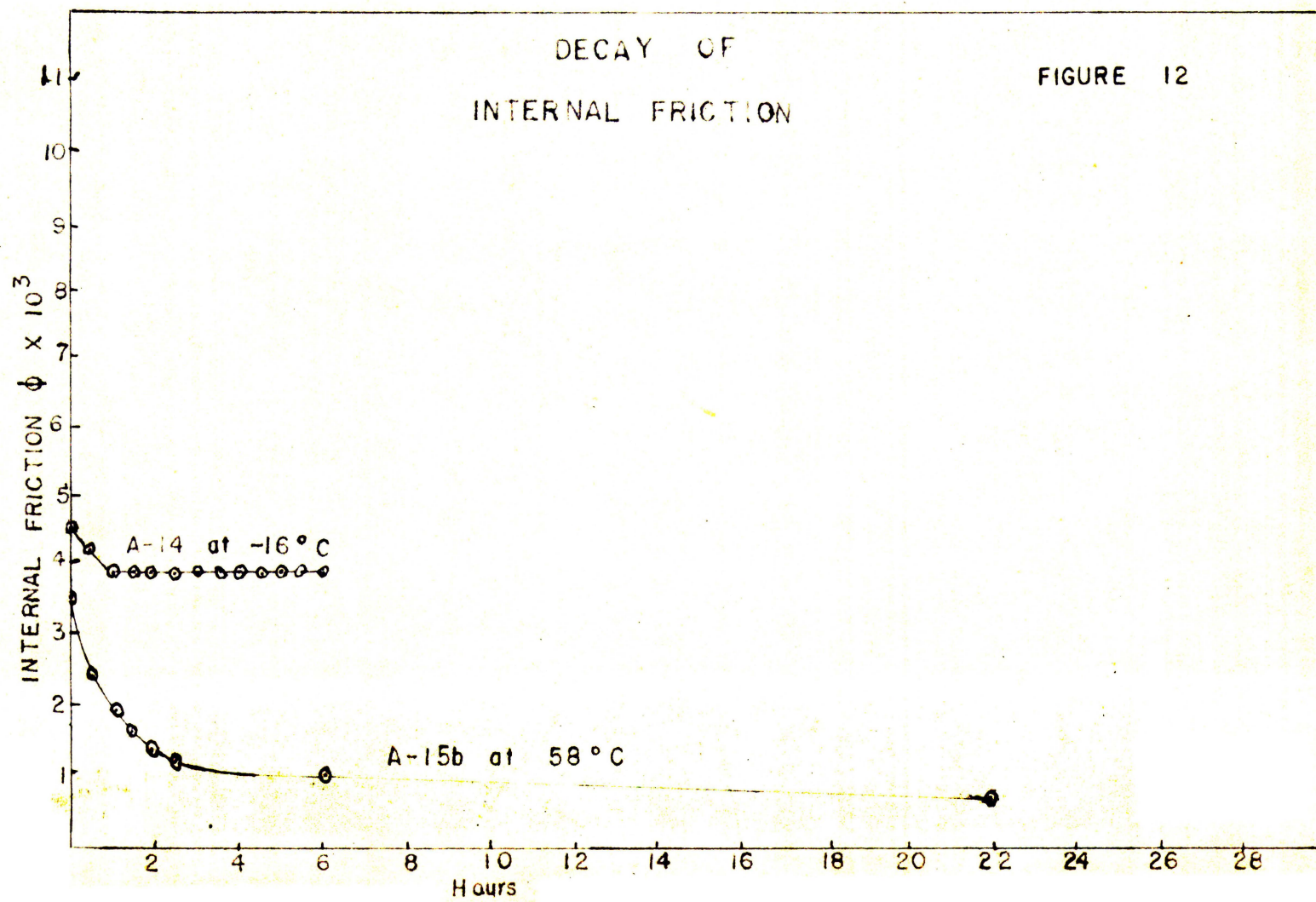
A specimen which had been heated to the recrystallization temperature was tested for uniformity of solution treatment throughout its length, but it was not held at that temperature long enough for the process to be completed. Sections of the wire were taken from the positions $3/4$ inch from the clamp and 6 inches from the clamp. The process of recrystallization was slightly more complete in the section 6 inches from the clamp than in the section near the end; however, the difference was so small that the structure of the latter was representative of the structure of the whole specimen. Sections from opposite ends appeared to be identical.



THE CHANGE IN INTERNAL FRICTION
OF A-19b WITH TEMPERATURE

FIGURE II





The average contribution of the specimen grips to the measured internal friction between 25° C. and -20° C. was found to be 0.00016. This was measured by comparing the internal friction of a low-damping-capacity 75 percent manganese alloy which was held in the pin vises with the internal friction of the same specimen when it was soldered into a rod. Internal friction values for runs at atmospheric pressure averaged 0.0005 greater than values obtained at 100 microns Hg.

The temperature of the specimen in the pendulum was determined by measuring the temperature of the air in the chamber near the specimen with an iron vs. constantan thermocouple. The accuracy of this measurement was tested by placing another thermocouple in the pin vise in the position of a specimen and comparing the temperature readings. The emf of the two thermocouples at 94° C. was the same to the nearest 0.01 mv, that is within about 0.2° C. temperature difference.

In the design of an inertia member for the pendulum it is necessary that all parts of the system be stable. The bending of any part may absorb more energy than the specimen. For example, in the Sickafus inertia member the addition of brass weights to the ends of the arms, which were of very light construction, made it unstable. The arms vibrated in a torsional mode which was perpendicular to the longitudinal axis of the pendulum. The apparent internal friction was thereby greatly increased. Coupling between the two modes of vibration caused a periodic change in the decrement. The frequency was reduced by building an inertia member with stronger arms which would carry without bending the added weight that was needed to increase the moment of inertia of the pendulum.

CONCLUSIONS

It was observed in this investigation that the rapid increase in internal friction of manganese-copper alloys starts at the same temperature in an 85 percent manganese alloy as the change in structure from cubic to tetragonal that was reported by Basinski and Christian,^{2/} and it increases as the temperature is lowered and the structure becomes more tetragonal. The mechanism for the structure change according to Basinski and Christian is a double shear on the (110) planes accompanied by twinning, as in a martensitic transformation. For a tetragonal specimen the c/a ratio decreases as the temperature is lowered, and the internal friction increases. It has been found in investigations at the U. S. Bureau of Mines that aging a specimen at 375° C. to 450° C. to precipitate alpha manganese raises the temperature of the transformation from cubic to tetragonal to a higher temperature than that reported by Basinski and Christian for solution-treated alloys. The results of this investigation show that aging also shifts the region of high internal friction to a higher temperature, but overaging has a retrograde effect on the internal friction as was also observed by Seifert and Worrell.^{23/} There is apparently an optimum size, amount, or configuration of alpha manganese precipitate for maximum internal friction, and there is also a possibility that these conditions are optimum for maximum tetragonality. A large amount of manganese precipitate did not greatly change the internal friction characteristics of an 85 percent manganese alloy from those of a solution-treated 85 percent manganese alloy with much less alpha

manganese precipitate. The specimen with the large amount of precipitate probably contained more than the optimum amount of precipitate, while the solution-treated specimen contained less than the optimum amount. Sickafus did not describe the heat-treatment of the 85 percent manganese specimen for which he reported a peak in internal friction at 220° C.; however, this peak was not reproduced in this project. In all other respects the results of this investigation correlate with the results of Sickafus.

Aging the 70 percent and the 75 percent manganese alloys at 440° C. and 445° C. respectively greatly increased the internal friction of both over the temperature range -24° C. to 120° C. High internal friction in these alloys is concurrent with tetragonal structure, but it is not directly related to the degree of tetragonality for an aged 70 percent manganese alloy with the same damping capacity, since an aged 75 percent manganese alloy has a larger c/a ratio. The aging and precipitation of alpha manganese appears to have shifted the temperature for transformation from cubic to tetragonal structure for the 75 percent manganese alloy from -50° C. to about 120° C. The same process appears to have shifted the temperature for transformation of the 70 percent manganese alloy an even greater amount to about 140° C.

The high internal friction which is not directly related to the c/a ratio in aged alloys of 70 percent or less manganese cannot be explained by the mechanism which has been suggested by Darling^{6/} for internal friction, in which the twin interface migrates in a direction perpendicular to the direction of shearing stress to relax the stress.

Neither does this mechanism explain the reason for the extreme sensitivity of the twin interface to the precise position of the atoms near it.

The decrease in internal friction with time at constant temperature which was observed by Sickafus and in this investigation was concluded to be caused by a structure adjustment. The c/a ratio changes with temperature, but this change is not uniform throughout a grain. It is proposed that for a short period of time after a change in temperature of a tetragonal alloy the metal is in a process of adjustment to the inhomogeneous c/a ratio. This adjustment absorbs energy and contributes to the internal friction for several hours, and as it is completed the internal friction decays to a lower value. The internal friction is related to the rate of change in temperature, but it is apparently independent of the numerical c/a ratio. The magnitude of high internal friction after the initial adjustment is complete is still increased by an increase in the strain amplitude at strains less than 10^{-4} . The migration of twin interfaces in a grain with a non-homogeneous structure would proceed at a faster rate at higher stresses. The higher stresses would promote movement of twin interfaces which require somewhat larger atomic movements as well as the movement of twin interfaces which require very small atomic movement for stress relaxation. This is consistent with the mechanism proposed by Darling.

More work is needed over a wide frequency range to correlate the results of this investigation with the results of Seifert and Worrell; the magnitude of internal friction that they report at 700 cycles per

second is a power of 10 less than that found in this investigation at 1 and 6 cycles per second. Moreover, they reported a peak for an 88 percent manganese solution-treated alloy at -7° C., whereas no peak was reached in this investigation at temperatures above -25° C.

It is suggested that the temperature range for measurement of internal friction should be extended below -150° C. in future work to find the peaks in internal friction in solution-treated alloys of less than 80 percent manganese and to follow the change in the peak of aged alloys with successive steps in aging. More work is suggested with wire of 65 percent manganese or less in which the internal friction does not appear to be related to tetragonal structure.

BIBLIOGRAPHY

1. Ang, C., and Wert, C. A torsional pendulum of low thermal inertia. Jour. Appl. Phys. Vol. 25, p. 1061 (1954)
2. Basinski, Z. S., and Christian, M. A. The cubic-tetragonal transformation in manganese-copper alloys. Jour. Inst. Metals. Vol. 80, pp. 659-666 (1952)
3. Cohen, M. The martensite transformation. Phase transformations in solids. Edited by Snoluchowski, Mayer, and Weyl. N. Y., John Wiley and Sons, 1951. pp. 588-660.
4. Cottell, G. A., Entwistle, K. M., and Thompson, F. C. The measurement of the damping capacity of metals in torsional vibration. Jour. Inst. Metals. Vol. 74, pp. 373-424 (1948)
5. Cottrell, A. H. Theory of dislocations. Progress in metal physics. Edited by B. Chalmers. N. Y., Interscience Publishers, Inc. 1949. Vol. 1, pp. 77-126.
6. Darling, A. S. Internal friction measurement. Metal Ind. Vol. 78, p. 291 (1951)
7. Dijkstra, L. J., and Sladek, R. J. Effect of alloying elements on the behavior of nitrogen in alpha iron. AIME Trans. Vol. 197, pp. 69-72 (1953)
8. Geisler, A. H. Precipitation from solid solutions of metals. Phase transformations in solids. N. Y., John Wiley and Sons, 1951. pp. 387-544.
9. Jensen, J. W. Torsion pendulum of improved design for measuring damping capacity. Rev. Sci. Inst. Vol. 23, pp. 397-401 (1952)
10. Josefson, A., and Kula, E. Internal friction measurements on iron wires of commercial purity. AIME Trans. Vol. 144, pp. 161-165 (1952)
11. Ke, T. S. Anomalous internal friction associated with the precipitation of copper in cold-worked Al-Cu alloys. Phys. Rev. Vol. 78, p. 420 (1950)
12. _____. A study of recrystallization and grain growth. AIME Trans. Vol. 188, pp. 581-585 (1950)
13. _____. Experimental evidence of the viscous behavior of grain boundaries in metals. Phys. Rev. Vol. 71, p. 533 (1947)

14. _____ . Internal friction and precipitation from the solid solution of nitrogen in tantalum. *Phys. Rev.* Vol. 74, p. 914 (1948)
15. _____ . Internal friction at very high temperatures. *Jour. Appl. Phys.* Vol. 21, p. 414 (1950)
16. _____ . Internal friction of cold-worked metals. *AIME Trans.* Vol. 188, pp. 575-580 (1950)
17. Ke, T. S., and Mark, R. An apparatus for measurement of extremely high internal friction. *Rev. Sci. Inst.* Vol. 20, pp. 795-799 (1949)
18. Nowick, A. S. Internal friction in metals. *Progress in metal physics.* Edited by B. Chalmers. N. Y., Interscience Publishers, Inc. 1953 Vol. 4, pp. 1-70.
19. Pearson, S., and Rotherham, L. Internal friction and grain boundary viscosity of silver and binary silver solid solutions. *AIME Trans.* Vol. 206, P. 881 (1956)
20. Potter, E. V. Damping capacity of metals. *Report of Investigations 4194.* U. S. Bureau of Mines. (1948)
21. Read, T. A. Internal friction of single crystals of metals. *Phys. Rev.* Vol. 58, p. 371 (1940)
22. Rowland, J. A., Armantrout, C. E., and Walsh, D. F. Casting and fabrication of high damping manganese-copper alloys. *Report of Investigations 5127.* U. S. Bureau of Mines. (1955)
23. Seifert, A. V., and Worrell, F. T. The role of tetragonal twins in the internal friction of copper-manganese alloys. *Jour. Appl. Phys.* Vol. 22, p. 1257 (1951)
24. Sickafus, E. An investigation of internal friction of manganese-copper alloys. *Thesis, Missouri School of Mines and Metallurgy, Rolla, Mo.*
25. Wenig, S., and Machlin, E. S. Investigations of the effects of solutes on the grain boundary stress relaxation phenomenon. *Jour. Metals.* Vol. 9, No. 1, pp. 32-41 (1957)
26. Wert, C. Diffusion and precipitation of carbon in some alloys of iron. *AIME Trans.* Vol. 144, pp. 602-603 (1952)

27. Worrell, F. T. Twinning in tetragonal alloys of copper and manganese. Jour. Appl. Phys. Vol. 19, pp. 929-933 (1948)
28. Zener, C. Elasticity and anelasticity of metals. Chicago. University of Chicago Press. 1948.
29. _____ . Internal friction in solids. Relationship between cold-work and internal friction. Phys. Rev. Vol. 53, 2nd series, p. 582 (1938)
30. _____ . Internal friction in solids. Theory of internal friction in reeds. Phys. Rev. Vol. 52 2nd series, p. 230 (1937)

VITA

William Paul Dixon, the son of Mr. and Mrs. Guy R. Dixon, was born 22 July 1928 in Jonesboro, Arkansas. He received his primary education in a one-room school near Bennett, Missouri. Limited means of the family prevented his entering high school until the end of World War II. He is deeply grateful to Mr. M. O. Gallaher of Van Buren, Mo., and Mr. Fred Birkicht of St. Louis, Mo., who took him into their homes for the school years 1945-6 and 1946-7 respectively. He graduated from Doniphan High School, Doniphan, Mo., in May 1949.

In September 1949 he enrolled in the Missouri School of Mines and Metallurgy and received a Bachelor of Science in Physics in June 1954. After two years of military service he returned in 1956 to study for a Master of Science in Physics at the Missouri School of Mines under a Research Fellowship at the U. S. Bureau of Mines.