Fatigue Studies of Non-Ferrous Sheet Metals[1]

By JOHN R. TOWNSEND and CHARLES H. GREENALL

The paper describes the development of a fatigue test machine for sheet metals and gives results of fatigue tests on five alloys of alpha brass, one alloy of nickel silver, one alloy of phosphor bronze and Everdur.

The results indicate that cold work raises the endurance limit but not proportionally to the increase in tensile strength produced by the same cause.

Micrographs are shown indicating that fatigue failure of the metals investigated is transcrystalline.

Dispersion hardening of alpha brass by nickel silicide increases the endurance limit.

The ratio of endurance limit to ultimate tensile strength of these alloys varies from .12 to .36 depending on composition, heat treatment, and cold work. These ratios are much lower than similar ratios for steel.

THE materials referred to in this paper are those non-ferrous sheet metals that are employed in electromechanical devices such as telephone apparatus and includes a wide variety of equipment, such as switches, relays, jacks, contact springs,[2] etc. These metals are employed principally in springs used for electrical contacting purposes. In many cases these springs have precious metal contacts welded to them and in other cases the metal itself is used for the contact. Many of these springs are subjected to millions of cycles of stress and it is important, therefore, that the endurance limit of these materials be known in order that apparatus may be designed which will endure for its required service life. Very little precedent has been established in the design of fatigue machines for the testing of sheet metals and it was necessary, therefore, to develop a form of fatigue machine especially suitable for these materials.

Another joint paper by one of the authors describes these non-ferrous metals and explains various methods of test and the commercial limits developed for specification purposes.[3]

SHEET METAL FATIGUE SPECIMEN

The specimen shown by Fig. 1 was designed to simulate in its major dimensions the normal size of the springs used in telephone apparatus. It will be noted that the design of the specimen provides a section of uniform stress for 3/8 inch at approximately 1/2 inch from the clamped end of the specimen. This is accomplished by

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[1] Presented before A. S. T. M. Convention, June 24–28, 1929.

[2] "Telephone Apparatus Springs," by John R. Townsend: *Proceedings A. S. M. E.*, 1928; *Bell System Technical Journal*, April, 1929.

[3] "Mechanical Properties and Methods of Test for Sheet Non-Ferrous Metals," by J. R. Townsend, W. A. Straw and C. H. Davis, presented before A. S. T. M. Convention, June 24–28, 1929.

designing a cantilever beam that will have a uniform bending moment for part of its length. The dashed lines indicate the shape of a beam of uniform bending moment; the heavy lines show the final shape of the specimen and how the portion of uniform bending moment has been connected by means of fillets. This is essential in order to eliminate the possibility of the clamping stresses affecting the applied stress as would be the case if a uniform rectangular cantilever beam specimen had been employed. The specimen is deflected at a point ½ inch from the operated end or, in other words, where the hypothetical beam of uniform bending moment terminates.

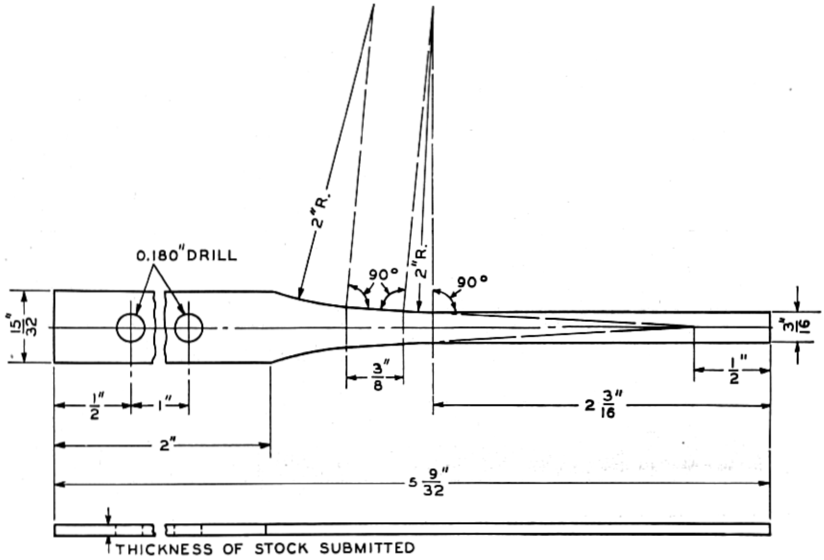

Fig. 1—Sheet Metal Fatigue Specimen.

The specimens are prepared by blanking rectangular samples which are clamped together and then cross milled with a form milling cutter in a manner similar to that described elsewhere for the preparation of tensile specimens.[4] The specimens were cut with the direction of rolling parallel with their length.

SHEET METAL FATIGUE MACHINE

Referring now to Fig. 2, it is seen that the specimens (S) are clamped between phenol fiber blocks (B). This is done in order that reasonably rigid material will be provided and at the same time a material

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[4] "Methods for Determining the Tensile Properties of Thin Sheet Metals," by R. L. Templin. *Proc. A. S. T. M.*, Part II, Vol. 27 1927.

sufficiently dissimilar to the metal to accomplish good clamping without scoring the surface of the clamped portion. Furthermore, the use of the phenol fiber blocks provides a means of automatically recording the breaking of the specimen since the specimen is insulated from the machine and may be employed to break an electrical monitoring circuit. The deflected end of this specimen is held between two fingers ($F_{1.2}$) which have a vertical cylindrical half section. The cylindrical portion is in contact with the specimen. This is necessary in order to compensate for the angular movement of the reciprocating arm (A) in relation to the specimen. One of these fingers (F_1) is fixed and the other is movable (F_2) but bears against the specimen with

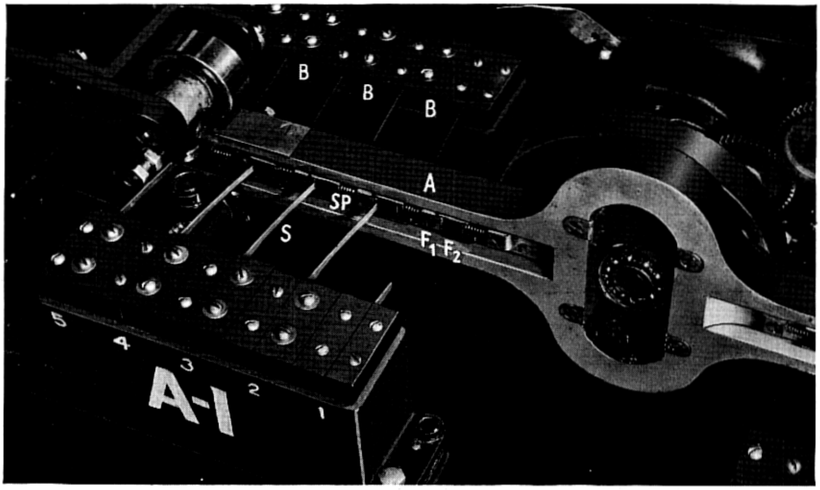

Fig. 2—Sheet Metal Fatigue Machine.

a tension provided by compression spring (S_p). This permits some slight movement of the specimen in relation to the fingers which is necessary by reason of the change in free length of the specimen as the reciprocating arm moves backward and forward. The deflection of the specimen is determined in two ways, first by measuring the movement of the reciprocating bar and also by observing the specimen in operation by means of a stroboscope. In this way the static and dynamic deflection of the specimen may be measured and for all practical purposes, these have been found to be the same within the range of deflection and speed used in this investigation.

The speed of the machine is approximately 1,500 r. p. m. It is necessary to adjust the speed of the machine to the material under test since if this is not done the machine may be operated near the

TABLE I

AVERAGE CHEMICAL ANALYSIS OF MATERIALS

Material *	Alloy	Copper	Lead	Iron	Zinc	Nickel	Manganese	Tin	Phosphorus	Silicon	Combined Carbon
[1] High Brass		65.09	0.02	0.03	Balance			0.00			
[1] Alloy "G" Brass		71.73	0.02	0.03	"	0.01					0.018
[1] Nickel Silver		55.23	0.005	0.06	"	18.38	0.11				
[1] Phosphor Bronze		91.84	0.02	0.03	0.00	0.00		8.08	0.03		
[1] Everdur		96.00							3.00	1.00	
Hardened Brass	33	Balance			9.89	2.32				.57	
	34	"			19.89	2.37				.57	
	35	"			30.12	2.36				.66	

* No graphite was present in any of the materials.

[1] Material and Analysis furnished by C. H. Davis, American Brass Co.

TABLE II

PHYSICAL PROPERTIES

Material	Heat Treatment	B & S Nos. Hard	Tensile Strength Psi	P Limit Psi	Mod. of Elasticity Psi × 10^6	% El. in 2″	Rockwell Hardness* 1/16″ Dia. Ball Red Figures	Endurance Limit Psi	Ratio Endurance Limit Ult. Tensile Strength
High Brass.......	600° C. Anneal	0	46,600	13,000	14.5	56	16	12,000	25.7
		4	77,200	32,000		6	79	13,500	17.5
		10	95,000	30,000		2	87	15,000	15.7
Alloy "G" Brass..	600° C. Anneal	0	46,300			61	16	12,000	25.9
		4	81,600			6	84	18,000	22.0
		10	97,800			2	92	20,000	20.5
Nickel Silver.....		0	66,900			42	19	14,000	36.0
		4	98,700			2	69	18,500	17.4
		10	116,200	60,000	20	1.5	79	22,000	18.9
Phosphor Bronze..		0	59,700			67	11	21,000	35.2
		4	95,500			14	71	22,000	23.0
		10	124,800	55,000	15	2	84	24,500	19.6
Everdur.........	"Spring Temper"		80,000	26,000	12.4	22	91	24,000	30.0
Hardened Brass Alloy No. 33....	Quenched 800° C. aged 1 hour at 500° C.		90,000	44,500	19.8	14	86	14,000	15.5
Alloy No. 34....	Quenched 850° C. aged 1 hour at 500° C.		85,800	37,200	17.2	21.5	85	12,500	14.6
Alloy No. 35....	Quenched 800° C. aged 1 hour at 400° C.		85,400	38,000	16.5	28.0	79	16,000	17.3

* 100 kg. load for brass alloys and 150 kg. load used for nickel silver, phosphor bronze and Everdur.

natural frequency of vibration of the specimen and this may superimpose additional stresses upon it. This is determined by observing the operation of this specimen by means of a stroboscope and accurately setting the speed of the machine to a point where the vibratory motion of the specimen is uniform.

The machine has a capacity of forty specimens. Twenty specimens are tested on each end of the motor drive. The machine is statically balanced and is smooth in operation. It is customary to test at least five specimens of each material at each stress. The machine therefore, has a capacity of four alloys of five specimens each at two deflections. The practice of using five specimens for each deflection was adopted because it was seen from the results of previous experimenters in fatigue testing that a more accurate result might be provided by doing so. The capacity of the machine is sufficiently large to permit this being done.

MATERIALS

The materials investigated consisted of five alloys of alpha brass, three of which had been hardened with nickel silicide and one alloy each of nickel silver, phosphor bronze and Everdur. The three alloys of hardened brass have been described previously.[5]

The chemical composition of these alloys is given in Table I and the tensile strength, proportional limit, modulus of elasticity, per cent elongation in 2 inches, Rockwell hardness and endurance limit are given in Table II. The heat treatments and amount of cold work expressed by number of B. & S. gauge reductions from standard anneal are shown also on Table II.

FATIGUE ENDURANCE TEST

Method of Determining Stress in Specimen

The method of determining the stress in the specimen consists in clamping a specimen in the same manner as on the fatigue machine. The clamped specimen is mounted on the table of a Société Genevoise Star Comparator so that its large surfaces are parallel with the vertical plane, the axis being parallel to the table. By mounting the specimen in this manner its weight has no appreciable effect on its deflection. The stress in the specimen is determined from the load deflection curve obtained by applying dead weights ½ inch from the end of the specimen and measuring the amount of deflection for various units of load by means of a microscope mounted on the comparator in such a

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[5] "Heat Treatment and Mechanical Properties of some Copper-Zinc and Copper-Tin Alloys Containing Nickel and Silicon," by W. C. Ellis and Earle E. Schumacher. *Proc. A. I. M. M. E.*, 1929.

manner that the rectangular coordinates of the deflected specimen may be read on the micrometer heads. Readings were taken to 1 micron. The stress per unit deflection is then calculated from the formula

$$S = \frac{6Pl}{bd^2},$$

where S = stress in pounds per square inch,
P = load in pounds,
l = length in inches,
b = width in inches,
d = thickness in inches.

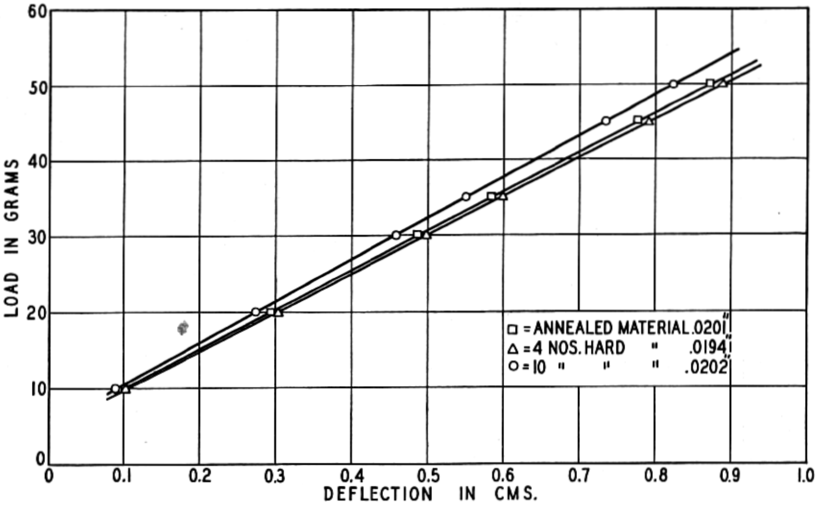

Fig. 3.—Relation of Load to Deflection, Alloy G Brass, No. 24 B. & S. Gauge.

The curve shown by Fig. 3 for alloy "G" brass sheet gives the load for uniform deflection of the specimen upon the fatigue machine. The various stresses are then obtained by varying the amount of deflection of the end of the specimen by adjustment of the roller bearing that operates the reciprocating bar.

Fatigue Endurance Results

The curves shown on Fig. 4 are for high brass sheet annealed and rolled four and ten numbers hard. Figs. 5, 6, 7 and 8 give similar results for alloy "G" brass, nickel silver, phosphor bronze and Everdur respectively for annealed material and rolled four and ten B. & S. gauges numbers hard. Fig. 9 gives the fatigue results for the alpha

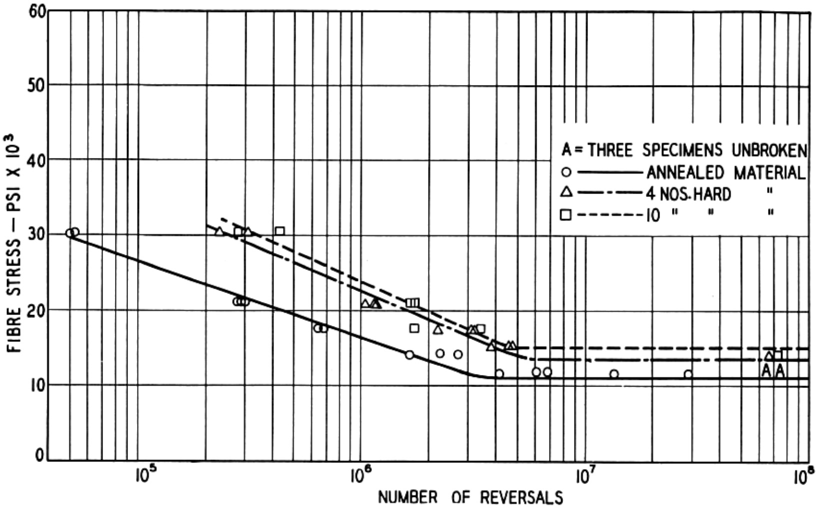

Fig. 4—Relation of Fibre Stress to Reversals, High Brass Sheet, No. 24 B. & S. Gauge.

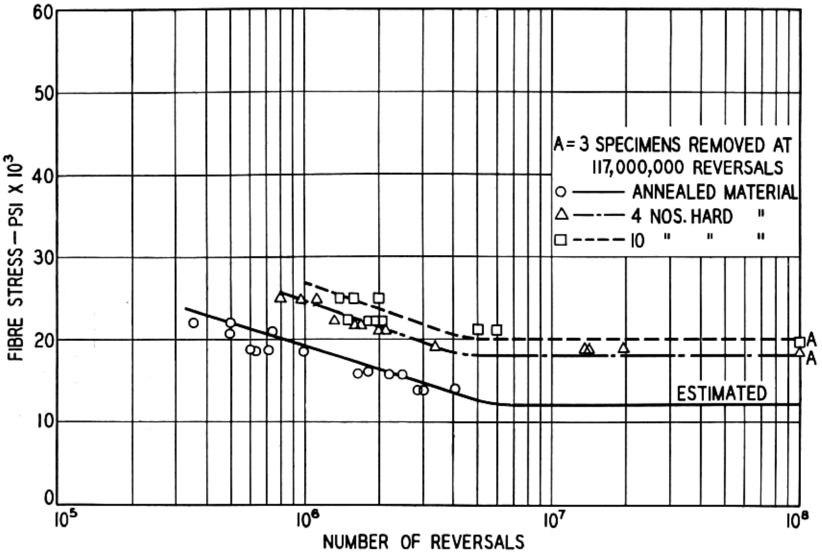

Fig. 5—Relation of Fibre Stress to Reversals, Alloy G Brass Sheet, No. 24 B. & S. Gauge.

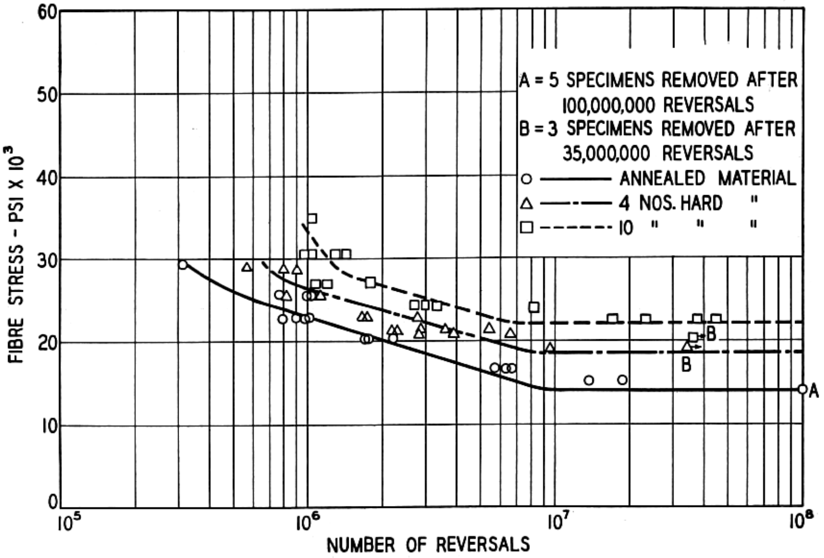

Fig. 6—Relation of Fibre Stress to Reversals, Alloy B Nickel Silver, No. 24 B. & S. Gauge.

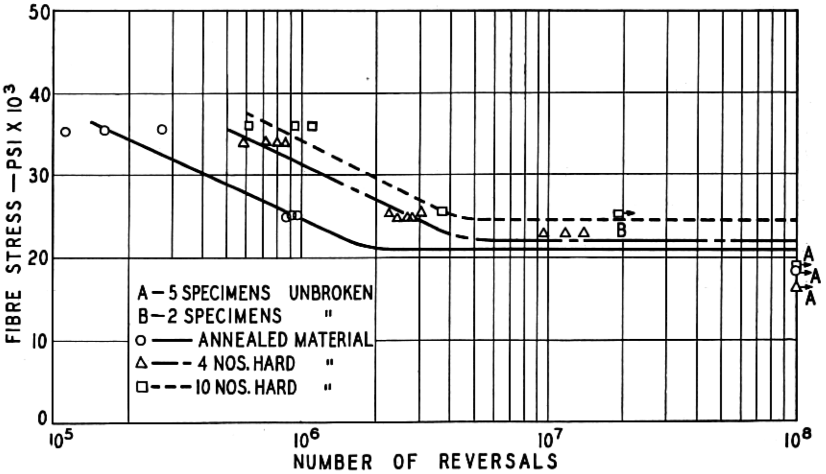

Fig. 7—Relation of Fibre Stress to Reversals, Alloy C Phosphor Bronze, No. 24 B. & S. Gauge.

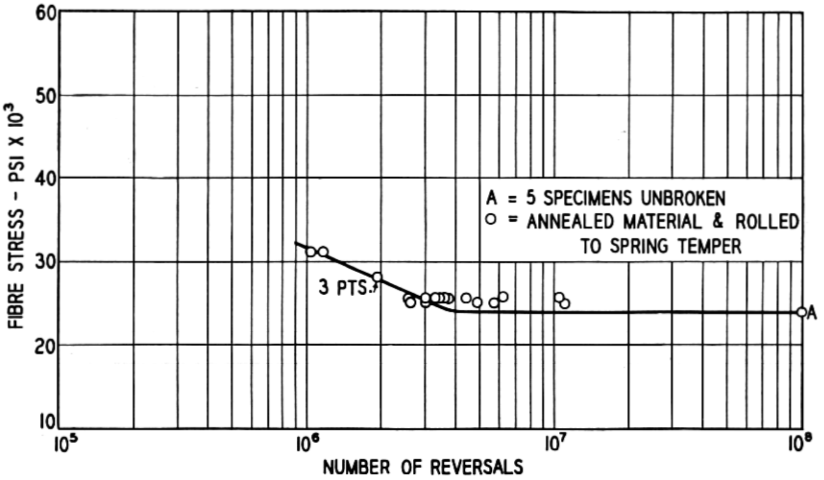

Fig. 8—Relation of Fibre Stress to Reversals, Everdur Alloy Spring Temper, No. 24 B. & S. Gauge.

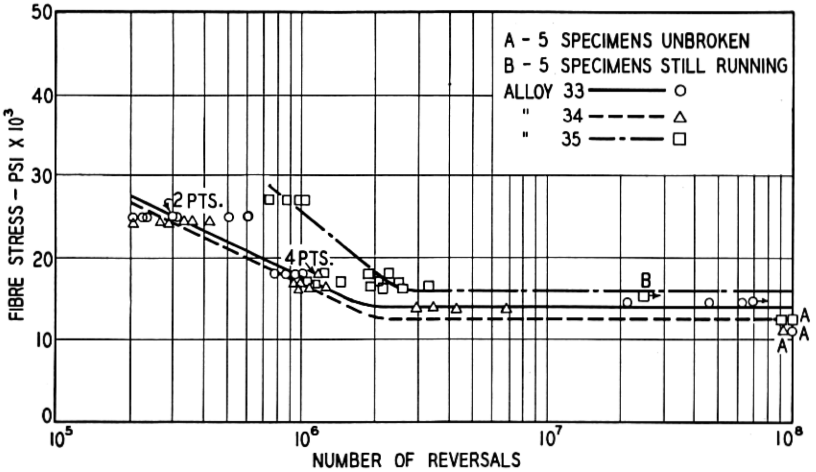

Fig. 9—Relation of Fibre Stress to Reversals, Dispersion Hardened Brasses, Alloys Nos. 33, 34 and 35, No. 24 B. & S. Gauge.

brasses hardened by nickel and silicon otherwise mentioned as alloys Nos. 33, 34 and 35 respectively.

MICROSTRUCTURE

Fig. 10 shows a photograph of a number of broken specimens. The regularity of the break is shown and in every case occurs within the uniformly stressed area. Photomicrographs shown by Fig. 11 are typical of the various alloys. In these cases incipient cracks are revealed within the uniformly stressed area. It is seen that these cracks are, without exception, transcrystalline and there appears to be no distortion of the metal adjacent to the fractures. With regard to the typical structure of the hardened brass alloys reference is made to the previous paper.[6]

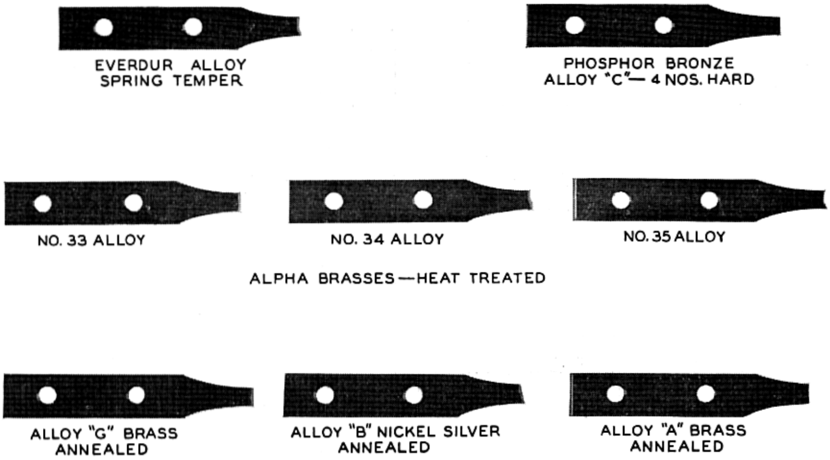

Fig. 10—Typical Broken Fatigue Specimens.

DISCUSSION

Examination of the results shown by Table II reveals that the ratio of endurance limit to tensile strength for sheet non-ferrous metals is much lower than that reported for steel rod.[7] These ratios reported for plain carbon and alloy steels in all heat treatments vary from .35 to .67 averaging about .40 whereas for these sheet non-ferrous metals these ratios vary from .14 to .36.

[6] "Heat Treatment and Mechanical Properties of some Copper-Zinc and Copper-Tin Alloys containing Nickel and Silicon," by W. C. Ellis and Earle E. Schumacher. *Proc. A. I. M. M. E.*, 1929.

[7] "The Fatigue of Metals," by H. J. Gough, Scott Greenwood & Sons. Also "The Fatigue of Metals," by H. F. Moore and J. B. Kommers, McGraw Hill & Co.

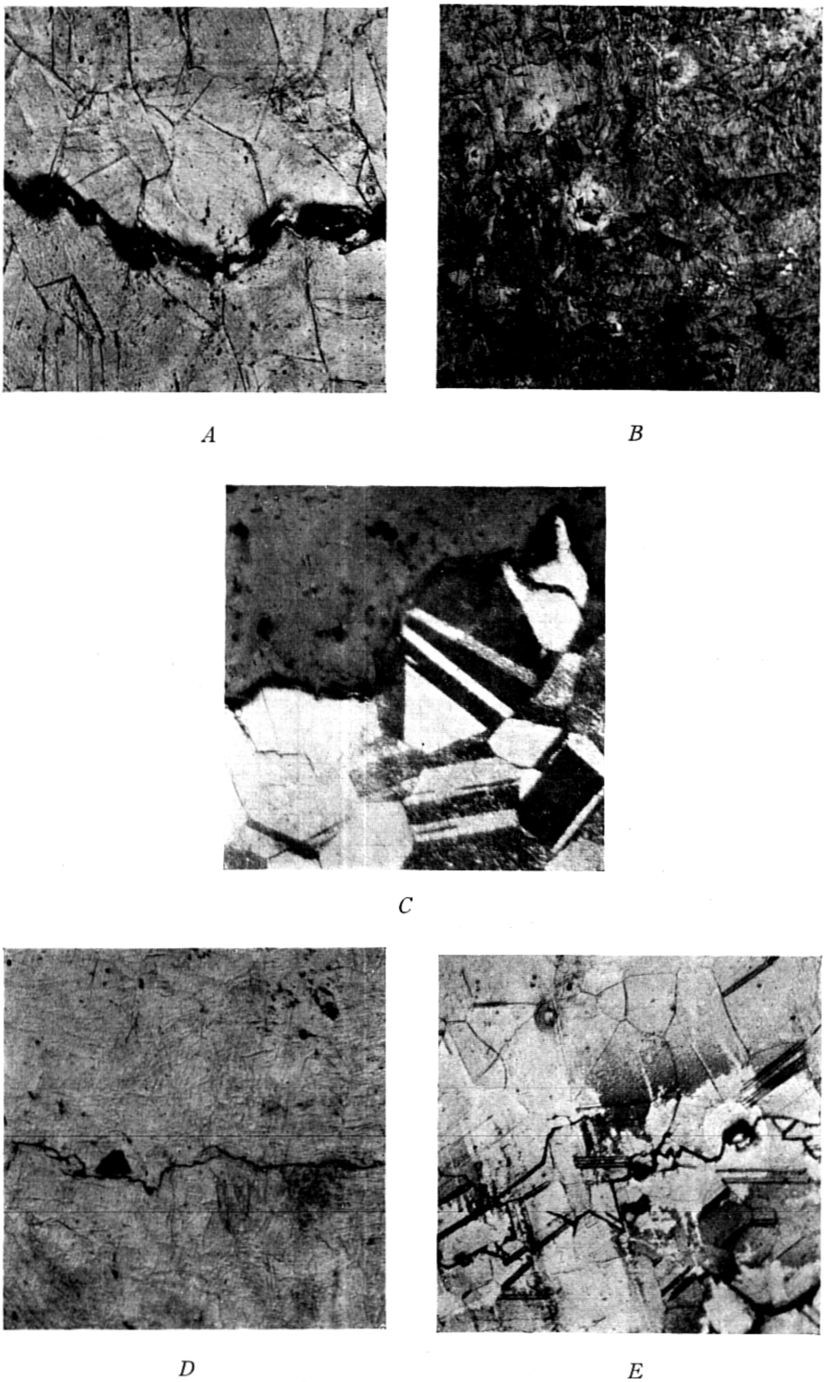

Fig. 11—Photomicrographs of Fatigue Specimens.

A. Nickel-Silver, 4 B. & S. Nos. Hard, Stress 28,750 Psi, 800,000 cycles, mag. 200.
B. Phosphor Bronze, 4 B. & S. Nos. Hard, Stress 25,500 Psi, 2,600,000 cycles, mag. 200.
C. Alloy G Brass, Annealed, Stress 15,750 Psi, 2,471,200 Cycles, Mag. 200.
D. Everdur, Spring Hard, Stress 25,500 Psi, 1,186,900 Cycles, Mag. 200.
E. Hardened Brass Alloy No. 33, Stress 18,200 Psi, 850,000 Cycles, Mag. 200.

Prepared by Miss A. K. Marshall

The improvement in the endurance limit due to cold rolling brass, nickel silver and phosphor bronze is not consistent with the increase in tensile strength produced by the same means. This is shown by Table II where in practically every instance material hardened by cold work shows a progressive decrease in the ratio of endurance limit to tensile strength.

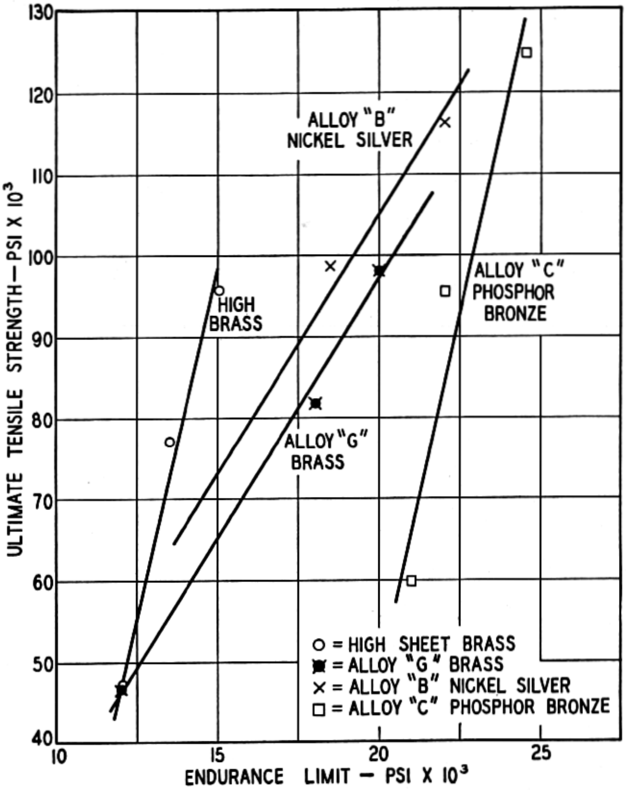

Fig. 12—Relation of Ultimate Tensile Strength to Endurance Limit, No. 24 B. & S. Gauge, Non-Ferrous Sheet.

Previous investigators have shown a close correlation between endurance limit and tensile strength for iron and steel. Fig. 12 fails to reveal such a general correlation for the sheet metals under test. For a particular alloy, however, there appears to be a progressive increase in endurance limit with increase in tensile strength due to cold work but the slope of the curves shown are widely different for the various alloys.

The results for alloy "G" brass and high brass show the effect of change in composition on the endurance limit. The greater improvement in fatigue endurance of alloy "G" brass due to cold work over high brass shows the superiority of this alloy for spring purposes. This was to be expected on the basis of its physical properties.[8, 9]

Alpha brass hardened by nickel and silicon shows considerable improvement in the endurance limit and also an improvement in the ratio of endurance limit to tensile strength. This offers a means whereby some non-ferrous alloys may be improved in this respect.

Attention is called to Fig. 6 which gives the stress cycle graphs for nickel silver in three tempers. It will be noted that the curves tend to turn sharply upward for the higher stresses. This indicates the effect of drastically overstressing the metal. The authors have observed this effect with other metals on the rotating beam machine. It seems that after a limiting stress value that the number of cycles to failure tends to become constant.

CONCLUSION

From the test results obtained on these non-ferrous metals it is seen that the fatigue endurance limit varies from approximately 12 to 36 per cent of the ultimate tensile strength, whereas the commonly accepted ratio of fatigue endurance to tensile strength of steel is in the neighborhood of 40 per cent of its ultimate tensile strength. In other words, it appears that the low endurance limit of these materials emphasizes the need for their careful selection for use as springs. High tensile strength or proportional limit are not sufficient guarantors that the material will perform satisfactorily in service.

Cold work raises the endurance limit but not in a manner proportional to the increase in tensile strength produced by the same cause. There is no correlation between tensile strength and endurance limit except for cold worked metal of a definite composition. For other compositions the correlation is different.

Precipitation hardening of alpha brass by nickel silicide increases the endurance limit.

The fatigue failure appears to be a result of a fracture across the crystals of the material. Photomicrographs are given showing incipient cracks that were developed in the uniformly stressed areas of the specimen.

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[8] "Physical Characteristics of Copper and Zinc Alloys," Bassett and Davis. *Proc. Inst. Metals Div. A. I. M. M. E.*, 1928.

[9] The authors are indebted to Mr. L. E. Abbott for his assistance in obtaining laboratory data.

The curves given for fatigue endurance show the results for each specimen tested. The shape of the fatigue endurance curve for these metals is similar to those published previously for other metals.

A special form of fatigue machine has been developed to test sheet metals. This machine will accommodate forty specimens. Capacity is thereby provided so that as many as five specimens may be employed for each of four materials at two deflections under test.