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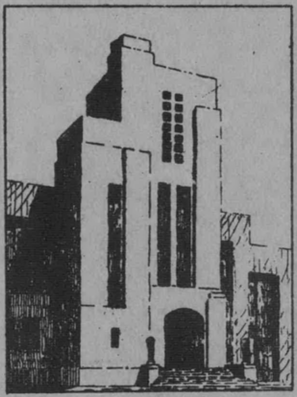
THE EFFECT OF REST PERIODS ON THE TIME AND FATIGUE STRENGTHS OF METALLIC MATERIALS

BY F. BOLLENRATH AND H. CORNELIUS



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TRANSLATION 104

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THE EFFECT OF REST PERIODS ON THE TIME AND FATIGUE STRENGTHS OF METALLIC MATERIALS

(DER EINFLUSS VON BETRIEBSPAUSEN AUF DIE ZEIT- UND DAUERFESTIGKEIT METALLISCHER WERKSTOFFE)

by

F. Bollenrath and H. Cornelius, Berlin

(VDI-Zeitschrift, Vol. 84, No. 18, 4 May 1940)

Translated by F. A. Raven

The David W. Taylor Model Basin
Bureau of Ships
Navy Department, Washington, D.C.

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DIGEST

On the premise that the majority of structures or structural units which are subjected to repeated or fatigue stresses will, during their useful lives, be subjected to relatively few cycles of stress equal to their endurance limits and to still fewer cycles of stress appreciably exceeding the endurance limit, it would be a waste of material and would produce unnecessarily heavy structures to base their design on endurance-limit stresses, i.e., on the assumption of an unlimited number of full load cycles. Furthermore, since the majority of machines which are subjected to repeated stresses are not in constant use, the periods of rest might possibly prove beneficial to their resistance to repeated stress.

An extensive series of tests was made to determine the effect of rest periods on the number of cycles of stress to failure. The materials used for these tests included one high-strength aluminum alloy, two magnesium alloys, ingot iron, and two iron alloys, pure electrolytic copper, and brass; the chemical compositions are given in Table 1. Test specimens machined from these materials were subjected to cycles of repeated tensile load in which the stress cycle varied between the limits of a small tensile stress, constant for a given material, and a larger tensile stress. Figure 2 shows the shape of the magnesium specimens and the method of holding them in the testing machine.

After determining the endurance limit and the S-N diagram* for a given material, additional tests were made covering the same ranges of stress, but in these additional tests the specimen was permitted to rest without load for 6 to 18 hours. These cycles of rest alternated with the cycles of stress, and in general there were from 7 to 10 rest periods before failure of the specimens. Typical test results are given in Figure 4 for the Magnesium Alloy 2 specimen.

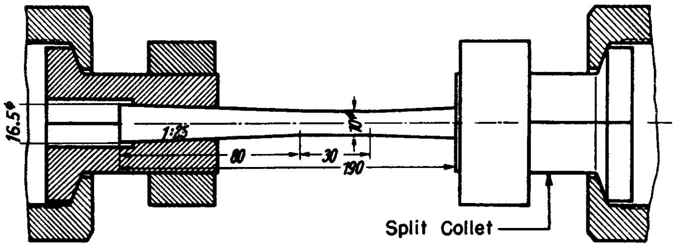

Figure 2 - Dimensions of the Test Bars made of the Magnesium Alloy, Material 3, and Method of Clamping

The conclusion to be drawn as a result of these tests is that, in general, the rest periods had no effect on the number of cycles of a given range of stress required to produce failure.**

The anomalous behavior of the specimens of ingot iron (Material 4) is, perhaps, the most interesting result of the report. For this material, tested under

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* A diagram giving the relationship between the repeated stress in an endurance test and the number of cycles to failure.

** In Bulletin 327 of the University of Illinois Engineering Experiment Station, pp. 58 to 62, Prof. W.M. Wilson reports that rest periods of 30 minutes or less have no appreciable effect on the fatigue strength of mild steel.

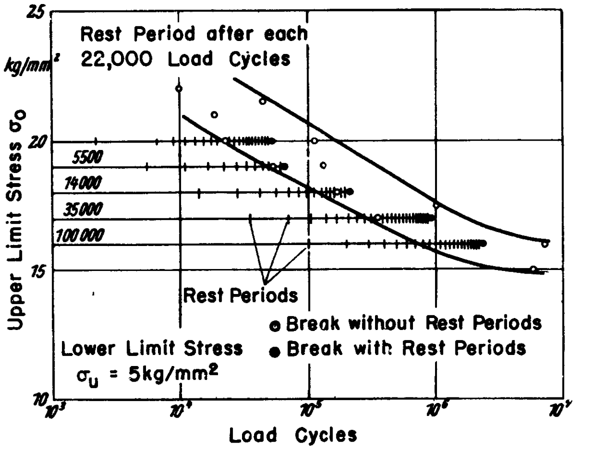

Figure 4 - Effect of Rest Periods on the Number of Stress Cycles to Failure for the Magnesium Alloy 2

repeated tensile loads with a minimum stress of 10 kg/mm² (14,225 pounds per square inch), failure occurred in some of the specimens at a relatively small number of cycles; instead of undergoing the usual fracture without appreciable elongation these specimens elongated and necked down as is usual for static tests. The explanation for this action is not apparent. When similar specimens were tested under cycles of stress in which rest periods alternated with stress cycles, necking down did not occur and no specimens failed at stresses up to 29 kg/mm² (41,250 pounds per square inch). In these cases the endurance limit was at about 94 per cent of the static tensile strength. Work-hardening and age-hardening appear to be factors in this behavior, but the tests were too few to permit definite conclusions.

In Appendix 1 is a brief discussion of French's "probable damage line" as given in Moore's "Materials of Engineering."

In Appendix 2 is a translation of the meaning of the expression "Time-Strength" as used in Germany. There is no exact English equivalent although fatigue-strength at a specified number of cycles for failure is often used with the same meaning.

In Appendix 3 is a description of the pulsating type of testing machine used for these tests.

THE EFFECT OF REST PERIODS ON THE TIME* AND FATIGUE STRENGTHS OF METALLIC MATERIALS

Problems dealing with actual operating conditions have recently increased in importance the strength testing of metallic materials subjected to alternating loads. Examples of this are loads which exceed endurance limits, effects of periodic alternation of stress limits and the effect of interrupted operation. The latter problem is the subject of this study.

ABSTRACT

The effect of interrupted loading on a variety of pure metals and alloys was studied in fatigue tests of tensile specimens subjected to a range of stress varying from a small tensile stress to a larger tensile stress. These metals and alloys represented a wide range of lattice structures, grain textures, and strength characteristics. The pulsating stress was zero during the rest periods. The test range covered both time strength and endurance strength. From these numerous tests it is concluded that periods of rest do not in general affect the S-N curve.

INTRODUCTION

In many engineering structures, as for example in all types of vehicles, and especially in the wing units of aircraft, a restricted life-span and therefore a limited, although occasionally large number of load cycles within definite stress limits can be assumed. Using the fatigue strength as a basis for calculating the dimensions of structural members would result in unnecessary consumption of material and greatly increased weight. The bases for calculation of dimensions with respect to a limited life-span, however, are scanty and insufficiently conclusive. Therefore, statistical data were collected for various types of airplanes under actual operating load conditions by W. Kaul (1)** and H. Freise (2) in the same way as W. Kloth and Thomas Stroppel (3) had previously done for agricultural machines. However, no relationship has yet been established between such statistical studies and material testing, since there has been little or no research as to the effect on strength of material under loads which alternate in unknown sequence with rest periods of arbitrary duration and succession, within limits which change irregularly. These loading conditions differ from usual methods in material testing by the fact that the fatigue strength values hitherto determined still offer no dependable basis for correct calculation of structural members (4). It is entirely conceivable that when the fatigue limit is frequently exceeded, a simple, dependable relationship should result for the strength under operating loads with respect to a time-strength for a stress amplitude lying between definite load limits.† Until operating effects have been explained in detail, it is necessary to rely strictly on operating conditions or operating statistics to

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* Translator's Note: For a definition of "Time Strength" see Appendix 2.

** Numbers in parentheses indicate references on page 10 of this translation.

† Translator's Note: See Appendix 1.

obtain stress curves which will permit a quick estimate of the load capacity of a structural member. The problem concerning the possibility and means of grouping loads into definite categories was recently studied by E. Gassner (5).

The object of the present study is to determine the effect of temporary relief from alternating loads on the number of load cycles when carried to the point of failure under entirely normal load conditions.

MATERIALS TESTED

Materials of greatly varied structure and composition were tested; see Table 1. Among them were pure metals such as an extremely low carbon steel, Material 4, and electrolytic copper, Material 7, as well as others of both high and low alloy content. These metals also represent varied atomic structures: Face-centered cubic lattice in the first, third (austenitic steel,* Material 6), and fourth groups for aluminum, iron and copper; body-centered cubic lattice (for iron, Materials 4 and 5); close-packed hexagonal lattice (for magnesium, Materials 2 and 3), and materials of homogeneous as well as heterogeneous texture. Moreover, the recuperative, recrystallization, and melting temperatures extend over a wide range. The strength characteristics shown in Table 2 are just as varied. From this it is evident that the tests rest upon a broad basis.

TABLE 1

Chemical Composition of the Materials Tested

Material Group	Material Number	Percentage of Components																
		Fe	Si	Cu	Mg	Mn	Al	C	S	P	Zn	Mo	Cr	Ni	Ce	As	Pb	La
Al-Alloy	1	0.35	0.32	4.26	0.55	0.67	93.85	-	-	-	-	-	-	-	-	-	-	-
Mg-Alloy	2	0.015	0.005	0.006	97.194	1.92	0.03	-	-	-	0.21	-	-	-	0.32	-	-	0.3
	3	0.02	0.01	0.08	92.44	0.17	6.25	-	-	-	1.03	-	-	-	-	-	-	-
Fe-Alloy	4	99.844	-	-	-	0.11	-	0.020	0.010	0.016	-	-	-	-	-	-	-	-
	5	97.643	0.25	-	-	0.58	-	0.24	0.016	0.021		0.24	1.01					
	6	71.946	0.66	-	-	0.46	-	0.10	0.017	0.017	-	-	18.2	8.6	-	-	-	-
Cu-Alloy	7	Trace	-	99.92	-	-	-	-	0.012	-	Trace	-	-	-	-	0.004	Trace	-
	8	-	-	69.4	-	-	-	-	-	-	30.45	-	-	-	-	-	-	

TEST PROCEDURE

First, in a pulsating tension test, a complete S-N curve for each material was obtained covering the range from the static strength, i.e., fracture under a single load, up to the endurance limit based on 10^7 cycles of stress. In all tests the range of stress varied from a constant minimum stress, σ_u, up to the maximum. Instead of falling on a smooth S-N curve, the scatter of the test points over a considerable

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* 18-8 stainless steel.

TABLE 2

Strength Properties of the Materials Tested

The stresses $\sigma_{0.02}$ and $\sigma_{0.2}$ are the equivalent of the yield strength determined for 0.02 per cent and 0.20 per cent offsets in the stress-strain curve.

Material Group	Material Number	Elastic Limit $\sigma_{0.02}$ kg/mm²	Elastic Limit $\sigma_{0.2}$ kg/mm²	Tensile Strength σ_B kg/mm²	Elongation δ_{10} per cent	Reduction of Area ψ per cent	Elastic Limit Ratio $\sigma_{0.2}/\sigma_B$	Brinell Number kg/mm²	Diameter of the Stock Bars mm
Al-Alloy	1*	23.8 to 25	29.2	41.4 to 42	14 to 15	20	0.70		30
Mg-Alloy	2**	15.3 to 16	24.9 to 28	27.6 to 30	19 to 22	31 to 43	0.87 to 0.91		35
	3**	13.5 to 14.95	21.5 to 22.7	32.9 to 33.4	13.3 to 15.2	19 to 28	0.67 to 0.69		35
Fe-Alloy	4**	18.7 to 20	19.2 to 20.6	30.5 to 31.5	31 to 32	60	0.62 to 0.67		30
	5†	59.75 to 61.75	61.2 to 64	76.4 to 79.8	15	50 to 52	0.80	231 to 246	30
	6**	18.1 to 19.4	22.5 to 22.3	63.5 to 63.6	59	74 to 75	0.35 to 0.37		35
Cu-Alloy	7†	3.2	4.6	21.6 to 21.8	51	85	0.19		35
	8**	7.4 to 7.8	7.9 to 8.0	31.6 to 32.0	66 to 68	76 to 77	0.25		35

* Tested at 4 points on the bar. ** Tested at 3 points on the bar. † Tested at 2 points on the bar.

range of cycles at failure makes it necessary to establish a region within which the various test points will fall.* This range is indicated by the two limiting curves drawn for each material. After the S-N diagram had been obtained for a material subjected to alternating stresses and a constant minimum stress, additional specimens were tested under the same stress conditions to determine the effect of permitting the specimen to rest without load. The rest periods were generally of 6 hours' and 18 hours' duration alternately, with occasional periods of 48 hours. The number of cycles of stress between rest periods was taken as 10 per cent of the minimum number of cycles at which failure occurred in specimens tested under the same stress conditions but without rest. The length of the interruptions assumes importance if a healing or recuperative process occurs. According to careful tests by Târo Uèda (4) (6) on the most varied types of materials, by far the greatest amount of recuperation, insofar as recovery from torsional stress is concerned, takes place during the first 6 to 10 hours after the load is removed. The interruptions of operation in ordinary commercial flying can be said to equal the rest periods of the tests.

The testing machines used were generally Losenhausen hydraulic pulsators** having a maximum load amplitude of 10 tons (22,000 pounds). With respect to the mean load, their capacity was plus and minus 9 tons (19,800 pounds). Hydraulic testing machines have the advantage that the load limits can be held constant as originally fixed, even when gradual elongation occurs. If the pre-stress is regulated by spring loading, the mean loads change in proportion to the plastic deformations.

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* Departure from smooth S-N curves may be an indication of erratic loading due to the pulsator.

** Translator's Note: The Losenhausen hydraulic pulsator is described in Appendix 3.

The test specimens were machined from round bars ranging from 30 to 35 mm (1.18 to 1.38 inch) in diameter, and in general were of the dimensions shown in Figure 1. As the strength of copper is low, specimens made of this material had a greater diameter throughout the test section. This permitted the stresses to be controlled and adjusted with sufficient accuracy when the bars were tested in the pulsator. For the magnesium alloy, Material 3, Tables 1 and 2, test bars having the dimensions given in Figure 1 failed because of their high notch sensitivity. They ruptured principally in the transition between the conical portion and the flanged clamping head, i.e., in the fillet. For this reason, these bars were clamped in tapered split collets as shown in Figure 2, and tested in a 5-ton Schenck pulsator at 3,000 load cycles per minute.

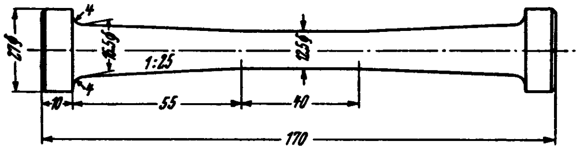

Figure 1 - Dimensions of the Test Bars

Dimensions different from those here given were chosen for electrolytic copper, Material 7. For example, the diameter of the test section was made 18 mm (0.70 inch) instead of 12.5 mm (0.49 inch). Test bars as shown in Figure 2 were used for the magnesium alloy, Material 3.

TEST RESULTS

In the case of hardened aluminum, Material 1 of Table 1, the curves of Figure 3 show that rest periods did not increase the number of load cycles endured before failure in any single instance. On the contrary, the effect of rest periods indicated by the limit curves of the range of failure might be considered unfavorable. From the results derived from tests on other materials, such a conclusion does not seem entirely justified; it is rather to be assumed that the range of failure extends from the broken lower limit curve to the solid upper limit curve of the number of load cycles up to failure.

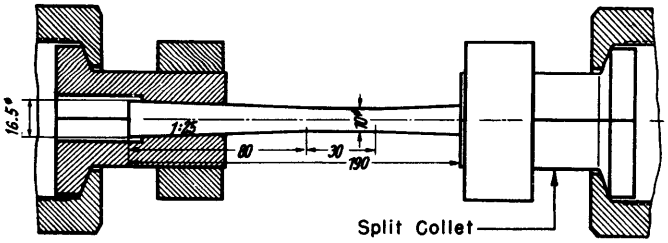

Figure 2 - Dimensions of the Test Bars made of the Magnesium Alloy, Material 3, and Method of Clamping

Figure 4 shows the S-N curves for the magnesium alloy 2 of Table 1. These curves show a rather wide range of failure and also prove that in interrupted operation the number of stress cycles before failure does not extend above the upper limit curve for failure plotted for uninterrupted operation. On the contrary, the stress cycles all lie rather close to the lower limit.

Magnesium alloy 3 showed such a wide scattering of stress cycles in the range of failure that no S-N curve could be plotted. In the pulsating tension tests, the lower limit stress was held at σ_u = 5 kg/mm^2 (7,100 pounds per square inch). With

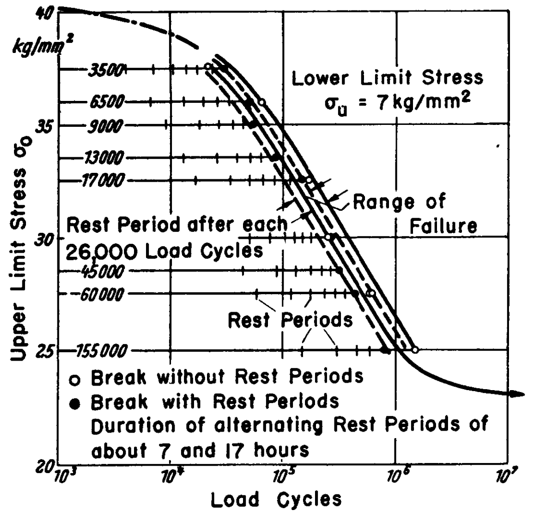

Figure 3 - Effect of Rest Periods on the Number of Stress Cycles to Failure for the Hardened Aluminum Alloy 1

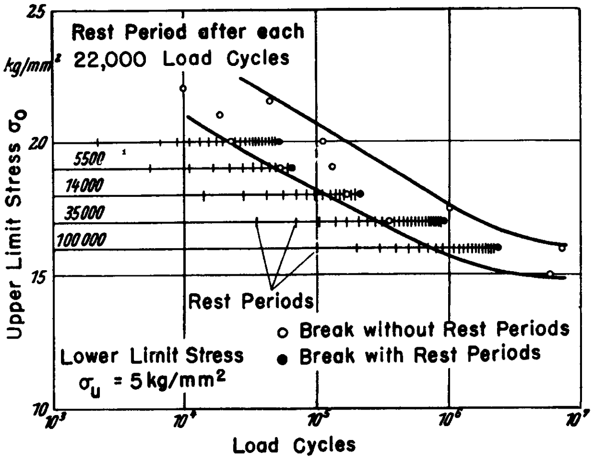

Figure 4 - Effect of Rest Periods on the Number of Stress Cycles to Failure for the Magnesium Alloy 2

this lower limit stress, and at upper limit stresses ranging from 16 to 26 kg/mm^2 (22,800 to 37,000 pounds per square inch), load cycles in the range of failure lay between 8 x 10^4 and 8 x 10^6, whereas, in the same stress range four test specimens withstood from 1 x 10^7 to 2 x 10^7 load cycles without failure. This was probably due to high notch sensitivity, since several test bars broke in the fillet from merely tightening the clamps or grips shown in Figure 2. Test bars with clamping heads of the type shown in Figure 1 all broke in the fillet where the bar flares into the clamping flange. The upper stress limit, σ_0, which can be indefinitely endured when the lower limit σ_u is 5 kg/mm^2 (7,100 pounds per square inch) may be assumed to lie between 12 and 14 kg/mm^2 (17,100 and 19,900 pounds per square inch).

The mild steel test bars, Material 4 of Table 1, behaved in a remarkable way under pulsating tensile stress (Zugschwellbeanspruchung)* and a lower stress limit of 10 kg/mm^2 (14,200 pounds per square inch). Due to extensive work hardening and insensitivity to notch effects, failure did not occur until after the upper maximum limit stress had risen far above the elastic limit. The fatigue strength under pulsating load is just below σ_0 = 28 kg/mm^2 (39,800 pounds per square inch), i.e., about 90 per cent of the tensile strength, and is therefore within the stress ranges where large plastic deformations are produced. As long as deformation is confined to symmetrical elongation, large numbers of load cycles above the fatigue strength can also

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* Translator's Note: For an explanation of the term "Zugschwellbeanspruchung," see "Festigkeit bei hohen und tiefen Temperaturen," by A. Pomp, in Handbuch der Werkstoffprüfung, vol. II, p. 294, "Wechselversuche bei hohen Temperaturen," §a: "Versuche bei schwellender Beanspruchung;" also "Testing Material in the Resonance Range," by R.K. Bernhard, American Society for Testing Materials, Proceedings, vol. 41, 1941, p. 747 ff.

be endured. The greater portion of symmetrical elongation occurs at the inception of the pulsating load, at a rate which depends on the adjustment of the control valve of the hydraulic pulsator. During the greater portion of the critical load cycles, symmetrical elongation occurs in the test section until shortly before fracture. Then, as a result of various causes which have not yet been individually determined, the specimen begins to neck down. This causes the true strain to rise so high in the area which is necking down that fracture ensues. The machine automatically shuts off before the bar breaks, if the loading valve is adjusted to prevent oil from flowing or feeding into the loading cylinder as fast as the load drops due to the rapid rate of elongation when the bar begins to neck down. Figure 5 shows a bar which necked down after 45,000 load cycles at an upper limit stress of 28 kg/mm^2 (39,800 pounds per square inch) and Figure 6 shows one which had not yet failed under the same stress at the end of 7,000,000 load cycles. Slightly above the fatigue limit, some test bars also withstand the entire 7,000,000 stress cycles without failure, whereas others neck down and soon break. Since the fatigue strength lies so close to the tensile strength the stress range of the S-N curve becomes very narrow, and slight changes of the stress limits can produce great variation in the number of cycles of stress before failure. Some interesting results are plotted here in Figure 7. However, because of the small number of tests and in view of previous findings, no great importance is attached to them. Loading was interrupted for 23 hours at approximately every seventh of the total number of cycles of stress endured under continuous operation. For example, when specimens were tested without interruption at maximum stresses of 29 kg/mm^2 (41,200 pounds per square inch), 28.5 kg/mm^2 (40,500 pounds per square inch), and 28.25 kg/mm^2 (40,200 pounds per square inch) they all failed. When tests were made at the same stresses, but with rest periods, the specimens did not fail and showed no necking down after 100 times as many stress cycles. In tests with rest periods, therefore, the fatigue strength rose to 94 per cent of the tensile strength.

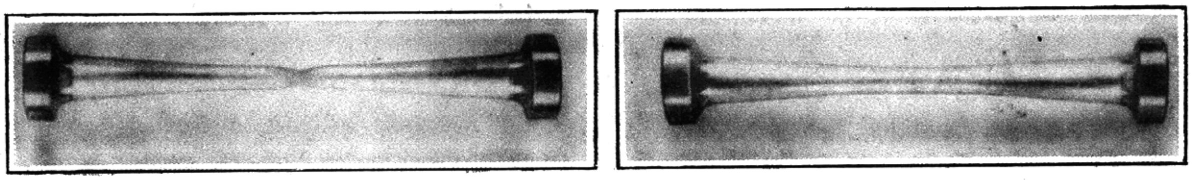

Figure 5 - Test Bar after 45,000 Load Cycles. Total Elongation 14.5 per cent

Figure 6 - Test Bar after 7,000,000 Load Cycles. Total Elongation 5.5 per cent

Figures 5 and 6 - Test Bars of Ingot Iron
Material 4, after Cycles of Tensile Stress with
Lower stress limit, σ_u = 10 kg/mm^2 = 14,200 lb/in^2
Upper stress limit, σ_0 = 28 kg/mm^2 = 39,800 lb/in^2

In this connection a recently published study by Daeves, Gerold and Schulz (7) on the life-span of structural members under cyclic loading must be mentioned.

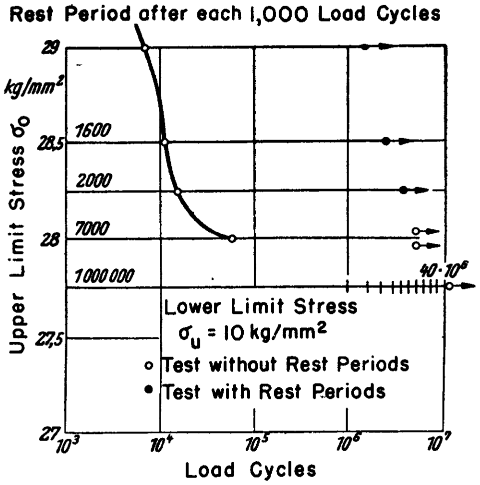

Figure 7 - Effect of Rest Periods on the Number of Stress Cycles for Mild Steel, Material 4

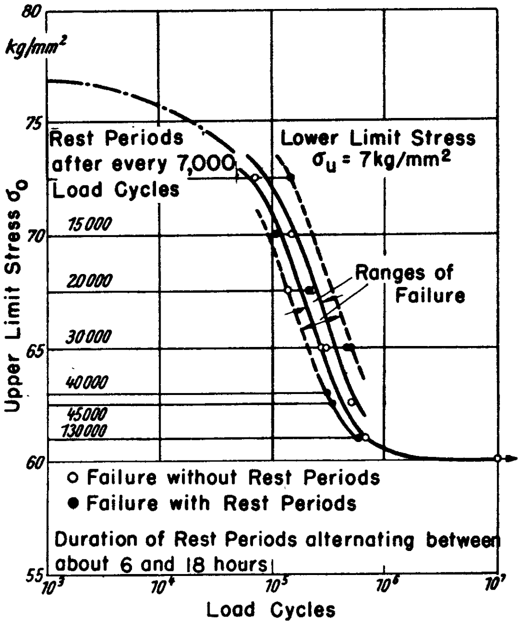

Figure 8 - S-N Diagram for Chrome-Molybdenum Steel Test Bars, Material 5

These authors noted an increase in the time-strength due to interruptions of operation for normally annealed and cold-drawn unalloyed steels containing "free ferrite." It was found that the number of load cycles withstood up to the breaking point increases if the number of cycles between rest periods is decreased and the rest period lengthened and, also, if the material is permitted to rest at high temperature.

The tests on chrome-molybdenum steel, Material 5, were based on a lower stress limit of σ_u = 7 kg/mm² (9,900 pounds per square inch). Results showed that the number of stress cycles endured to failure was scarcely affected by interrupted operation; see Figure 8. Even if the range of failure seems to be widened by rest periods, it can still be assumed, however, that the failure in previous continuous fatigue tests accidentally fell within a narrower range. In addition to tests with the Losenhausen Pulsator* on bars which measured 12.5 mm (0.49 inch) in diameter in the test section, comparative tests with similar result were made with a Schenck Pulser* on bars 10 mm (0.39 inch) in diameter.

The fatigue strength of austenitic chrome-nickel steel, Material 6, is about 39 kg/mm² (55,400 pounds per square inch) at a lower limit stress of 5 kg/mm² (7,100 pounds per square inch). The scatter range of failure in the field of time-strength was accurately determined by tests based on uninterrupted operation. In interrupted operation, all the numbers of load cycles at failure also lay within this range, as

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* Translator's Note: See Zeitschrift des Vereines Deutscher Ingenieure; vol. 80, part 2, No. 47, 21 November 1936, p. 1404, pp. 1433-1439 inc. for a description of these testing machines.

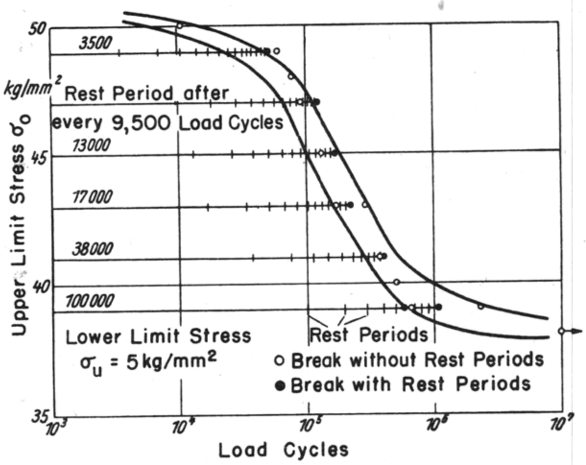


Figure 9 - S-N Diagram for Austenitic Chrome-Nickel Steel, Material 6

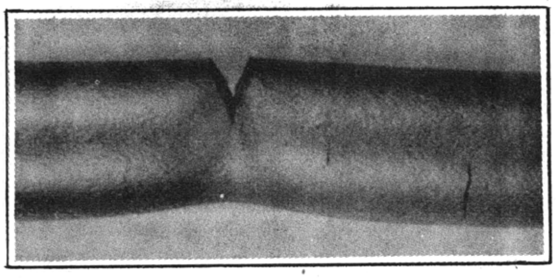


Figure 10 - Failure of a Chrome-Nickel Steel Bar, Material 6, Subjected to Pulsating Tensile Load

Figure 9 shows. The material was very uniform, hence a large number of initial cracks occurred simultaneously. Some of these, however, extended quite deeply into the bar, and one of them finally developed into a fracture. At the same time the remainder of the cross section, in spite of the sharp notch effect due to the fatigue crack, continued to deform strongly while necking down on the remaining side. Figure 10 shows the necking down at a crack just prior to failure and reveals the great degree of toughness and low notch sensitivity of this steel.

As in the case of mild steel, the fatigue strength of electrolytic copper, Material 7, is considerably higher than the elastic limit $\sigma_{0.2}$, and for a minimum stress, σ_u = 5 kg/mm² (7,100 pounds per square inch) it is 3.7 times as high. The test bars undergo strong plastic elongation with attendant work-hardening until the upper limit stress is reached. In the time-strength tests the bars begin to neck down some time before breaking, just as mild steel does. At this point many small initial cracks are frequently produced, which are visible to the naked eye. Occasionally one of these will increase in depth while the rest of the cross section continues

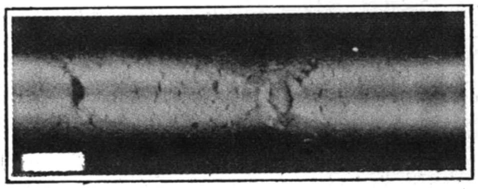


Figure 11

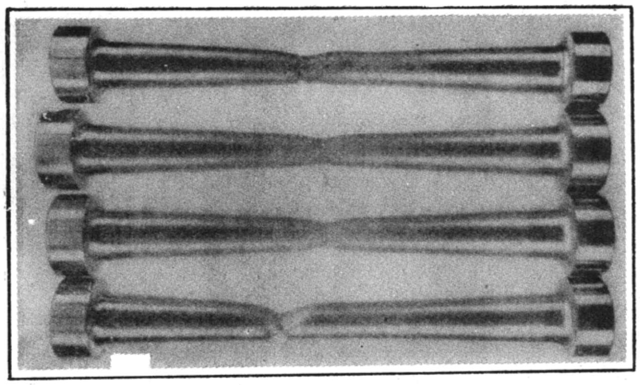


Figure 12

Figures 11 and 12 - Phenomena of Failure for Electrolytic Copper Bars, Material 7, in Pulsating Tensile Tests

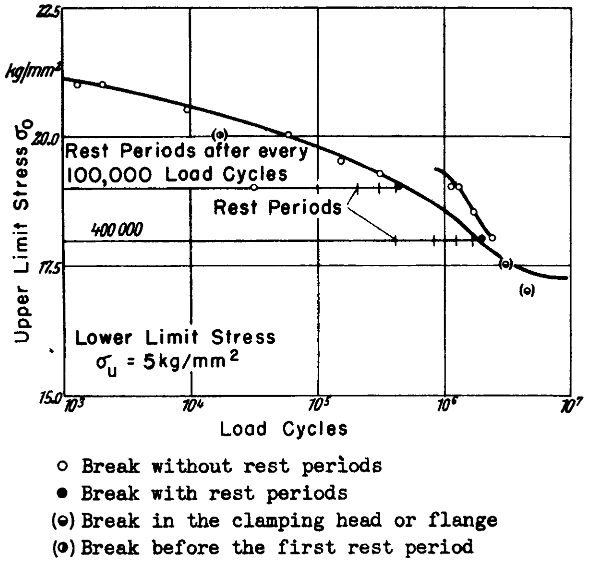


Figure 13 - S-N Diagram for Electrolytic Copper, Material 7

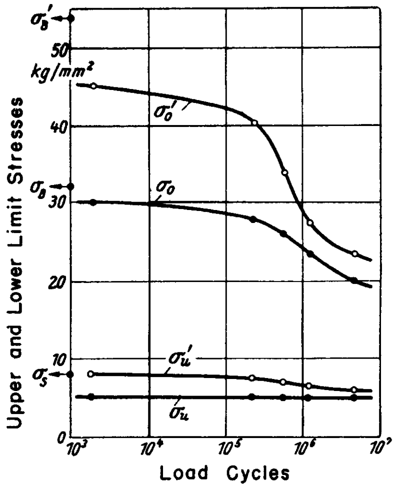


Figure 14 - S-N Diagrams for Brass, Material 8. Stresses Based on the Initial Cross Section (σ_u, σ_0) or the True Cross Section (σ_u', σ_0').

The value for the static tensile strength σ_B, based on the initial cross section is likewise plotted. σ_s is the elastic limit.

to neck down and deform strongly. The phenomena of failure shown in Figures 11 and 12 are characteristic of the uniformity and plastic qualities of the material. In spite of this it was impossible to determine the fatigue strength exactly because the test bars ruptured in the notched conical section or fillet between the bar and the clamping flange at low maximum stresses before any crack appeared in the cylindrical test section. This was traced to the effect of variable stress distribution which hindered deformation in the notch; this in turn checked work-hardening. The results scattered quite sharply as shown by the flat drop of the S-N curve, Figure 13. Hence, but few tests with interrupted operation were made. These sufficed to show that there is no effect due to rest periods.

Finally, the behavior of brass, Material 8, under interrupted cyclic loading, was studied. The minimum stress was 5 kg/mm² (7,100 pounds per square inch). For brass, the fatigue strength under pulsating tensile stress also lies above twice the stress at the elastic limit. Brass also takes a large permanent deformation at the beginning of the load series. Since the stresses are related to the initial cross section as

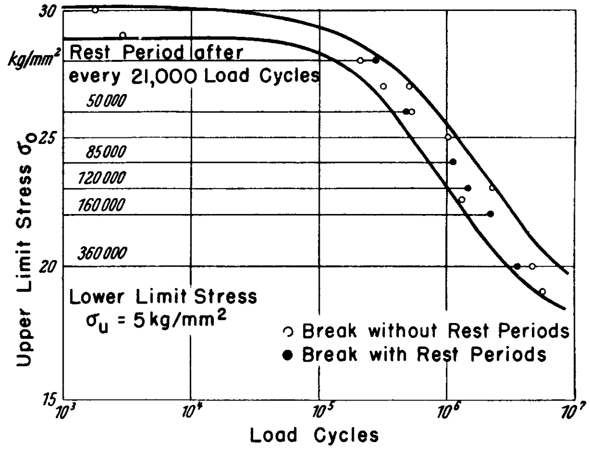


Figure 15 - Effect of Rest Periods on the S-N Curve for Brass, Material 8

usual and the corresponding loads are held constant at the upper and lower load limits, the true stresses actually change continually owing to reduction in diameter. For this reason it would be of definite value if S-N curves were plotted for true stresses. Using brass as an example, Figure 14 shows the displacement of S-N curves due to inclusion of the true stresses. As is apparent, the lower limit stress shifts, and hence the mean stress is displaced throughout the entire series of tests. As was previously noted almost without exception for other materials, the numbers of cycles of stress at failure for interrupted operation lie within the scatter range determined for the number of cycles of stress at failure for continuous loading; see Figure 15.

REFERENCES

(1) "Die erforderliche Zeit- und Dauerfestigkeit von Flugzeugtragwerken" (Requisite Time and Fatigue Strength of Airplane Wing Units), by W. Kaul, in Jahrbuch der deutschen Luftfahrtforschung I, 1938, pp. 274-288; ibid.: "Statistische Erhebungen über Betriebsbeanspruchungen von Flugzeugflügeln" (Statistical Studies on the Operating Loads on Airplane Wings), pp. 307-313.

(2) "Spitzenwerte und Häufigkeit von Böenbelastungen an Verkehrsflugzeugen" (Peak Values and Frequency of Loads Due to Squalls on Commercial Aircraft), by H. Freise, in Jahrbuch der deutschen Luftfahrtforschung I, Munich and Berlin, 1938, pp. 289-303.

(3) "Kräfte, Beanspruchungen und Sicherheiten in den Landmaschinen" (Forces, Loads, and Factors of Safety in Agricultural Machines), by W. Kloth and Thomas Stroppel, in Zeitschrift des Vereines Deutscher Ingenieure, vol. 80, 1, 1936, pp. 85-92.

(4) "Zeit- und Dauerfestigkeit der Werkstoffe" (Time and Fatigue Strength of Materials), by F. Bollenrath, in Jahrbuch der deutschen Luftfahrtforschung, Ergänzungsband (supplementary volume), Munich and Berlin, 1938, pp. 147-157.

(5) Luftwissen, vol. 6, E. Gassner, 1939, pp. 61-64.

(6) "On the Distribution of Internal Shearing Stress in the Cross Section of Cold-Twisted Metallic Bar and the Change of the Stress Caused by Annealing," by Târo Uèda, in The Science Reports of the Tohoku Imperial University, First Series (Mathematics, Physics, Chemistry), vol. XXVI, No. 4 Sendai, Japan, 1938, pp. 433-544.

(7) Stahl und Eisen, article by K. Daeves, E. Gerold and E.H. Schulz, vol. 60, No. 5, 1 February 1940, pp. 100-103.

(8) "Testing Material in the Resonance Range," by R.K. Bernhard, Proceedings of the American Society for Testing Materials, vol. 41, 1941, p. 747 ff.

APPENDIX 1

A somewhat related investigation has been reported by Mr. H.J. French in a paper "The Fatigue and Hardening of Steels," Transactions of the American Society of Steel Treating, volume 21, page 899, 1933, covering results of tests made to determine the resistance of a metal to occasional overstress. The following description of the method of determining the "probable damage line" is taken from "Materials of Engineering," by H.F. Moore, Sixth Edition, page 60-61, McGraw-Hill Book Company, New York, 1941.

The ability of a metal to resist a relatively large number of cycles of overstress without starting a destructive crack is evidently important in many machine and structural parts, for example in railroad rails and car axles, and in parts of dredges and hoisting machinery. H.J. French has devised a test for evaluating this resistance to occasional overstress. The accompanying figure, Figure 26 of his paper, shows his method in diagram. Specimens a, b, c, d, e, and f are used to determine the S-N diagram and the endurance limit of the virgin metal (36,000 pounds per square inch in Figure 26). Then specimens g, h, and j are given a definite number of cycles of stress at different stresses (100,000 cycles of reversed flexure at 50,000, 45,000 and 40,000 pounds per square inch in Figure 26) and removed from the testing machine unfractured. In Figure 26 specimen g, overstressed at 40,000 pounds per square inch, was then put in the testing machine at the virgin endurance limit (36,000 pounds per square inch) and "ran out" to 10,000,000 cycles of stress without fracture; evidently the fatigue strength of the specimen was not lowered by the 100,000 cycles at 40,000 pounds per square inch. A similar result was obtained for specimen h at 45,000 pounds per square inch. Specimen j, however, after its overstressing at 50,000 pounds per square inch for 100,000 cycles fractured under a subsequent repeated stressing at 36,000 pounds per square inch. Evidently the stress which the metal could withstand 100,000 times without reduction of its virgin endurance limit was between 45,000 and

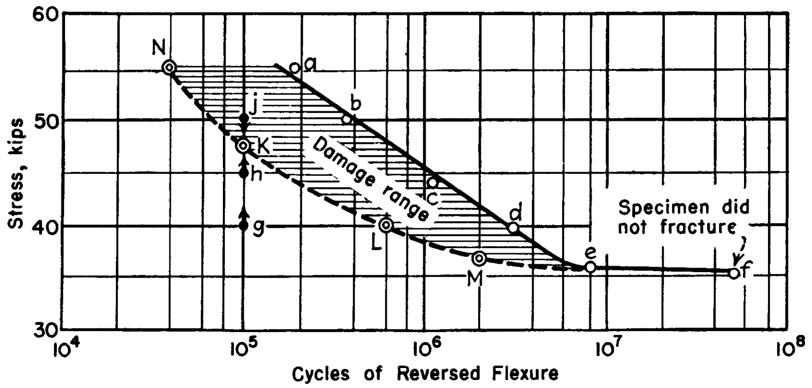


Figure 26 - Determination of Probable Damage Line under Cycles of Overstress

50,000 pounds per square inch. This stress was then estimated at 47,500 pounds per square inch and K locates a point on what Mr. French calls the "probable damage line."

Making tests for specimens under 40,000, 180,000 and 2,000,000 cycles of stress, other points N, L and M on the probable damage line were located and the line drawn through the four points. Of course, these particular values chosen for overstress and number of cycles are merely illustrative, and would be different for different metals. Probably for satisfactory determination of points on the probable damage line it would be necessary to test more specimens than are shown in Figure 26.

The size and shape of the "damage range" area between the probable damage line NKLM and the S-N diagram of the virgin metal, abcdef, give an indication of the resistance of the metal to occasional overstress. A broad area indicates low resistance to overstress, a narrow area, high resistance.

APPENDIX 2

As no idiomatic English term denoting "Zeitfestigkeit" seems to exist, it has been rendered in this and other translations of articles by Bollenrath and Cornelius simply as "Time Strength." The following definition was translated quite literally from "Handbuch der Werkstoffprufung" to avoid misconceptions arising on the part of those readers who may possibly be unfamiliar with this peculiarly German term. The complete title dealing with "Zeitfestigkeit" is:

III. "Festigkeit bei schwingender Beanspruchung" (Strength under Alternating Stresses), Section B, 1, c: Dauerfestigkeit und Zeitfestigkeit (Fatigue Strength and Time Strength), by A. Thum, in Handbuch der Werkstoffprufung, vol. II, Prufung der Metallischen Werkstoffe, Erich Siebel, Berlin 1939, pp. 181-182.

If the stress amplitude is greater than that at the endurance limit, we speak of time strength, since then the life-span is only a limited number of load cycles, i.e., for practical purposes only a definite number of operating hours. After the number of stress cycles determined from the S-N curve (Wöhler-Kurve) have been applied, fracture is to be expected. In this respect it must be noted that by comparison of the number of stress cycles at failure as found for various materials under identical load conditions, i.e., by comparison of time strength values, the ratio of their fatigue strengths cannot be determined directly, since the S-N curves (Wöhler-Kurven) of various materials may intersect; see Figure 11.

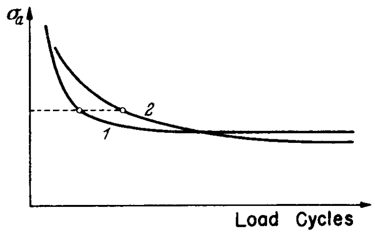


Figure 11 - Various Forms of S-N Curves

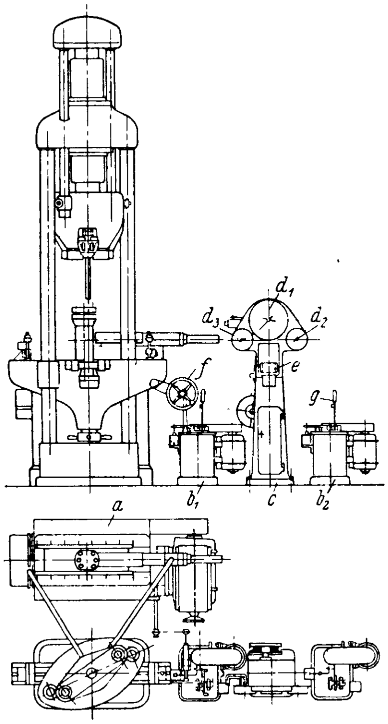
A comparison of the number of stress cycles at fracture at a definite stress does not always permit conclusions to be made as to the fatigue strength of the materials.

APPENDIX 3

A MATERIAL TESTING MACHINE WITH A WIDE RANGE OF APPLICATION*
(Vielseitig verwendbare Prüfmaschine)

A recent testing machine is reported to combine the possibility of testing machines or structural parts as well as materials.

Pure static load tests, pulsating load tests with a static pre-stress, cyclic load tests including tension-compression and alternate bending tests (bending to each side of the neutral axis) can be carried out with this pulsator type testing machine designed by the Losenhausenwerke in Düsseldorf-Grafenberg, and shown in Figures 1 and 2.



a	Pulsator
b_1, b_2	Pumps
c	Deflection pendulum
d_1	Pendulum manometer
d_2, d_3	Manometers
e	Recording gear
f	Adjustment for cyclic loading
g	Lever to control speed and to throw load on or off.

Figures 1 and 2 - Testing Machine with Pulsator

The upper clamping head is connected to the upper cross-head by two uprights. This framework houses the pistons of the two cylinders. The lower clamping head also serves as a set of supports for bending tests. The clamping chucks can accommodate not only flanged or unflanged, threaded or threadless test specimens, but machine and structural parts as well. Dependable clamping of specimens in tension-compression tests is assured because the clamping head with the specimen in clamped position can be pre-stressed in compression by a spindle drive or gear.

One of the two drive pumps is connected to the compression cylinder, the other to the tension cylinder. The two pumps operate simultaneously only in cyclic loading tests.

The pulsator a produces pulsating or cyclic loading; it feeds or withdraws oil from the cylinders as the desired amplitude requires and also governs the load cycle frequency up to 1,000 per minute. The higher load cycle frequencies are used for standard test bars, the lower ones for machine parts and other fabricated structures.

A deflection pendulum in conjunction with two pressure gages is used to measure forces. The pendulum-operated manometer dial d_1 indicates the

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* This abstract describing the Losenhausen pulsating machine for material testing was translated from the Zeitschrift des Vereines Deutscher Ingenieure, vol. 80, part II, No. 47, November 21, 1936, p. 1404.

static load and the minimum load in pulsating tests, and is also used to regulate the load in cyclic tests. The manometer dial d_2 shows the peak load in pulsating tests, while d_3 shows the alternating load, either positive or negative in cyclic loading, i.e., the load to one side of the zero line. The accessory recording equipment e permits stress-strain diagrams to be recorded in static tests and load curves in dynamic tests. A counter indicates the number of cycles to which the test specimens are subjected.

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