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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 960

CREEP STRENGTH OF STABILIZED WROUGHT-ALUMINUM ALLOYS

By W. Müller

Aluminum Industrie A.G.
Neuhausen, Switzerland, December 1939

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1. PREVIOUS TESTS

Report No. 540/35 contained a description of then-available equipment for testing the creep strength of aluminum alloys as well as the test results. This original equipment, employing the Rohn system, is semiautomatic and affords practical values corresponding approximately to the creep strength. Individual strain measurements with the Martens mirror instrument on test bars at a load corresponding to the creep strength obtained earlier at elevated temperature, disclosed a rate of strain substantially lower than specified, according to the definition of "creep strength" (DVM standard): rate of elongation = 1/1000 percent per hour, from the 25th to 35th hour of loading; the plastic deformation after the 45th hour of loading should not exceed 0.2 percent.

2. NEW TESTING ARRANGEMENT

Since then the Rohn-type equipment has been mounted on rubber blocks, for the purpose of damping the vibrations of the ground and of rendering the plastic yielding of the test bars less subject to outside interferences. New equipment also included three shockproof creep-testing machines with the Martens mirror instruments for recording the strain curve of the fatigue-tested specimens. For the control and maintenance of a constant test temperature in the heating oven of the creep-testing machines, rheostats were mounted on a special control panel, and for the elimination of voltage fluctuations in the alternating-current system, each group of machines is fitted with an auxiliary oven that keeps the supplied quantity of electricity con-

* Abbreviated copy of Report No. 556, entitled: "Warmdauerstandfestigkeit stabilisierter Aluminium-Knet-Legierungen." Aluminum-Industrie A.G.-Neuhausen, Switzerland, December 30, 1939.

stant, and so assures a constant heat supply in the separate ovens, as well as a constant temperature by constant heat removal.

With these auxiliary ovens, the rheostats and - depending upon the choice of tapping the ovens - the test temperature can be regulated by degree from 20° to 500° C, and kept constant for any length of time to within $\pm 0.5^{\circ}$ C accuracy. The change in cooling conditions caused by variable room temperature on the separate ovens can be compensated by proper selection of the auxiliary oven temperature. Eventually, existing temperature differences on the lower, middle, or upper part of the test bar can be compensated by suitably chosen section of the ventilating holes on the upper end of the vertically suspended tube furnace of the creep-strength machines.

Photograph No. P 3036 shows the installation.

3. NEW TEST RESULTS

a) Static Creep Strength (Short-Period Test)

Since, prior to the present creep-strength tests, the amount of data on the behavior of aluminum alloys at elevated temperature and static tensile stress was not very great, the experiments described hereinafter were made exclusively on stabilized aluminum alloys. Even though such alloys (in completely softened state) are not likely to be used for structural parts, their testing is nevertheless justified because the test values obtained represent extreme cases which eventually could occur after long-time, continuous reheating; and on the stabilized aluminum alloys, the hot-hardening or softening phenomena are not the same as on age-hardened or cold-worked aluminum alloys. Now that the behavior of stabilized aluminum alloys is known and certain experimental data have been accumulated, age-hardened and cold-formed alloys of aluminum can also be investigated concerning their creep strength.

To compensate for any difference in structure in the extrusions which might cause nonuniformities in the individual test values, the separate extrusions were redrawn cold, to test bars of from 25- to 20-millimeter diameter; from 22- to 18-millimeter diameter; or from 20- to 18-millimeter diameter, before being stabilized by annealing.

The tests, so far, include the following alloys:

Aluminum, 99.5 percent pure, extruded to 25 mm diameter; redrawn cold to 20 mm diameter, and stabilized.

Anticorodal, 1 percent Si, routine cast, extruded to 22 mm diameter; redrawn cold to 18 mm diameter, and stabilized.

Avional D, extruded to 20 mm diameter; redrawn cold to 18 mm diameter, and stabilized.

Peraluman 2, extruded to 25 mm diameter; redrawn cold to 20 mm diameter, and stabilized.

Peraluman 7, extruded to 25 mm diameter; redrawn cold to 20 mm diameter, and stabilized.

The static testing of these alloys yielded the following data:

Static Test Data (at 20° C)

Alloy	Identification	σ 0.02	σ 0.2	σ_B	E	HB	δ	ψ
Al pure 25/20 diam.	BZ	0.9	1.5	8.1	6750	18	37	85
Anticorodal 22/18 diam.	BQ	3.4	6.5	11.3	7000	32	31	68
Avional D 20/18 diam.	BU	6.5	9.8	18.7	7300	51	13	55
Peraluman 2 25/20 diam.	CC	7.0	7.9	22.4	6750	53	19	55
Peraluman 7 25/20 diam.	CD	11.2	12.9	30.6	6600	82	9	10

To ascertain the relationship between the elastic properties (σ 0.02, σ 0.2, strain limit and the E modulus) and the momentary test temperature, records were made throughout the temperature range from 20° to 480° C, with the Martens mirror instrument, and the obtained findings plotted on sheets MP 2351a, 2353a, 2354a, 2355a, and 2356a.

: On comparison of the $\sigma_{0.2}$ strain-limit values of the present test with the earlier values (Reports No. 527a/32 and 555/36) obtained in normal high-temperature tensile test, it is seen that the earlier $\sigma_{0.2}$ strain limits for stabilized pure aluminum (99.3 percent) and for stabilized Peraluman 2, were considerably higher. This is due to the fact that, on the one hand, the $\sigma_{0.2}$ limit was determined from the machine diagram and the tensile-test period is from 2 to 5 minutes only; whereas the period with Martens mirror instrument and with direct-weight application, takes about one hour. It was known from earlier experiments that the values for the $\sigma_{0.2}$ strain limit would be as much lower as the period of loading is greater. On the other hand, the extruded bars used in the tests described here, are cold-worked before annealing and completely softened, accordingly. On conclusion of the elasticity measurement on the individual test bars, the Martens instrument was removed, the specimens reheated to the same temperature, and then loaded to failure in stages by direct application of weights through a transmission lever.

The obtained data on proof stress σ_B , elongation at failure δ_{10} , and contraction ψ , are reproduced on sheets MP 2351c, 2353c, 2354c, 2355c, and 2356c. All the tested alloys manifest a drop in tensile strength with ascending test temperature; the proof stress and the contraction increase with ascending temperature up to a certain maximum value, but decrease at further increased test temperature. The test bars disclosed at the same time a coarse recrystallization during the extremely high-temperature tensile test.

Since the earlier tensile tests had been made at temperatures of, at most, 450°C , optimum values could be ascertained solely on Peraluman 2 and Peraluman 7. Of interest is the fact that these test temperatures at which the individual aluminum alloys manifest maximum elongation and contraction values, are in agreement with the practically ascertained optimum hot-working temperatures. Further hot-forming, at still higher temperatures, induces heat cracking.

b) Creep Strength

In the present investigation the creep strength was explored by two methods and the results compared. By the Rohn method, the test bar is subjected to a certain load and the test temperature raised in stages until it yields

under the effect of the continuous load and the last set temperature. The thereby-induced stretching diminishes the test temperature across regulating contacts and relays until the specimen is practically through stretching. The automatically regulated end temperature corresponds fairly exactly with the temperature at which the material can be loaded as long as desired under the chosen fatigue tensile stress without the plastic flow exceeding admissible bounds.

The objection raised against this test method is that the test bar, by the chosen load stage, is subject to plastic flow as a result of the initial necessary overtemperature, and so becomes a little strain-hardened. The thus-changed material might, unless this strain-hardening is voided by the existent test or overtemperature, result in excessive creep-strength values. On the other hand, this method requires that the automatically adjusted end temperature remain practically constant for some time, which is the case for the studied aluminum alloys after about 30 days, as seen from the appended diagrams MP 2351d, 2353d, 2354d, 2355d, and 2356d.

It suggests itself now to establish, by strain measurements on the one hand, the plastic flow of the test bars when stressed in the different load stages at the end temperature by the Rohn method. On the other hand, it is desirable to ascertain the temperature at which the test specimen stretches from the 25th to the 35th hour of loading, with a strain rate of 1/1000 percent per hour since, according to the DVM standard of creep rate for steel, a strain rate of 1/1000 percent per hour is permissible between the 25th and 35th loading hours, while the total strain, after 45 hours, must not exceed 0.2 percent.

These measurements would indicate whether a short-time test method, as suggested for steel, would be practical for creep-strength testing of aluminum alloys.

We made a number of time-yield records in conjunction with the Martens mirror instruments. The obtained test points were plotted in curves, from which the strain rates at the individual test temperatures and load stages can be computed. To establish the further strain curve of the fatigue-loaded specimens, the experiments were extended to a 550-hour test period, and the strain rate determined between the 450th and 550th hour. Because of the many curves, the individual time-yield records have not been included in the present report.

The rates of strain recorded at the different load stages and the temperatures are included in MP 2351d, 2353d, 2354d, 2355d, and 2356d. So far as the bars have been tested at different temperatures at the individual load stages, they are indicated by thin lines, the intersection of which with the heavier horizontal straight line (strain rate = 1/1000 percent per hr), gives the desired temperature at which the bars stressed with the corresponding load stage, manifest a strain rate of 1/1000 percent per hour from the 25th to 35th hour of loading. Plotting this temperature with the related load stage in a curve, gives the heavy solid curve of the creep strength shown in the graphs. This curve is, with the exception of Anticorodal (MP 2353d), somewhat higher throughout the entire temperature range than the curve obtained by the Rohn method. The curve for the hot yield point ($\sigma_{0.2}$ strain limit), included for comparison, discloses that up to a certain temperature the obtained creep strength lies above the $\sigma_{0.2}$ strain limit. This is due to a cold-working occurring at the comparatively high load stages, which strain-hardens the stabilized material and which cannot be removed again by the present test temperature and the employed test period.

However, since the structural parts of a design should not be stressed beyond the $\sigma_{0.2}$ strain limit because of plastic flow, the $\sigma_{0.2}$ limit may, up to around 1000 C, be looked upon as the maximum safe stress for the fatigue tensile load also. Of course, it must be borne in mind that the plastic flow of a specimen, stressed at the height of the $\sigma_{0.2}$ limit, can be substantially greater than the 0.2-percent stretch obtained by the elasticity measurement.

Sheet MP 2358 gives the achieved creep-strength values of the tested aluminum alloys. A comparison with the earlier data (Report No. 540/35) discloses that, in spite of the completely softened aluminum alloys used, the present creep-strength values are, on the whole, up to 50 percent higher than the others. The reason for this is, that in the earlier tests the testing machines were without shockproof mounting, hence the ground vibrations actually accelerated the flow process in the test bars. The conclusion, therefore, is that when using creep-strength machines with direct weight application, the vibrations occurring during the test must be recorded. The standards for creep-strength specifications should therefore contain also an indication of the maximum admissible stress variations in the test bar.

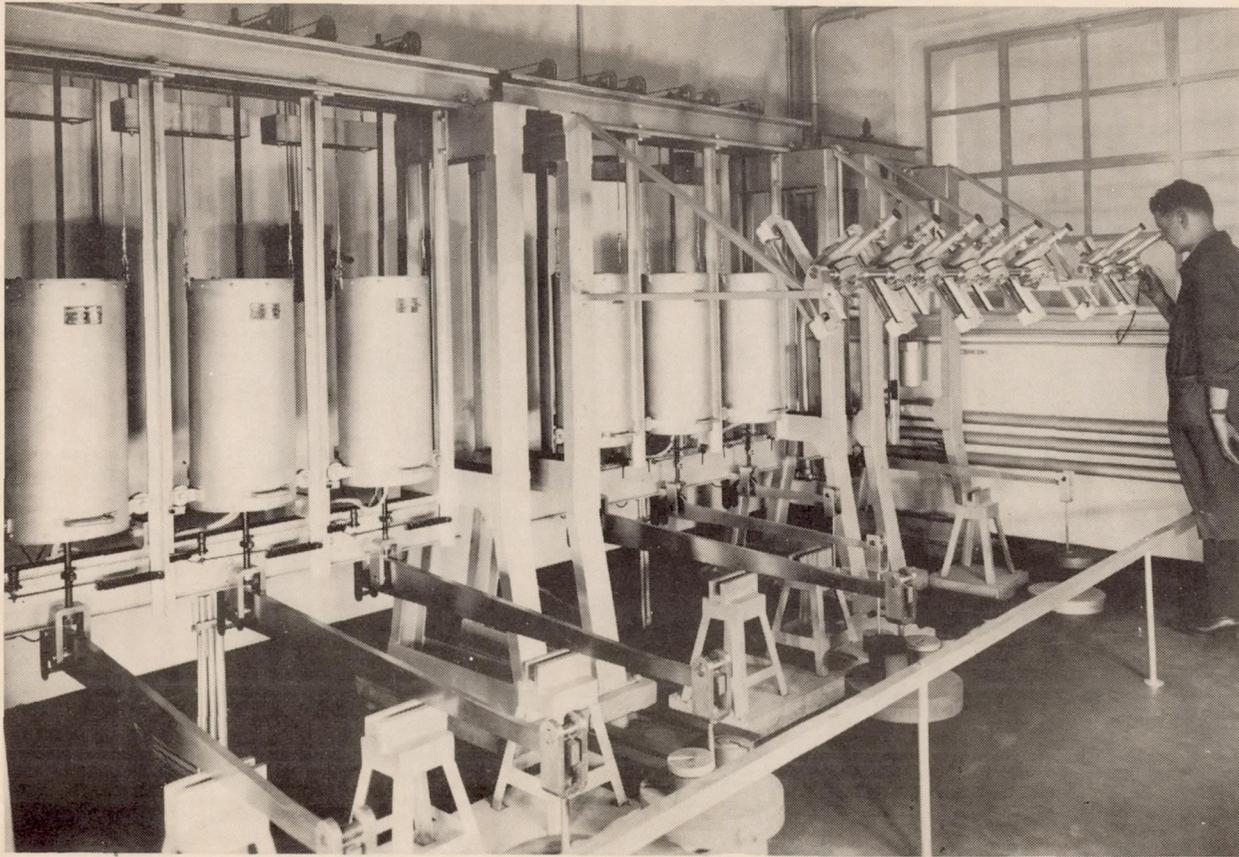
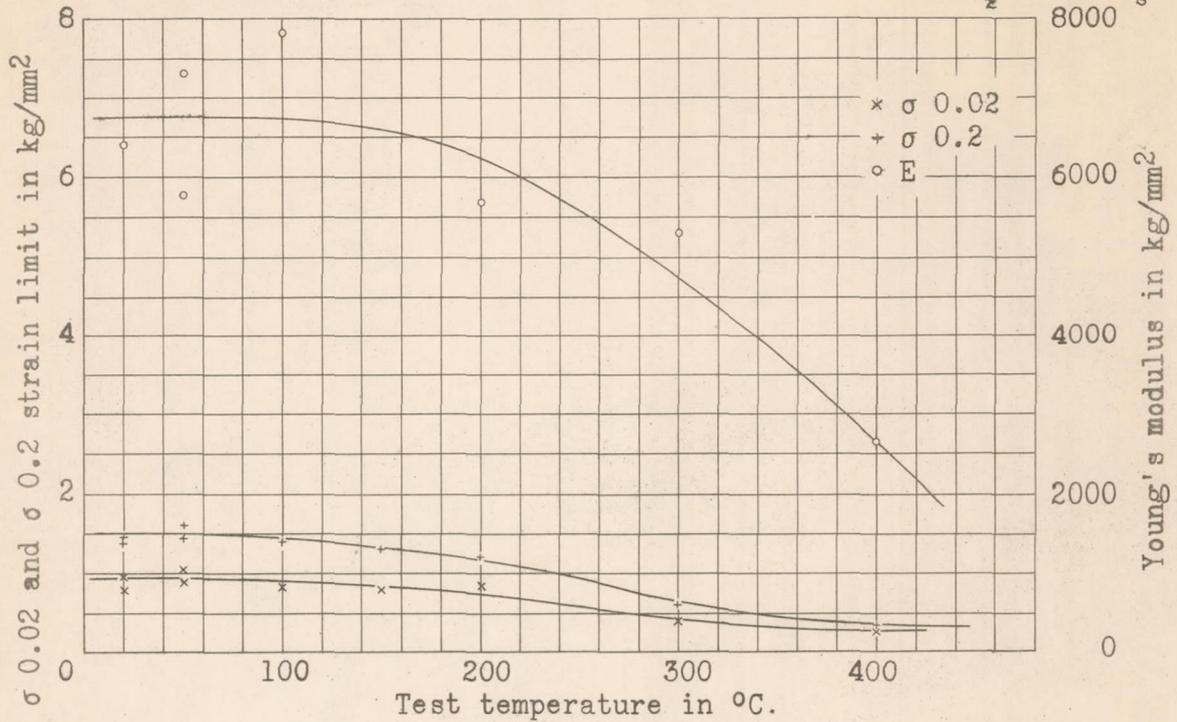
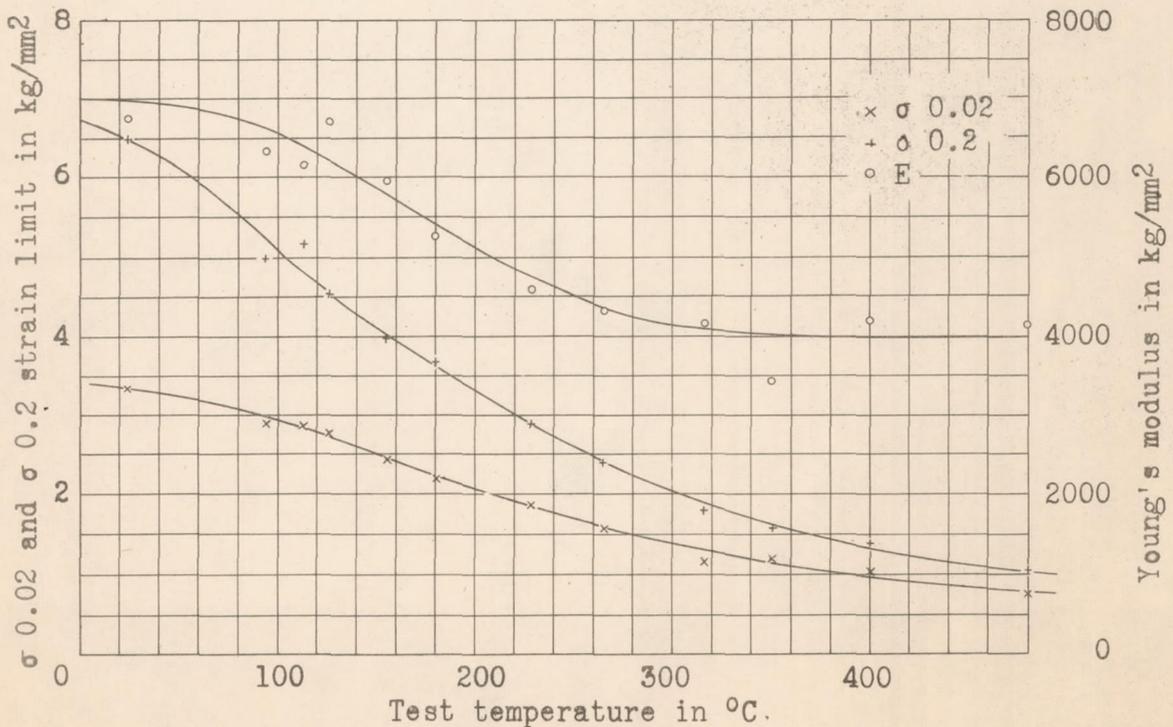


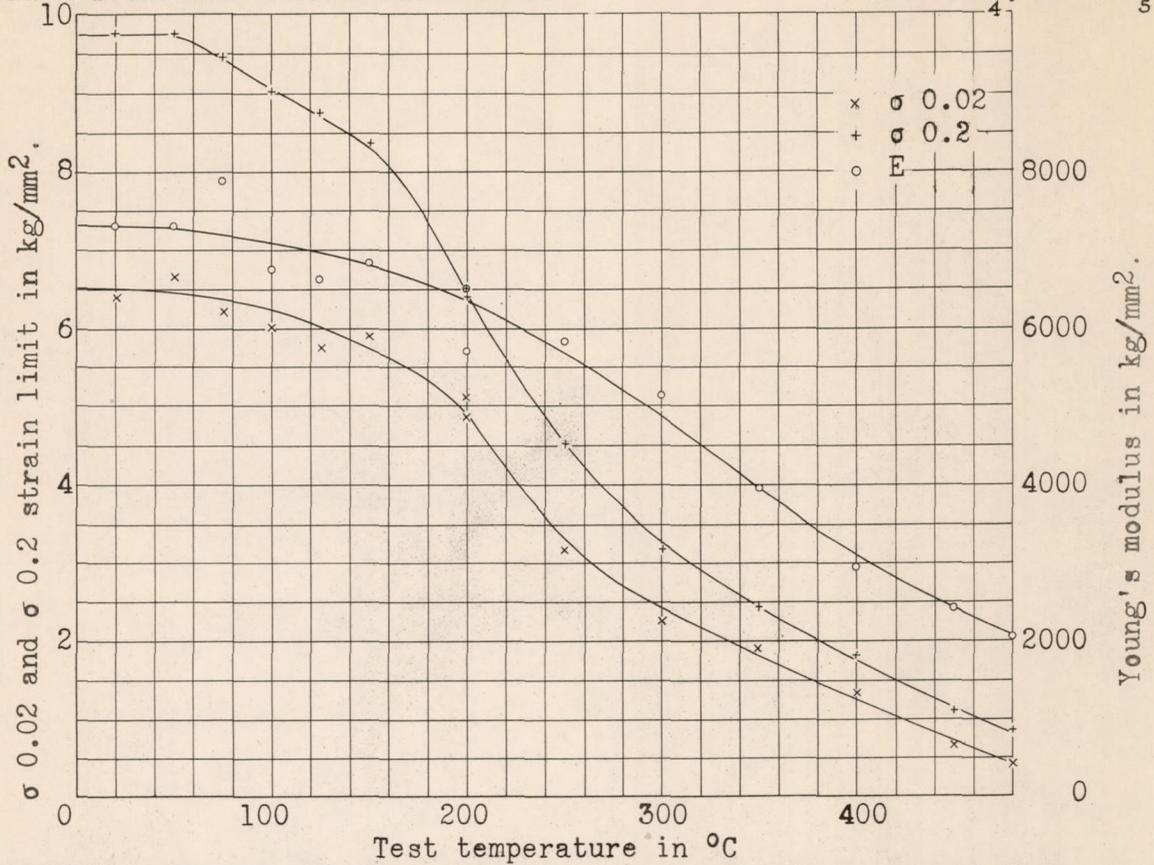
Photo P-3036.- Creep strength testing machines.
Left, Rohn method; right, strain
recording system.



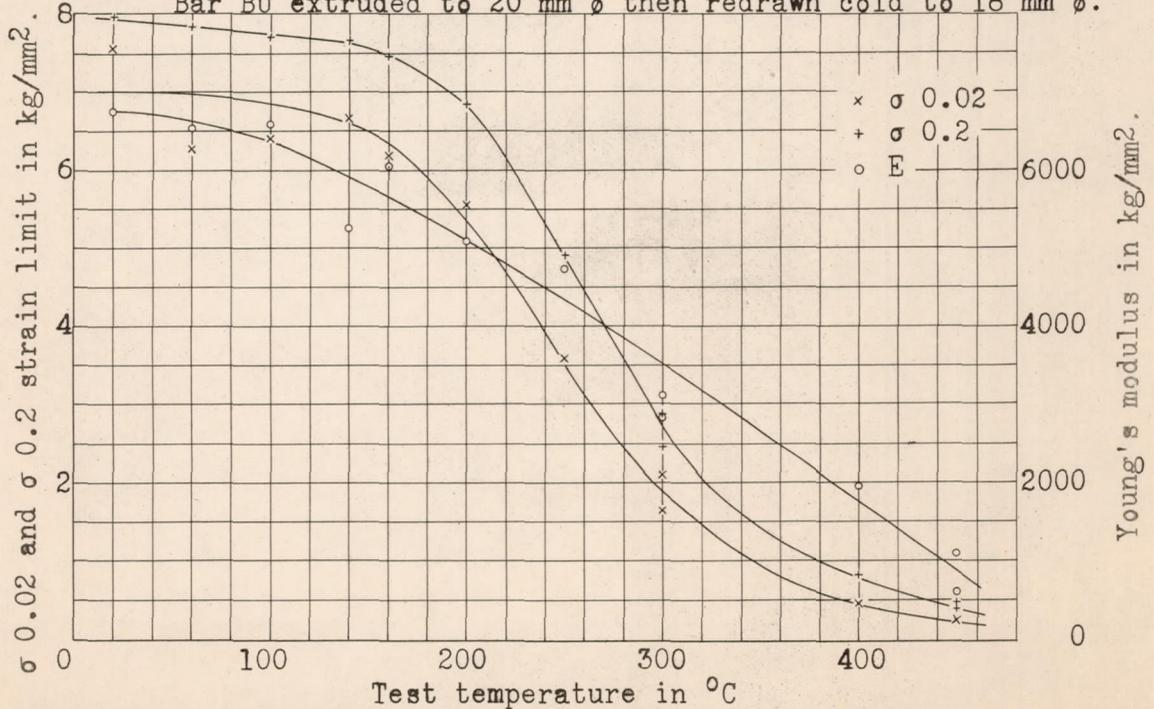
MP2351a- Hot-elasticity measurement on stabilized pure aluminum.(99.5%). Bar BZ extruded to 25 mm ϕ then redrawn cold to 20 mm ϕ .



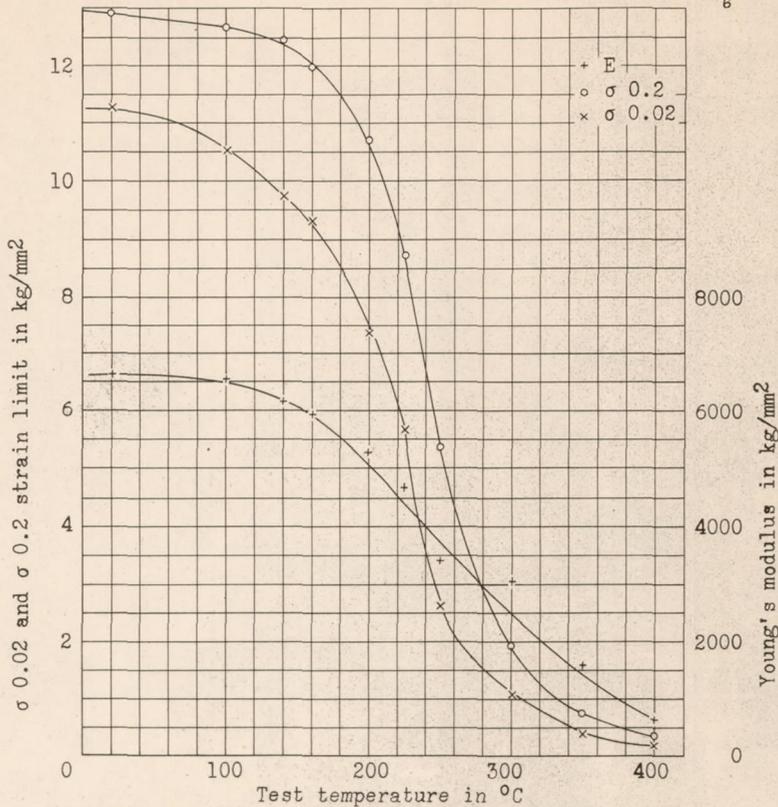
MP2353a- Hot-elasticity measurement on stabilized anticorrosional. Bar BQ extruded to 22 mm ϕ then redrawn cold to 18 mm ϕ .



MP2354a- Hot-elasticity measurements on stabilized avional D.
Bar BU extruded to 20 mm ϕ then redrawn cold to 18 mm ϕ .

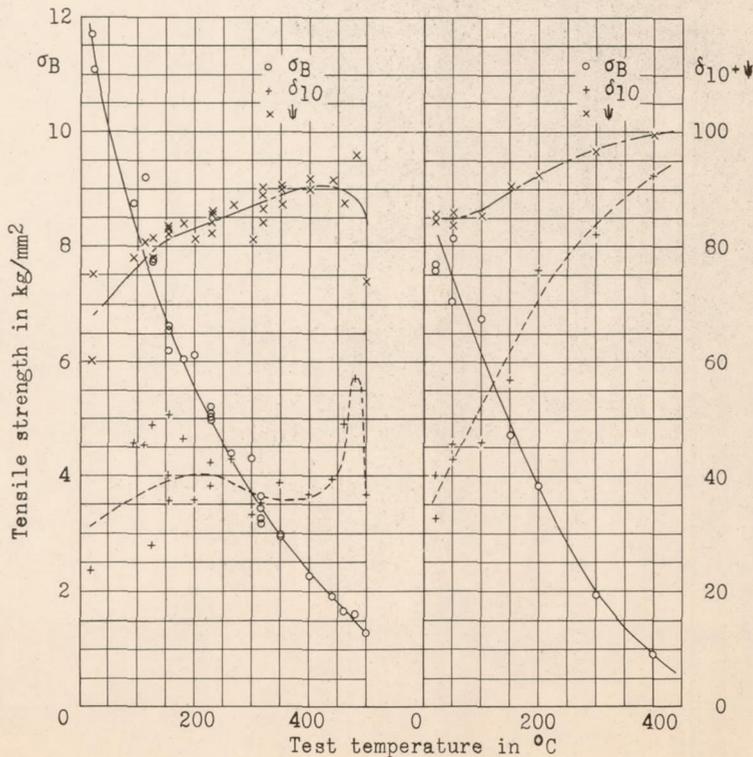


MP2355a- Hot-elasticity measurements on stabilized peraluman 2.
Bar CC extruded to 25 mm ϕ then redrawn cold to 20 mm ϕ .



MP2356a- Hot elasticity measurements on peraluman 7.
Bar CD extruded to 25 mm ϕ then redrawn cold to 20 mm ϕ .

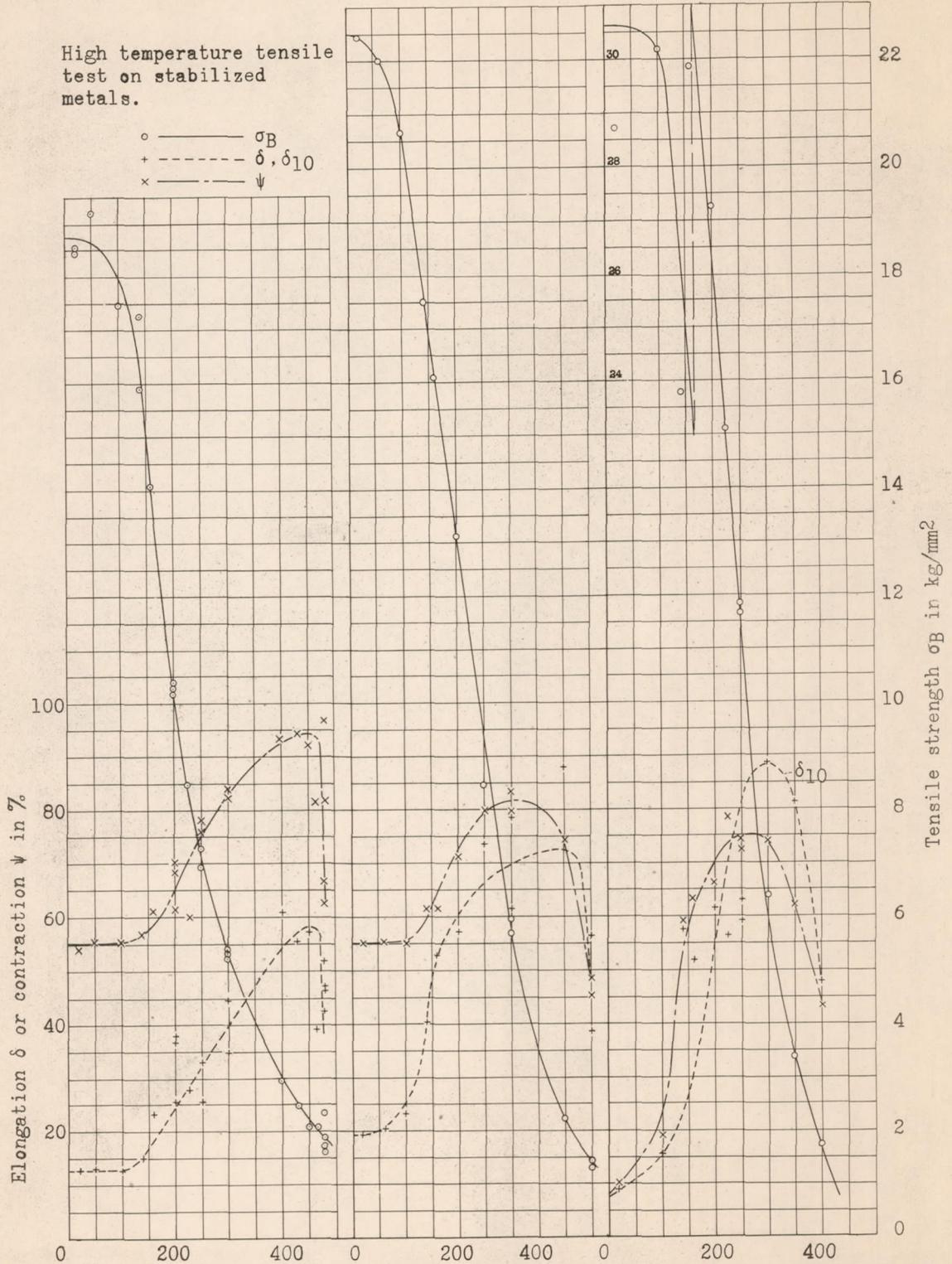
MP2353c- High temperature tensile test on stabilized anticorodal. Bar BQ extruded to 22 mm ϕ then redrawn cold to 18 mm ϕ .



MP2351c- High temperature tensile test on stabilized pure aluminum. (99.5%). Bar BZ extruded to 25 mm ϕ then redrawn cold to 20 mm ϕ .

High temperature tensile test on stabilized metals.

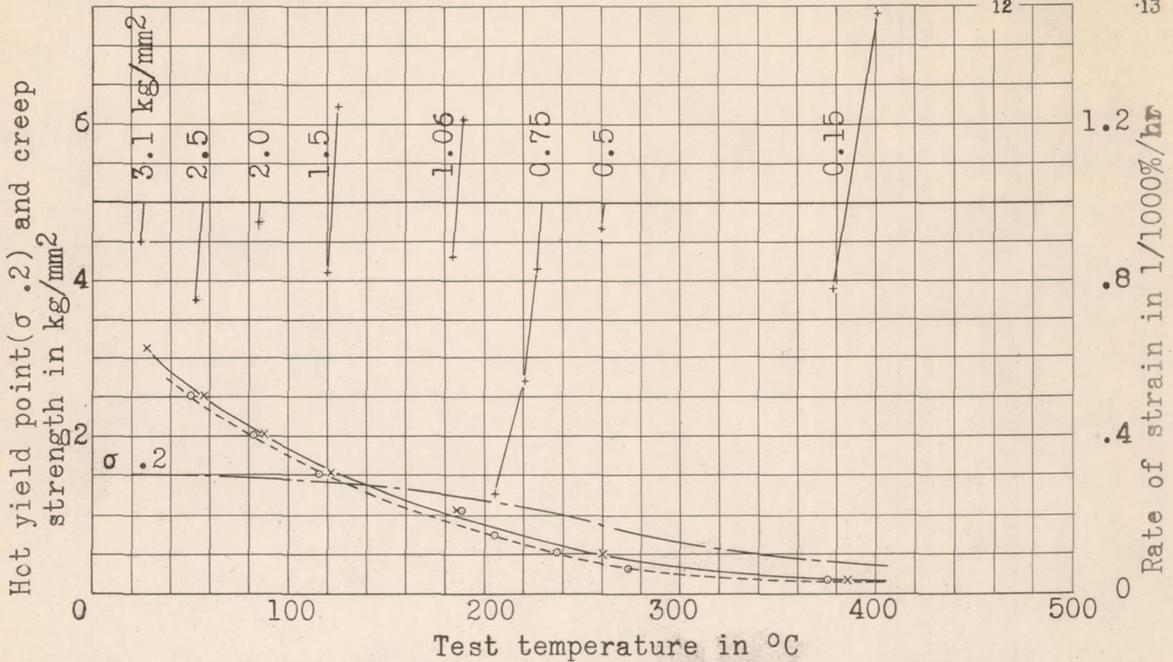
○ ——— σ_B
 + - - - δ, δ_{10}
 x - - - ψ



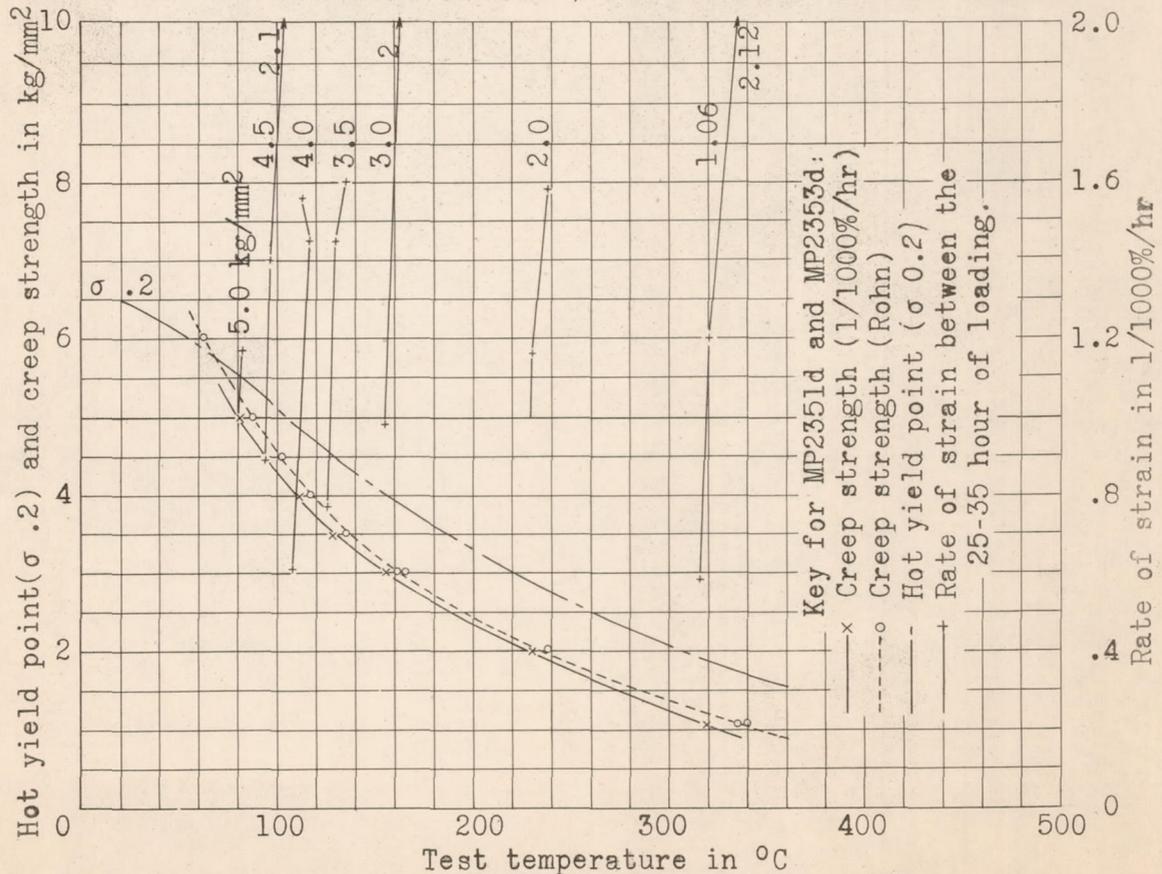
MP 2354c- Avional D.
 Bar Bu ex-
 truded to 20 mm ϕ then
 redrawn cold to 18 mm ϕ .

MP 2355c- Peraluman 2.
 Bar CC ex-
 truded to 25 mm ϕ then
 redrawn cold to 20 mm ϕ .

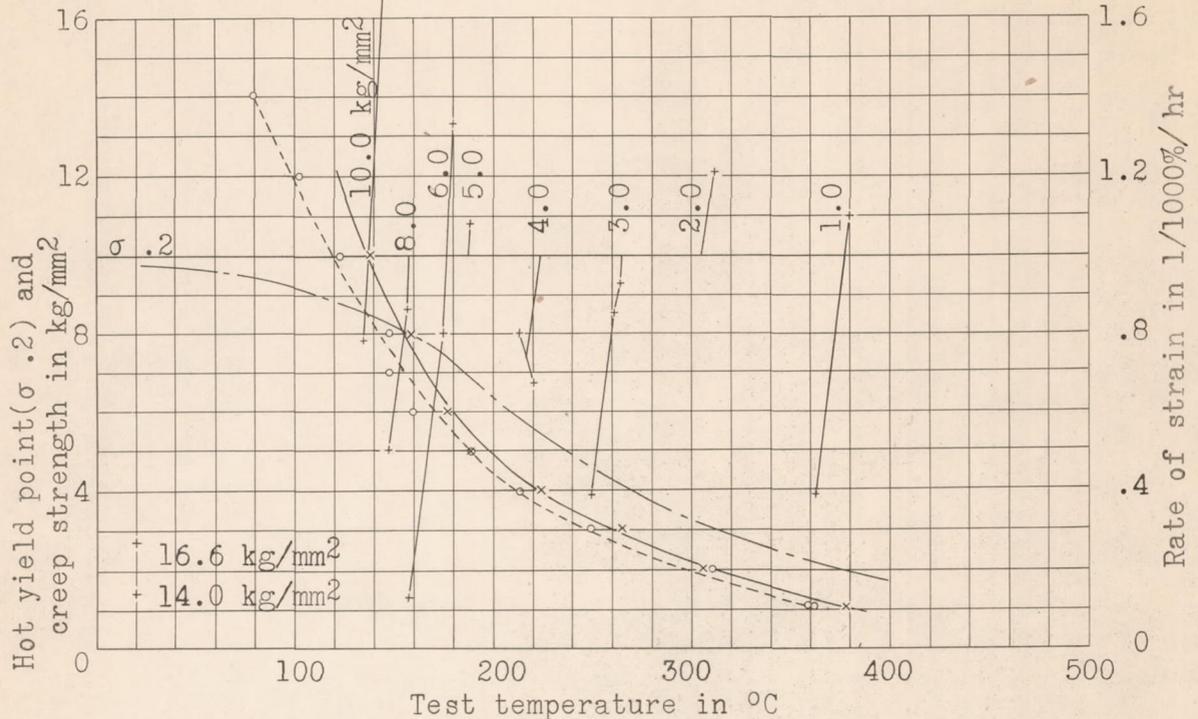
MP 2356c- Peraluman 7.
 Bar CD ex-
 truded to 25 mm ϕ then
 redrawn cold to 20 mm ϕ .



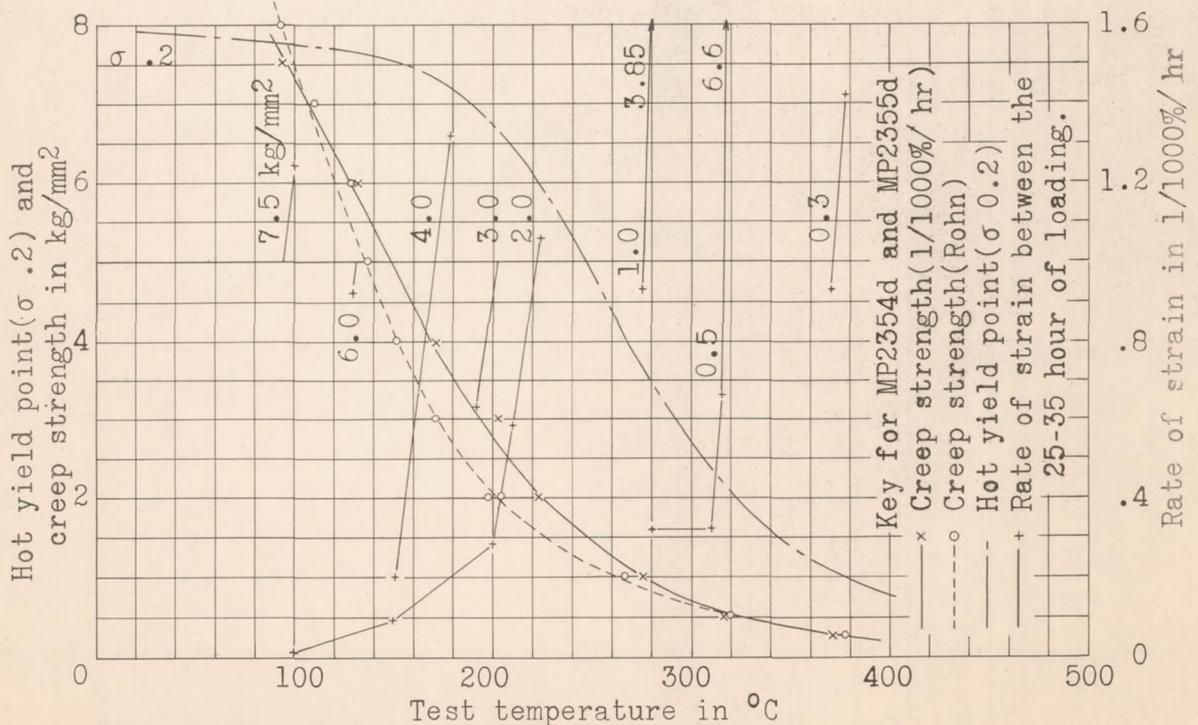
MP2351d- Creep strength of stabilized pure aluminum (99.5%).
Bar BZ extruded to 25 mm ϕ then redrawn cold to 20 mm ϕ .



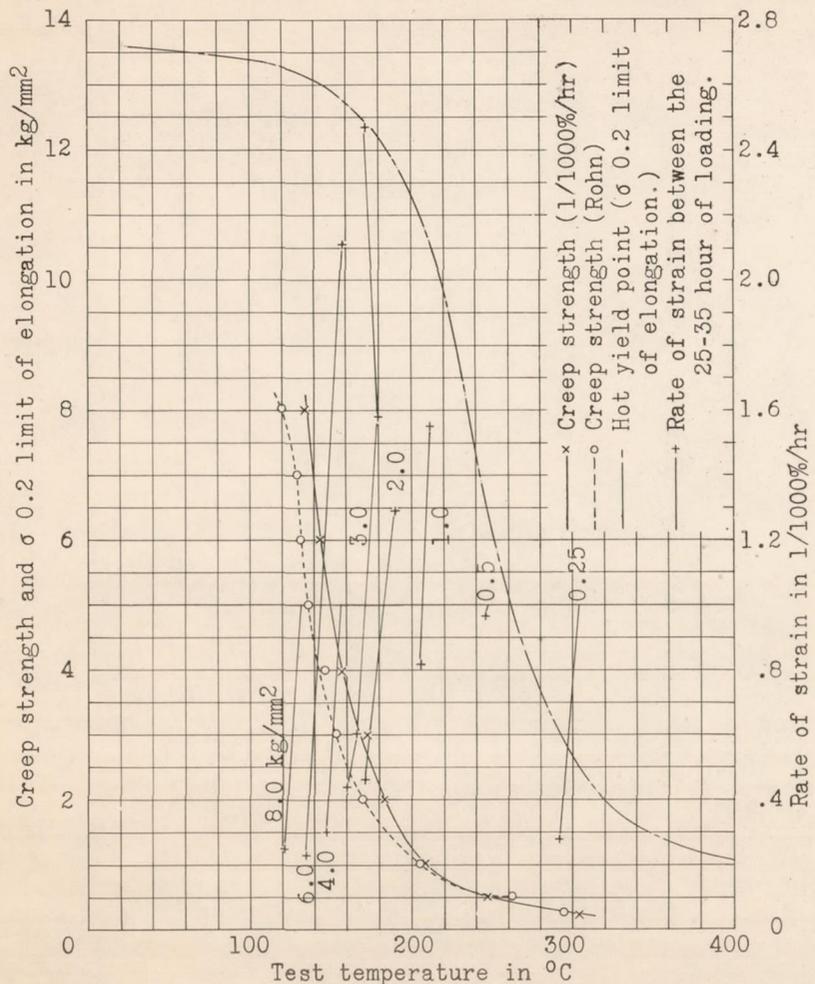
MP2353d- Creep strength of stabilized anticorrosional, Bar BQ extruded to 22 mm ϕ then redrawn cold to 18 mm ϕ .



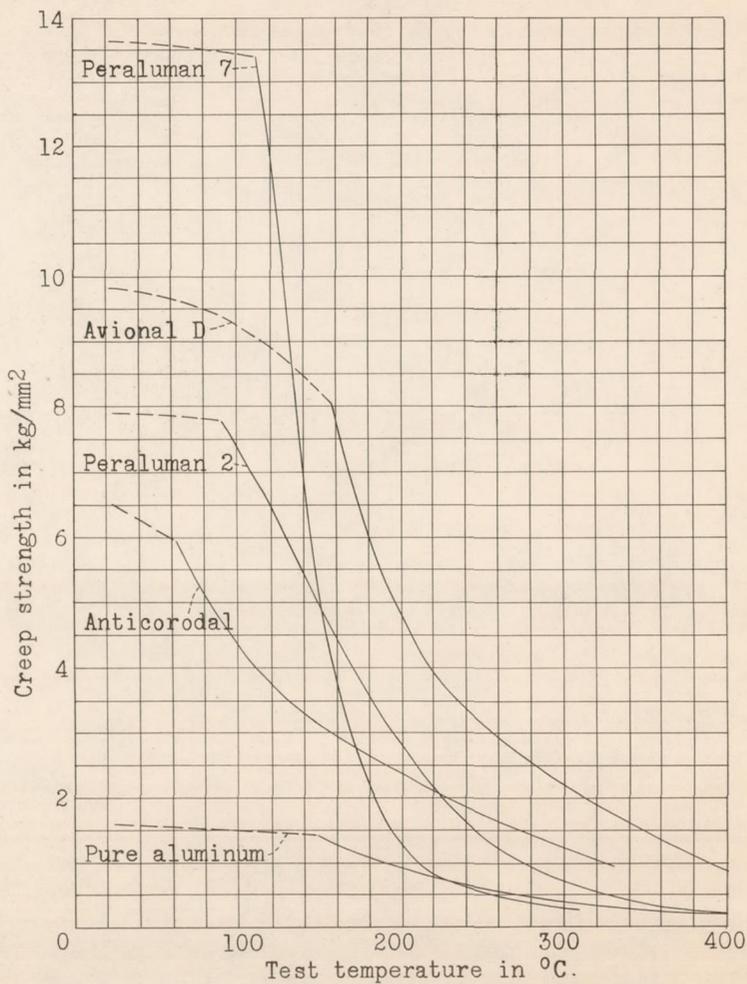
MP2354d- Creep strength of stabilized avional. Bar BU extruded to 20 mm ϕ then redrawn cold to 18 mm ϕ .



MP2355d- Creep strength of stabilized peraluman 2. Bar CC extruded to 25 mm ϕ then redrawn cold to 20 mm ϕ .



MP2356d- Creep strength of stabilized peraluman 7.
Bar CD extruded to 25 mm ϕ then redrawn
cold to 20 mm ϕ .



MP2358- Creep strength of stabilized wrought
aluminum alloys. Rate of strain between
the 25 and 35 hour of loading = 1/1000%/hr.