Elastic Limit of an Aluminium Rod and the Size of the Crystal Grains

By

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Abstract

The limit of elasticity of an aluminium rod composed of a single crystal scarcely varies with the difference of the orientation of the crystal. If it varies, the amount of the variation is relatively small. In the case of rods composed of comparatively large crystals, the limit of elasticity decreases rapidly with the increase of the linear crystal size, but after exceeding the crystal size of about 0.3 cm., it decreases very slowly. For the determination of the elastic limit of a rod composed of a large crystal, the method of gradually increasing loads is preferable to that in which the load is applied and removed repeatedly.

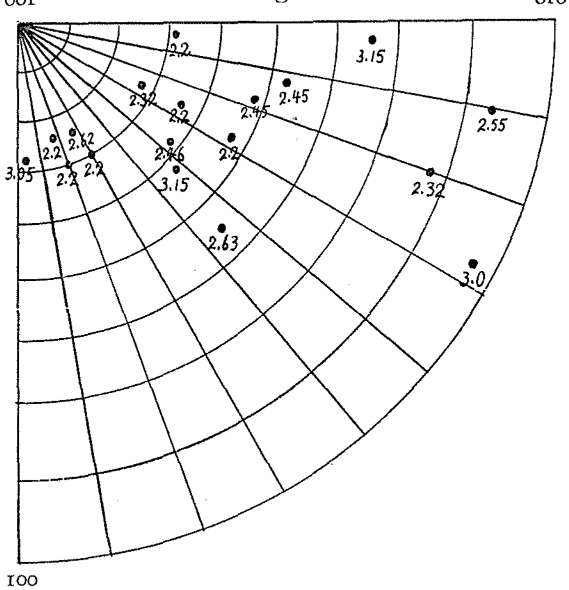
Experimental Method

Ten commercial cold-worked aluminium rods about 20 cm. in length and about 5 mm. in diameter were put into the electric furnace together, and heated at about 400°C for two days. When cooled to the room temperature, they were taken out of the furnace. After being elongated by a certain percentage ranging between 0.5% and 24%, they were heated in the furnace again for two days at about 640°C. Thus they were recrystallized. Eight different groups of rods were elongated separately to different percentages. Thus many specimens were obtained composed of crystals having various sizes.

For the special purpose of letting the crystals grow larger, the elongation of about 1.5% was given to the rods, and eighteen specimens having crystals of linear size from 9 cm. to 15 cm. were obtained. The surfaces of the specimens were slightly etched with dilute solution of hydrochloric acid so as to make the crystals clearly visible. For each rod thus etched, its diameter was measured at several parts with a micrometer screw guage, and the average value was taken. The stress exerted on the rod was expressed by the load applied to it per unit initial area.

In order to determine the orientation of the crystal in each rod composed of a large single crystal, one side of the rod was illuminated perpendicularly by an X-ray beam. From the distribution of the Laue-spots thus produced on a photographic plate, the orientation of the crystal was determined by means of the crystallographic globe devised by Prof. U. Yoshida.[1] The orientations of the crystals of 18 rods examined are shown by a stereographic projection in Fig. 1. In this figure the longitudinal direction of the rod is represented by a dot referring to the three crystallographic axes [100]. The writer measured small elongations of the above-mentioned specimens by means of the extensometer previously designed by him,[2] and plotted the curve showing the relation between the stress per unit area and the elongation per unit length. From this curve he determined the elastic limit of the specimen by using the contact point finder previously reported by him.[3] Linear grain number and linear crystal size were measured by examining the etched surface of the specimen by a travelling micrometer.

Fig. 1



Experimental Result

The guage length employed in the present experiment was 10 cm., so that in the case of the specimens having the linear crystal size a little shorter than 10 cm., another crystal having different orientation was contained within the guage length. But the effect of this fact was negligible. The result of the measurements is shown in Table I. As is seen from this table, the limit of elasticity expressed by the elongation per unit length, takes various values from 2.2×10^{-5} to

1. U. Yoshida, Jap. J. Phys., **4**, 133, (1927).
2. These Memoirs, A, **20**, 19, (1937).
3. These Memoirs, A, **20**, 27, (1937).

3.15×10^{-5}. It is very difficult to determine acculately the elastic limit, and the limit of the experimental errors was estimated to be about $\pm 0.4 \times 10^{-5}$ in the present case. Hence it seems legitimate to state that the limit of elasticity is almost the same for all the specimens tabulated in Table I, irrespective of the crystal orientations. To examine this point more clearly, the values multiplied by 10^5 of the elastic limits were respectively written under the dots in Fig. 1, which show the orientations of the longitudinal directions of the rods. In this figure, no systematic change of the values of the elastic limit with the difference of the crystal axes can be detected. Consequently it may be stated that the limit of elasticity is almost independent of the orientation of the crystal. Thus by taking the average for different specimens of various crystallographic orientations, the value 2.52×10^{-5} was obtained for the limit of elasticity of a single crystal of aluminium.

Table I

Specimen	Limit of elasticity		Young's Modulus
No.	Stress per unit area	Elongation per unit length	in C. G. S. unit
1	15 $\frac{kg}{cm^2}$	2.20×10^{-5}	6.68×10^{11}
2	15	2.20	6.68
3	17	2.45	6.80
4	18	2.63	6.71
5	17.5	2.55	6.73
6	15	2.20	6.68
7	22	3.15	6.84
8	15	2.20	6.68
9	17	2.46	6.77
10	21	3.05	6.75
11	18	2.62	6.73
12	15	2.20	6.68
13	22	3.15	6.84
14	15	2.20	6.68
15	16	2.32	6.76
16	16	2.32	6.76
17	21	3.00	6.83
18	17	2.45	6.76
Average	17.4	2.52	6.74

For each different group of the specimens composed of crystals smaller than the above, the average values of the elastic limit and the grain number were taken respectively by examining five or six specimens belonging to the same group. Such an example is given in Table II.

For ten different groups of the specimens, the elastic limit, the Young's modulus, the grain number and the crystal size are given in Table III, where the grain number and the crystal size are mutually

Table II

Specimen	Limit of elasticity		Young's Modulus	Grain number per unit length
No.	Stress per unit area	Elongation per unit length	in C. G. S. unit	per one cm.
1	28 $\frac{kg}{cm^2}$	4.1×10^{-5}	6.69×10^{11}	14
2	27	3.9	6.78	13.5
3	30	4.3	6.84	13
4	27	3.9	6.78	15
5	32	4.6	6.81	14.5
6	27.5	4.0	6.74	14
Average	28.6	4.13	6.77	14

Table III

Specimen	Limit of elasticity		Young's modulus	Grain Number per unit length	Linear grain size
Group Number	Stress per unit area	Elongation per unit length	in C. G. S. unit	per one cm.	
1	17.4 $\frac{kg}{cm^2}$	2.52×10^{-5}	6.74×10^{11}	0.100	10 cm.
2	19.2	2.77	6.73	0.22	4.5
3	22.8	3.31	6.77	3.54	0.282
4	28.6	4.13	6.77	14	0.072
5	30.6	5.76	6.74	54	0.019
6	50.8	7.38	6.75	197	0.005
7	54.2	7.83	6.78	301	0.003
8	64.6	9.44	6.70	506	0.002
9	81	11.9	6.68	773	0.0013
10	98	14.4	6.68	1049	0.00095

reciprocal. From the table, it is seen clearly that the Young's modulus has the same value within the limit of experimental errors for all the specimens as has been previously reported by the writer.[1] In this table, the numbers in the last two horizontal rows are taken from the previous report,[2] for the sake of comparison.

The curve showing the relation between the limit of elasticity and the linear grain number is given in Fig. 2, where the small dots denote the values observed in the present experiment and the small circles those in the previous one. It is clearly seen from the curve,

1. These Memoirs, A, **17**, 389, (1934).
2. These Memoirs, A, **20**, 27, (1937).

Fig. 2

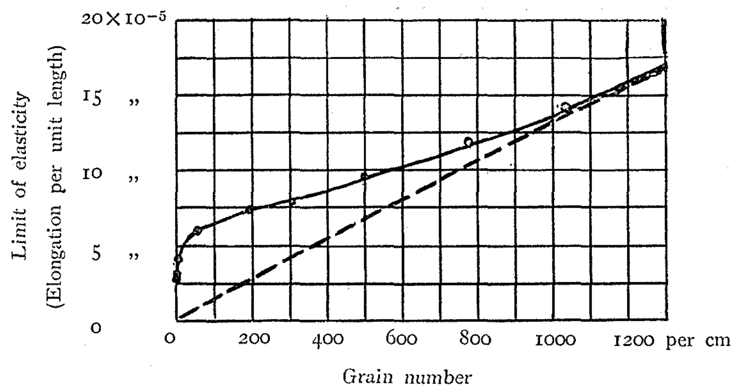
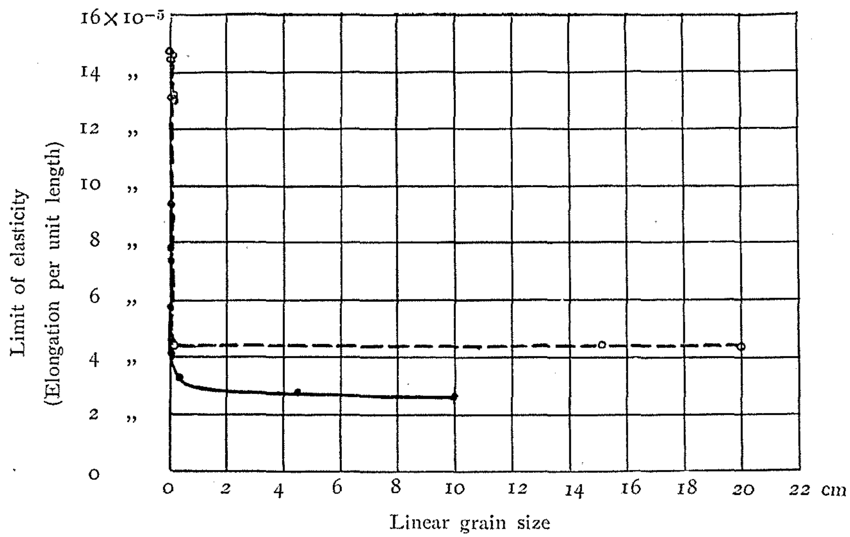


Fig. 3



that the connection of the present result and the previous one is perfect. The broken line denotes the extension of the empirical formula obtained previously for comparatively small crystals.[1] The disagreement between these two curves becomes larger with the decrease of grain number. Accordingly the empirical formula can not be applied to the case of the large grain size.

Fig. 3 shows the relation between the limit of elasticity and the linear grain size. From this figure it is clearly found that the limit

1. These Memoirs, A, **20**, 27, (1937).

of elasticity decreases rapidly with the increase of the grain size, and after exceeding the grain size of about 0.3 cm. it decreases very slowly.

In order to compare the present result with the previous one,[1] the elongation per unit length and the linear grain size are calculated respectively from the values of the stress per unit area and the areal grain size given in the previous report, and they are tabulated in Table IV. The broken line in Fig. 3 represents the result given in Table IV, and shows a similar tendency as the above-mentioned one; but it gives somewhat greater values for the elastic limit than the other does. This discrepancy between the two results is due to the difference of procedure for measuring the elongation. For the broken line, the following procedure was followed. By the application of a certain load to the rod, its elongation was measured, and on its removal the permanent set was measured; and again by applying a larger load, its elongation and the set caused by the release of the load were measured. Such an operation was repeated several times until a well-defined and increasing permanent set was reached. This procedure seems to distort the crystals somewhat, and gives a larger value for the elastic limit. Thus such a procedure is not suitable for measuring the elongation of the rod composed of larger crystal grains.

Table IV

Specimen	Limit of elasticity	Linear grain size
No.	Elongation per unit length	
1	4.37×10^{-5}	20 cm.
2	4.44	15
3	4.42	0.1
4	13.22	0.05
5	13.09	0.04
6	13.28	0.03
7	14.65	0.03
8	14.81	0.02
9	14.48	0.02

In conclusion, the writer wishes to express his sincere thanks to Prof. U. Yoshida for his kind guidance in the research.

1. These Memoirs, A, **17**, 389, (1934).