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EUROPEAN ATOMIC ENERGY COMMUNITY - EURATOM

INTERNAL FRICTIONS AND YOUNG'S MODULUS MEASUREMENTS ON SAP

by

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1965

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Paper presented at the "Convegno sui Metalli non fissili nei reattori nucleari",
Bologna - Italy, December 16-18, 1963

Reprinted from
ALLUMINIO . NUOVA METALLURGIA
N. 11 - 1964

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Internal Frictions and Young's Modulus Measurements on SAP *

The elastic behaviour of SAP shows considerable differences from that of Al with the same impurity content. Young's modulus measurements led to the following conclusions: *a*) SAP's modulus is considerably higher than that of Al; *b*) the dynamic modulus of SAP is higher than the static one; *c*) the dynamic modulus decreases after a slight plastic deformation but recovers after a heat treatment at 500 °C.

The measuring equipment consists in two different apparatus. One is built at Ispra following the model of the elastometer used by Bordoni at the Istituto Nazionale di Ultracustica O. M. Corbino in Rome. The sample-holder (see fig. 1) is suited to disc-shaped samples. The frequency range is 5-100 kc. The other apparatus is that of the dr. Försters Institute, Reutlingen, Germany, suitably modified. It has a frequency range of 600 c-25 kc (see fig. 2).

Measurements are carried out at a pressure of 5 μ Hg maximum. The results concern extruded SAP.

1. Dynamic Young's Modulus

Figure 3 compares the relative values of the unrelaxed moduli of aluminium and SAP samples in the kilocycle range as a function of temperature. The overlap of the curves is noteworthy.

The absolute values were measured at 23 °C and 18 kc and were the following:

Al polycrystaline 99,5%	6 870 kg/mm²
Al single crystal . . .	6 930 kg/mm²
SAP 960 (4% oxide) .	7 790 kg/mm²
SAP 860 (14% oxide) .	8 580 kg/mm²

2. Static Young's Modulus

Static measurements carried out by ISML (Istituto Sperimentale dei Metalli Leggeri) gave for SAP 960, 7 120 kg/mm² and for SAP 860, 7 600 kg/mm² while the value for pure aluminium is about 6 950 kg/mm².

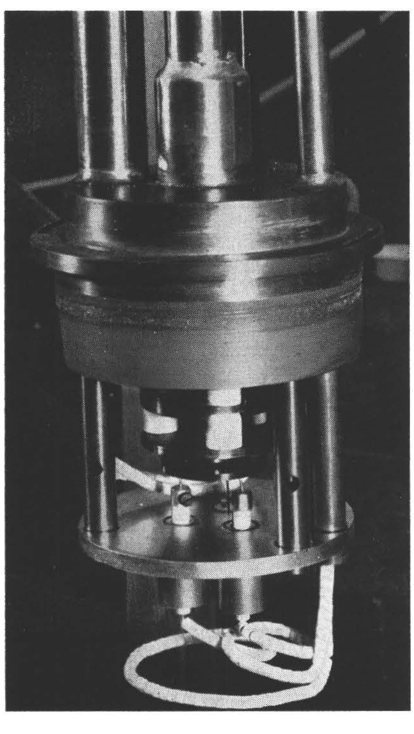
The dynamic values for SAP are apparently much higher than the static ones.

3. Influence of Deformation

The Young's modulus of SAP diminishes by nearly 2% after cold rolling. The results were the following:

directly after extrusion	7 790 kg/mm²
after 0.8% plastic deformation	7 660 kg/mm²
after 3.5% plastic deformation	7 645 kg/mm²

(*) Paper presented at the « Convegno sui metalli non fissili nei reattori nucleari ». Bologna, 16-18 dicembre 1963.



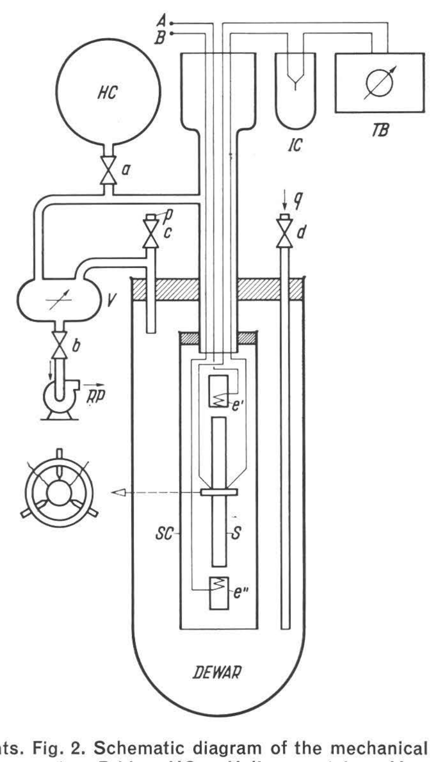


Fig. 1. Sample mounted in holder on three points. Fig. 2. Schematic diagram of the mechanical components of the modified elastomat. TB = Temperature Bridge; HC = Helium container; V = Valve; RP = Rotary pump; IC = Ice container for zero references; SC = Sample-container; S = Sample; q = Liquid air-inlet; p = outlet; e' e" = Exciters; a-b-c-d = Valves; AB = To control panel.

TABLE I Weight Percentage, Calculated and Measured Densities, and Volume Percentage of Al_2O_3 in SAP

Weight %	Calculated	Measured	Volume % (p)
0 (Al 99,5)	2.70	2.699	0
4	2.73	2.738	3.6
7	2.76	2.742	6.3
10	2.78	2.777	9.1
14	2.82	2.809	12.7

TABLE II Values of M/M_A for oxide oriented along the extrusion axis, for different values of « p » and « q »

q	p = 0,036	0,063	0,091	0,127
1	1.00	1.00	1.00	1.00
2	1.04	1.06	1.09	1.13
3	1.07	1.13	1.18	1.25
4	1.11	1.19	1.27	1.38
5	1.14	1.25	1.36	1.51
6	1.18	1.32	1.46	1.64

TABLE III Values of M/M_A for oxide oriented normally to the extrusion axis for different values of « p » and « q »

q	p = 0.036	0.063	0.091	0.127
1	1.00	1.00	1.00	1.00
2	1.02	1.03	1.05	1.07
3	1.02	1.04	1.06	1.09
4	1.03	1.05	1.08	1.11
5	1.03	1.05	1.08	1.11
6	1.03	1.06	1.08	1.12

after annealing for 2
hours at 500 °C . . . 7 780 kg/mm²

4. Damping Measurements

Figure 4 gives the damping of a laminated 960 sample before and after anneals at respectively 200 °C and 300 °C for two hours. The internal friction peak which appears at 120 °K is known as the Bordoni peak. It has been observed for face-centered cubic metals such as Al, Cu, Ni, Au, etc. The peak height is reduced to one half after the anneal. It disappears completely after an anneal at 500 °C.

A small increase of the damping has been noticed between 220 °K and 230 °K but for studying this effect the measurements need to be more accurate.

A high temperature peak appears at 350 °C (30 kc) (see fig. 5). The sample used was the Canadian SAP type M 257 which contains about 7% of aluminium oxide.

5. Comparison Al-SAP

A comparison with similar measurements on aluminium gives the following results:

1) The internal friction peak at low temperature is higher and broader in SAP than in aluminium.

2) This peak decreases after a two hour anneal at 200 °C. A subsequent treatment at 300 °C does not change it. After a heat treatment at 500 °C it disappears completely. Bordoni and others observed that in aluminium the peak disappears after a one hour anneal at 100 °C.

3) The peak at 350 °C at 30 kc in M 257 and in SAP observed by Gelly, Federighi (2) and Seeman (3) is also observed in aluminium at 500 °C.

4) The Young's modulus of SAP decreases after a slight plastic deformation (0.8%) while this is not the case with a 99.5% Al sample.

5) The Young's modulus of SAP measured dynamically is considerably higher than that of aluminium.

6) The Young's modulus of SAP measured dynamically is different from the static value, which is not the case with aluminium.

6. Discussion

The theory proposed by Seeger and his group and described by Niblett and Wills (1), about kink formation in dislocations and its movements in f.c.c. metals, to explain the Bordoni peak (point 1) is generally accepted. A single relaxation process gives rise to a narrow peak. The real form of the Bordoni peak as found in the different metals can be explained by the action of a big number of processes, each of them having its proper activation energy and relaxation time. For instance, in aluminium different types of dislocations and local stress fields combine to broaden the peak. Since in SAP the peak is still broader than in Al, this may indicate more important local stress fields e.g. due to the difference of the thermal expansion of the oxide and the bulk. The height of the peak is governed by the number of dislocation segments and so point 2 proves that between room temperature and 200 °C a part of the dislocation pinning points lose their efficiency. Above 500 °C these dislocations are free to move to the grain boundaries and the formation of kinks will not occur.

The Young's modulus from dynamical experiments (M_u) for aluminium is about one half percent higher than from static measurements (M_r) because the first is an adiabatic and the second an isothermal process. The relation between them is given by:

$$\frac{M_u - M_r}{M_r} = \frac{\lambda^2\, T\, M_u}{\varrho\, C_p}$$

λ = linear expansion coefficient
T = temperature
ϱ = density
C_p = heat capacity at constant pressure.

To calculate the volume percentage of Al_2O_3 in SAP we need to know the density of the oxide. Unfortunately there exist several different phases of this oxide. X-ray diffraction patterns have shown that at least the η and the χ phase with their respective densities of 3.2 g/cc and 2.5-3.6 g/cc are present in SAP, but their quantities are not known. Since no bubbles or pores were observed under the microscope the mean density can be roughly evaluated from the density measurements of SAP.

A good fit with the measured values is obtained by assuming a density of 3,0 g/cc (see table I) keeping in mind that weight percentages are not very accurate.

To estimate theoretically the Young's modulus of a mixture of a material B dispersed in a bulk material A a relation can be derived res two limiting configurations. Suppose that the Young's modulus (M_B) of material B is a factor q greater than that of A, so that $M_B = q\, M_A$. The configuration with the highest modulus will consist of flat particles of B which oriented along the axis of the rod. If p is the volume fraction of B, the relation will be

$$M = (1 - p + p\, q)\, M_A$$

If the particles are normal to the rod axis:

$$M = \frac{q}{p + q - p\, q} M_A$$

The Young's moduli of the η and χ phases of Al_2O_3 are not known. However it is known that the q of

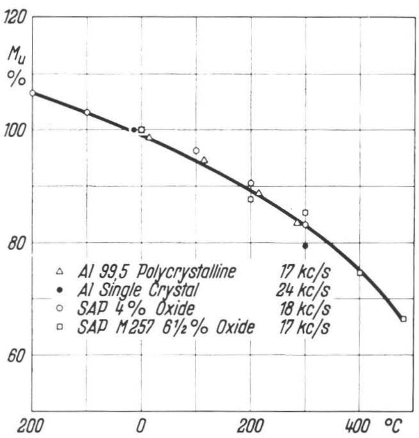


Fig. 3. Normalized unrelaxed Young's modulus (M_u = 100 at 0 °C) as function of temperature.

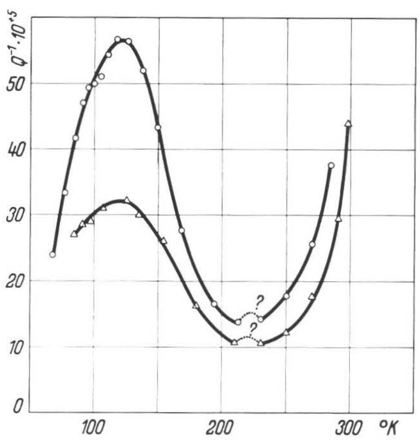


Fig. 4. SAP 4%. Internal damping after a two-hours anneal at 300 °C (Δ) and deformation (0).

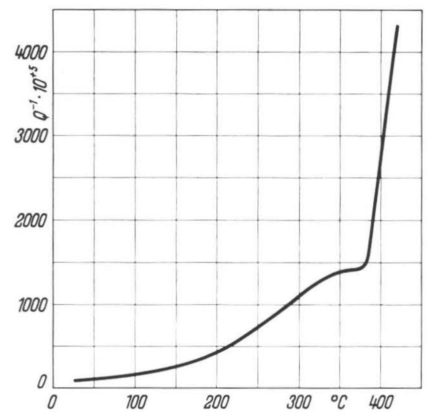


Fig. 5. Internal damping at 30 kc of the Canadian SAP M 257 as a function of temperature.

the α-phase of Al_2O_3 (Sapphire), which has probably the highest value is 6. In tables II and III M/M_A is calculated for different values of p and q.

The measured values are:

p =	0,036	0,063	0,091	0,127
M/M_A	1,13	1,18	1,21	1,24

These values match those of table II, notwithstanding the error introduced by neglecting the effect of the grain boundary to volume ratio on the Young's modulus. This lead to the following conclusions:

a) The Al_2O_3 phase in SAP has a mean value of the Young's modulus which is at least $4.5 \times 7\,000 = 31\,000$ kg/mm² at room temperature (Sapphire has 40 000 kg/mm²).

b) The oxide in extruded material must have the shape of flat particles which are mainly oriented parallel to the extrusion direction.

c) Because of this configuration and the great difference between the Young's moduli of Al and the oxide there must be presented important local tensile and shear stresses in SAP even when loaded within the elastic limits. These stresses increase with increasing dimensions of the oxide particles.

Seeman believes that the damping peak at high temperature is related to vacancy diffusion between grain boundaries. The temperature difference of this peak with the peak in aluminium could be caused by differences in grain size and thus diffusion lengths.

The expansion coefficient of the oxide phase in SAP is different from that of aluminium and therefore at low temperature stresses must be present around the oxide particles. The Bordoni peak in SAP thus is broader than in aluminium.

During determination of the static Young's modulus, local tensile and shear stresses are excited. These can be considerably higher than the bulk stresses. The combined effects of the expansion-caused stresses and the concentrated stresses around the oxide particles due to elastic deformation are thought to cause important local plastic deformation. Under extreme conditions little cracks may occur. These lower the Young's modulus and could explain its decrease after a slight plastic deformation. During dynamic experiments this cannot occur as bulk strains are at least 10^3 times lower than those of static experiments.

This mechanism becomes more important as temperature increases since M/M_A is higher. The elongation to rupture will then decrease till the temperature at which annealing becomes important, i.e. vacancy diffusion is greatly enhanced.

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Estratto dalla Rivista « Alluminio . Nuova Metallurgia » n. 11 - 1964 - pp. 571-573

To disseminate knowledge is to disseminate prosperity — I mean general prosperity and not individual riches — and with prosperity disappears the greater part of the evil which is our heritage from darker times.

Alfred Nobel