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Room temperature torsional fatigue properties of an iridium - 5% tungsten alloy

- by -

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The work reported has been carried out at the request, and under the support, of the Platinum Metals Division of the International Nickel Co. (Mond) Ltd. The results are confidential to the College and the Company.

Introduction

Fine wires of an iridium-5% tungsten alloy have been developed as a potential material for use in springs operating at high temperatures. Their suitability for such applications will to a considerable extent depend on satisfactory fatigue properties. The Materials Department of The College of Aeronautics was approached with a view to determining these torsional fatigue properties. This report covers preliminary work into this problem, namely the torsional fatigue behaviour of 0.020 ins. diameter wires at room temperature.

Procedure

Initially torsional fatigue loads were applied to the 0.020 ins. cold drawn wires to give maximum fibre stresses comparable to those being used in a concurrent programme into the tensile fatigue properties (see CofA Memo Mat. 61). However, it was found that even using nominal fibre stresses, which in tension would produce failure in about 10^4 cycles, no torsional fatigue failures could be produced. The testing was discontinued at 10^7 cycles. Observation of these wires after testing, and later of wires under test, revealed fine surface markings. In addition it was discovered that after periods of fatigue the wires had less torsional rigidity. This decrease in modulus meant therefore that although the fatigue tests had been carried out at a constant amplitude they had been carried out under a reducing torsional stress.

Some crude experiments were then conducted at a nominally constant torque. The reducing modulus in this case resulted in an increasing fatigue amplitude and soon led to failure. The development of this failure was studied by means of a cine film of such a test. As the amplitude increased the surface striations appeared, at the same time the surface showing many glistening facets. The wire then appeared to disintegrate into a bundle of fibres. The fibres then 'ballooned' out at the centre, the outer ones fracturing and falling away until ultimate fracture occurred.

This mode of failure, and some preliminary torque-twist curves produced after given amounts of fatigue, were discussed at a meeting held at the Platinum Metals Division, Acton, in early December. It was then decided to carry out the series of experiments reported here. Since with the equipment that was immediately available, it was easiest to carry out fatigue tests at a constant fatigue amplitude and frequency, these conditions were maintained throughout. Torque-twist curves were determined after given fatigue times, the severity of the fatigue being varied by altering the gauge length under test. This gauge length was initially $^1/_{32}$ ins. and was progressively increased until the fatigue no longer produced a deleterious effect on the torsional properties.

The experimental arrangement is illustrated in Figure 1. The wires are gripped between a pair of pin-chucks. This method of gripping has been found completely satisfactory, no fretting or failure being encountered at the grips. The upper chuck is rigidly attached to a framework. The lower pin-chuck can be rotated by two means. During fatigue it is connected via a brass connector to a torque motor. For the determination of the torque-twist curves two arms have been attached to the chuck and its lower end pointed to fit into a pivot bearing. Fine wires are attached to both arms each at exactly 1 in. from the centre-line. These wires pass over pulleys and have small equal weights hung on them to maintain tension without exerting a couple on the specimen. A given weight is then added to one wire and the rotation of the specimen noted. The weight is then removed from the first wire and placed on the second. The rotation in the opposite direction is also recorded. The average of the two rotations is taken as the twist produced by the given load.

The specimen rotation is measured optically by the movement of a light beam on a scale 77.77 cms from the specimen, the reflecting mirror being attached to the lower pin chuck. This arrangement produces a movement across the scale of 2.71 cms for 1° rotation of the specimen.

The torque motor is fed at mains frequency and low voltage through a variable and a fixed transformer. The amplitude of rotation is controlled by the applied voltage.

In each experiment a torque-twist curve was determined before fatigue. At intervals during the fatigue, the fatigue was temporarily stopped and fresh determinations of the torque-twist curve made. The maximum duration of fatigue applied was 500 hours i.e. 9.0×10^7 cycles. The specimen lengths employed were $^1/_{32}$ ins, $^1/_4$ ins, $\frac{1}{2}$ ins, 1 ins giving, at the fixed overall fatigue amplitude of $\pm 5.05°$, strains of $\pm 2.82 \times 10^{-2}$, $\pm 3.52 \times 10^{-3}$, $\pm 1.76 \times 10^{-3}$ and $\pm 8.81 \times 10^{-4}$ respectively.

Results

The results are given in tabular form in Table 1. The calculations used in deriving the results are outlined in Appendix 1.

Fatigue amplitudes down to $\pm 17.6 \times 10^{-4}$ strain caused significant changes in the torque-twist behaviour. These changes were noticeably less after the fatigue amplitude $\pm 8.81 \times 10^{-4}$. Even at the maximum torque used (0.06 lbs) the change after 500 hours fatigue (9×10^7 cycles) was only 7.25%. The changes in modulus with fatigue are collected graphically on Fig. 2.

Discussion

A point immediately apparent in the results is the variation in modulus found before fatigue. This, it is felt, is only an apparent and not a real effect. It is believed to be due to the severe end effects experienced with such short gauge lengths as were used in this work. The true modulus will of course be approached as the gauge length is increased. However within each geometry it is possible to study the effects produced by fatigue.

If a 5% decrease in modulus is accepted as the maximum change tolerable for service, this decrease would be achieved in the following times:-

Fatigue Amplitude	Time to 5% reduction in modulus
$\pm 2.82 \times 10^{-2}$	55 mins approx. = 1.65×10^{5} cycles
$\pm 35.25 \times 10^{-4}$	less than 1 hr. = $> 1.8 \times 10^{5}$ cycles
$\pm 17.6 \times 10^{-4}$	about 30 mins. = 9×10^{4} cycles
$\pm 8.8 \times 10^{-4}$	about 160 hrs. = 2.9×10^{7} cycles.

There appears therefore, to be a possibility of using these materials for protracted periods providing the fatigue amplitude is less than about $\pm 8 \times 10^{-4}$. In the results shown here, however, the properties show a marked deterioration in the early fatigue life and then appear to stabilise. Thus it may be worthwhile to take as the modulus, the figure obtained after 1 hour fatigue, i.e., after 1.8×10^{5} cycles. In this case a further 5% loss in properties occurs after:-

Fatigue Amplitude	Time to 5% reduction in modulus
$\pm 2.82 \times 10^{-2}$	1 hour = 1.8×10^{5} cycles
$\pm 35.25 \times 10^{-4}$	8 hours = 1.44×10^{6} cycles
$\pm 17.6 \times 10^{-4}$	10 hours = 1.8×10^{6} cycles
$\pm 8.81 \times 10^{-4}$	600 hours = 1.08×10^{8} cycles

On this basis, therefore, at a fatigue amplitude of $\pm 8.81 \times 10^{-4}$ or less, the wire should be within 5% of specification up to lives of 10^{8} cycles. It would appear that lesser fatigue amplitudes would yield longer lives within specification.

It has also been noted in the course of this work that wires which have been subjected to push-pull tensile fatigue loading also have somewhat reduced torsional properties.

It is concluded therefore that these wires do have acceptable fatigue properties provided the strain amplitude is kept small. The possibility of a reduction in properties due to chance overloading cannot however be completely discounted.

Table 1

The torque-torsional strain properties of 0.020 ins. diameter wires of iridium-5% tungsten alloys after torsional fatigue loading.

a. $^{1}/_{32}$ ins. gauge length giving torsional strain amplitude of ± 2.82×10^{-2}

Torque	Torsional Strain x 10^4			
lbs.ins.	Before Fatigue	After 1 hr. Fatigue	After 4 hrs. Fatigue	After 21 hrs. Fatigue
0.02	3.08	3.08	3.60	8.23
0.04	6.68	7.71	7.72	19.0
0.06	10.28	11.32	12.33	31.9
0.08	14.4	15.41	17.50	44.2
0.10	18.5	19.52	21.6	-
0.12	22.6	24.2	28.8	-
Approx. Modulus 10^6 p.s.i.	34.5	32.75	29.4	11.5

b. $^{1}/_{4}$ ins. gauge length giving torsional strain amplitude of ± 35.25×10^{-4}

Torque	Torsional Strain x 10^5						
lbs.ins.	Before Fatigue	After 1 hr.	After 4 hrs.	After 6 hrs.	After 23 hrs.	After 30 hrs.	After 50 hrs.
0.02	4.5	4.5	4.5	4.5	4.82	5.14	5.78
0.04	7.25	9.3	9.3	9.3	11.6	12.2	12.5
0.06	11.1	12.8	13.5	14.1	16.7	18.0	20.2
0.08	16.4	17.7	18.0	18.0	22.5	23.7	25.7
0.10	19.9	22.8	23.1	23.1	28.9	30.8	33.4
Modulus 10^6 p.s.i.	32.0	27.9	27.5	27.5	22.0	20.6	19.0

c. $\frac{1}{2}$ in. gauge lengthgiving torsional strain amplitude of ± 17.6×10^{-4}

Torque	Torsional Strain x 10^5			
lbs.	Before Fatigue	After 1 hr.	After 19 hrs.	After 79 hrs.
0.02	5.46	5.78	6.12	6.42
0.04	10.3	11.9	12.52	12.85
0.06	14.8	18.3	18.7	21.2
0.08	20.5	22.8	25.0	29.2
0.10	27.0	28.9	31.5	37.2
Modulus 10^6 p.s.i.	23.6	22.05	20.2	17.1

d. 1 in. gauge length giving torsional strain amplitude of ± 8.81 x 10^4

Torque	Torsional Strain x 10^5						
lbs.ins.	Before Fatigue	After 1 hr.	After 43 hrs.	After 67 hrs.	After 91 hrs.	After 193 hrs.	After 500 hrs.
0.02	4.67	4.67	4.67	4.67	4.67	4.67	4.67
0.04	9.34	9.34	9.34	9.49	9.49	9.65	9.65
0.05	11.82	12.15	12.15	12.15	12.15	12.60	12.75
0.06	14.65	14.92	14.92	14.92	15.25	16.80	16.95
Modulus 10^6 p.s.i.	26.9	26.2	26.2	26.2	26.2	25.3	24.95

Appendix 1

Calculations involved in this work

a) Relationship between light-beam movement on the scale and specimen rotation.

Specimen - scale distance = 77.77 cms.

Since light beam angular movement = 2 x angular movement of the specimen

a 180° rotation of the specimen would give a 360° rotation of the light beam i.e. a deflection of 2π 77.77 cms.

$\therefore$ 1° rotation of specimen produces a scale movement of $\frac{2\pi\ 77.77\text{ cms}}{180}$

$= 2.71$ cms.

This calculation assumes that the scale has a radius of curvature of 77.77 cms whereas in fact it was flat. Since however the maximum deflection from the zero point was 7 cms these calculations may, to a first approximation be taken as correct.

b) Calculation of torsional strain in specimen.

Length of wire under torsion = ℓ ins.
Angle of twist = $x°$

$\therefore$ for a 0.020 ins. diameter wire, a point on the surface at the end subject to the rotation will have moved

$$= \text{circumference} \times \frac{x}{360}$$

$$= \frac{x\ \pi\ 2 \times 10^{-2}}{360°}\ \text{ins.}$$

But total length over which this twist is applied = ℓ ins.

$$\therefore\ \text{Strain/unit length} = \frac{x\ \pi\ 2 \times 10^{-2}}{\ell\ 360}$$

$$= \underline{\underline{x/\ell\ \ 1.747 \times 10^{-4}}}$$

For a more detailed treatment see Strength of Materials by A. Morley 11th Edition, Chapter X, pp. 321-2.

c) Calculation of Modulus

For a wire $G = \frac{rT}{\gamma J}$

where G is the modulus of rigidity, T is the applied torque, γ is the torsional strain and J the polar moment of inertia.

$$J = \frac{\pi R^4}{2}$$

where R = radius of wire

$\therefore$ for 0.020 ins. diameter wires

$$J = \frac{\pi\ 10^{-8}}{2}\ \text{ins}^4$$

For the calculations of rigidity quoted in the results section the torsional strains produced under 0.10 lbs-ins. torque have been used (except for the 1 ins. gauge length where 0.05 lbs-ins. torque figures were employed).

e.g. For $^1/_{32}$ ins. gauge length, a torque of 0.10 lbs-ins. produced a strain of 18.5×10^{-4}

$$\therefore\ G = \frac{0.01 \times 0.1 \times 2}{18.5 \times 10^{-4}\ \pi \times 10^{-8}}$$

$$= \frac{2}{1.85 \times \pi} \times 10^{8}$$

$$= \underline{34.5 \times 10^{6}\ \text{p.s.i.}}$$

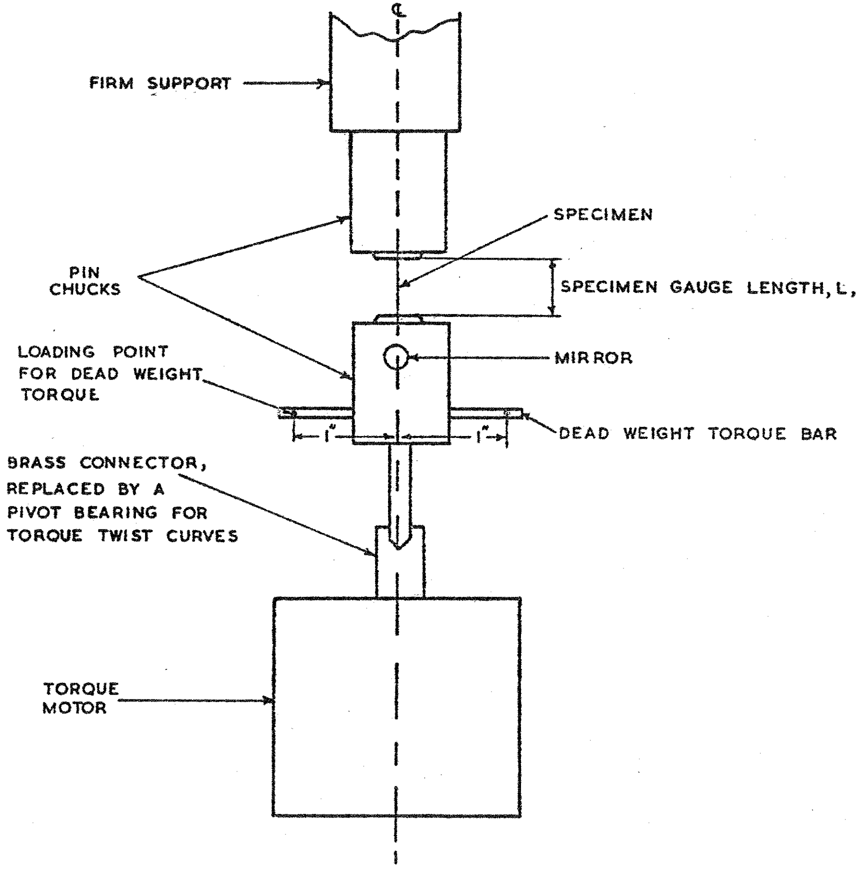

FIG.1. ARRANGEMENT FOR TORSIONAL FATIGUE

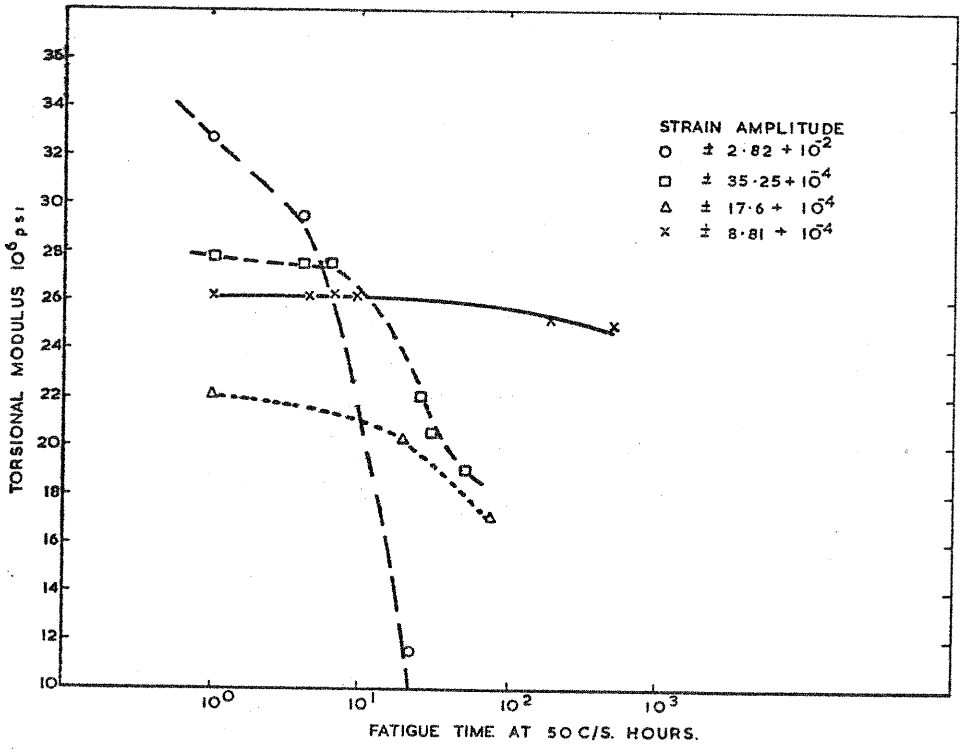

FIG.2. DECREASE IN TORSIONAL MODULUS WITH FATIGUE AT DIFFERENT FATIGUE AMPLITUDES.