THE SPRING RESEARCH AND MANUFACTURERS' ASSOCIATION

# LOW TEMPERATURE PROPERTIES OF SPRINGMAKING MATERIALS (PART I)

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## SUMMARY

Data down to -80°C for the modulus of elasticity has been obtained for BS 5216, BS 2803 and Inconel X750. By March 1985, data will also be established for BS 2056 302S26, BS 2056 301S81, BS 2056 316S42 and Inconel 600 down to -80°C for both the modulus of elasticity and modulus of rigidity. The experimental technique has now been established, by an undergraduate under the supervision of Professor Greenwood at Sheffield University.

The results for BS 5216, BS 2803 and Inconel X750 indicate that a small increase in modulus of elasticity has occurred down to -80°C. Extrapolation of high temperature moduli data would be valid for these three materials.



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# LOW TEMPERATURE PROPERTIES OF SPRINGMAKING MATERIALS (PART 1)

## 1. INTRODUCTION

Data exists for the static properties of springmaking materials at ambient and elevated temperatures. However, there is no data for the moduli of elasticity and rigidity below room temperature.

The objective of this project is to experimentally determine the low temperature moduli and Poisson's ratio for springmaking materials at temperatures down to -80°C.

In the absence of suitable equipment at SRAMA for determining sub zero properties, the co-operation the Department of Metallurgy at Sheffield University, was sought and the work undertaken as a final year undergraduate project.

## 2. MATERIALS INVESTIGATED

The commonly used springmaking materials as shown in Table I were used. The wires were subjected to the stress relieving heat treatment given to springs after coiling, to render them in a similar metallurgical condition. The heat treatment procedures are also listed in Table I.

The wires tested and reported here are to BS 2803, BS 5216 and Inconel X750. Materials to be tested are BS 2056 302S26, BS 2056 316S42, BS 2506 301S81 and Inconel 600.

## 3. EXPERIMENTAL METHOD

Two test methods were used; one to determine the modulus of elasticity (E) by Searle's Bifilar method, the other to determine the modulus of rigidity (G) by a dynamic method.[1]

The apparatus to determine the modulus of elasticity is shown in Figure 1. The two blocks are similtaneously pushed towards each other at one end, and allowed to swing. The time period for the oscillation is measured by eye counting swings, and by a stroboscopic technique.

Sub-zero temperatures were achieved by placing the apparatus in an insulated container, containing metal trays below and above the test wire, and pouring liquid nitrogen into the trays. Thermocouples were placed adjacent each block to record temperature.

It was found that E varied with wire length, thus a correction factor was introduced (see appendix II).

The apparatus used to determine the value of the modulus of rigidity is shown in Figure 2. One block is rotated perpendicularly to the wire axis so that the wire twists and oscillates in simple torsion.

4. RESULTS

The determination of modulus of elasticity (E) was made from measurements of wire length, l, and period of oscillation, T, using equations in appendix I.

The modulus of elasicity was determined at room temperature for four materials as shown in table II. Reasonable agreement with accepted room temperature values for E of the materials tested was found.

E was determined for temperatures down to $-80^{\circ}C$.

The wires tested showed an increase in modulus of elasticity with decreasing temperature. Insufficient results were produced to enable modulus/temperature relationships to be evaluated.

The results for BS 5216, BS 2803 and Inconel X750 were as shown in tables III, IV and V,.

The modulus of rigidity (G) was determined from measurement of wire length, l, and period of oscillation, T, from the equations in appendix I.

Room temperature results for BS 5216 and BS 2803 are shown in table IV.

## 5. CONCLUSION

The wires tested all showed the expected increase in modulus of elasticity with decreasing temperature. Definite relationships cannot be derived due to the lack of data through the whole range of temperatures (caused mainly by practical difficulties), for each material tested.

The change in modulus of elasticity between ambient temperature and minus 80°C was of the order of a 4% increase for BS 5216, 2% for BS 2803 and 1% for Inconel X750.

Testing techniques have been established this year (1983/84) and data for all the materials will be established in the next academic year (1984/85) by an undergraduate student at Sheffield University.

## 6. DISCUSSION

Much of the testing time was spent correcting measuring techniques, and obtaining results which were comparable with room temperature values of the modulus of elasticity. The technique has now been established for low temperature evaluations of the modulus of elasticity.

Practical difficulties were encountered. The ensuring of oscillation in a bifilar mode only (ie the bending oscillation occuring in one horizontal plane only with no lateral swinging of the whole apparatus) was difficult, particularly for BS 5216 accounting for poor correlation of measured values of E with accepted values. Temperature measurement of the wire was imprecise if thermal currents arose in the apparatus, causing the two large blocks to be at measurably different temperatures. Counting techniques were subjected to error with thicker wire, since oscillations were rapid. These errors mean that accurate results may not be obtainable, particularly for wires that are not straight. However, by using smaller diameter wires the errors may be minimised and any sudden changes of modulus at low temperatures would be detected.

The observed increases in modulus of elasticity were not large. The modulus of rigidity (G) would be expected to change in a similar manner as temperature decreases to $-80^{\circ}C$. Thus, there is no reason to doubt that extrapolation of high temperature data is valid for BS 2803, BS 5216 and Inconel X750 materials to $-80^{\circ}C$.

Below $-80^{\circ}C$, there was some suggestion that there was a sudden increase in value of modulus of elasticity of about 6% for Inconel X750.

## 7. RECOMMENDATIONS

1. Smaller wires be expedited in the size range 1.0-1.5 mm diameter. (This should make counting and periodic time evaluations easier and more accurate whilst using the same apparatus).

2. Obtain wires as straight as possible.

## 8. REFERENCE


1. P42-43, Laboratory Manual of Physics, F Tyler, Edward Arnold Publishing Ltd, 1960.

2. Springs: Materials, Design and Manufacture: Spring Research Association.

# APPENDIX I

## Modulus of Elasticity

Searle's Experiment for Bifilar Oscillations

$$T = 2\pi\sqrt{\frac{2Il}{\pi a^4 E}}$$

T = Time period (s)

I = Moment of Inertia of rectangular blocks (kg $m^2$)

a = Wire radius (m)

l = Wire length (m)

E = Modulus of Elasticity ($N/m^2$)

$$I = \frac{M\ (b^2 + x^2)}{12}$$

M = Mass of rectangular block = 1.690 kg

b = 0.038 m

x = 0.150 m

$I = 3.372 \times 10^{-3}$ $kgm^2$

## Modulus of Rigidity

Torsional Pendulum Method

$$T = 2\pi\sqrt{\frac{2Il}{\pi a^4 G}}$$

G = Modulus of rigidity ($N/m^2$)

I, l, a and T as defined above

# APPENDIX II

## Correction Factor for Length (l)

Since $$T = 2\pi\sqrt{\frac{2Il}{\pi a^4 E}}$$

then a graph of l versus $T^2$ should produce a straight line through the origin of gradient m

$$m = \frac{Ea^4}{8\pi I}$$

However, a graph of l versus $T^2$ for the test apparatus gave a straight line with a value of $l_o = 0.024$ m at $T^2 = 0s^2$.

Thus

$$l = l_o + mT^2$$

$$(l - l_o) = mT^2$$

As a consequence length of wire measurements were corrected to (l - 0.024) m in order to evaluate the modulus of elasticity (E).

$$E = \frac{8\pi I}{a^4 T^2}(l - l_o)$$

TABLE I MATERIALS TESTED AND HEAT TREATMENT CONDITION

| Material | Heat Treatment Condition | Wire Diameter (mm) | UTS ($N/mm^2$) |
|---|---|---|---|
| BS 2803 | 400°C, ½ hour. Oil hardened and tempered wire. | 2.03 | 1640-1650 |
| BS 5216 | 375°C, ½ hour. Patented hard drawn carbon steel wire. | 2.02 | 1350-1360 |
| BS 2056 302S26 | 450°C, 2 hours. Hard drawn stainless steel wire. (En58a) | 2.07 | 1600-1600 |
| BS 2056 316S42 | 450°C, 2 hours. Hard drawn Mo containing stainless wire. | 1.90 | 1780-1880 |
| BS 2056 | 480°C, 1 hour. Hard drawn and aged. 17/7 precipitation hardening stainless wire. | 2.04 | 2000-2020 |
| Inconel 600 | 480°C, 1 hour. Hard drawn and aged Ni/Cr/Fe precipitation hardening wire. | 1.62 | 1360-1360 |
| Inconel X750 | 650°C, 4 hours. Hard drawn and aged Ni/Cr/Fe precipitation hardening wire. | 1.37 | 1920-1930 |

TABLE II COMPARISON OF EXPERIMENTAL AND ACCEPTED VALUES OF MODULUS OF ELASTICITY

| MATERIAL | MODULUS OF ELASTICITY AT ROOM TEMPERATURE ($N/m^2 \times 10^{11}$) | |
|---|---|---|
| | Accepted Value[2] | Experimental* |
| BS 2803 | 2.068 | 2.05 |
| BS 5216 | 2.068 | 1.93 |
| BS 2056 | 1.827-1.931 | 1.89 |
| Inconel X750 | 2.137 | 2.14 |

* Average of 3 results

TABLE III VARIATION OF MODULUS OF ELASTICITY WITH TEMPERATURE FOR BS 5216

| Temperature ($^{o}C$) | Time Period of Oscillation (s) | Modulus of Elasticity ($N/m^2 \times 10^{11}$) |
|---|---|---|
| +23 | 0.3720 | 1.95 |
| -86 | 0.3659 | 2.02 |
| -90 | 0.3633 | 2.05 |
| -99 | C.3660 | 2.02 |
| -100 | 0.3642 | 2.04 |

Wire Lenght, L = 0.388 m

TABLE IV VARIATION OF MODULUS OF ELASTICITY WITH TEMPERATURE FOR BS 2803

| Temperature ($^{o}C$) | Time Period of Oscillation (s) | Modulus of Elasticity ($N/m^2$ c $10^{11}$) |
|---|---|---|
| +22 | 0.3589 | 2.05 |
| -51 | 0.3544 | 2.10 |
| -54 | 0.3550 | 2.10 |
| -55 | 0.3543 | 2.11 |
| -57 | 0.3530 | 2.12 |
| -57.5 | 0.3529 | 2.12 |
| -57.5 | 0.3550 | 2.10 |
| -60 | 0.3536 | 2.11 |
| -66 | 0.3550 | 2.10 |

Wire length, L = 0.331 m
Wire radius, a = 0.015 m x $10^{-3}$ m

TABLE V VARIATION OF MODULUS OF ELASTICITY WITH TEMPERATURE FOR INCONEL X750

| Temperature ($^{o}C$) | Time Period of Oscillation (s) | Modulus of Elasticity ($N/m^2 \times 10^{11}$) |
|---|---|---|
| +22 | - | 2.14 |
| -30 | 0.752 | 2.14 |
| -34 | 0.756 | 2.12 |
| -36 | 0.752 | 2.14 |
| -75 | 0.750 | 2.15 |
| -76 | 0.746 | 2.17 |
| -100 | 0.780 | 2.14 |
| -108 | 0.730 | 2.27 |
| -112 | 0.730 | 2.27 |

Wire length, L = 0.314 m

TABLE VI COMPARISON OF EXPERIMENTAL AND ACCEPTED VALUES OF MODULUS OF RIGIDITY

| MATERIAL | MODULUS OF RIGIDITY AT ROOM TEMPERATURE ($N/m^2 \times 10^{10}$) | |
|---|---|---|
| | Accepted Value[2] | Experimental* |
| BS 5216 | 7.929 | 7.96 |
| BS 2803 | 7.929 | 7.92 |

Temperature = +23°C

* Average of 9 results

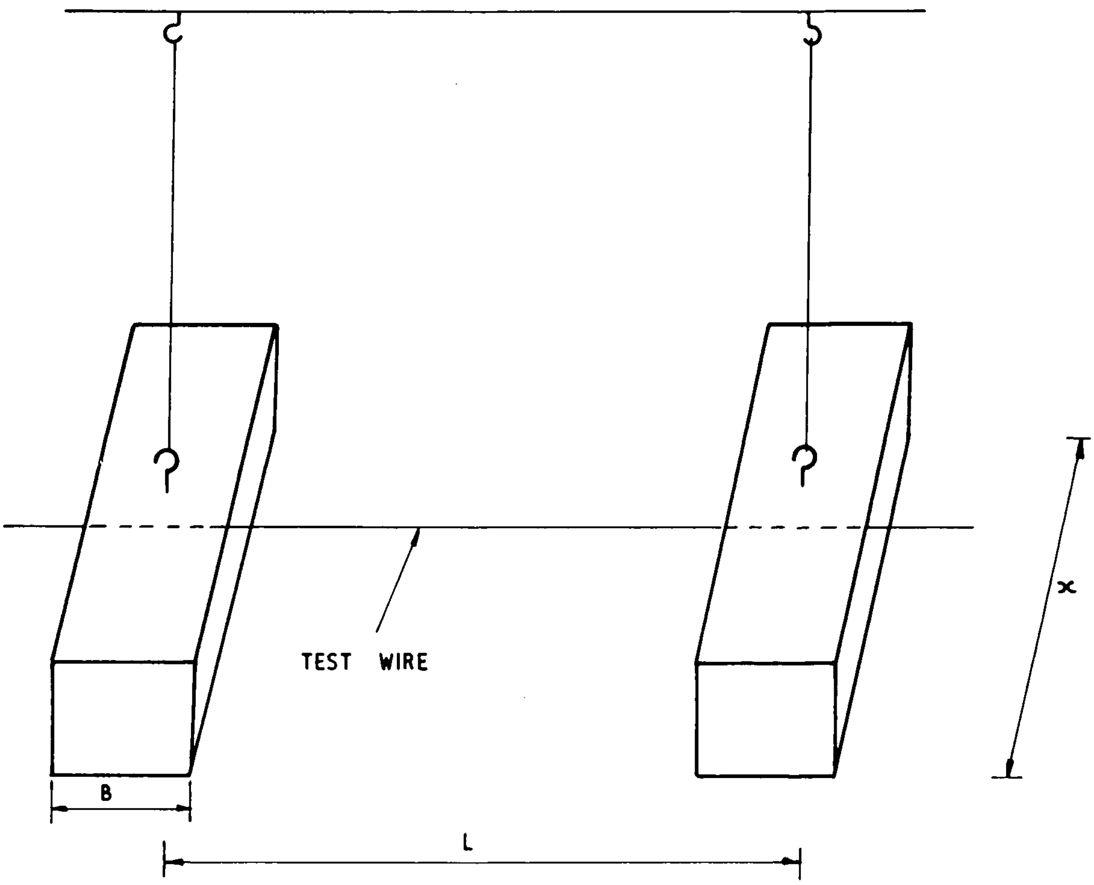


FIG. 1 SEARLE'S APPARATUS FOR THE MODULUS OF ELASTICITY.

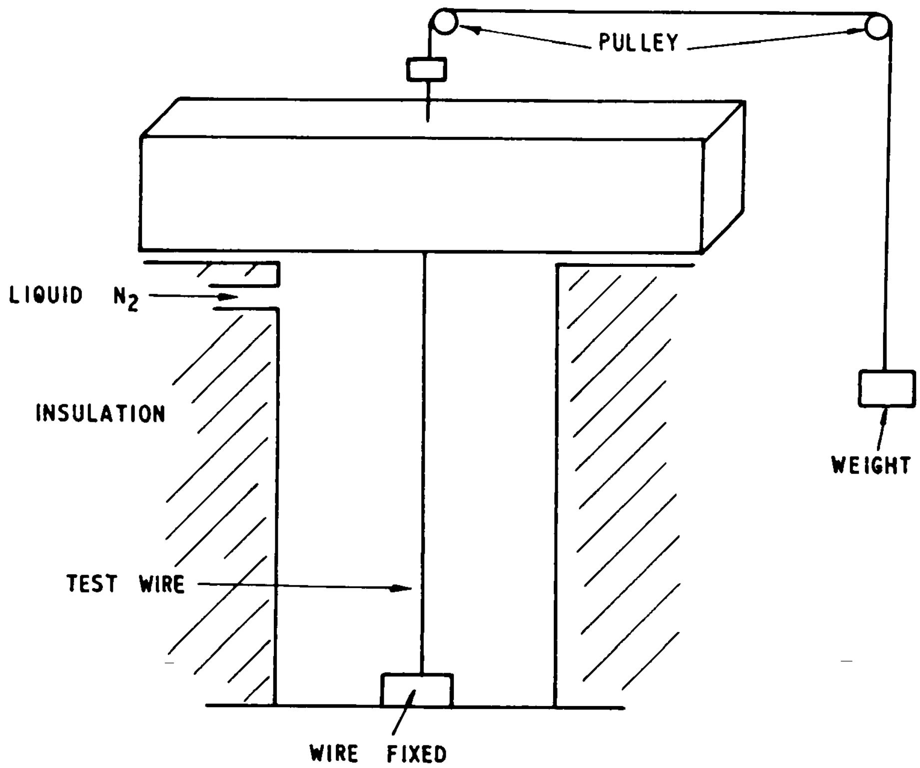


FIG. 2. PROBABLE APPARATUS FOR MODULUS OF RIGIDITY.