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MEASUREMENT OF POISSON'S RATIO OF BERYLLIUM WITH ELECTRIC STRAIN GAGES

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TECHNICAL DIVISION
Engineering Development Section

MEASUREMENT OF POISSON'S RATIO OF BERYLLIUM WITH ELECTRIC STRAIN GAGES

H. C. Savage

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1.0 ABSTRACT

The results of a limited investigation of Poisson's Ratio, Modulus of Elasticity and the Modulus of Rigidity (Shear Modulus) of beryllium are presented in this report.

Electric strain gages were used to measure unit lateral and axial strain in specimens of extruded and QM beryllium in tension and compression. For the limited number of pieces tested the following results and conclusions are reported.

1) Poisson's ratio was measured as 0.020 - 0.060 at stresses under 5,000 psi. Up to 12,000 psi. (maximum stress used) Poisson's ratio increased to 0.10 - 0.13.

2) The modulus of elasticity was found to be between 36×10^6 psi. and 45×10^6 psi. in tension and compression for extruded beryllium (both transverse and longitudinal) with stresses up to approximately 7,000 psi. A few exceptions were noted above 7,000 psi. where the value of E decreased to about $30 - 35 \times 10^6$ psi.

3) The modulus of rigidity (shear modulus) as determined from Poisson's ratio and the modulus of elasticity is between 17×10^6 psi. and 22×10^6 psi. with few exceptions noted for extruded beryllium.

4) For one sample of QM metal tested, a value of Poisson's ratio of 0.020 to 0.050 in both tension and compression was obtained. On the initial tensile test a value for E of 41 to 50×10^6 psi. was obtained. A compressive test on the same piece gave a value of 17 to 25×10^6 psi. for E. Two subsequent tensile tests gave values for E of $26 - 35 \times 10^6$ psi. A number of tests on additional samples would be required to establish a better working value for the QM metal and to evaluate the effect of cold working, repeated loads, etc., on the physical properties.

1.0 ABSTRACT (Con't.)

5) Electric strain gages (type SR-4) provide a rapid, but accurate method for strain measurements in both a longitudinal and transverse direction. When used in conjunction with a universal test machine or other accurate loading machine, very accurate measurements of physical properties of various materials can be made. (see Conclusions).

2.0 INTRODUCTION

Evaluation of the physical properties of beryllium for use in mechanical and thermal stress calculations has become increasingly important due to its extensive use in reactor design.

Probably due to the uncertainty in the quality of beryllium produced in the past, reported values for Poisson's ratio have varied from 0.2 down to approximately 0.01. Thus the primary purpose of this investigation was to establish a working value for the beryllium currently produced.

In addition to the above consideration values of the modulus of elasticity and modulus of rigidity were easily determined from the data obtained. It can also be noted that the method used for strain measurements is very simple and accurate and should be considered by anyone desiring to make additional measurements of this type.

3.0 PROCEDURE

The experimental procedure used was to measure directly the unit axial and unit lateral strain of beryllium metal when stressed. Poisson's ratio, ν , is then easily determined since, by definition, ν = unit lateral strain/unit axial strain.

Baldwin-Southwark SR-4 electric strain gages, types A-1 and A-7, in conjunction with a type K strain recorder were used to measure strain. With this equipment it was possible to measure strains of 1×10^{-6} in./in. with an error of $\pm 1 \times 10^{-6}$ in./in. These gages were applied to a test piece according to manufacturer's recommendations so that simultaneous measurements of lateral and axial strain could be made when a load, either tension or compression, was applied.

A Baldwin-Southwark tensile machine was used to apply tensile or compression loads to all test pieces. Poisson's ratio was measured on extruded beryllium, both transverse and longitudinal, and QM beryllium.

4.0 RESULTS

All results reported were obtained using the measured values of stress and strain in the formulas listed below.

ν = Poisson's Ratio = $\frac{\text{unit lateral strain, in/in.}}{\text{unit axial strain, in/in.}}$

E = Modulus of Elasticity = $\frac{\text{Stress, psi.}}{\text{Axial strain, in./in.}}$

F = Modulus of Rigidity (Shear Modulus) = $\frac{E}{2(1+\nu)}$

As a check of the test method, a preliminary test was conducted on a piece of cold rolled steel. Poisson's ratio and the modulus of elasticity were found to be 0.26 and 30 x 10^6 psi. respectively which are in agreement with literature values.

Test results on all pieces tested are given in Tables I through V. It is noted that a variation in Poisson's ratio exists. Some of the discrepancies can be accounted for in the low values of unit lateral strain. Some of the values, especially at low loads, were in the same order of magnitude as the lower limit of the strain indicator. This could easily produce an error of 20 - 50% in the unit lateral strain reading. The axial strains were very much larger and the error in these values is about 2 - 5%, depending on the magnitude.

A. Poisson's Ratio - Extruded Beryllium

1. Tensile Properties in Direction of Extruding

One piece with a square cross section, 2 1/2" x 2 1/2", had a Poisson's ratio of 0.050 to 0.077 and a modulus of elasticity of

33 to 36 x 10^6 psi. at stresses under 5,000 psi. Above a 5,000 psi. stress Poisson's ratio increased to 0.10 and the modulus of elasticity decreased to 27 x 10^6 psi. (see Table I).

Two pieces, with a 1 inch O.D. round cross section, had a Poisson's ratio of 0.04 to 0.07 and a modulus of elasticity of 38 to 43 psi. for stresses up to 7600 psi. (see Table III). These two pieces were from an extrusion for which the fabrication procedure is known.

2. Compressive Properties in Direction of Extruding

The same 2 1/2 inch square piece tested in tension gave a Poisson's ratio of 0.03 - 0.06 and a modulus of elasticity of 38 - 40 x 10^6 psi. up to the maximum applied stress of 3800 psi. (see Table I).

A second piece with a square cross section 3" x 3" x 4" long, cut from the same extrusion as the 2 1/2" square sample indicated a Poisson's ratio of 0.02 to 0.04 up to stresses of 6,000 psi - the ratio increasing with increasing load. The corresponding values of E were 36 to 39 x 10^6 psi. When a stress of 12,000 psi. was applied, Poisson's ratio increased to 0.11 with a corresponding value for E of 31 x 10^6 psi. After removal of this stress, a load of 8,000 psi. was applied and values of 0.04 and 40 x 10^6 were obtained for ν and E respectively.

3. Compressive Properties Transverse to Direction of Extruding

The maximum length obtainable for samples cut transverse to direction of extruding was 3". This limited the tests to compression values with the test method used.

One piece 2" long x 1" O.D. gave values of 0.03 to 0.05 and 28 to 32 x 10^6 for ν and E up to a stress of 3800 psi. For stresses from 3800 to 6300 psi. ν increased to 0.13 and E increased to 40 x 10^6 psi. However, as was the case in all tests, ν decreased to the lower load value when a second load less than the maximum was applied (see Table IV).

B. Poisson's Ratio- QM Beryllium

Only one piece of QM beryllium was tested. The order of testing was tensile-compression - tensile. Since only one piece of material was tested, the values shown are of questionable statistical value.

1. Tensile Properties

Tests were conducted using stresses to 6300 psi. Values for ν were 0.04 to 0.06 with no trend noted. The modulus of elasticity was 41 to 50 x 10^6 psi. decreasing with increasing load.

A second tensile test, performed after the piece was subjected to a compressive load of 5100 psi., gave values for ν and E of 0.020 to 0.040 and 26 to 34 x 10^6 psi. respectively. Thus a rather large decrease in E in tension is observed after a compressive load is applied.

A third tensile test gave values for E of 31 to 36 x 10^6 up to a load of 7000 psi. Corresponding values of ν were 0.025 to 0.050.

2. Compressive Properties

One set of compressive tests were run using stresses up to 5100 psi. The following results were obtained:

ν = 0.02 to 0.05

E = 20 to 25 x 10^6 psi.

Here again Poisson's ratio increased with stress.

TABLE I*

Poisson's Ratio of Extruded Beryllium
(Properties in direction of extruding)

Tension				Compression			
Stress psi.	ν	E, psi	F, psi	Stress psi.	ν	E, psi.	F, psi.
1280	0.077	33.0 x 10^6	15.1 x 10^6	640	0.061	38.6 x 10^6	18.4 x 10^6
2560	0.077	32.6 x 10^6	15.2 x 10^6	1280	0.046	39.4 x 10^6	18.9 x 10^6
5150	0.10	27.0 x 10^6	12.3 x 10^6	2560	0.031	39.4 x 10^6	19.1 x 10^6
3200	0.050	35.6 x 10^6	17.0 x 10^6	3840	0.037	40.0 x 10^6	19.2 x 10^6

* Test piece = 2 1/2 in. x 2 1/2 in. x 8 in. long.

Compression and tension on same piece-compression first.

TABLE II*

Poisson's Ratio of Extruded Beryllium
(Properties in direction of extruding)

Compression			
Stress, psi.	ν	E, psi.	F, psi.
2,000	0.019	38.5×10^6	18.8×10^6
3,000	0.018	36.2×10^6	17.7×10^6
4,000	0.020	39.2×10^6	19.2×10^6
5,000	0.026	37.8×10^6	18.3×10^6
6,000	0.039	38.6×10^6	18.6×10^6
12,000	0.11	31.2×10^6	14.2×10^6
8,000	0.038	40.3×10^6	19.3×10^6

* Test piece = 3 in. x 3 in. x 4 in. long from same extrusion as test piece in Table I.

TABLE III*

Poisson's Ratio of Extruded Beryllium
(Properties in direction of extruding)

Tension							
Specimen #1				Specimen #2			
Stress psi.	ν	E, psi.	F, psi.	Stress psi.	ν	E, psi.	F, psi.
5100	0.041	42.5×10^6	20.4×10^6	2540	0.048	41.0×10^6	19.5×10^6
7600	0.060	38.0×10^6	18.2×10^6	5100	0.073	37.5×10^6	17.5×10^6
6350	0.046	42.5×10^6	20.4×10^6	3820	0.043	41.3×10^6	19.8×10^6
5100	0.050	42.5×10^6	20.2×10^6	6350	0.073	39.0×10^6	18.3×10^6
This sample subjected to compressive load (axial) of 5100 psi, and sample retested in tension with following results.				5100	0.056	40.7×10^6	19.4×10^6
3800	0.068	43×10^6	20×10^6				
5100	0.090	42×10^6	19×10^6				
5100	0.050	42×10^6	20×10^6				
6350	0.050	40×10^6	19×10^6				
6350	0.058	41×10^6	19×10^6				

* Test pieces = 1" O.D. x 15" long extruded by M.I.T. at Revere.
Temp. = 1870° F. Reduction = 6 to 1. Samples from trailing end.

TABLE IV*

Poisson's Ratio of Extruded Beryllium
(Properties transverse to direction of extruding)

Compression			
Stress, psi.	ν	E, psi.	F, psi.
2540	0.031	27.8×10^6	13.0×10^6
3800	0.050	31.8×10^6	15.0×10^6
5100	0.10	37.8×10^6	17.2×10^6
5100	0.046	39.2×10^6	18.8×10^6
6350	0.13	37.2×10^6	16.5×10^6
6350	0.051	40.8×10^6	19.5×10^6
3800	0.028	36.0×10^6	17.4×10^6

* Test piece = 1 in. O.D. x 2 in. long. Cut from same extrusion as samples in Table III.

TABLE V*

Poisson's Ratio of QM Beryllium

Tension				Compression			
Stress psi.	ν	E, psi.	F, psi.	Stress psi.	ν	E, psi.	F, psi.
2540	0.060	50×10^6	24×10^6	2540	0.032	16.5×10^6	8.0×10^6
3820	0.038	48×10^6	23×10^6	3820	0.032	20.6×10^6	10.0×10^6
5100	0.041	42×10^6	20×10^6	3820	0.036	23×10^6	11.0×10^6
6350	0.051	41×10^6	19×10^6	5100	0.049	22.5×10^6	10.7×10^6
Piece retested in tension after compressive tests at right with following results -				5100	0.030	25.4×10^6	12.3×10^6
				3820	0.019	24.6×10^6	12.1×10^6
2540	0.020	25.4×10^6	12×10^6				
3820	0.025	31.0×10^6	15.1×10^6				
5100	0.037	32×10^6	15.4×10^6				
6350	0.036	32×10^6	15.4×10^6				
6350	0.038	34×10^6	16.3×10^6				

* Test piece = 1 in. O.D. x 3 in. long.
Sintering pressure = 150 psi.

5.0 CONCLUSIONS

Test results indicate that Poisson's ratio for extruded and QM beryllium is of the order 0.02 to 0.06 when the applied stresses are less than approximately 6,000 psi. A reported value of 0.0122 was obtained by ultrasonic propagation measurements on a single crystal and other values of 0.0754 and 0.035 found from compressibility data (1).

One revealing result of this investigation is the fact that at stresses approaching 7,000 psi. and larger, Poisson's ratio for beryllium increases to 0.10 and over. The maximum value observed was 0.13 at 12,000 psi. - the largest stress applied.

It is quite obvious that a large number of additional tests are required to establish better "average" values for Poisson's ratio of beryllium. The history of the metal tested must be considered since this factor affects the physical properties.

The test method is quite accurate except at low lateral strains. A more sensitive strain indicator would be an improvement in this respect. In addition the method of applying tensile loads could be improved by using threaded-end specimens with ball and socket grips rather than plain-end specimens with the Vee jaws. This would result in equalizing the load distribution in the specimen. This factor undoubtedly accounted for some of the variations in results.

6.0 REFERENCES

(1) Gold, Louis - Evaluation of the Stiffness Coefficients for Beryllium from Ultrasonic Measurements in Polycrystalline and Single Crystal Specimens, AECD - 2644.

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