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Specimen Thread
Strength Tests

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WESTINGHOUSE ASTRONUCLEAR LABORATORY

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REPORT ON BERYLLIUM THREAD TEST

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SUMMARY

Strengths at failure are reported for a number of threaded beryllium specimens loaded in tension at room temperature and -320°F . Loads greater than normal bolt strengths were repeatedly carried. The standard fine thread was somewhat stronger than the standard coarse thread. Material at the entrance of the hole should be counter-bored about one diameter deep in order to resist cone-type fracture. Pure tensile loading should be used. Possible shear loading should be carried by separate pins to avoid bending moments, since this effect has not yet been evaluated. Two diameters of thread engagement is sufficient for strength; greater engagement has no advantage.

OBJECTIVES

A Westinghouse outer reflector uses tapped holes in beryllium, but only as part of a redundant system. The parts are backed up by another device which takes over in the event of beryllium fracture. To eliminate this design requirement, and to be able to use tapped holes in other parts of the reflector and thereby save weight, cost, and complexity, it is desired to establish confidence in them. This can be done by loading a number of tapped beryllium blocks to failure and demonstrating that the load carried is consistently greater than expected design loads.

TEST EQUIPMENT AND PROCEDURE

The specimens were loaded in tension in a tensile test machine. The set-up is shown in Figure 1 . The urethane foam container was filled with liquid nitrogen for the -320°F . tests.

In the initial tests the specimen was supported by a flat plate with a .290 in. diameter clearance hole for the quarter inch bolt (Figure 3). In later tests the specimen was supported around its edge (Figure 2) and from both ends by bolts (Figure 3). Deflection measurements were made with clip-gages mounted remotely from the specimen. The gage signal was recorded on a rotating drum as a function of load. These do not give precise values of deflection since the fixture effects are included, but they do serve to identify sharp changes in load and deflection and to distinguish between ductile and brittle failure.

In most cases, the specimen was merely loaded in tension at a slowly increasing rate until failure occurred. Testing time was about ten seconds. For the low temperature cases, the liquid nitrogen was added and specimen soaked until the liquid stopped boiling vigorously. This usually took about five minutes.

For the cycling tests, limit switches were installed in the tensile machine and the loading set at "fast." The load cycled from 2500 to 5000 lbs. and back again in 15 seconds.

TEST SPECIMENS

The specimens were machined from hot pressed beryllium. The holes were tapped in the axial direction of the raw material block. For all specimens except No. 3F and No. 4F, the raw material was the same as that used in the brittle fracture tests reported in Reference 2. The holes were tapped with normal shop methods. A class "2" tapped hole was used. Specimen dimensions were 1-1/2" O.D. and .740" thickness. The bolts used were commercial steel bolts of two kinds:

- 1) S.P.S. Co., Part No. EWB 22-4.52, 1/4-28 bolt, 3-3/4" long.
Room temperature yield strength = 220,000 psi.
- 2) S.P.S. Co., Part 1/4-20 tension bolt, 50 C. head; 3" long.
Room temperature yield strength = 190,000 psi.

Both bolts had threads formed by rolling and thread dimensions were probably class "3".

Specimen no. 2C was counterbored according to the following sketch.

The material for all the specimens except No. 3F and 4F is described by the following vendor's test results:

Chemical Analysis:

Beryllium Assay	98.8%
Beryllium Oxide	1.29%
Iron	.11%
Aluminum	.04%
Carbon	.02%
Magnesium	.04%
Silicon	.11%

Density: 1.86 gms/cc

Tensile Results (room temperature):

	<u>Ultimate</u>	<u>Yield</u>	<u>Elongation</u>
Longitudinal	45,400 psi	35,500 psi	1%
Transverse	55,800 psi	35,200 psi	4%

The material was not annealed, nor was any other thermal treatment or surface treatment used. Specific data on the material for specimens No. 3F and 4F was not obtained.

TEST RESULTS

The loading conditions and resulting failures are described in Table I and Figure 4. Trends in strength exist for the variables of temperature and length of engagement, and these are shown in Figures 5 and 7. Four types of specimen failure were obtained:

- 1) Specimen threads pulled out (3 cases) -- 6750, 6350, 7100 lbs.
- 2) Specimen broke in radial pieces (1 case) -- 7120 lbs.
- 3) Cone section pulled out of specimen (3 cases) -- 5225, 4075, 4250 lbs.
- 4) Specimen shattered after a bolt failure (1 case) -- 11,950 lbs.

It seems that type (3) is the general type of failure, at least for the coarse threads. Length of engagement has a strengthening effect in this mode, however; it seems to be a second order effect. This may be due to the well known fact (Reference 3) that thread loading is much greater near the entrance to a hole. The elasticity of the bolt and threads reduces the stress at threads which are more deeply engaged. Thus, it is possible to have a cone type failure in the first few shallow threads followed by a pull-out type of failure of the deeper threads (see cases 3C,4C). The shock of the first failure probably assists the latter effect.

The type (1) and type (4) failures occurred at higher loads than type (3), and this is due to restraint of the type (3) mode. In three cases the specimen was supported over its whole surface, completely precluding a type (3) failure, and in one case (2C), the specimen was counterbored to remove the load from the region of material stressed in type (3). A type (3) failure could still occur in this specimen but it would require breaking out a much larger cone of material and consequently a higher load. It should be noted that type (3) (cone-type) failures occurred for two different types of specimen support: (a) supported around the outer edge; and (b) unsupported, except for loads applied at each end of the threaded hole. In both cases the cone type failure occurred, and moreover, the cone angle, size of cone, and failure load were approximately the same (see photos Pg. 15 and Pg. 16, cases 3C). This tends to indicate that the edge type

support (for the dimensions used) is fairly realistic in simulating the case of a very large block of beryllium loaded in tension at a point. The included cone angle for all failures was approximately 120° . The height of the cone of material removed in each of the type (3) fractures was measured, and fracture load is plotted against this height in Figure 6. A fairly linear curve was obtained. It can be seen from this curve that if normal cone type fracture is precluded, for instance by removal of material from the upper stressed area by machining, a greater strength can be carried, since a much larger cone carries the tensile load. This is done for the point at the far right (Specimen 2C) and a 36 per cent higher load was carried before the bolt finally broke and the threads pulled out.

From the limited data, it appears that the effect of temperature is as follows:

- a) lower temperature strengthens the threads against tearing out (see case 1C, Figure 5).
- b) higher temperature strengthens the specimen against type (3) (cone type) failures (see Figure 5).

This is logical if we agree that thread tear out is governed by un-notched strength properties and that cone type failure is governed by brittle fracture crack propagation phenomena. References 1 and 2 show that the former property increases at lower temperature and the latter property (resistance to crack propagation) decreases at lower temperature.

The effect of a finer thread seems to be an increase in strength. Specimens 2F (fine) and 4C (coarse) were loaded in very similar manner and the fine thread specimen proved 36% stronger. One fine thread specimen (1F) carried 11,950 lbs. while supported over the full flat surface. This load corresponds to a bolt shank stress of 244,000 psi. In this case, the bolt broke first, and the resulting shock wave traveled down the bolt and fractured the specimen.

An attempt was made to evaluate the effect of cyclic loading. Specimen 2F was cycled between 2500 and 5000 lbs. for 520 cycles with full flat surface support at

-320°F. Thread engagement was .43 in. Time for each cycle was 15 seconds. The same specimen was then supported around its edge only and subjected to 500 more similar cycles. Specimen 4C was cycled between 500 and 3500 lbs. with edge support and .37 in. engagement. Temperature was -320°F. No apparent damage was done by any of the cyclic loading used. Specimen 2F broke in a somewhat unusual manner under high (7120 lbs.) static loading following the cycling test. It broke into a number of radial, pie-shaped pieces and was the only specimen to fail in this manner. However, it was also the only fine-thread specimen to be loaded under edge support, and it is difficult to separate this effect from the question of possible un-noticeable damage from previous cycling.

Figure 7 shows the expected strength of different size tapped holes in a large beryllium block. The values all correspond to a thread shear stress of about 30,000 psi. This is the tear out stress obtained for a number of specimens with 1/4 inch holes and one diameter of engagement. With two diameters engagement, the bolts broke before a 30,000 psi. shear stress could be reached; however, two ultra high strength steel bolts ($\sigma_{.2\% \text{ yield}} = 220,000 \text{ psi.}$) failed in tension at values just below this shear stress. When larger bolts are used, provided they are engaged two diameters, the tear out strength (in pounds) should be proportional to the second power of diameter since the circumference is increased as well as the length of engagement. Thus the same ratio of bolt strength to tapped hole strength should prevail for larger size bolts than 1/4 inch, both values being proportional to D^2 . General design practice limits bolt stresses to less than 80,000 psi., and so a safety factor of about three to one will usually be obtained for these tapped holes in beryllium $\left(\frac{220,000}{80,000} = 2.76\right)$. It should be repeated that Figure 7 gives the hole strength. The size of beryllium block required to insure against hoop type fracture is probably less than four bolt diameters in width and depth.

CONCLUSIONS

Very high loads can be carried by tapping into solid beryllium block, both at room temperature and cryogenic temperatures. By using proper design techniques, the ultimate strength of the bolt can be exceeded. A set of general ground rules can be listed:

- 1) A standard fine thread is preferred.
- 2) Material at the entrance of the hole should be removed by counterboring (see Figure, Page 6) to resist cone-type fracture. Counterbore depth should be about one diameter.
- 3) Pure tensile loading should be used. Possible shear loading should be carried by separate pins. Either spherical seats or else very precise tolerances should be used to eliminate misalignment and consequent bending moments.
- 4) If oscillating loads are expected, a preload should be used to insure against load reversals on the beryllium threads.
- 5) Two diameters of thread engagement should be used to guard against room temperature tearout.

Second order effects of the following variables should be evaluated by further testing if more precise strength values are desired:

- (a) different "heats" of material
- (b) loading directions other than the axial pressing direction of the material
- (c) different size holes
- (d) completely reversing, high frequency loading
- (e) combined bending and tension
- (f) thread galling or stress corrosion effects

Strength probabilities and confidence factors can be obtained by running more tests with most of the controllable variables held constant. In this way, the effect of the unavoidable variables such as exact tap and bolt dimensions, and material inhomogeneity can be expressed in statistical terms (see Reference 4).

Specimen No. 4C Showing Brittle Fracture Surface

Specimen No. 4C Showing Cone-Type Fracture

Specimen No. 4C Reassembled

Specimen No. 3C Showing Cone-Type Fracture After Being Loaded From Both Ends

(Note: The cone sections were inadvertently switched between this photo and the photo on page 16)

Specimen No. 3C (inverted) Showing Cone-Type Fracture During Edge Support

(Note: The cone sections were inadvertently switched between this photo and the photo on page 15.)

Specimen No. 2F showing Combined Hoop-Tension Type and
Cone-Type Fractures

Specimen No. 2F Reassembled

Specimen No. 1F Showing Aircraft Bolt Failure and Resulting
Specimen Fracture Due to Shock Wave

Specimen No. 1C (inverted) Showing Thread Tear Out

Specimen No. 2C (counterbored) Showing Thread Tear Out

TEST SET UP

FIGURE 1

SET UP HARDWARE SHOWING SPECIMEN LOADED AROUND EDGE

TYPES OF LOADING

FIGURE 3

TABLE I - TEST RESULTS

Specimen Number	Temp. °F.	Type of Support	Thread Engage.	Load at Failure	Type of Failure
1F	-320	flat	.43	11,950	bolt broke, and then specimen shattered.
1C	-320	flat	.43	7,850	bolt broke, specimen not damaged.
1C	68	flat	.25	6,350	bolt broke, signs of yielding at threads.
1C (inverted)	-320	flat	.25	6,750	specimen threads pulled out.
2F	-320	around edge	.43	7,120	specimen broke in several pieces.
4C	-320	around edge	.37	5,225	cone section and many chips pulled out, cone height = .310 in.
3C	-320	threaded from both ends	.37	4,075	cone section and two threads pulled out, cone height = .243 in.
3C (inverted)	68	around edge	.40	5,950	bolt failed plastically, specimen not further damaged.
3C (inverted)	-320	around edge	.32	4,250	cone section and one thread pulled out, cone height = .282 in.
2C (counter-bored)	-320	around edge	.493	5,975	bolt broke, specimen not damaged.

TABLE I - continued

Specimen Number	Temp. °F.	Type of Support	Thread Engage.	Load at Failure	Type of Failure
2C (counter-bored)	-320	around edge	.443	6,525	bolt broke, specimen not damaged.
2C (counter-bored)	-320	around edge	.393	6,500	bolt broke, specimen not damaged.
2C (counter-bored)	-320	around edge	.343	6,500	bolt broke at 1-1/2 threads engage, pulled out those threads.
2C (counter-bored)	-320	around edge	.293	7,370	bolt broke, no further apparent damage to specimen.
2C (counter-bored)	-320	around edge	.243	6,850	bolt broke near top thread, specimen not further damaged.
2C (counter-bored)	-320	around edge	.243	6,600	bolt broke after plastic extension.
2C (counter-bored)	-320	around edge	.243	7,100	about two threads back from tip bolt broke, remainder of threads pulled out.
3F (counter-bored)	68	around edge	.250	6,650	specimen threads pulled out.
4F (counter-bored)	68	around edge	.475	10,000	bolt broke, specimen not damaged.

FIGURE 4

FAILURE LOADS VS TEMPERATURE FOR BERYLLIUM BLOCKS
 TAPPED FOR 1/4 INCH BOLTS AND LOADED IN PURE TENSION
 (ALSO FROM RESULTS OF BERNETT AND KALLIN, REFS. NO.1 AND NO. 2)

FIGURE 5

FIGURE 6

FAILURE STRENGTH OF A TAPPED HOLE IN A LARGE BLOCK OF HOT PRESSED BERYLLIUM, COUNTERBORED ONE DIAMETER, AND WITH TWO DIAMETERS OF THREAD ENGAGEMENT

FIGURE 7

REFERENCES

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