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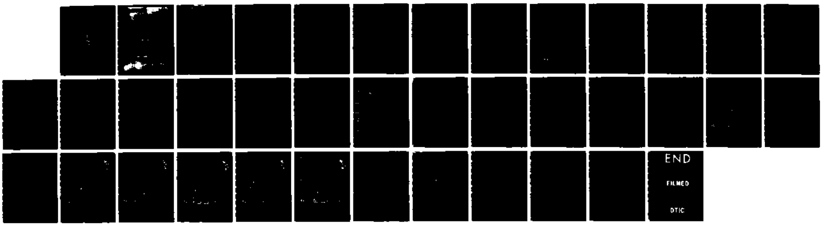

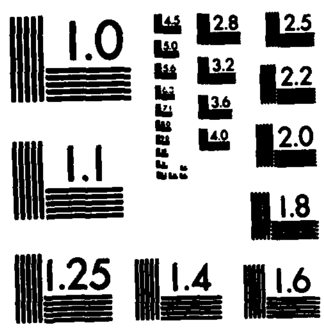

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[illegible]OPMENT OF A COMPRESSION TESTING METHOD FOR GRAPHITE/EPOXY COUPONS

Christopher [illegible]
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[illegible]epartment of Aeronautics and Astronautics
Massachusetts Institute of Technology
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The purpose of this investigation was to develop a method of testing the standard TELAC (Technology Laboratory for Advanced Composites) graphite/epoxy coupon directly in compression. Since thin coupons buckle under compressive loads, a "compression jig" was needed to support the coupon and prevent it from buckling. The most successful design for a compression jig was a set of 300 steel balls that are pressed onto both sides of the coupon. These ¼ inch diameter steel balls are free to rotate insuring that no shear load is applied to the coupon. These steel balls are housed in two steel plates, one for each side of the coupon. An Aluminum cage bolted onto each plate holds the balls onto the plate. Preliminary tests indicate that this compression jig could provide valid test results.

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ABSTRACT

The purpose of this investigation was to develop a method of testing the standard TELAC (Technology Laboratory for Advanced Composites) graphite/epoxy coupon directly in compression. Since thin coupons buckle under compressive loads, a "compression jig" was needed to support the coupon and prevent it from buckling. The most successful design for a compression jig was a set of 300 steel balls that are pressed onto both sides of the coupon. These 1/4 in. diameter steel balls are free to rotate insuring that no shear load is applied to the coupon. These steel balls are housed in two steel plates, one for each side of the coupon. An Aluminum cage bolted onto each plate holds the balls onto the plate. Preliminary tests indicate that this compression jig could provide valid test results.

FOREWORD

This report describes work done at the Technology Laboratory for Advanced Composites (TELAC) at the Massachusetts Institute of Technology for the Air Force Office of Scientific Research under contract AFOSR 82-0071. The work was conducted as part of the Undergraduate Research Opportunities Program at M.I.T. Professor Paul A. Lagace supervised the work.

Table of Contents

I. Introduction

In order for graphite/epoxy composite material to be widely accepted and used by the aerospace industry, its properties must be well understood and documented. In an effort to investigate graphite/epoxy's compressive behavior, it is desirable to use the standard tensile test coupon specimen. In order to test coupons in compression however, one needs to support the coupon to prevent instability failures. The purpose of this investigation was to develop and document such a testing method.

This project was undertaken during the summer of 1982 under the auspices of the Undergraduate Research Opportunities Program and was partially funded by the Air Force Materials Research Laboratory. I would like to acknowledge and thank Professor Paul Lagace, Al Supple, Earl Wassmouth and Steve Nolet for their very helpful ideas and assistance.

II. Project Background

The standard graphite/epoxy coupon used for tensile tests is shown in Figure 1ab. If this specimen were to be used for a compression test, the coupon would simply buckle as shown in Figure 1c. Therefore, to obtain compressive moduli and failure stresses, a beam specimen is generally used (Figure 2). This beam specimen, which consists of 2 coupons bonded onto opposite sides of an Aluminum honeycomb core, is tested in 4-point bending or uni-axial compression to produce compressive stresses. Due to the difficulties in manufacturing beam specimens and the assumptions made in interpreting test results, it would be desirable to test coupons directly in compression using a "compression jig". This compression jig would prevent the coupon from buckling without interfering with the compressive behavior of the material.

This task has been approached in the past in several ways. Methods for preventing buckling include using thick laminates and a short gage length [1] (numbers inside brackets refer to references listed in the bibliography), necked down specimens and a short gage length [2], using rods for a lateral support of the coupon [3], and metal plates clamped onto both faces of the coupon [4]. These methods achieved varying degrees of success, but they required either extremely accurate machining of the test specimen, or there was doubt as to the interpretation and validity of the test results. Since it was desired to use our standard coupon for compression tests, none of these methods were directly applicable.

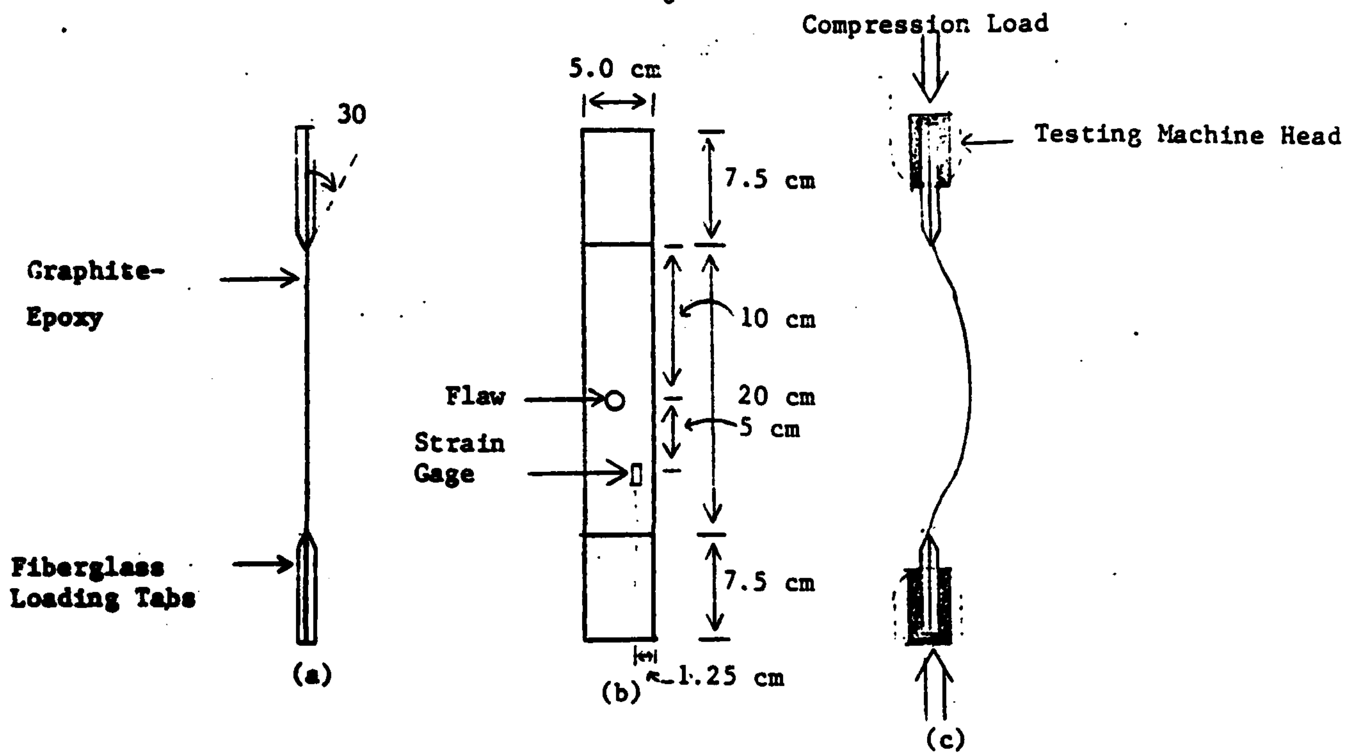


Figure 1. Standard TELAC (tensile test) coupon
(a) Side view (b) Front view (c) Buckled under compression loac

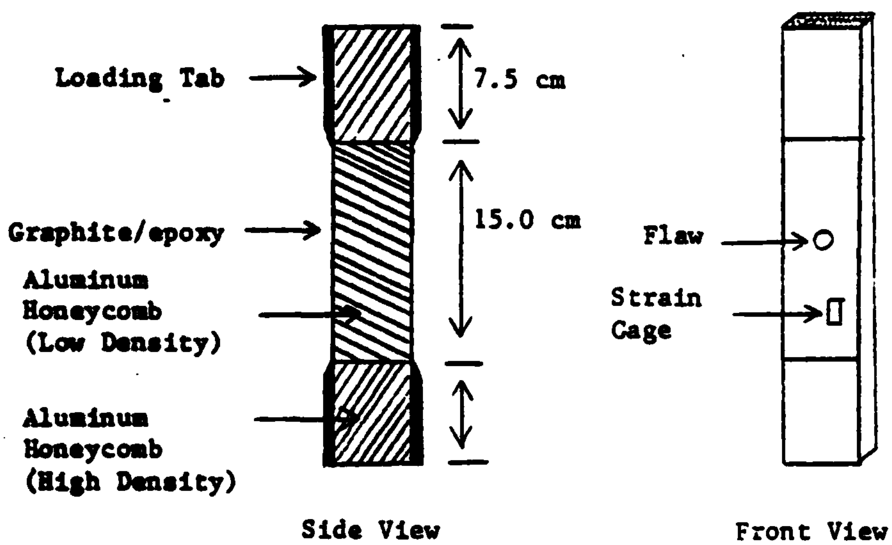


Figure 2. Beam Specimen

III. Design Considerations

In the design of a compression jig, the following considerations must be dealt with:

1) Jig must prevent instability failures
2) Jig must not prevent delamination failures
3) Jig must not alter the coupon's measured compressive strength (via coupon/jig friction for example)
4) Jig must produce failures at the coupon's flaw (as opposed to end-crushing or end-brooming failures)

All of the previous coupon compression methods address these considerations with varying degrees of success. The first three considerations can be met by using no jig at all by vastly altering the specimen geometry, but since the coupon specimen is to be used, all four of these design constraints must be met with a compression jig.

IV. Unsuccessful Compression Jigs

A. Steel Plate Compression Jig

The first compression jig that was tested was designed and built several years ago by two graduate students at TELAC, Jerry Fanucci and Curt Rogers. It consists of 4 steel plates that prevent the coupon from buckling (see Figure 3). Teflon tape was placed on the inside of the jig to minimize the shear load that is transferred from the coupon onto the jig. The gap in between the top and bottom of the jig was cut for safety considerations; in case the testing machine begins compressing the jig itself the gap provides a 1/2 in. safety margin before the 3/4 in. thick steel jig begins to resist the testing machine's applied compressive stroke. The circular hole in the jig was drilled so that the graphite/epoxy in the immediate vicinity of the coupon's flaw is not restrained from delamination.

Preliminary tests revealed that the jig tends to bend at the gap in between the upper and lower plates. Steel reinforcement plates were clamped onto the jig to prevent this bending, but the loading tab would bend and cause fracture at the tab/graphite interface (see Figure 4). For this reason, this jig is unusable for compression tests. Tab bending could be detected by noting that the compressive load increases more slowly during the constant stroke rate when the tab begins to bend.

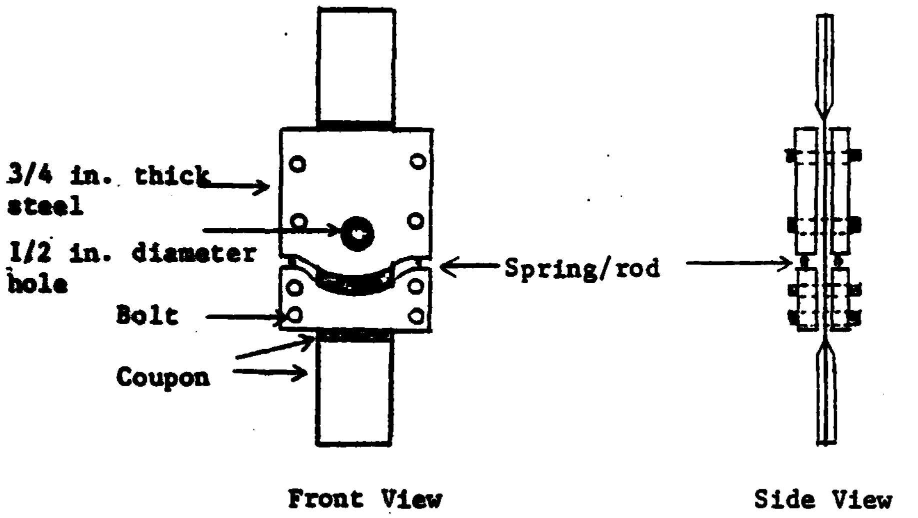


Figure 3. Steel Plate Compression Jig

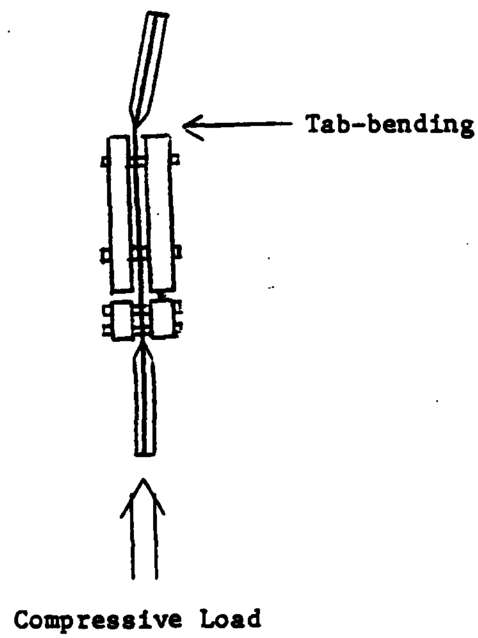


Figure 4. Coupon Tab-bending

B. Honeycomb Compression Jig

The honeycomb compression jig (see Figure 5) is a variation of the beam specimen idea (Figure 2). A light density honeycomb material, like American Cyanimid Aluminum honeycomb is clamped onto opposite sides of a coupon. The honeycomb material resists crushing in the direction perpendicular to the face of the coupon, but provides virtually no resistance to deformation parallel to the plane of the coupon. It is therefore possible to prevent coupon buckling without increasing the coupon's measured compressive strength.

Preliminary tests led to tab bending and fracture at the tab/graphite interface. The honeycomb material was then extended over the tabs in hope of preventing tab bending. Tab bending still occurred however, and this problem plus coupon buckling (despite the honeycomb) prevented the honeycomb jig from being usable as a compression jig. The compressive loads that could be applied before tab bending occurred were close to the expected failure loads but some improvement was necessary.

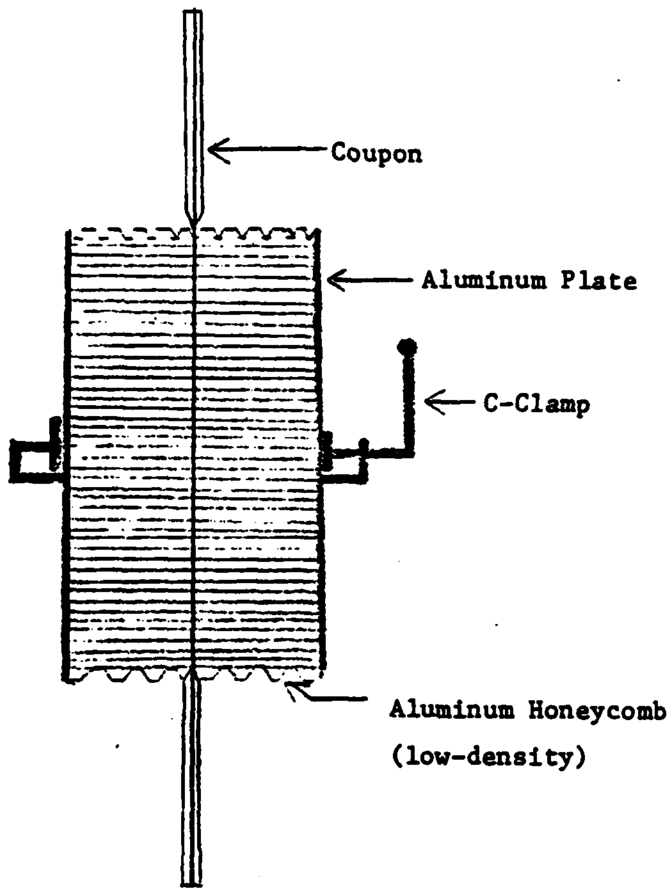


Figure 5. Honeycomb Jig

C. Plexiglass Compression Jig

The plexiglass compression jig shown in Figure 6 was constructed to raise the compressive load that could be applied to the coupon before failure occurred at the tab/graphite interface. The beveled surface was created to reduce the stress concentration caused at the jig/tab gap. The inside surface of the plexiglass was sprayed with a silicone spray to reduce coupon/jig friction. Washers were placed on the bolts inside the two plexiglass plates to keep them separated by slightly more than the coupon thickness.

Initial tests of the plexiglass compression jig caused buckling of the entire coupon/jig assembly as shown in Figure 7. Aluminum plates were clamped onto the jig to avoid this buckling, but tab bending still occurred before the expected failure load.

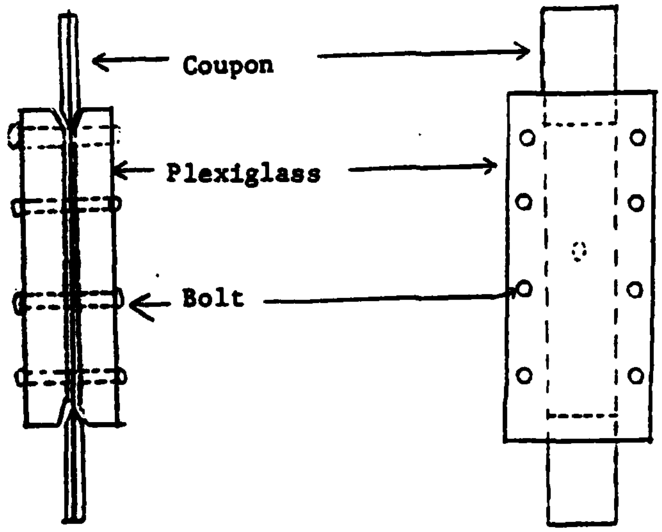


Figure 6. Plexiglass Jig

Figure 7. Buckled Plexiglass Jig

D. Tab-supporting Compression Jig

The tab supporting compression jig (Figure 8) was constructed espescially to prevent tab bending. This jig is similar to the steel plate compression jig except that it extends over the loading tabs. The metal bar down the center was included to keep the jig from bending at the gap. Metal bars slightly thicker than an 8-ply coupon were used to keep the Aluminum plates properly separated. Teflon cloth was applied to the inner surface of the jig with double-stick tape to minimize coupon/jig friction.

Preliminary tests of this jig produced a coupon failure which apparently started at the coupon's flaw. At this point, a hole was drilled in the jig so that strain gages on the coupon could be monitered during a test. Strain gages were also bonded onto the jig to determine if it was undergoing a compressive load caused by friction with the coupon.

Figure 9 shows the results of a typical test done with this jig. The coupon (Hercules AS1-3501-6 Graphite/epoxy [±45/0]s with a 12.7 mm diameter hole) was tested monotonically to failure under a constant compressive stroke rate. Strain gages were placed on opposite sides of the outside surface of the top half of the jig. A gage was also placed on the coupon as shown in Figure 8.

At 110 MPa compressive stress, the coupon visibly buckled inside the jig. The shape of the coupon at this point is shown in Figure 10. The buckling was audible and noted during the test by the x's on the graphs shown in Figure 9.

After the coupon buckled the second time the jig itself showed a compressive strain, implying that a compressive load was being carried to the jig by friction with the coupon. The stress-strain non-linearity shows that bending stresses in the coupon are of the same order of magnitude as the applied compressive stress. This jig is clearly unacceptable, since it produces stresses that cannot be calculated from the applied load.

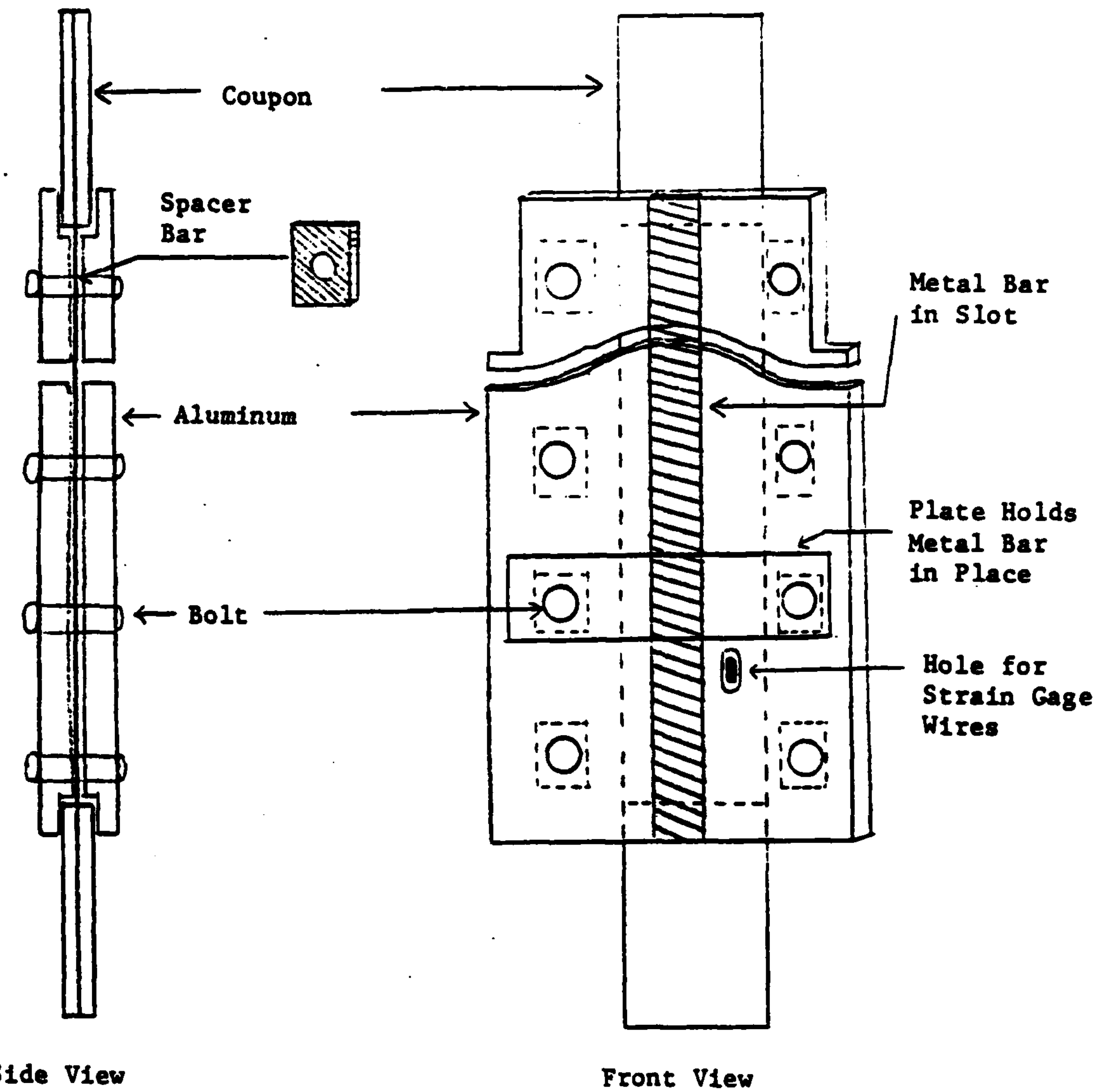


Figure 8. Tab-supporting Compression Jig

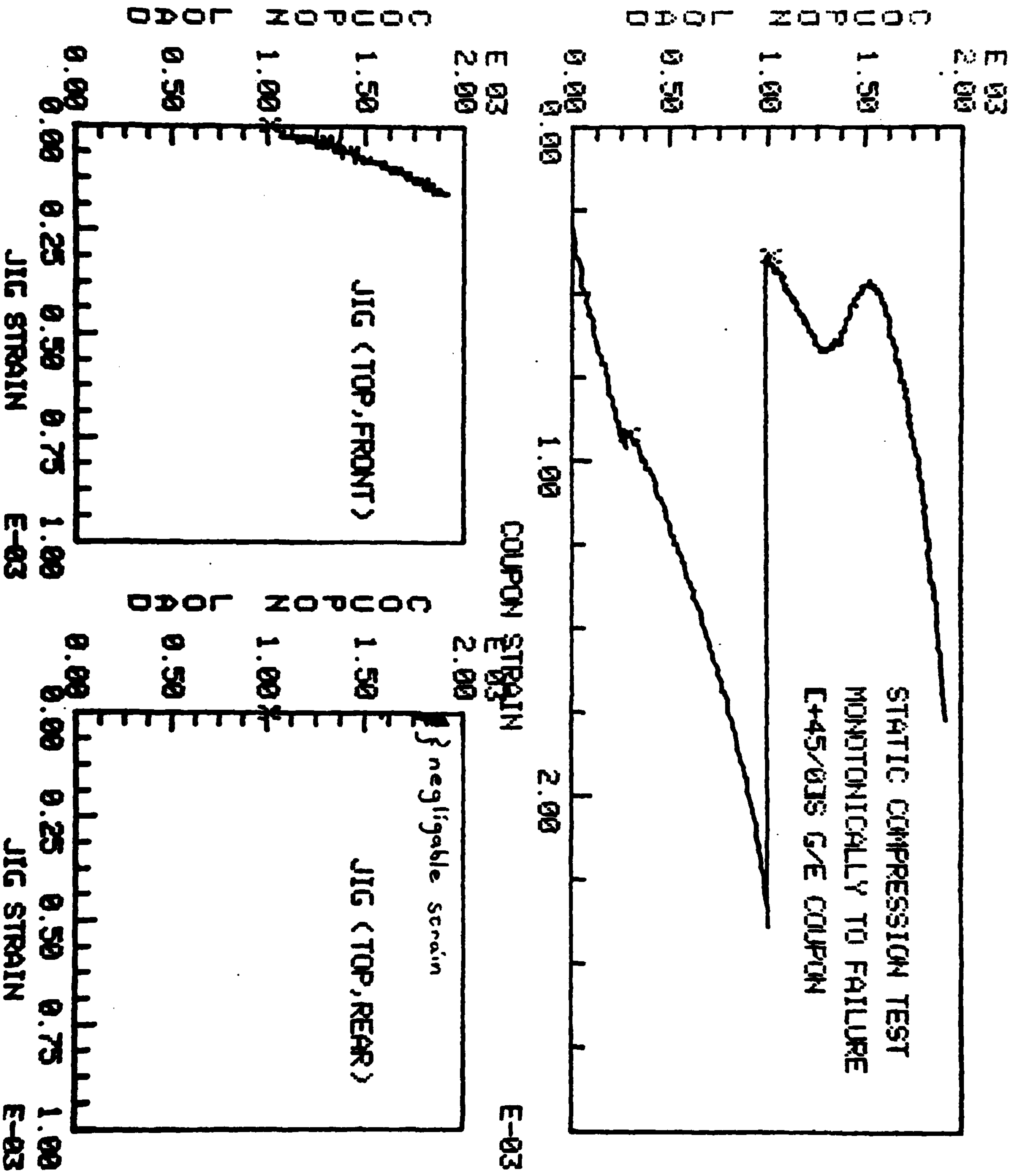


Figure 9. Tab-supporting Jig
Test Results

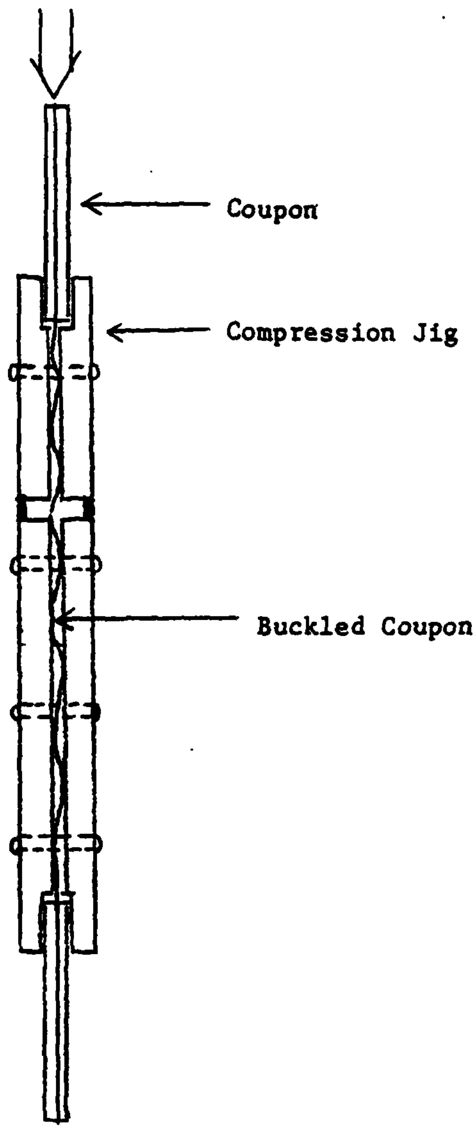


Figure 10. Coupon Buckling Inside Tab Supporting Compression Jig

V. Ball-bearing Compression Jig

A. Four-part Jig.

In order to solve the problems inherent in the tab-supporting jig, a ball-bearing compression jig was constructed as shown in Figure 11. Two hundred steel balls that extend above a steel housing support the coupon. These steel balls are free to roll insuring that no load is transferred to the jig by the coupon through friction. Since these balls are in contact with the coupon, the coupon cannot buckle like it did with the previous tab-supporting jig. The loading tabs are kept vertically aligned by clamping them as shown in Figure 11. The Aluminum reinforcing plates were needed to prevent the jig from bending at the gaps in the steel plates. The coupon is not supported in the vicinity of its flaw so that delamination at the flaw is not inhibited.

Coupons were tested in this jig in the same way as with the previous tab supporting jig. The nuts of the jig were finger tightened to avoid crushing the coupon. Strain gages were bonded onto opposite faces of the test coupons. The results of these tests are shown in Appendix A. The separation of the strain readings on the opposite faces of the coupon indicate that the coupon undergoes bending. It was thought that the jig bends slightly at the gaps between the metal plates.

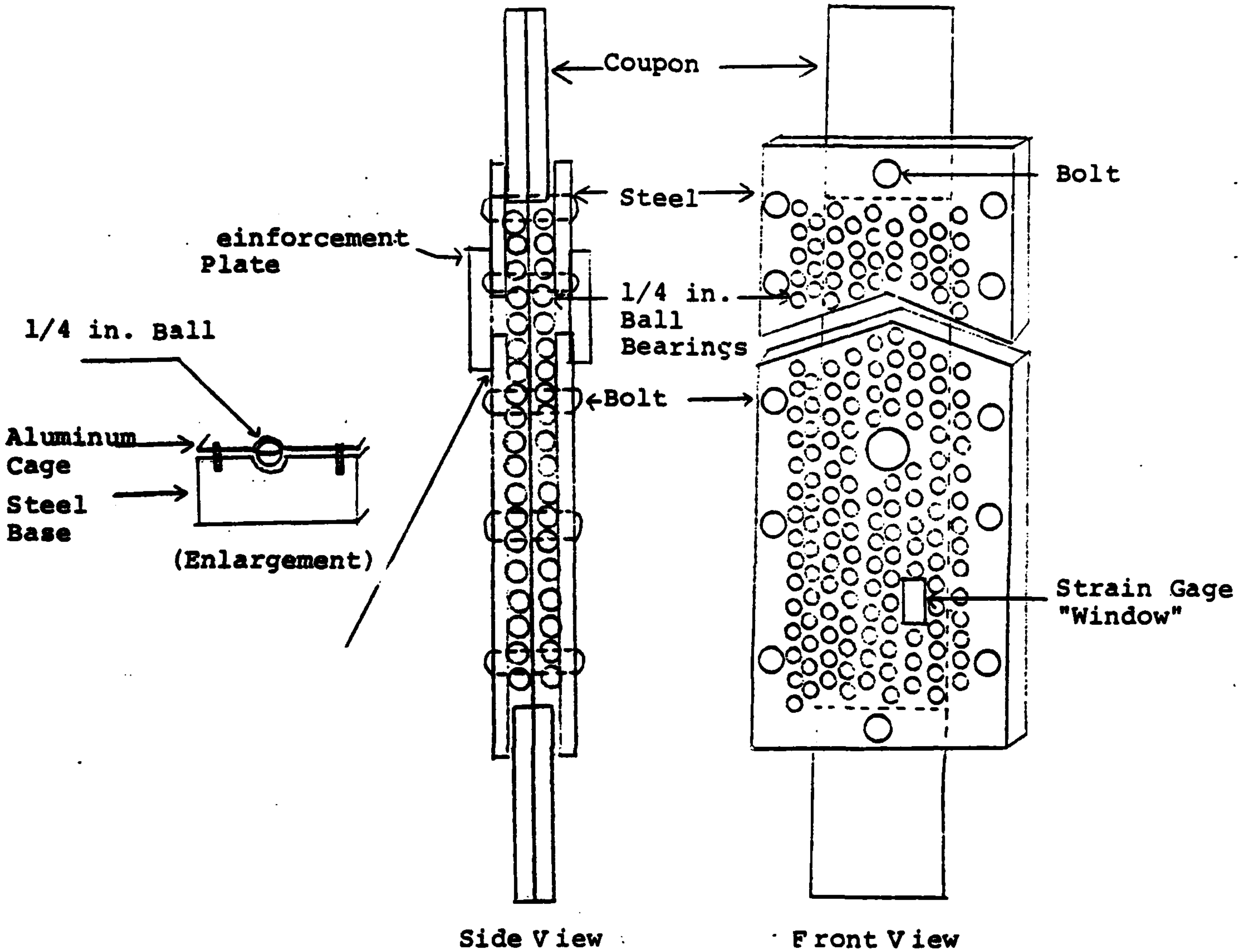


Figure 11. Four-part ball-bearing compression jig

B. Two-part Jig.

To overcome the jig bending problem the jig design was modified slightly to that shown in Figure 12. This jig consists of only 2 steel plates, making jig bending impossible. This jig was tested as before with similar results to the four-part jig. The jig was then tested again making sure that the loading tabs were not bent with respect to the rest of the coupon. The results of this test are shown in Figure 13. The strain measurements on opposite sides of the coupon are approximately equal, indicating that coupon bending did not occur. Subsequent tests again showed coupon bending strains however, (see appendix B) with coupon bending in the strain gage window being suspected.

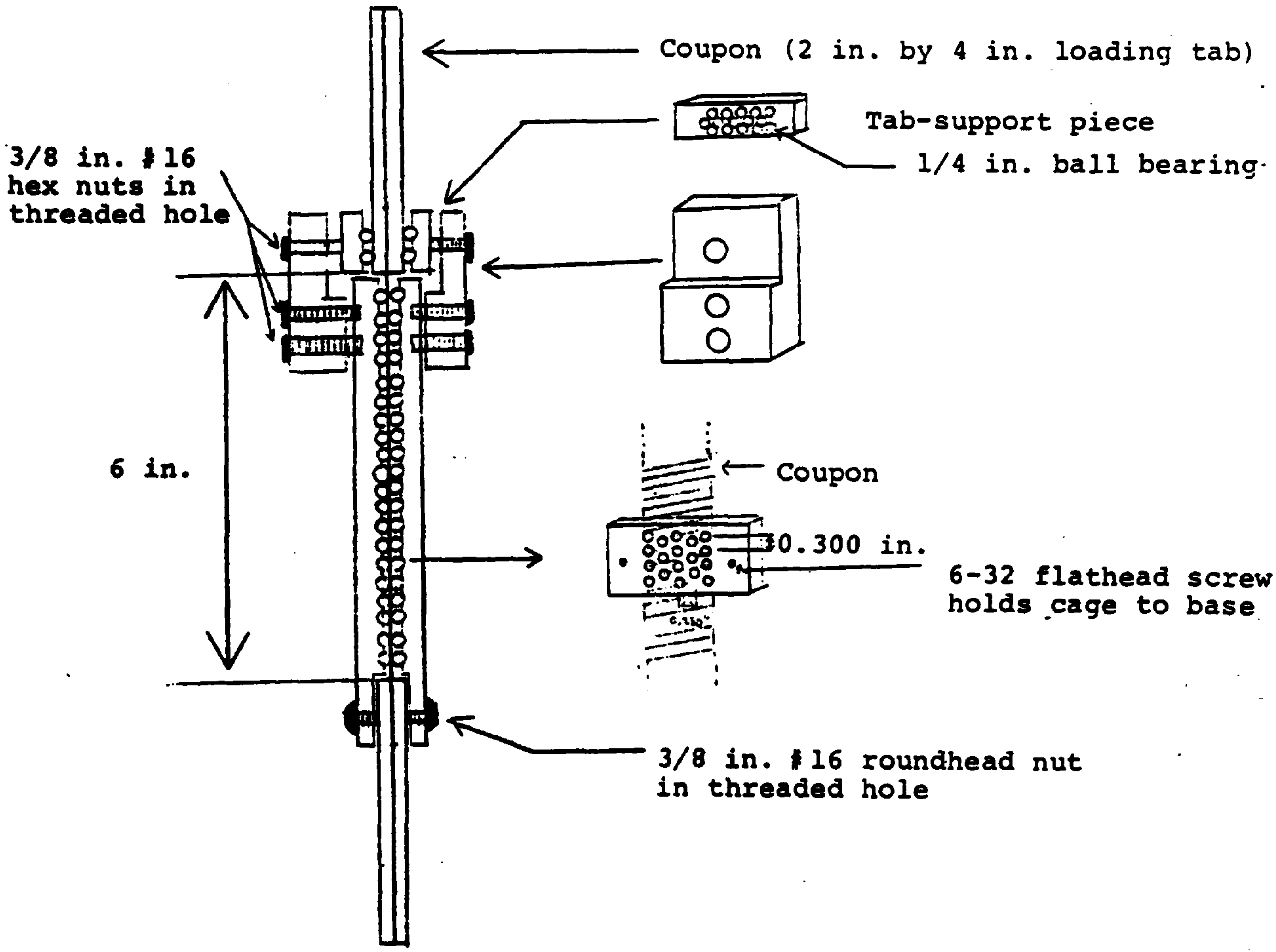
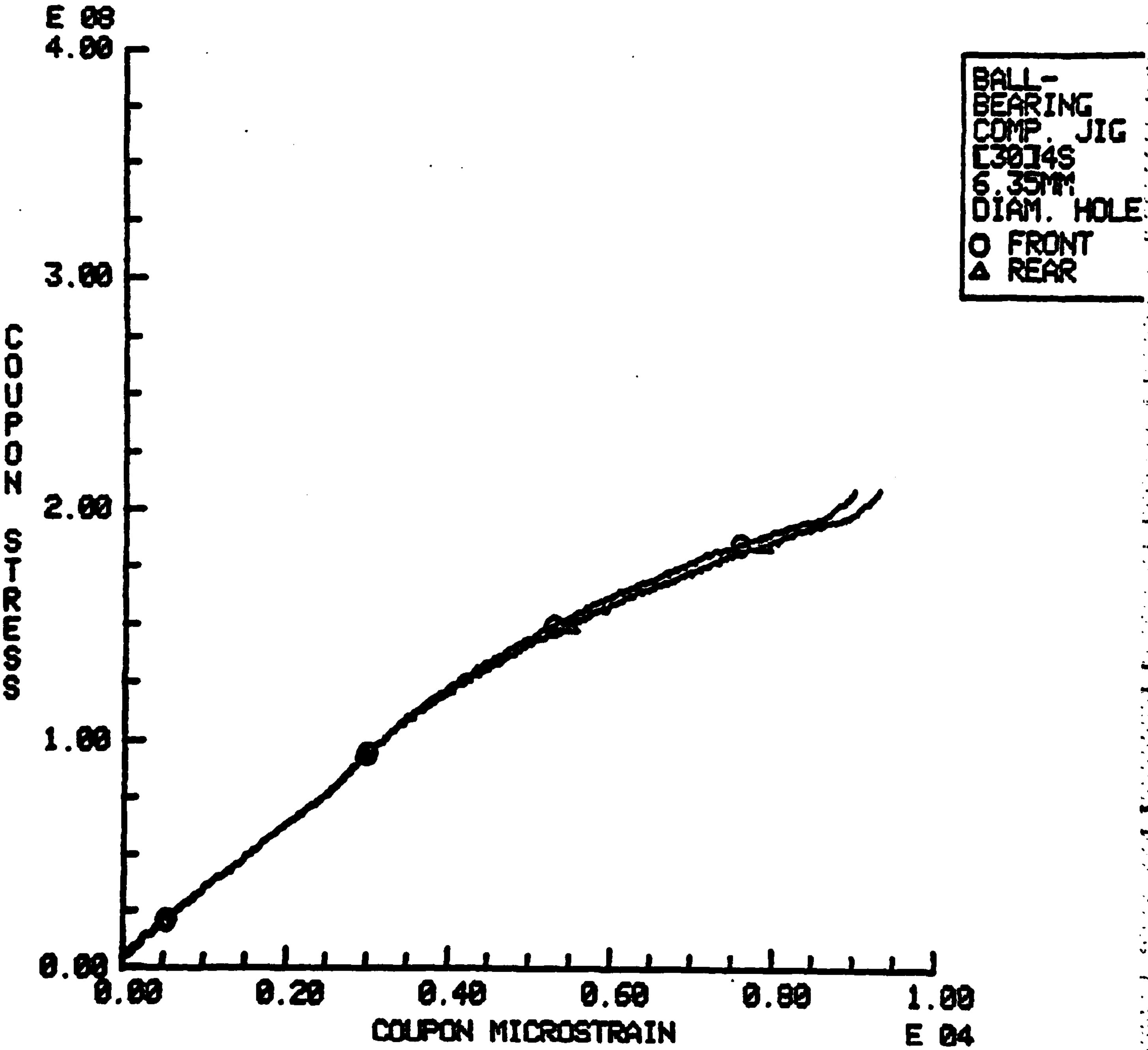


Figure 12. Two-part ball-bearing compression jig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COUPON MICROSTRAIN

Figure 13

VI. Conclusions

In conclusion, the two-part ball-bearing compression jig succeeds in keeping a graphite/epoxy coupon aligned during a compression test. However, strain gages bonded onto opposite faces of test coupons indicate that bending stresses are present in the coupon, probably due to localized coupon buckling inside the jig's strain gage window. The fact that steel balls which are free to rotate support the coupon insures that the applied axial load is not transferred to the compression jig through shear from the coupon. The coupon is not supported in the immediate vicinity of its flaw, so a coupon may fail via delamination. For these reasons, compressive tests of coupons in this jig (perhaps with a smaller gage window) should provide valid test results; however, more comprehensive tests must be performed before this jig is used to obtain compression test data (see Recommendations section).

VII. Recommendations

Before the two-part ball-bearing compression jig is used, the following tests should be performed:

1.) Tests monotonically to failure of unflawed coupons

2.) Tests monotonically to failure of coupons with strain measured at many points on the coupon

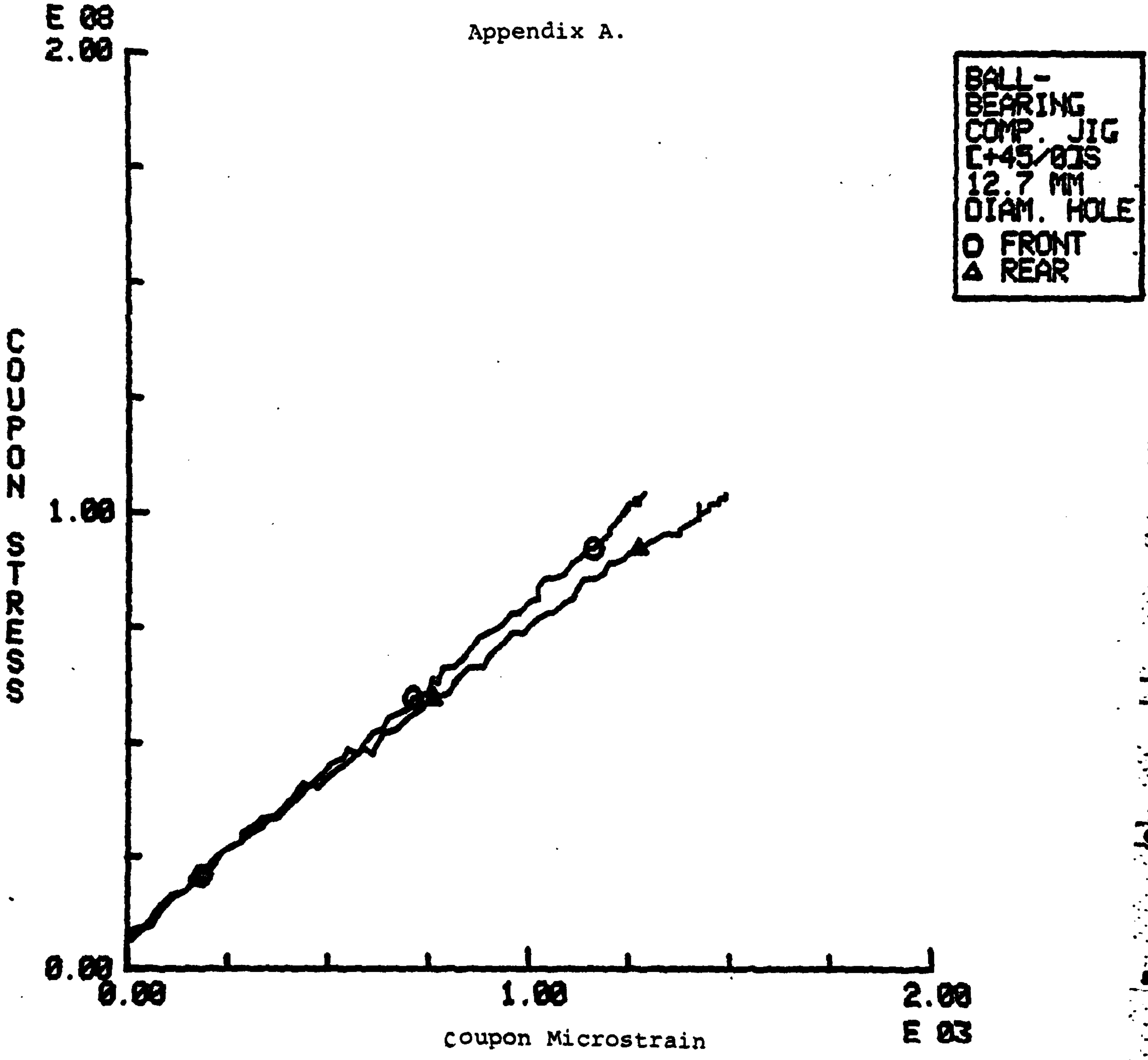
3.) Tests monotonically to failure of coupons with diminishing flaw sizes or necked-down sections to determine what stress concentration is required to guarantee failure at a given point

4.) Tests monotonically to failure of unidirectional coupons with various fiber directions to verify that the coupon will not buckle inside ball supports of the jig

5.) Repeated tests monotonically to about 25% of the expected failure load with varying torque applied to the nuts which bolt the 2 sides of the jig together, then comparison of the obtained moduli for consistency

6.) Tests monotonically to failure of various coupons with smaller strain gages, placed in between ball supports of the jig

Appendix A.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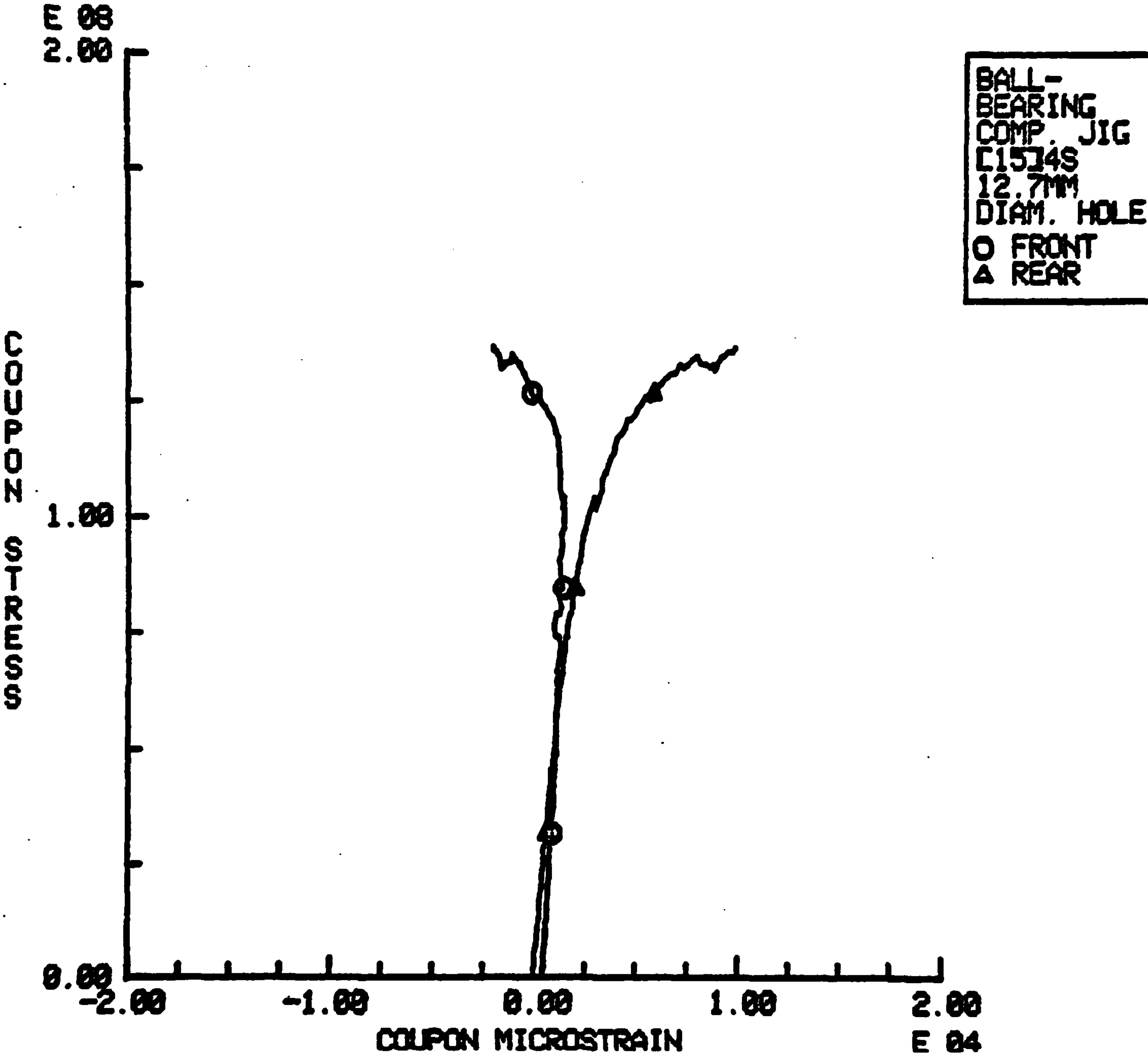
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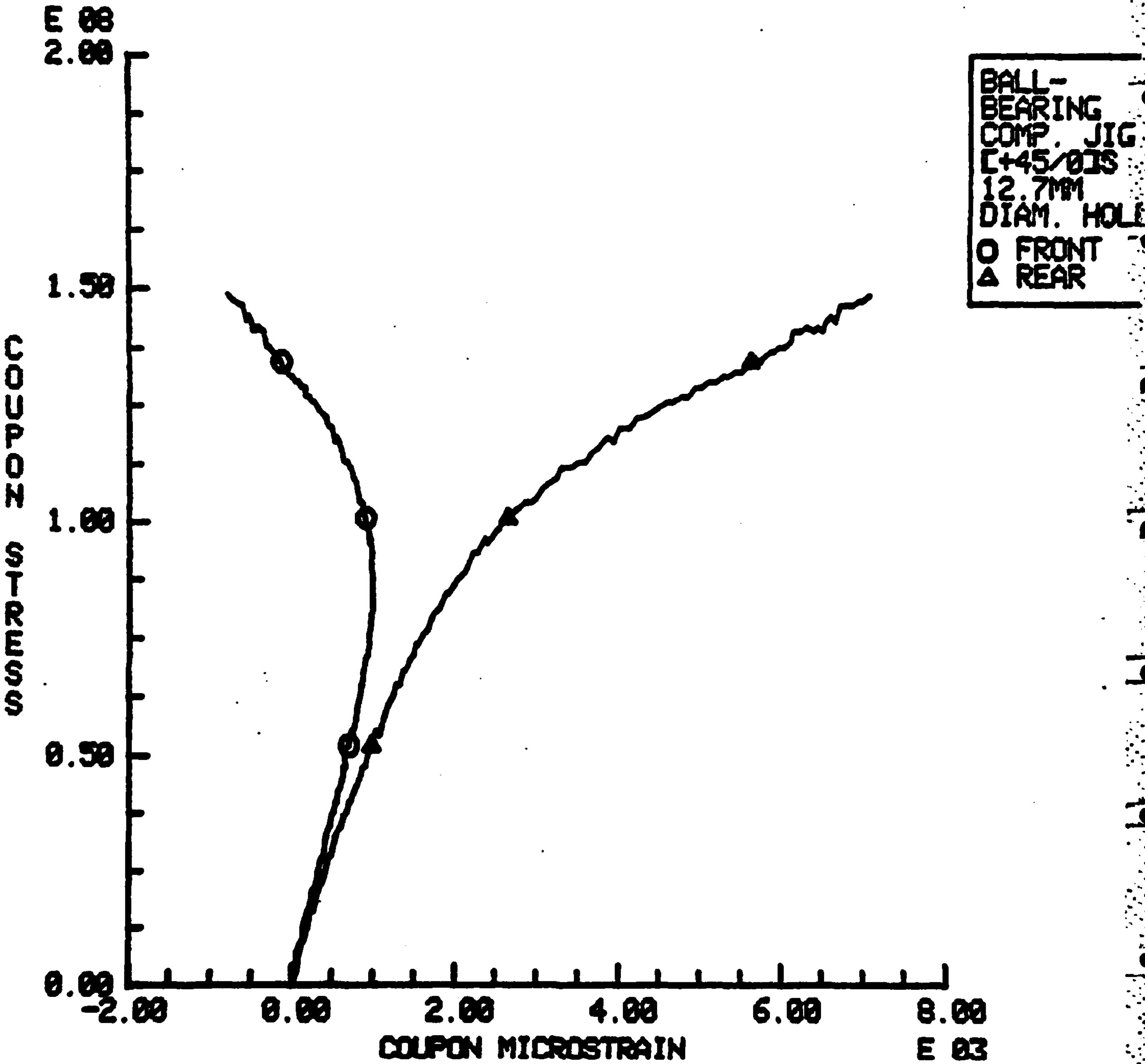
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COUPON MICROSTRAIN
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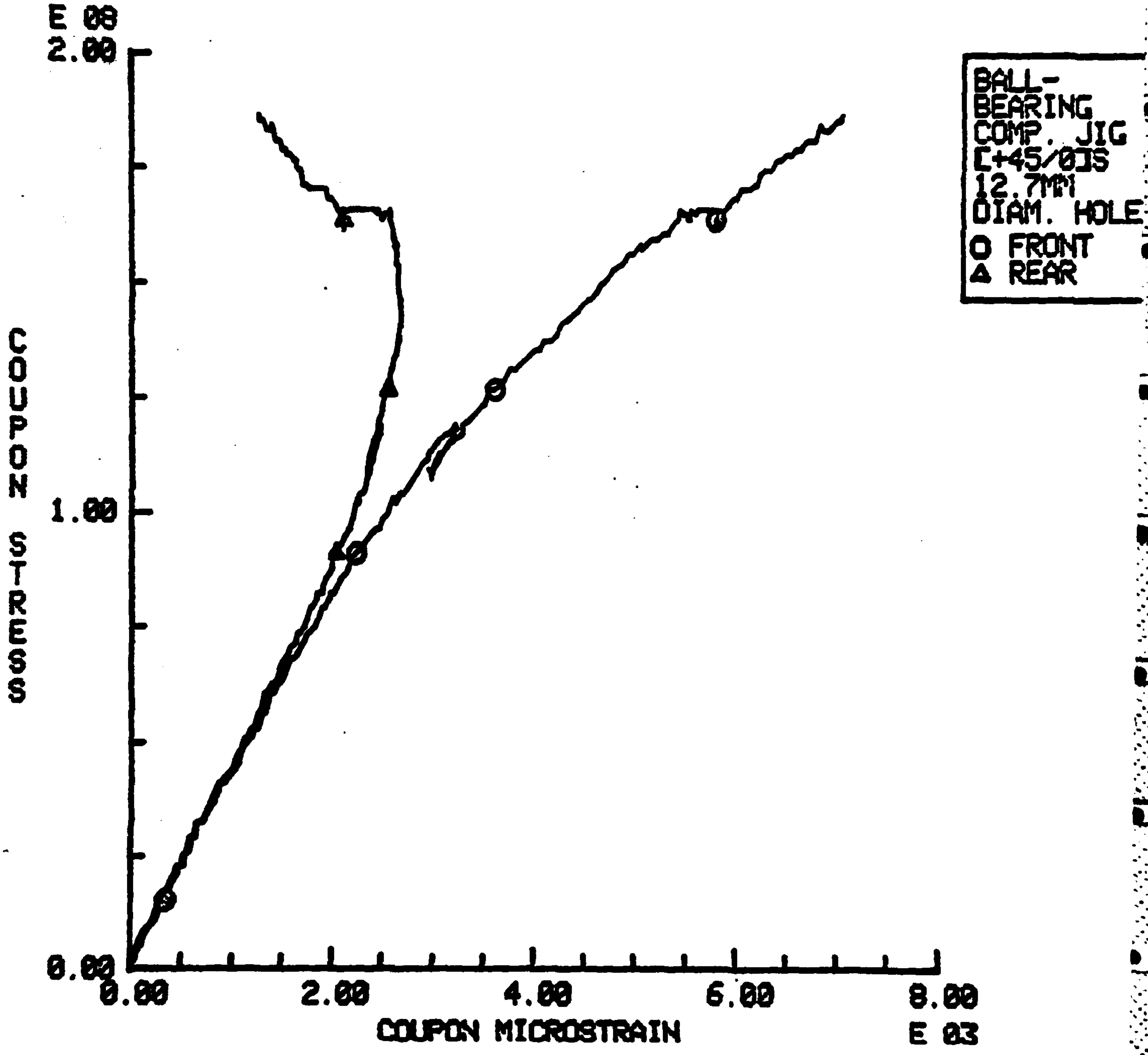
Appendix B.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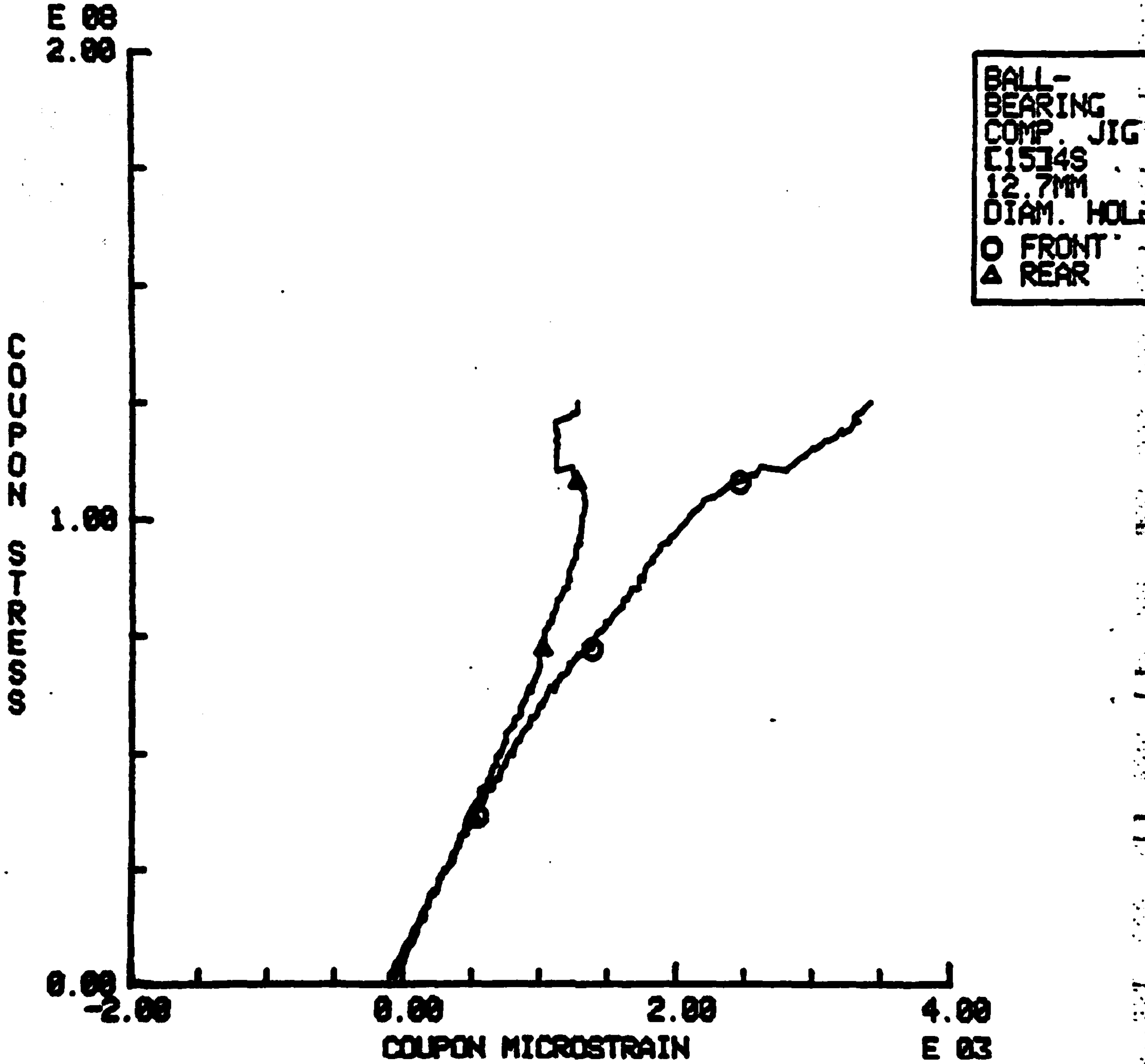
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Appendix C. Ball-bearing Compression Jig Manufacturing Instructions

The ball-bearing compression jig shown in Figure 12 was machined at two MIT machine shops, rooms 37-084 and 41-116. This appendix is intended to provide the details necessary to reproduce it with standard metal-working facilities.

The steel parts of this jig can be obtained from 1/2 in. by 4 in. stainless steel stock. Two of these steel plates are 1/2 in. by 4 in. by 7 in. and two are 1/2 in. by 4 in. by 2 in. Approximately 300 1/4 in. diameter steel balls will also be needed. The Aluminum cage must be 0.50 to 0.70 mm thick, and should be cut to two 4 in. by 6 in. and two 2 in. by 4 in. pieces. A 1/4 in. ball-end mill will be needed to drill the hemishperical holes in the stainless steel plates. The first step in machining the jig is to drill each plate with 0.016 in. holes at the locations shown in Figure 15.

Then holes must be drilled as shown in Figure 16. The 0.106 in. holes in the cage plates are then drilled to a larger diameter with a 0.190 in. diameter drill bit and the 0.106 holes in the steel plates are then tapped with a 6-32 plug tap. Then the holes shown in Figure 16 must be tapped with their indicated thread sizes.

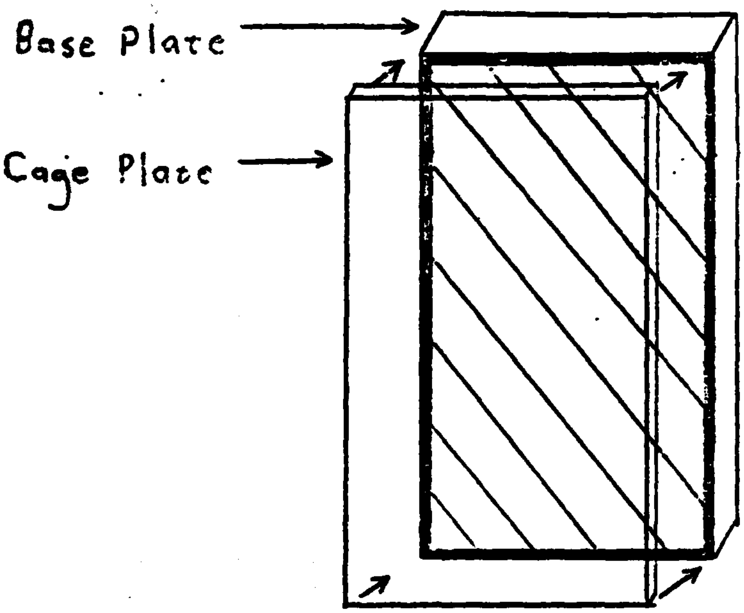

Figure 14. Base Plate and Cage

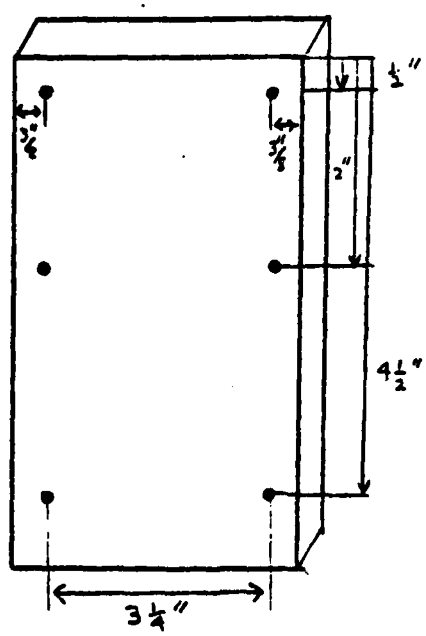

Figure 15 Hole Drilling Locations

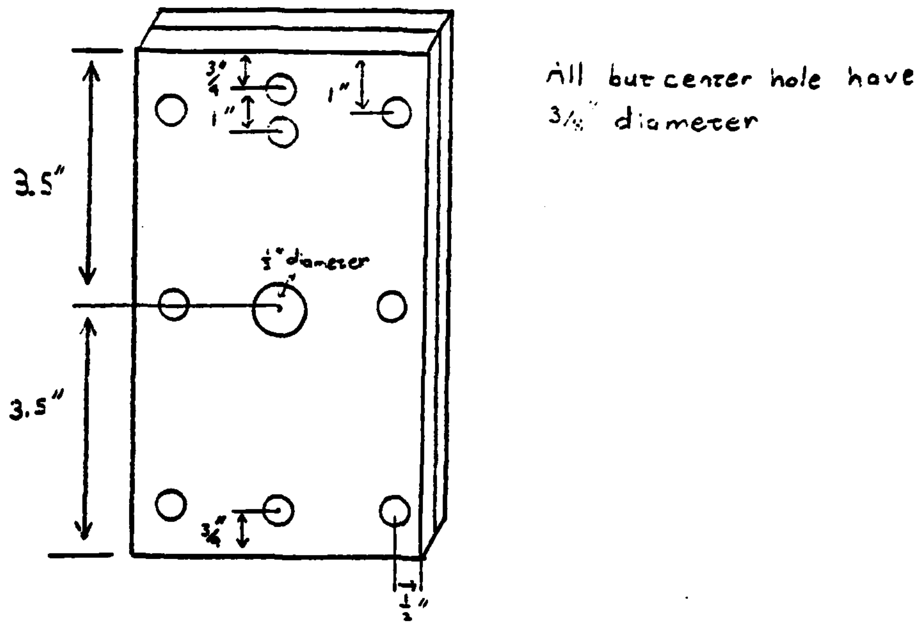

Figure 16. Hole drilling locations

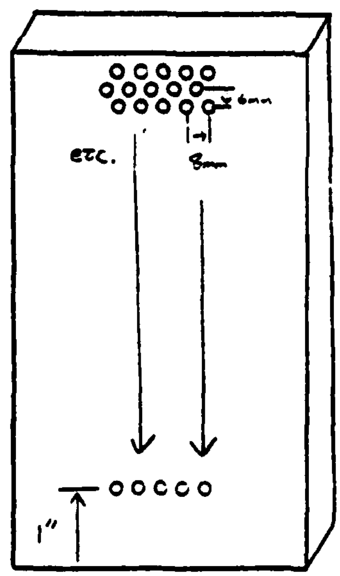

Figure 17. Hemispherical hole drilling locations

The jig is now ready for the next part of construction, machining the housing for the steel balls. The holes shown in Figure 17 should be drilled to exactly the same depth. Drill these holes at exact intervals so that the pattern can be reproduced on the cage. Next drill 3/16 in. diameter holes in this same pattern through the cage plate.

Next soak the plates in Acetone and to remove any residues. Clean each ball housing with a cotton tipped applicator and spray it with silicone spray. Place clean steel balls in each housing and place cage on top; bolt cage to base plate with 6-32 flat-head screws. The rest of the jig can be machined in the same way to produce the parts as shown in Figure 12. The jig can now be used to test coupons.

Bibliography

[1] Pipes, R.B.: Compression Failure of Composite Laminates. Center for Composite Materials, College of Engineering, University of Delaware, Newark, Delaware

[2] Hoggatt, J. T., "Test Methods for High-Modulus Carbon Yarn Composites," Composite Materials: Testing and Design, ASTM STP 460, American Society for Testing and Materials, 1969, pp. 48-61.

[3] Adsit N.R. and Forest, J.D., "Compression Testing of Aluminum-Boron Composites," Composite Materials: Testing and Design, ASTM STP 460, American Society for Testing and Materials, 1969, pp. 108-121.

[4] Elkin, R.A., Fust, G., and Hanley, D.P., "Characterization of Graphite Fiber/Resin Matrix Composites," Composite Materials: Testing and Design, ASTM STP 460, American Society for Testing and Materials, 1969, pp. 321-335.

[5] Lagace, P., and Brewer, J., TELAC Manufacturing Course, Class Notes. Technology Laboratory for Advanced Composites, Department of Aeronautics and Astronautics, Massachusetts Institute of Technology, Cambridge, Massachusetts.

[6] Hadcock, R. N. and Whiteside, J. B., "Special Problems Associated with Boron-Epoxy Mechanical Test Specimens." Composite Materials: Testing and Design, ASTM STP 460, American Society for Testing and Materials, 1969, pp. 27-36.

[7] Lenoe, E.M., Knight, M., and Schoene, C., "Preliminary Evaluation of Test Standards for Boron Epoxy Laminates," Composite Materials: Testing and Design, ASTM STP 460, American Society for Testing and Materials, 1969, pp. 122-139.

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