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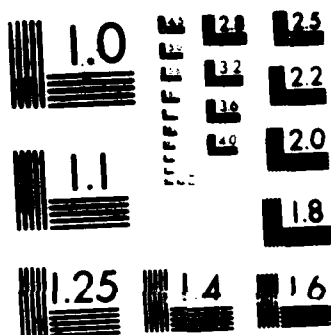
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TECHNICAL REPORT ARCCB-TR-87006

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**AN EVALUATION OF THE SERVICE
FAILURE OF ALUMINUM NOSE CONES
USING FOUR TEST TECHNIQUES**

**J. A. KAPP
R. R. FUJCAK
R. T. ABBOTT**

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WATERVLIET, N.Y. 12189-4050**

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PROBLEM STATEMENT AND INTRODUCTION

In the past few years nose cone failures have occurred during acceptance testing. The back end of the nose cone is sealed by a shear plate. During service, the pressure developed in the nose cone cavity creates an aft directed force that acts on the pusher plate transmitting it through the submunitions to the aft end shear plate. For effective operation, the force must be sufficient to fracture the shear plate. The failures cited occurred when the connection between the nose cone and the projectile body failed before the aft end pusher plate failed. These failures normally occur by a failure of the threads in the nose cone.

The nose cone is manufactured from 7075-T6 aluminum and is pictured in Figure 1. Production nose cones are manufactured by two different manufacturing methods. The first method, referred to as lot "A", produces the nose cones by cold forging the cavity to finished dimensions, heat treating, and machining the outside dimensions. The other method, lot "B", produces a pre-form by forging at 630°-720°F, machining the cavity, heat treating, then finish machining the outside dimensions. Both methods use ALCOA aluminum. Failures have been exclusive to lot "A".

Several material characterization studies and simulation tests were conducted at the Army Research, Development, and Engineering Center (ARDEC), Dover, New Jersey. The materials studied showed some difference in the microstructure of lot "A" versus lot "B" nose cones, but no substantial material property differences. The results of the simulation study, in which nose cones were sealed and pressurized within, showed substantial differences in behavior. Lot "A" nose cones failed at the thread at containment pressures

substantially below those which were required to fail lot "B" nose cones. Furthermore, these tests showed that the lot "B" nose cones did not fail at the thread. These nose cones failed by ductile rupture with the crack running in the longitudinal direction. The other important finding of these previous studies was that in sectioning required to obtain the metallographic specimens, substantial motion of the nose cones was observed. In one case (lot "B"), when a longitudinal cut by sawing was attempted, the resulting motion caused the gap to close down causing friction on the saw blade. Applying the same procedure to a lot "A" nose cone, the opposite resulted - the cut opened. These motions were the result of residual stresses in the hoop direction that were compressive in the lot "B" nose cone and tensile in the lot "A" nose cone.

The authors of this report were contacted to evaluate certain other aspects of the premature failures, primarily the crack initiation toughness of nose cones from each lot. In preliminary meetings it was decided to perform other tests at Benet Weapons Laboratory that might contribute to the resolution of these failures. In all, four tasks were performed: (1) measuring the residual stress in nose cones from each lot by the use of the hole drilling method; (2) conducting notched crack initiation toughness tests; (3) verifying the fracture toughness of the materials; and (4) conducting simulation tests of finished nose cones ensuring that failure of the thread occurs.

EXPERIMENTAL PROCEDURES

The residual stresses were measured at several locations on two nose cones - one from lot "A" and one from lot "B"; the hole drilling method was used. With this technique, a strain gage rosette was placed on the object

containing residual stresses and connected to recording equipment. A small hole was then drilled in the center of the three-gage pattern. Since material that was supporting residual stress was removed by the drilling, the stress was relieved and a strain was measured on the strain gage rosette. From the strain gage reading, the magnitude of the residual stress at the location of the drilled hole can be determined.

Since failures occurred in the threaded region, we measured residual stresses there. In order to obtain measurements, the threads had to be removed. This was accomplished by grinding, followed by polishing the ground surface. This machining could affect the measurement. To overcome this potential problem, measurements were also made on the smooth surface on the outside taper close to the transition between threaded and tapered regions. In all, four measurements were made on each nose cone.

The two material property measurements were made using Charpy type specimens obtained from the same nose cones on which the residual stress measurements were made. The exact specimen is shown in Figure 2. These specimens were obtained such that the fracture plane was the same plane that failed in actual service. Also, an attempt was made to position the notch so that it corresponded to the location of the most forward thread (the failure position).

To measure crack initiation toughness, the specimen was tested as-machined. The load and load-line displacements were simultaneously measured. Toughness is simply the total area under the load/displacement plot. Although not an absolute measurement with direct application, these initiation toughness measurements are useful in determining relative behavior between two

separate materials (refs 1,2). For J-integral toughness, the specimen was first precracked so that the total notch depth plus crack was approximately one-half of the specimen thickness. Precracked specimens were then loaded to fracture, again measuring the load and load-line displacements. The area under the curve can be related to the elastic-plastic energy release rate (the J-integral). The J that causes crack advance is a measure of the crack or fracture toughness of the material. Also, the elastic-plastic toughness can be used to estimate the more familiar elastic fracture toughness (K_{IC}). Initiation toughness and J-integral toughness were measured at both room temperature and -50°F .

The final series of experiments consisted of simulation tests. A fixture was devised allowing the nose cone cavity to be loaded along its axis until failure. The test is pictured schematically in Figure 3. Loading nose cones in this manner results in a maximum tensile stress occurring at the same location and in the same direction that would result in the failure of nose cones in the same way as the service failures occurred. The assembled test fixture was measured in a high capacity compression test rig and loaded to failure. During loading, the displacement of the loading ram was also measured.

¹J. H. Underwood and M. A. Scavullo, "Fracture Behavior of a Uranium and a Tungsten Alloy in a Notched Component With Inertia Loading," Fracture Mechanics: Sixteenth Symposium, ASTM STP 868, (M. F. Kanninen and N. T. Hopper, eds.), American Society for Testing and Materials, Philadelphia, 1985, pp. 554-568.

²G. A. Pflegl, J. H. Underwood, and G. P. O'Hara, "Structural Analysis of a Kinetic Energy Projectile During Launch," ARRADCOM Technical Report ARLCB-TR-81028, Benet Weapons Laboratory, Watervliet, NY, July 1981.

RESULTS

The residual stress measurements appear in Table I. As stated, the threads were removed at two locations 180 degrees apart and measurements were also taken in the smooth section adjacent to the threads. Residual stresses in both the hoop and longitudinal directions are also reported in the table. The results suggest two things: first, the lot "A" nose cone contained tensile residual stress in the longitudinal direction near the point where the failures occurred, and second, the lot "B" nose cone contained compressive residual stress near the failure locations. It may seem that tensile residual stresses may be present in the threaded area of nose cones from both manufacturers. But as stated above, in order to measure stresses in the vicinity of the threads, the threads must be removed. Gross material removal may, and probably did, affect the residual stress readings. Since no machining was performed on the outer surfaces (gage locations 2 and 4), the readings at these positions are probably accurate. It is from these measurements that we base the statement that tensile residual stresses in the longitudinal direction are present in the lot "A" nose cones and that compressive residual stresses are present in the lot "B" nose cones.

The J-integral fracture toughness measurements are given in Table II. These results clearly show that there is no difference in fracture properties of the material used to manufacture nose cones by either producer. If anything, it appears that the lot "A" material had marginally better properties. These findings are in agreement with previous measurements of nose cone material (ref 2). The measurements are included only as verification of the

²G. A. Pflegl, J. H. Underwood, and G. P. O'Hara, "Structural Analysis of a Kinetic Energy Projectile During Launch," ARRADCOM Technical Report ARLCB-TR-81028, Benet Weapons Laboratory; Watervliet, NY, July 1981.

previous work in which full-size Charpy specimens were used to measure K_{IC} . The Charpy samples are not sufficient in size to produce a valid J-integral test. As a matter of reference, the K that corresponds to $J = 100$ lbs/in. in aluminum is $31.6 \text{ Ksi}\sqrt{\text{in.}}$. Thus, J-toughnesses on the order of 100 lbs/in. as measured are in excellent agreement with the previous findings (ref 2) even though the previous measurements were not valid.

Results of the energy to initiate a crack in a notched specimen are shown in Table III. These results yield the same observation as the crack toughness results mentioned above. There seems to be a small change in property with testing temperature, but no difference between lots. Little more can be said from these material property measurements, except that it is unlikely that premature failures of lot "A" nose cones can be related to material property differences between lot "A" and lot "B" material.

Simulation test results are given in Table IV. A schematic of the applied load-ram displacement plot is given in Figure 4. All specimens fractured at the same location as the service failures. From both the table and the figure it is clear that the lot "A" nose cones failed at consistently lower loads than the lot "B" nose cones. Also, the fracture loads were more scattered for lot "A" as can be seen with the larger standard deviation.

Although the previous simulation studies indicated the same result as reported here, we can draw direct comparisons from the fracture load data of Table IV. In the prior study, nose cones were loaded by internal pressure and lot "A" nose cones failed in a different manner than the lot "B" nose cones.

²G. A. Pflegl, J. H. Underwood, and G. P. O'Hara, "Structural Analysis of a Kinetic Energy Projectile During Launch," ARRADCOM Technical Report ARLCB-TR-81028, Benet Weapons Laboratory, Watervliet, NY, July 1981.

A brief analysis can be made to relate the failure loads to other measurements made in our study. The mean fracture load of the lot "B" nose cones was 13.7 percent higher than the mean fracture load of the lot "A" nose cones. The difference cannot be explained by either material property measured, but there is a quantitative relationship with residual stress. Consider from Table I that lot "A" contains tensile longitudinal residual stresses of approximately 5,000 psi. If we assume that the yield strength of the aluminum is 70,000 psi, then the amount of externally applied stress necessary to yield the material would be $70,000 - 5,000 = 65,000$ psi. Also, from Table I, we may assume that the lot "B" nose cones might contain compressive longitudinal residual stresses of about 9,000 psi. In order to yield a nose cone with compressive residual stress, the magnitude of the residual stress must first be overcome, then the yield stress must be applied. Thus, for the lot "B" nose cones it could be estimated that the required external stress for yielding would be $70,000 + 9,000 = 79,000$ psi. This would suggest that an additional external load would be necessary for yielding lot "B" material. The relative extra stress required would be $(79,000/65,000 - 1) \times 100 = 21.5$ percent. This is in reasonably good agreement with the actually measured increase, especially since this analysis is a very simplified explanation of the complex biaxial loading with stress concentration that resulted in service addition of the failure.

CONCLUSIONS AND RECOMMENDATIONS

The premature failure of lot "A" nose cones in acceptance testing can be verified by a straightforward simulation test that compared lot "A" with lot "B". The structural failures cannot be related to material property

meaasurements, but are probably due to the presence of tensile residual stress in lot "A" nose cones.

Since residual stress seems to be the culprit in this case, insuring that tensile residual stresses are not present in nose cones may be a solution to the problem. This could be accomplished by several methods. Ultrasonic surface waves can be used to measure surface residual stresses. Since this is a nondestructive method, it may be applied to all nose cone bodies and reheat treatment may be used to salvage nose cones with improper residual stresses. The hole drilling method may also be used, but must be done on a sample basis, since it is a destructive method. Reworking (reheat treating) nose cones with tensile residual stress would be more expensive since entire heats of nose cones would be tested with samples from the heats and the entire heat would have to be reworked. The other method that may be used is also a destructive method, namely simulation testing using the method described above. This also would have to be done on a sample basis and the tested sample must be finished machined. This would probably be the most expensive method, but would also be the most discriminating, since we would be simulating actual loading.

In our opinion, using ultrasonics to measure the presence of surface tensile residual stresses would be the most useful quality control measure to reduce or eliminate the occurrence of premature nose cone failures.

REFERENCES

1. J. H. Underwood and M. A. Scavullo, "Fracture Behavior of a Uranium and a Tungsten Alloy in a Notched Component With Inertia Loading," Fracture Mechanics: Sixteenth Symposium, ASTM STP 868, (M. F. Kanninen and N. T. Hopper, eds.), American Society for Testing and Materials, Philadelphia, 1985, pp. 554-568.
2. G. A. Pflegl, J. H. Underwood, and G. P. O'Hara, "Structural Analysis of a Kinetic Energy Projectile During Launch," ARRADCOM Technical Report ARCLB-TR-81028, Benet Weapons Laboratory, Watervliet, NY, July 1981.

TABLE I. RESIDUAL STRESS DATA

Lot "A" Gage Location	Hoop Stress (psi)	Longitudinal Stress (psi)
1	5842(T)	8590(T)
2	6196(T)	5144(T)
3	6875(T)	- 341(T)
4	4387(T)	- 779(C)
Lot "B" Gage Location	Hoop Stress (psi)	Longitudinal Stress (psi)
1	3319(T)	15081(T)
2	-3386(C)	-11414(C)
3	146(T)	9454(T)
4	-2282(C)	- 8918(C)

TABLE II. J-INTEGRAL FRACTURE TOUGHNESS
SMALL SPECIMEN LONGITUDINAL PROPERTIES

Temp.	Lot "A"		Lot "B"	
	Spec. No.	J(lbs/in.)	Spec. No.	J(lbs/in.)
R.T.	CF-1	154.8	HF-3	103.2
	CF-2	109.9	HF-4	90.2
	CF-3	120.9	HF-1	115.9
	CF-4	92.0	HF-2	114.4
	CF-5	101.9	HF-5	99.2
	Mean	115.9	Mean	104.6
	S.D.	24.2	S.D.	10.7
	CF-11	95.1	HF-6	90.0
	CF-12	102.9	HF-7	96.7
	CF-13	106.1	HF-8	100.9
-50°F	CF-14	99.1	HF-9	100.4
	Mean	103.0	Mean	99.6
	S.D.	6.5	S.D.	7.3

TABLE III. SLOW NOTCH BEND ENERGY
SMALL SPECIMEN LONGITUDINAL DIRECTION

Temp.	Lot "A"		Lot "B"	
	Spec. No.	Energy (in.-lbs)	Spec. No.	Energy (in.-lbs)
R.T.	CF-6	27.1	HF-11	21.5
	CF-7	34.2	HF-12	23.0
	CF-8	26.3	HF-13	23.8
	CF-9	25.9	HF-14	23.6
	CF-10	25.4	HF-15	22.5
	Mean 27.8		Mean 22.9	
	S.D. 3.6		S.D. 0.9	
	CF-16	20.8	HF-16	19.3
	CF-17	21.0	HF-17	17.2
	CF-18	18.3	HF-18	16.7
-50°F	CF-19	21.0	HF-19	16.2
	CF-20	16.1	HF-20	22.3
	Mean 19.6		Mean 18.3	
	S.D. 2.4		S.D. 2.5	

TABLE IV. RESULTS FROM SIMULATION TEST

Lot "A"		Lot "B"	
Specimen No.	Load at Fracture (kips)	Specimen No.	Load at Fracture (kips)
6	185.7	5-A	208.8
5	194.4	4-A	218.4
4	196.3	3-A	208.8
3	211.3	2-A	225.0
2	156.9	1-A	213.1
Mean 188.9		Mean 214.8	
S.D. 20.1		S.D. 6.9	

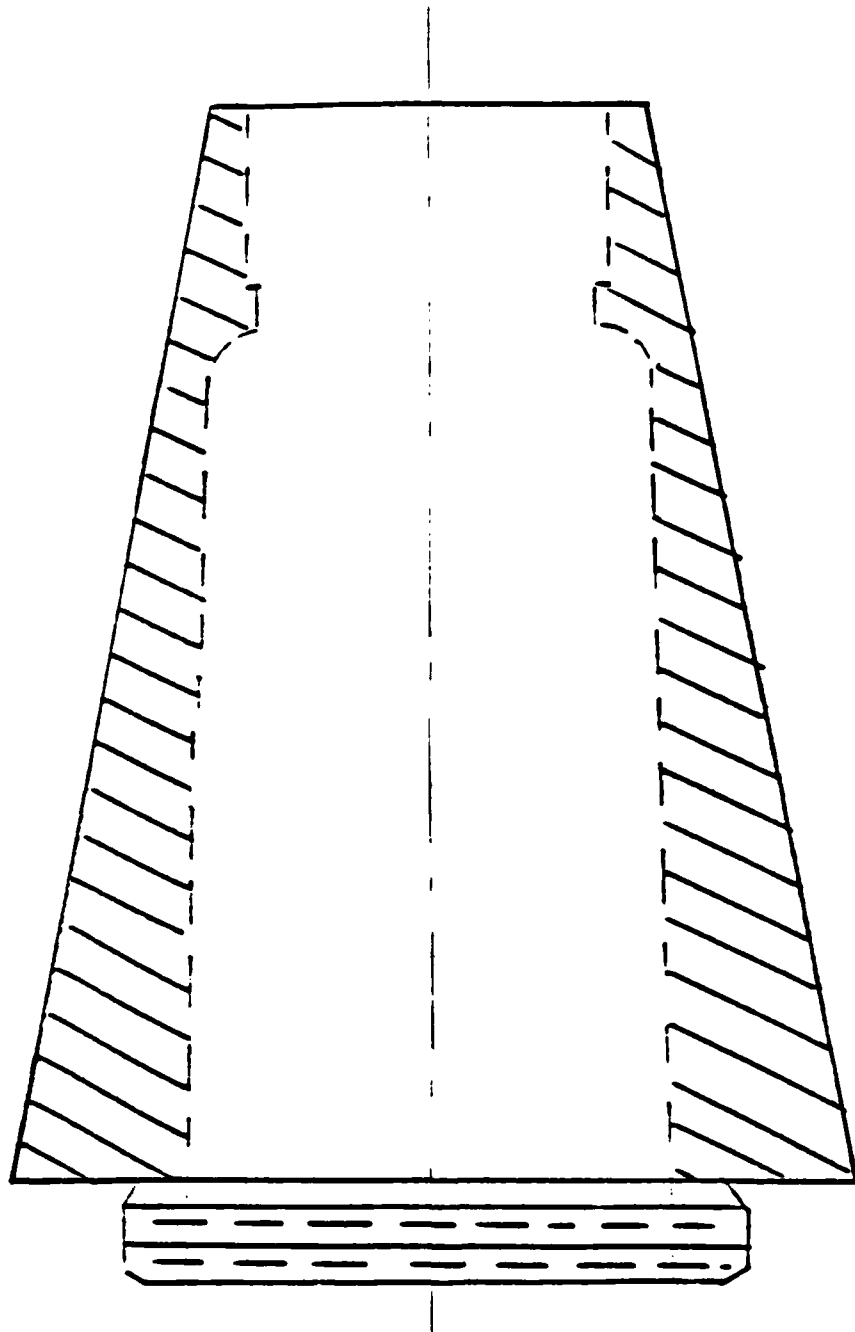


Figure 1. Schematic of nose cone.

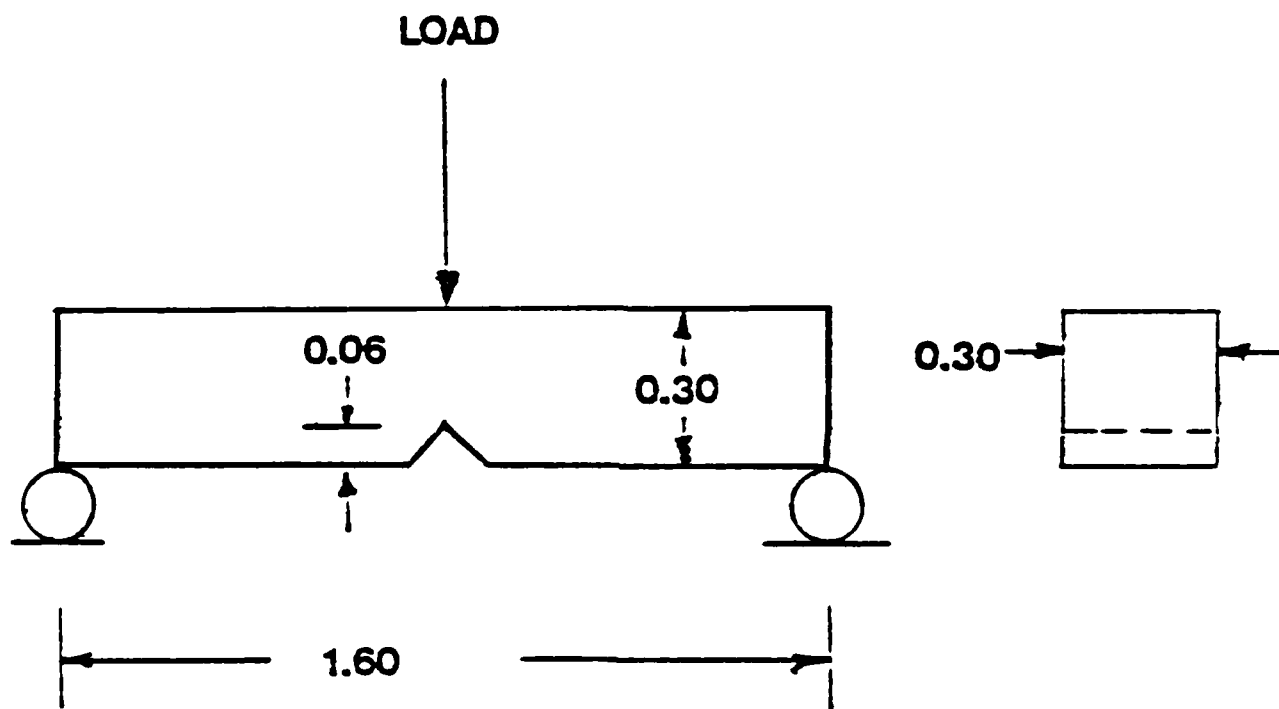


Figure 2. Subsize Charpy specimen.

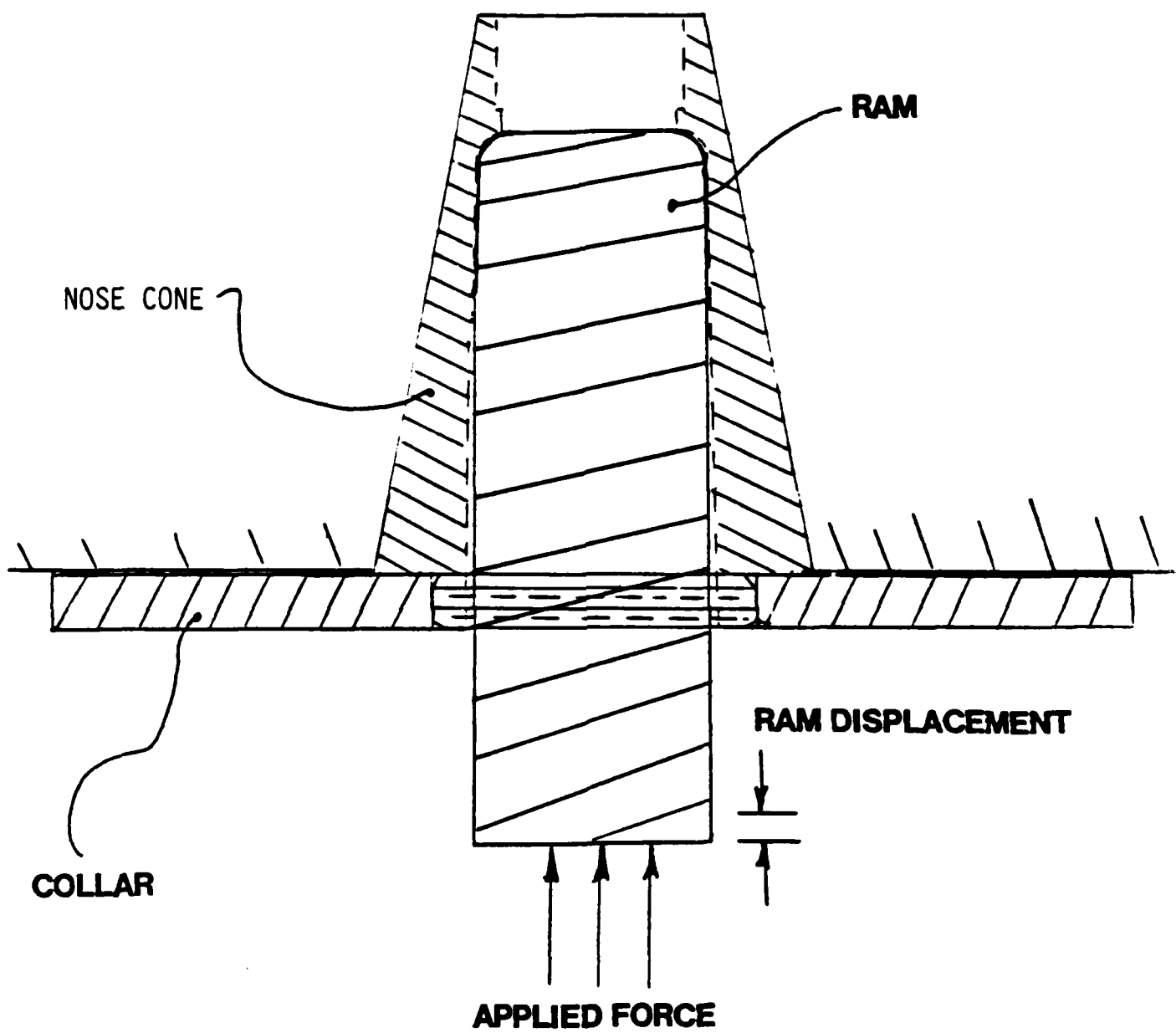


Figure 3. Simulation test fixture.

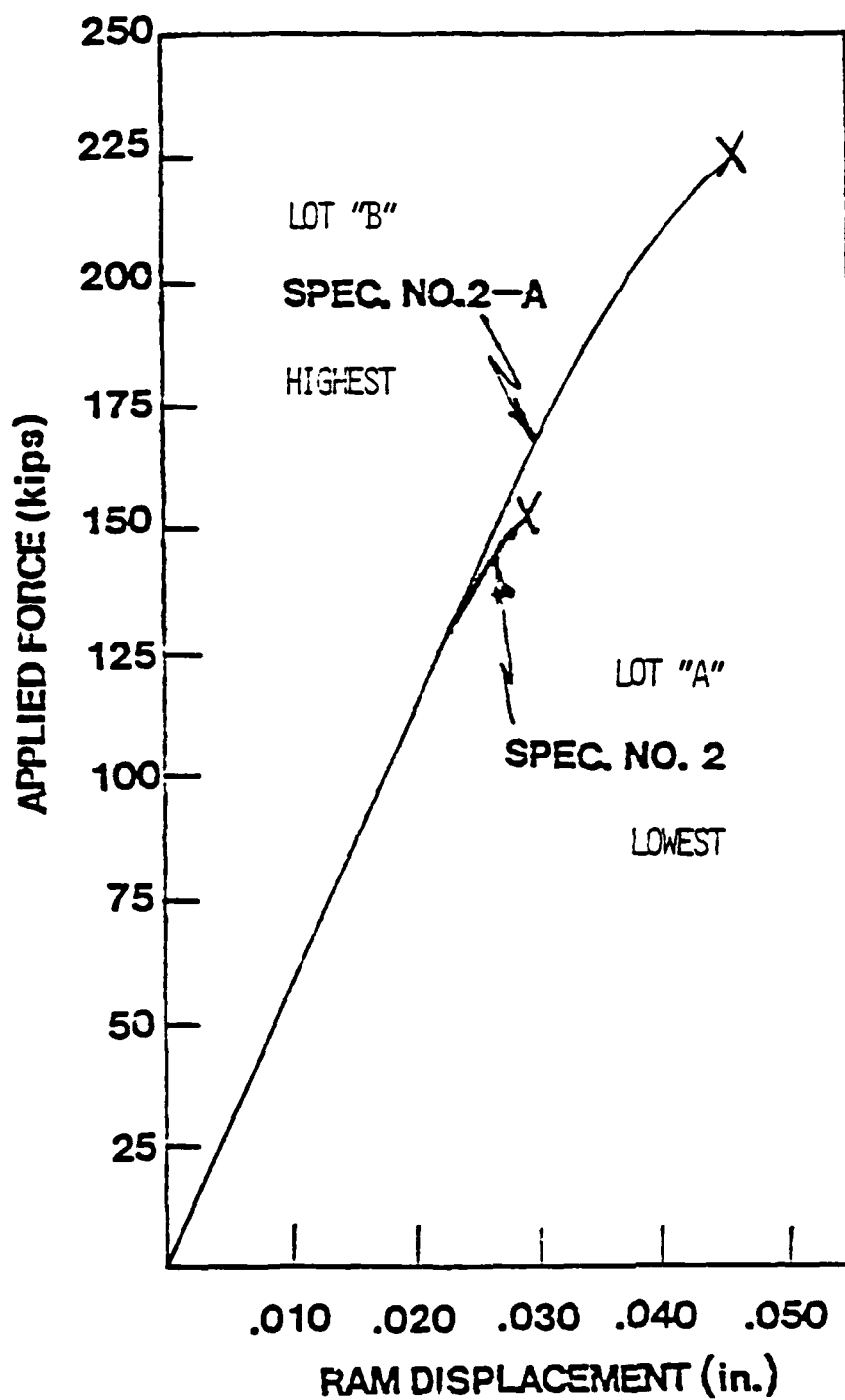


Figure 4. Force displacement plot from the simulation test.

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