AD NUMBER

ADB279856

NEW LIMITATION CHANGE

TO

Approved for public release, distribution unlimited

FROM

Distribution: Further dissemination only as directed by Office of Scientific Research and Development, Washington, DC 20301, 19 FEB 1945, or higher DoD authority.

AUTHORITY

OTS index dtd Jun 1947

[redacted]

NDRC
M-460

NATIONAL DEFENSE RESEARCH COMMITTEE

of

OFFICE OF SCIENTIFIC RESEARCH AND DEVELOPMENT

WAR METALLURGY DIVISION

DISTRIBUTION STATEMENT F:
Further dissemination only as directed by
OSRD, Wash, DC 20330
or higher DoD authority.
Feb 1945

Progress Report

on

BEHAVIOR OF METALS UNDER DYNAMIC CONDITIONS (NS-109): APPLICATION OF PURE STRAIN RATE TESTS TO AN INVESTIGATION OF TWO 76 MM GUN TUBES

by

P. E. DUWEZ, H. E. MARTENS, D. A. ELMER, AND D. S. CLARK
CALIFORNIA INSTITUTE OF TECHNOLOGY

20020513 114

OSRD No. 729

Serial No. M-460

Copy No. 88

February 19, 1945

[redacted]

February 19, 1945

To: Dr. James B. Conant, Chairman
National Defense Research Committee of the
Office of Scientific Research and Development

From: War Metallurgy Division (Div. 18), NDRC

Subject: Progress Report on "Behavior of Metals Under Dynamic Conditions (NS-109): The Application of Pure Strain Rate Tests to an Investigation of Two 76mm Gun Tubes".

The attached progress report submitted by D. S. Clark, Technical Representative on NDRC Research Project NRC-82, has been approved by representatives of the War Metallurgy Committee in charge of the work.

This report presents the results of an investigation of the static and the dynamic tensile properties of specimens from two 76mm gun tubes which had been ruptured previously by detonation of a high explosive shell in the bore.

Acceptance as a satisfactory progress report under Contract OEMsr-348 with the California Institute of Technology is recommended.

Respectfully submitted,

Clyde Williams

Clyde Williams, Chief
War Metallurgy Division, NDRC

Enclosure

PREFACE

This report is pertinent to the problems designated by the Office of the Coordinator of Research and Development, Navy Department, as NS-109, and to the project designated by the War Metallurgy Committee as NDRC Research Project NRC-82.

The distribution of this report is as follows:

Copies No. 1 thru 8 - Dr. Irvin Stewart, Executive Secretary, OSRD
Copy No. 9 - Clyde Williams, Chief, War Metallurgy Division (Div. 18), NDRC and Chairman, War Metallurgy Committee
Copy No. 10 - Office of the Executive Secretary, War Metallurgy Committee
Copy No. 11 - V. H. Schnee, Chairman, Products Research Division, War Metallurgy Committee
Copy No. 12 - H. W. Gillett, Member, Division 18, NDRC
Copy No. 13 - S. D. Heron, Member, Division 18, NDRC
Copy No. 14 - Zay Jeffries, Member, Division 18, NDRC
Copy No. 15 - R. F. Mehl, Member, Division 18, NDRC
Copy No. 16 - R. C. Tolman, Chairman, Subcommittee for Division 18, NDRC
Copy No. 17 - Roger Adams, Member, Subcommittee for Division 18, NDRC
Copy No. 18 - J. E. Jackson, Staff Aide for Division 18, NDRC
Copies No. 19 thru 40 - Dr. Franklin S. Cooper, Senior Liaison Officer, Liaison Office, OSRD
Copy No. 41 - E. B. Wilson, Jr., Chief, Division 2, NDRC
Copy No. 42 - Army Air Forces, Headquarters, Assistant Chief of Air Staff, Attn: Lt. Colonel J. M. Gruitch, Air Ordnance Office
Copies No. 43 and 44 - Army Air Forces, Commanding General, Wright Field Attn: Major J. P. AuWerter, NDRC Branch Liaison Officer.
Copy No. 45 - Army Service Forces, Commanding General, Frankford Arsenal Attn: Lt. Colonel C. H. Greenall
Copy No. 46 - Army Service Forces, Commanding General, Watervliet Arsenal. Attn: Colonel S. L. Conner
Copies No. 47 and 48 - Army Service Forces, Office, Chief of Engineers Attn: Lt. Colonel W. J. New, Equipment Development Branch
Copy No. 49 - Army Service Forces, Office, Chief of Ordnance Attn: Colonel S. B. Ritchie
Copy No. 50 - Jerome Strauss, Research Supervisor for Gun Steels Projects
Copy No. 51 - D. L. Edlund, Technical Representative, NDRC Research Project NRC-81
Copy No. 52 - G. R. Fitterer, Technical Representative, NDRC Research Project NRC-85
Copy No. 53 - Cyril Wells, Investigator, NDRC Research Projects NRC-38 and 39
Copy No. 54 - D. S. Clark, Technical Representative, NDRC Research Project NRC-82
Copy No. 55 - P. E. Duwez, Investigator, NDRC Research Project NRC-82
Copy No. 56 - H. E. Martens, Investigator, NDRC Research Project NRC-82
Copy No. 57 - Ensign D. A. Elmer, Investigator, NDRC Research Project NRC-82

Project Liaison Officers

Copy No. 58 - Navy Department, Bureau of Ordnance Attn: Commander T. J. Flynn
Copy No. 59 - Navy Department, Bureau of Ordnance Attn: A. Wertheimer

Project Liaison Officers (Cont'd)

Copy No. 60 - Navy Department, Bureau of Ships
Attn: Captain W. P. Roop
Copy No. 61 - Navy Department, Bureau of Ships
Attn: Captain T. A. Solberg
Copy No. 62 - Navy Department, Bureau of Ships
Attn: Comdr. C. H. Gerlach
Copy No. 63 - Navy Department, Bureau of Ships
Attn: Ensign R. C. Madden
Copy No. 64 - Navy Department, Bureau of Ships
Attn: E. Rassman
Copy No. 65 - Navy Department, Commanding Officer, Dahlgren Naval Proving Ground
Attn: Lt. Commander R. A. Sawyer
Copy No. 66 - Navy Department, Director, Naval Research Laboratories
Attn: Ross Gunn
Copy No. 67 - Army Air Forces, Commanding General, Wright Field
Attn: Captain R. T. Franzel, Aircraft Laboratory
Copy No. 68 - Army Service Forces, Commanding General, Aberdeen Proving Ground
Attn: Oswald Veblen
Copy No. 69 - Army Service Forces, Commanding General, Watertown Arsenal
Attn: Colonel H. H. Zornig, Director of Laboratories

Members of the Project Committee

Copy No. 70 - P. E. Kyle, Chairman
Copy No. 71 - T. N. Armstrong
Copy No. 72 - H. F. Bohnenblust
Copy No. 73 - F. B. Bolte
Copy No. 74 - L. R. Jackson
Copy No. 75 - John Johnston
Copy No. 76 - J. E. Lipp
Copy No. 16 - R. F. Mehl
Copy No. 77 - F. R. Shanley
Copy No. 78 - A. P. Spooner

Members of the Testing and Research Panel,
Aircraft War Production Council, Inc.

Copy No. 79 - Boeing Aircraft Company, W. E. Beall
Copy No. 80 - Consolidated-Vultee Aircraft Corp., Vultee Field Div., Harold Boyvey
Copy No. 81 - Douglas Aircraft Company, Inc., J. R. Goldstein
Copy No. 77 - Lockheed Aircraft Corporation, Factory "B", F. R. Shanley
Copy No. 82 - North American Aviation, Inc., L. P. Spalding
Copy No. 83 - Northrop Aircraft, Inc., T. E. Piper
Copy No. 84 - Ryan Aeronautical Company, J. C. Scurlock

Copy No. 85 - California Institute of Technology, Rear Admiral R. S. Holmes, USN Ret.
Copy No. 86 - California Institute of Technology, Theodore Von Karman
Copy No. 87 -
Copy No. 88 -
Copy No. 89 -
Copy No. 90 -
Copy No. 91 -
Copy No. 92 -
Copy No. 93 -
Copy No. 94 -
Copy No. 95 -
Copy No. 96 -
Copy No. 97 -
Copy No. 98 -
Copy No. 99 -
Copy No. 100 -

Total number of copies - 100

RESTRICTED

RESTRICTED

National Defense Research Committee

Division 18

NRC Project 82

OSRD Contract OEMsr-348

California Institute of Technology

Report No. XL

The Application of Pure Strain Rate Tests to An Investigation of Two 76 MM Gun Tubes

------

15 December 1944

Submitted by:
P. E. Duwez
H. E. Martens
D. A. Elmer, Ens. U.S.N.R.
D. S. Clark

Approved by:
D. S. Clark
Technical Representative
for Contract OEMsr-348

RESTRICTED

RESTRICTED

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

THE APPLICATION OF PURE STRAIN RATE TESTS TO AN INVESTIGATION OF TWO 76 MM GUN TUBES

ABSTRACT

This report presents the results of a study of two 76 MM gun tubes supplied by Watervliet Arsenal, and which had been ruptured by detonation of a high explosive shell in the bore. One tube fragmented badly while the other exhibited a ductile fracture. Specimens taken from each tube consisted of thin wall tubular cylinders which were tested both statically and dynamically under uniaxial stress conditions. The dynamic tests were made at strain rates as high as 190 in./in./sec. Rupture of some of the specimens occured with very low maximum uniform strain. Static tensile tests and Izod impact tests failed to reveal any difference in the two gun tubes. The tests on the uniaxial thin wall specimens show that the gun tube which failed in a brittle manner has a very low maximum uniform strain while the gun tube that failed in a ductile manner has a much higher maximum uniform strain. These results are discussed in relation to the influence of strain rate on the properties of each material and the effect of metallographic structure on the results. The conclusions of this investigation cannot be applied to all gun tubes until other guns are investigated.

Introduction

The Watervliet Arsenal submitted 9 in. sections taken from the mid-section of two 76 MM gun tubes. These guns were ruptured by detonation of a high explosive shell in the bore. One gun fragmented badly with no visible evidence of ductility, while the other exhibited a ductile fracture. Static tensile tests and Charpy impact tests made at Watervliet Arsenal failed to show any marked difference between the materials of the two gun tubes at **ordinary temperature.**

Under the conditions to which these tubes were subjected, pure strain rate prevails, that is, strain propagation is negligible. In view of the marked difference in the performance of these two materials under

the severe dynamic condition imposed upon them and the absence of a difference in static properties, strain rate studies were initiated. The principles underlying strain rate as distinct from impact have been presented in a previous report.[1)]

The purpose of this report is to present the results of strain rate tests made on specimens from the two gun tubes in the hope that a difference in properties might be revealed.

Testing Equipment

A vertical impact testing machine and recording facilities were used for these strain rate tests. A complete description of this equipment was given in a previous report.[2)] In these tests a pure rate of strain is attained by using a tubular specimen (Fig. 1-a) filled with mercury which is subjected to an increasing internal pressure. The rate of pressure rise is controlled by the motion of a piston in a cylinder connected directly to the specimen. The desired speed of the piston is attained by striking one end of the piston with a hammer moving at the required velocity.

The vertical impact machine (Fig. 2) consists of a pair of vertical rails which guide the hammer. The hammer is accelerated by rubber bands or allowed to fall freely, depending upon the velocity required. The specimen and pressure cylinder assembly (Fig. 3) is mounted on a column. The lower end of this column rests on the floor and the upper end is supported between the guide rails. The strain rate of the test is computed from the velocity of the hammer. Values obtained are accurate

1) The influence of pure strain rate on the tensile properties of three types of ship plate by P. E. Duwez, H. E. Martens, D. A. Elmer, and D. S. Clark, Contract OEMsr-348, Report No. XXXIX.

2) Reference 1.

to within ± 5 percent.

The lower end of the specimen is unsupported and provided with a close, but free fitting plug, which makes the axial component of stress in the specimen zero and thus gives uniaxial loading conditions. This plug transmits the internal fluid force to a resistance-sensitive strain gage type dynamometer. The change in resistance of the gage is recorded with a cathode-ray oscillograph. Considering the accuracy of response of the electrical system and the variation in cross sectional area of the specimen, the stress values obtained are accurate to within ± 10 percent. The values of maximum uniform circumferential strain are computed from the measured diameter of the ruptured specimen with an accuracy of within ± 6 percent.

Static uniaxial tests were made on tubular specimens similar to those used in the dynamic tests (Fig. 1-b). The pressure is applied by means of oil in a piston and cylinder assembly in a universal testing machine. Stress values are obtained from the applied load and the cross-sectional area of the specimen with a resulting accuracy of within ± 6 percent. Circumferential strain is measured by means of a dial gage with an accuracy of within ± 2 percent.

Static tensile tests were made on specimens shown in Fig. 1-c with a Riehle 30000 lb universal testing machine.

Materials Tested

The materials tested were from the tubes of two 76 MM guns submitted by Watervliet Arsenal. Sections 9 in. long were taken from approximately the mid-section of the tubes.

RESTRICTED

In accordance with information from Watervliet Arsenal, these guns were ruptured by the detonation of a high explosive shell in the bore. Gun No. 351 fragmented badly with no visible evidence of ductility. Gun No. 2129 exhibited a definitely ductile fracture. Data supplied by Watervliet Arsenal is given in Tables I, II, and III.

Uniaxial strain rate specimens were taken from the tube sections with the axis of the specimen parallel to the bore. The tensile specimens were taken perpendicular to the bore. The location of the specimens is shown in Fig. 4.

Photomicrographs were taken of the structure of the steels in sections both parallel and perpendicular to the bore and at the inner and outer surfaces of the cross section. See Figs. 5, 6, 7, and 8. Both steels have a tempered structure. The structure of gun No. 351 contains rather extensive regions of free ferrite which do not appear as pronounced in the structure of gun No. 2129. There appears to be more pro-eutectoid ferrite in the structure near the outside of gun No. 351 than in the inside. The difference between the inner and outer portions of gun No. 2129 is not very great.

Static Test Results

Static tensile tests and static tests using a tubular specimen under internal fluid pressure were performed on specimens taken from the two gun tubes. The test results are presented in Table IV and curves of tensile stress vs. strain and hoop stress vs. hoop strain are given in Fig. 9 and Figs. 10 and 11 respectively. A photograph of tubular specimens before and after testing is shown in Fig. 12.

The proportional limit and ultimate strength of tubular specimens from gun No. 351 were within the ranges of 90,000 and 112,000 lb/in.^{2} and 99,000 to 135,500 lb/in.^{2} respectively. The range of maximum uniform strain varied from 0.4 to 1.7 percent. The proportional limit and ultimate strength of tubular specimens from gun No. 2129 were within the ranges of 106,000 to 128,000 lb/in.^{2} and 134,000 to 147,500 lb/in.^{2} respectively. The maximum uniform strain varied from 1.2 to 4.3 percent. Two of the tests on gun No. 351 failed prematurely as evidenced in Table IV, both by the low values of stress and small uniform strain. If results in which the specimens failed prematurely are disregarded, the ultimate strength and proportional limit of both gun tubes are about the same respective values as reported by Watervliet Arsenal. It will be noted by comparing Figs. 10 and 11 that the maximum uniform hoop strain of the two materials is markedly different.

The results of the static tensile tests made in the present investigation showed no appreciable difference in elongation of the two gun tube materials. However, the ultimate strength of gun No. 2129 was somewhat higher than that of gun No. 351.

Dynamic Test Results

The results of uniaxial strain rate tests made on tubular specimens from the two gun tubes are presented in Tables V and VI. All of the specimens tested had an inside diameter of 0.250 in. and a gage length of 1.25 in. The velocity given in the fourth and fifth columns of tables V and VI is the velocity of the actuating piston. The velocity given in column four is computed from the height of fall of the drop hammer, That given in column five is measured by a series of electrical contacts passed over by a finger attached to the rubber band accelerated hammer. The rate of strain ($\frac{d\epsilon}{dt}$) in in./in./sec is computed according to the following equation:

$$\frac{d\epsilon}{dt} = \left(\frac{r_p}{r}\right)^2 \frac{v_p}{2L}$$

in which r_p is the radius of the piston.

r is the inside radius of the specimen

L is the gage length of the specimen

v_p is the velocity of the piston

This equation has been derived in the appendix.

The values of proportional limit and ultimate strength are computed from the force-time diagrams recorded by the cathode-ray oscillograph. Two typical diagrams recorded at strain rates of 42.2 and 98.9 in./in./sec are shown in Figs. 13 and 14 respectively. The maximum fluid pressure is computed from the value of maximum force recorded in the test. From this the ultimate strength is computed by means of the formula:

$$\sigma = \frac{pe}{r_a}$$

where p is the fluid pressure, e is the wall thickness and r_a is the average radius of the tubular specimen. When the recorded diagram presents oscillations a smooth curve is traced through an average value and the maximum force is determined from this smooth curve. The proportional limit is taken as the stress corresponding to the force at which the diagram starts to curve to the right. Only the diagrams recorded for a rate of strain of 42 2 in./in./sec have the shape shown in Fig. 13. For higher rates of strain all of the force-time diagrams are of this type shown in Fig. 14 and the proportional limit is taken as equal to the ultimate strength. In cases where the maximum hoop strain is less than about 1.5 percent a value of ultimate strength cannot be determined because fracture takes place prematurely.

The diameter of the specimen was measured after the test. This measurement was made on that portion of the specimen which remained nearly cylindrical in shape and not in the region of the rupture. In general, that part of the specimen which remains nearly cylindrical after the rupture occupies more than half of the gage length. A photograph of the specimens before and after testing is shown in Fig. 15. The photographs of the fractured specimens give the appearance that the diameter is less at the point of rupture. This is due to reflections and is not the condition that exists.

The ultimate strength and proportional limit are plotted against rate of strain for each gun tube in Figs. 16, 17, and 18 using different symbols to correspond to the location of the specimens in the gun tubes referred to in Fig. 4.

All of the specimens taken from the inside of gun No. 351 (C in Fig. 4) exhibited very low strain and no values of ultimate strength could be determined. In spite of the fact that 7 of the 17 specimens taken from the outside of the tube (A and B in Fig. 4) showed premature failure, the 10 good records give enough data to show the trend of variation of stress vs. strain rate. Values of ultimate strength and proportional limit obtained at a strain rate of 42.2 in./in./sec are less than static values (10 percent lower and 20 percent lower respectively). At a strain rate of 75.8 in./in./sec the proportional limit is equal to the ultimate strength. The latter is about the same as that obtained in static tests. Values of maximum uniform strain vary from 0 to 5.8 percent and are so scattered that no correlation can be made with rate of strain.

In the case of gun No. 2129, two of the specimens failed prematurely. There is no apparent difference in behavior of specimens taken from the inside or outside sections of the gun tube. At a strain of 42.2 in./in./sec the ultimate strength is about 10 percent lower than the static value and the proportional limit is about 30 percent lower than the static proportional limit. At higher strain rates the ultimate strength tends to become equal to the static value. At strain rates above about 70 in./in./sec the proportional limit becomes equal to the ultimate strength. Values of maximum uniform strain vary from 0.7 to 7.2 percent and are so scattered that no systematic variation with rate of strain can be seen.

Discussion of Results

The occurance of premature rupture of the tubular specimens in both the static and dynamic state is a significant factor in comparing the characteristics of the two gun tubes. Most of the specimens taken from gun No. 351 failed prematurely with very low values of maximum uniform strain while relatively few specimens of gun No. 2129 failed in this manner and the maximum uniform strain was in most cases greater than 3 percent. The appearance of this difference in the results of the uniaxial tests and not in the results of the usual tensile and Izod impact tests may be related to the thin wall of the tubular specimen employed. The wall thickness is only about 0.013 in. and therefore, inhomogeneities in the structure of the steel might be expected to have a marked effect on the results while in a thicker specimen they might be of less significance. Even with thick specimens these inhomogeneities in the structure might be of great importance under conditions associated with detonation. In the present case the ductile performance of gun tube No. 2129 and the brittle performance of gun tube No. 351 under detonating conditions seem to correlate with the appearance of premature fracture in the uniaxial tubular specimens.

The ultimate strength of specimens from the two gun tubes seems to be effected in about the same way by increasing the strain rate. It is somewhat difficult to understand how the ultimate strength at a strain rate of 42.2 in./in./sec can be less than the static value and about the same as the ultimate strength at a strain rate of 75.8 in./in./sec. It is possible that the dip in the curve of ultimate strength versus strain rate is associated with normal scatter of data. More tests would be required to prove this.

The proportional limit of the material from both gun tubes seems to decrease at first with increasing strain rate and then to increase until it becomes equal to the ultimate strength at a strain rate of about 70 in./in./sec. From results of similar tests on other materials previously reported,[3] the decrease of the proportional limit is unusual, but the increase to the ultimate strength is normal.

The values of maximum uniform strain determined by measuring the specimens after rupture are so scattered that nothing can be said of their relationship to strain rate. In general the maximum uniform strain is less with the specimens from gun No. 351 than from gun No. 2129. It is probable that the conditions which initiate rupture are not easily reproduced because of structural inhomogeneities in the steel and the small wall thickness of the tubular specimens.

---

3) Reference 1

While it is difficult to establish what inhomogeneities in the structure may be responsible for the behavior of the materials in each gun tube, certain differences of structure may be observed in the photomicrographs. For example, tube No. 351 appears to have not only a coarser grain structure than tube No. 2129, but the former has considerably more free ferrite than the latter. It is of interest to note that there is considerably more free ferrite in the outside portion of tube No. 351 than in the same region of tube No. 2129. Some of the dynamic specimens taken from this portion of tube No. 351 failed prematurely with very low values of maximum uniform strain while almost all of the dynamic specimens from tube No. 2129 gave satisfactory results. However, all specimens taken from the inside of tube No. 351 failed prematurely and had less free ferrite than specimens from the outer portion.

Conclusions

It may be concluded from this investigation that for the particular gun tubes studied the uniaxial strain rate tests correlate with the results of tests made by the detonation of an explosive shell in the bore of the tubes. Gun tube No. 351 which fragmented badly in the explosion test gives very low maximum uniform strain values when tested under uniaxial stress conditions with thin wall specimens. The maximum uniform strain values of specimens of gun tube No. 2129 are considerably greater than for the other tube. Tube No. 2129 failed in a ductile manner in the explosion test. Further tests would be required on other gun tubes with a larger number of specimens before widespread conclusions could be made.

APPENDIX

Derivation of the Equation for the Rate of Strain

The rate of strain in the specimen can be found as a function of the geometry of the apparatus and the velocity of the piston, provided it is assumed that the fluid is incompressible. If L is the length of the gage section of the tube, the volume of mercury necessary to produce an increase dr of the inside radius r of the specimen during a time dt, is equal to $2\pi r \frac{dr}{dt} L$. This volume is equal to the volume of mercury displaced by the piston during the time dt, which is equal to $\pi r_p^2 v_p$, in which r_p and v_p are the radius and the velocity of the piston respectively. The following relation results:

$$2\pi r \frac{dr}{dt} L = \pi r_p^2 v_p$$

from which the rate of strain $\frac{1}{r}\frac{dr}{dt}$ is found to be:

$$\frac{d\varepsilon}{dt} = \frac{1}{r}\frac{dr}{dt} = \left(\frac{r_p}{r}\right)^2 \frac{1}{2L} v_p$$

TABLE 1

CHEMICAL COMPOSITION OF GUN TUBES

Gun No.	Forging No.	Heat No.	Chemical Composition (per cent) C	Mn	P	S	Cr	Mo	V
351	15410	1790	.28	.73	.014	.013	.99	.51	.14
2129	15836	E-1797	.29	.73	.014	.014	1.00	.50	.10

TABLE 11

HEAT TREATNEBT OF GUN TUBES

Gun No.	Condition of Tube	Heat Treatment
351	Solid	1700 up 27 hrs., hold 24 hrs., furnace cooled 1675 up 18 hrs., hold 9 hrs., water quenched 1140 up 13 hrs., hold 9 hrs., furnace cooled 1675 up 14 hrs., hold 9 hrs., water quenched 1150 up 11 hrs., hold 10 hrs., furnace cooled
2129	Hollow	1700 up 24 hrs., hold 24 hrs., furnace cooled 1675 up 17 hrs., hold 12 hrs., water quenched 1150 up 14 hrs., hold 8 hrs., furnace cooled

TABLE 111*

AVERAGE PHYSICAL PROPERTIES OF GUN TUBES

	Watervliet Arsenal Data					Manufacturer's Data			
Gun No.	Yield Point ($lb/in.^2$)	Ultimate Strength ($lb/in.^2$)	Elong. (percent)	Red. Area (percent)	Charpy Impact (ft-lb.)	Yield Point ($lb/in.^2$)	Ultimate Strength ($lb/in.^2$)	Elong. (percent)	Red, Area (percent)
351	107400	137400	11.3	25.3	6.3	126100	140000	12.4	34.6
2129	104500	143700	14.7	43.3	18.8	134900	145800	13.6	42.1

* Locations of specimens on which Watervliet tests were made are not known.

TABLE IV

RESULTS OF STATIC TESTS ON SPECIMENS FROM GUN TUBES

Type Test	Specimen Number	Proportional Limit $(lb/in.^2)$	Ultimate Strength $(lb/in.^2)$	Uniform Hoop Strain (percent)	Elongation in 3 in. (percent)	Reduction of Area (percent)
GUN TUBE 351 - Average hardness 28.7 Rockwell C						
Uniaxial Tubular	A-1	108000	133000	1.5		
	A-2	112000	135500	1.3		
	B-1	106000	125000	1.0		
	B-2 *	90000	99000	0.5		
	C-1	104000	130000	1.7		
	C-2 *	100000	107000	0.4		
Tensile	1	94000	128000		6.0	21.3
	2	98000	128200		7.6	40.8
GUN TUBE 2129 - Average hardness 29.6 Rockwell C						
Uniaxial Tubular	A-1	128000	147500	4.3		
	A-2	120000	145000	4.1		
	B-1	112000	137000	4.3		
	B-2	113000	134000	2.2		
	C-1	126000	144000	1.2		
	C-2	106000	138000	4.0		
	D-1	108000	137500	4.0		
	D-2	110000	140000	2.5		
Tensile	1	110000	134000		6.6	47.1
	2	108000	136000		6.8	44.4

* Premature failure.

TABLE V

RESULTS OF DYNAMIC STRAIN RATE TESTS ON GUN NO. 351

Specimen Number	Profilometer Reading (μ in. r.m.s.)	Outside Diameter (in.)	Velocity of Hammer (ft/sec.) Free Fall (computed)	Velocity of Hammer (ft/sec.) Rubber Accelerated (measured)	Rate of Strain (in/in/sec.)	Proportional Limit (lb/in.^{2})	Ultimate Strength (lb/in.^{2})	Outside Diameter After Rupture (in.)	Maximum Uniform Strain at Rupture (percent)
A-1 *	6	0.276	10	-	42.2	-	-	0.278	0.7
A-2 *	9	0.278	10	-	42.2	-	-	0.280	0.7
A-3	9	0.277	10	-	42.2	90500	118000	0.282	1.8
A-4	9	0.278	10	-	42.2	95000	118000	0.283	1.8
A-5	10	0.277	10	-	42.2	91500	119000	0.291	5.1
A-6	11	0.277	18	-	75.8	-	125000	0.281	1.4
A-7	13	0.277	18	-	75.8	-	134000	0.285	2.9
A-8	12	0.277	18	-	75.8	-	142000	0.293	5.8
A-9 *	10	0.281	-	25.3	103	-	-	0.284	1.1
B-1	10	0.276	10	-	42.2	76000	115000	0.280	1.4
B-2 *	6	0.277	10	-	42.2	-	-	0.280	1.1
B-3	11	0.277	10	-	42.2	78500	111000	0.287	3.6
B-4	9	0.277	10	-	42.2	94000	113000	0.279	0.7
B-5 *	11	0.276	10	-	42.2	-	-	0.277	0.4
B-6	9	0.277	10	-	42.2	80000	119000	0.286	3.3
B-7 *	9	0.277	18	-	75.8	-	-	0.277	0.0
B-8 *	10	0.277	18	-	75.8	-	-	0.279	0.7
C-1 *	7	0.276	10	-	42.2	-	-	0.276	0.0
C-2 *	15	0.276	10	-	42.2	-	-	0.276	0.0
C-3 *	5	0.277	10	-	42.2	-	-	0.279	0.7
C-4 *	6	0.277	10	-	42.2	-	-	0.278	0.4
C-5 *	9	0.277	18	-	75.8	-	-	0.278	0.4
C-6 *	9	0.278	18	-	75.8	-	-	0.280	0.7
C-7 *	10	0.278	18	-	75.8	-	-	0.279	0.4
C-8 *	7	0.277	-	25 **	104 **	-	-	0.279	0.7
C-9 *	6	0.278	-	25 **	104 **	-	-	0.280	0.7
C-10	9	0.278	-	25 **	104 **	-	-	0.285	2.5
C-11 *	6	0.277	-	45 **	190 **	-	-	0.278	0.4
C-12 *	9	0.278	-	45 **	190 **	-	-	0.281	1.1
C-13 *	9	0.278	-	45 **	190 **	-	-	0.278	0.0
C-14	-	0.278	-	45 **	190 **	-	-	0.285	2.5

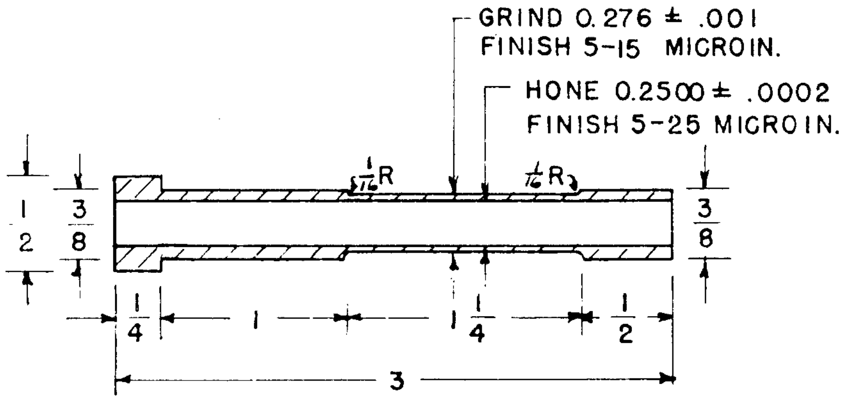
* Premature failure
** Estimated

TABLE VI

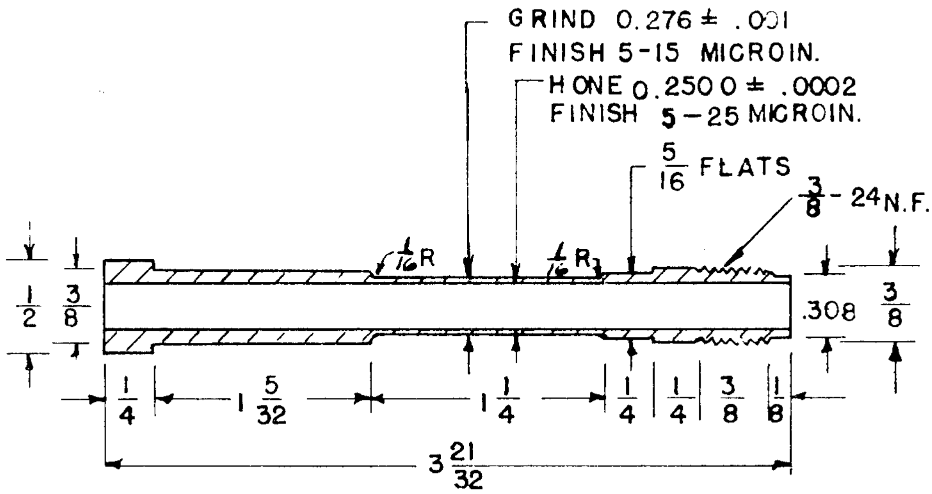
RESULTS OF DYNAMIC STRAIN RATE TESTS ON GUN NO. 2129

Specimen Number	Profilometer Reading (μ in. r.m.s.)	Outside Diameter (in.)	Velocity of Hammer (ft/sec) Free Fall (computed)	Velocity of Hammer (ft/sec) Rubber Accelerated (measured)	Rate of Strain (in./in./sec)	Proportional Limit (lb/in.^{2})	Ultimate Strength (lb/in.^{2})	Outside Diameter After Rupture (in.)	Maximum Uniform Strain of Rupture (percent)
A-1	10	0.276	10	-	42.2	-	-	0.291	5.4
A-2	4	0.278	10	-	42.2	93500	129000	0.292	5.0
A-3	10	0.278	10	-	42.2	89000	126000	0.287	3.2
A-4	9	0.277	10	-	42.2	87000	134000	0.283	2.2
A-5	9	0.277	18	-	75.8	-	128000	0.280	1.1
A-6	8	0.277	18	-	75.8	-	122000	0.289	4.3
A-7	-	0.281	-	25.3	103	-	128000	0.283	0.7
A-9	8	0.281	-	24.4	98.9	-	154000	0.288	2.5
B-1	7	0.276	10	-	42.2	81000	119000	0.293	6.2
B-2	12	0.276	10	-	42.2	83000	117500	0.290	5.1
B-3	12	0.277	10	-	42.2	-	-	0.295	6.5
B-4	8	0.277	10	-	42.2	78000	125000	0.291	5.1
B-5*	8	0.277	18	-	75.8	-	-	0.279	0.7
B-6	9	0.276	18	-	75.8	-	128000	0.296	7.2
B-7	6	0.276	18	-	75.8	-	141000	0.289	4.7
B-8	8	0.277	18	-	75.8	-	134000	0.291	5.1
B-9	6	0.277	-	25.4	107	-	151000	0.288	4.0
B-10	-	0.281	-	45.2	183	-	142000	0.293	4.3
C-1	6	0.277	10	-	42.2	82000	120000	0.285	2.9
C-2	13	0.276	10	-	42.2	82000	124500	0.285	3.3
C-3	12	0.276	10	-	42.2	76000	105000	0.280	1.4
C-4	6	0.275	18	-	75.8	-	142000	0.285	3.6
C-5	14	0.277	18	-	75.8	-	130000	0.282	1.8
C-6	9	0.278	18	-	75.8	-	130000	0.280	0.7
C-7	-	0.306	-	24.9	105	-	-	0.309	1.0
D-1	15	0.276	10	-	42.2	81000	108000	0.278	0.7
D-2	9	0.277	10	-	42.2	86000	119000	0.287	3.6
D-3	15	0.277	10	-	42.2	82500	124000	0.288	4.0
D-4	10	0.277	18	-	75.8	-	-	0.290	4.7
D-5	9	0.277	18	-	75.8	-	145000	0.288	4.0
D-6	6	0.276	18	-	75.8	-	134000	0.283	2.5
D-7	9	0.277	18	-	75.8	-	123000	0.282	1.8
D-8*	8	0.277	-	25.3	107	-	-	0.282	1.8

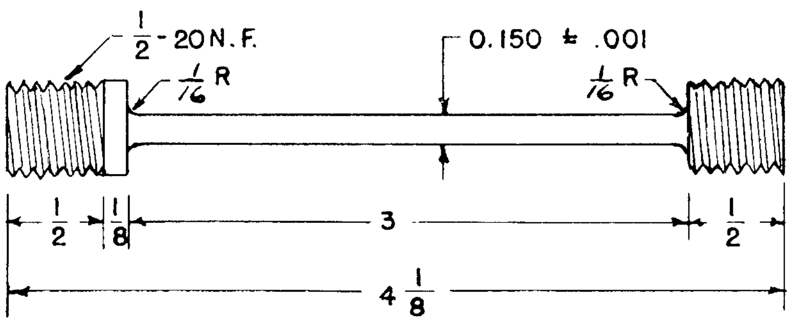
* Premature failure



(a) **Strain rate specimen.**



(b) Static tubular specimen.



(c) Static tensile specimen.

Fig. 1 Test Specimens.

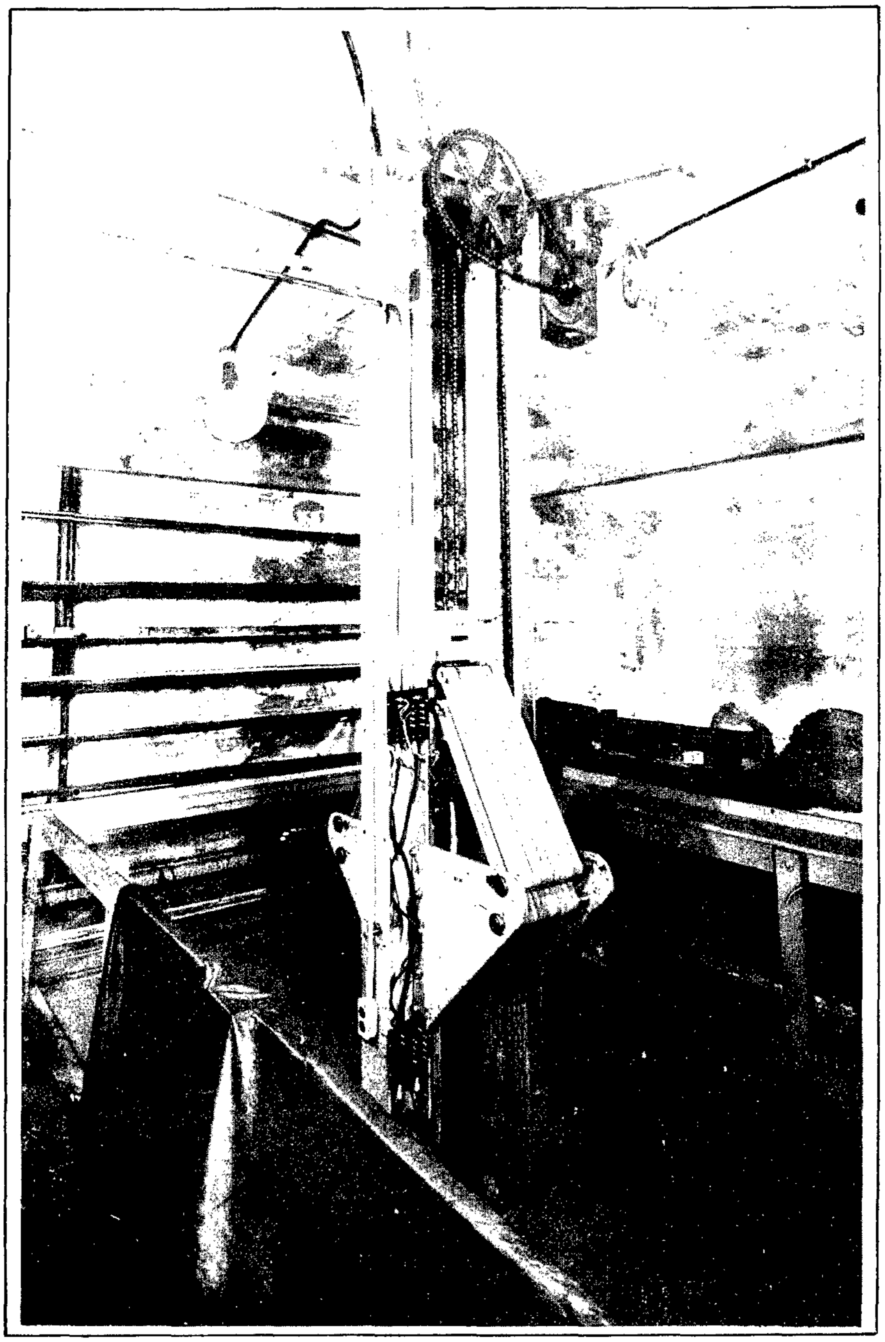
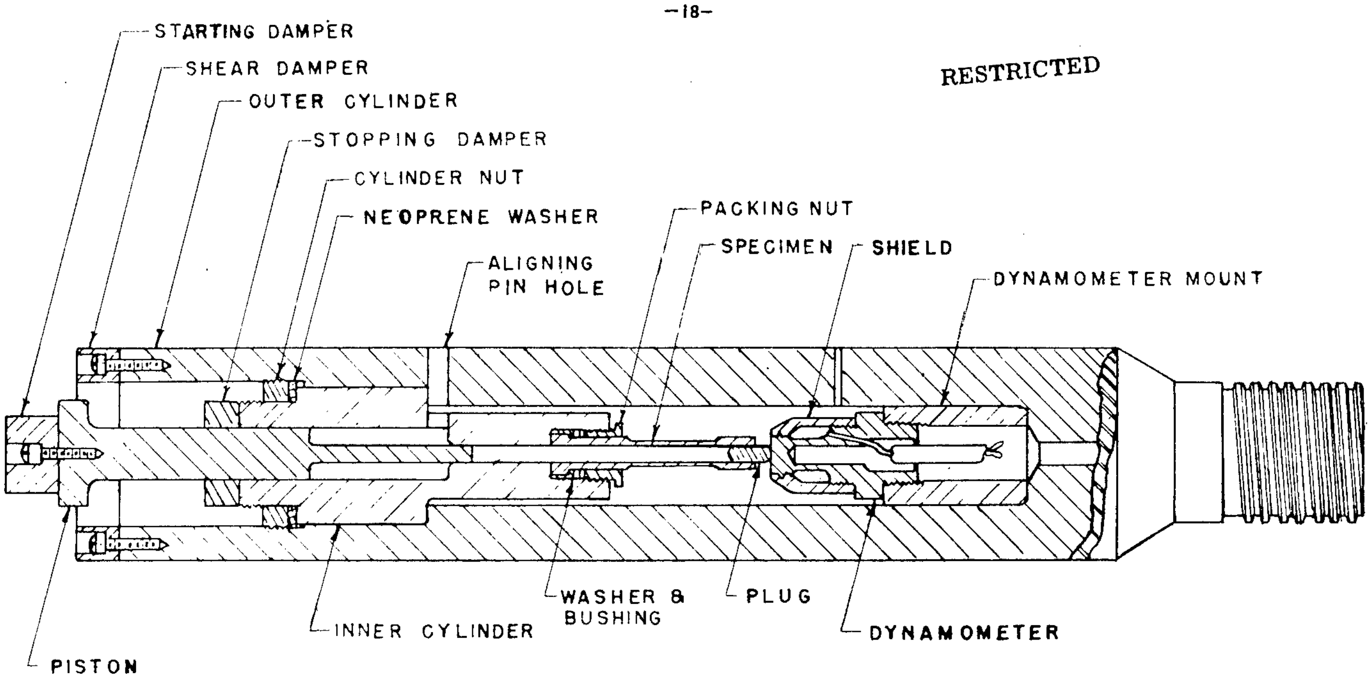


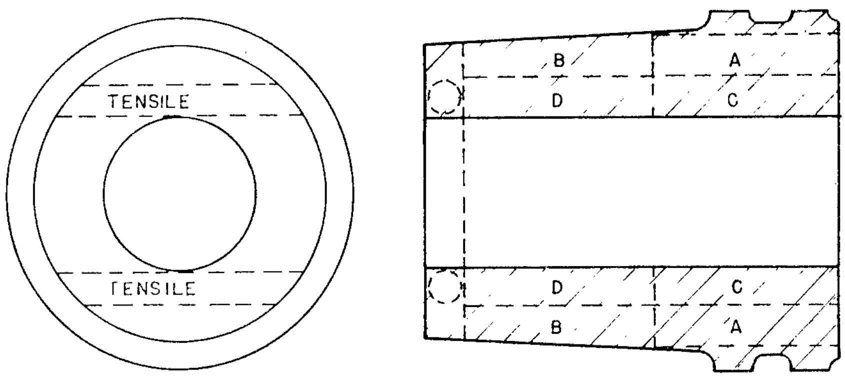
Fig. 2 Vertical impact testing machine.

RESTRICTED



Scale ½in. = 1in.

Fig. 3 Cylinder assembly, strain rate testing.



RESTRICTED

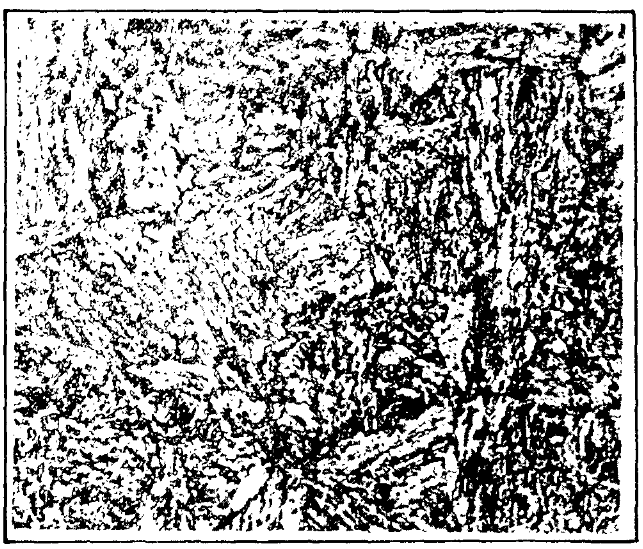
Fig. 4 Location of specimens.

(Specimens C and D of gun No. 351 were not separated and all marked C).

500 X

1500 X

Parallel to bore

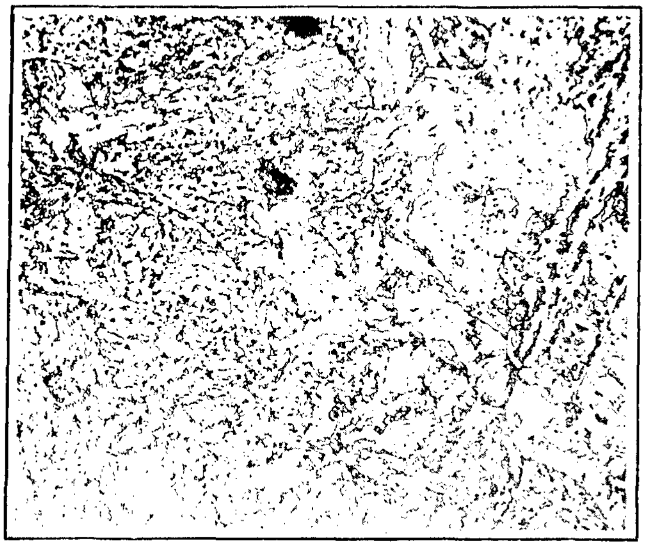


500 X

1500 X

Perpendicular to bore

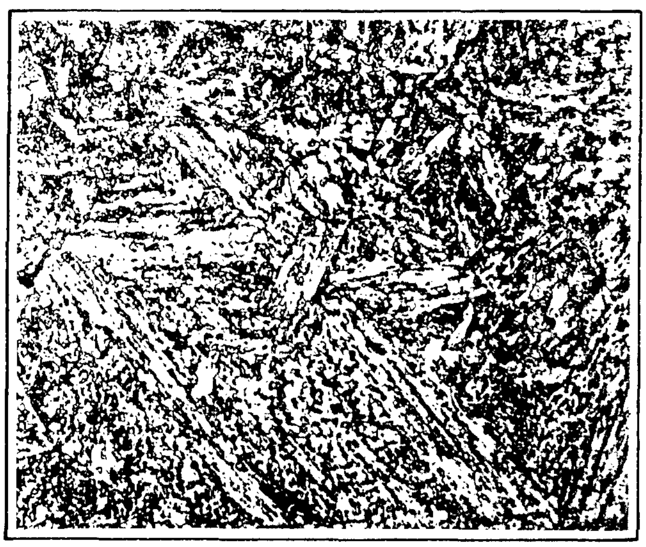
Fig. 5 Photomicrographs of gun tube No. 351, outside of tube.



500 X

1500 X

Parallel to bore



500 X

1500 X

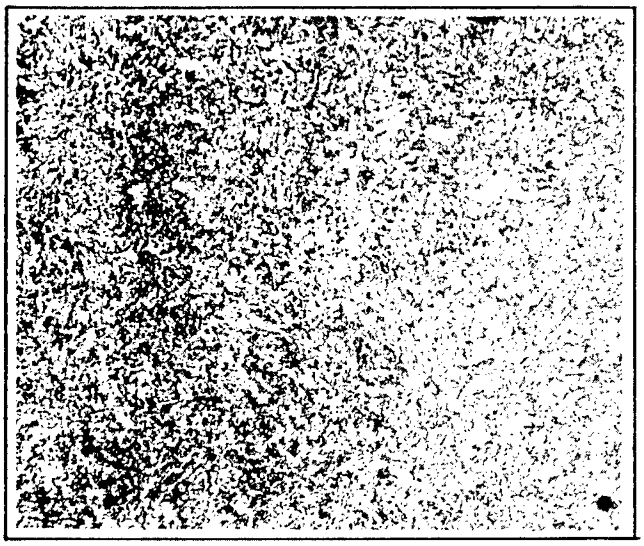
Perpendicular to bore

Fig. 6 Photomicrographs of gun tube No. 351, inside of tube.

500 X

1500 X

Parallel to bore



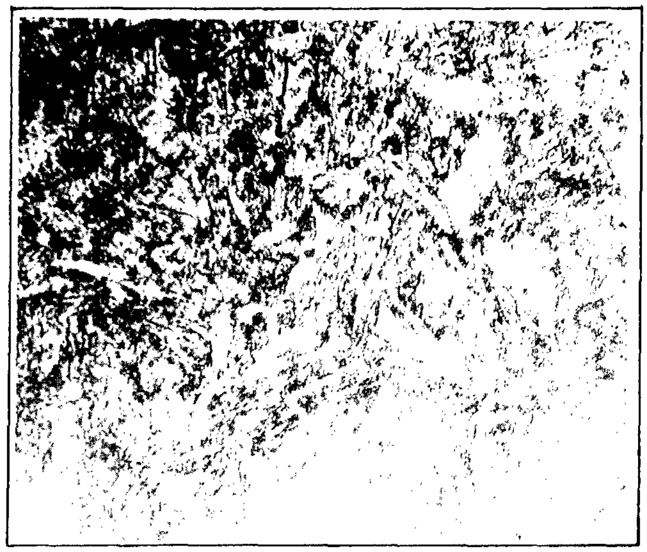
500 X

1500 X

Perpendicular to bore

Fig. 7 Photomicrographs of gun tube No. 2129, outside of tube.

500 X



1500 X

Parallel to bore

500 X

1500 X

Perpendicular to bore

Fig. 8 Photomicrographs of gun tube No. 2129, inside of tube.

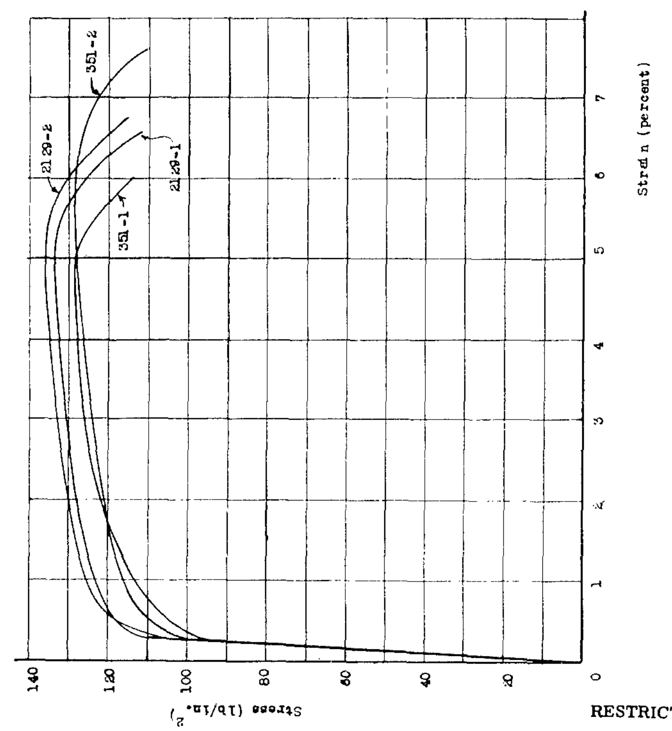


Fig. 9 Static tensile stress-strain curves for gun tube steels.

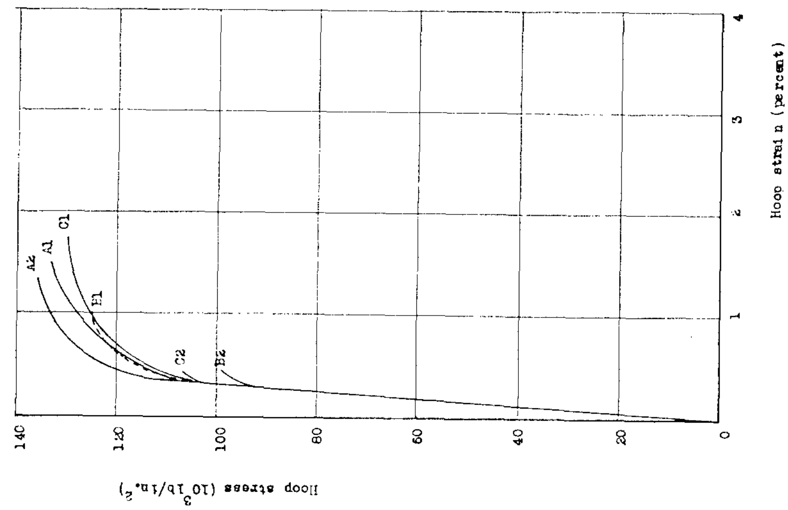


Fig. 10 Stress vs. strain for static uniaxial specimens taken from gun No. 351.

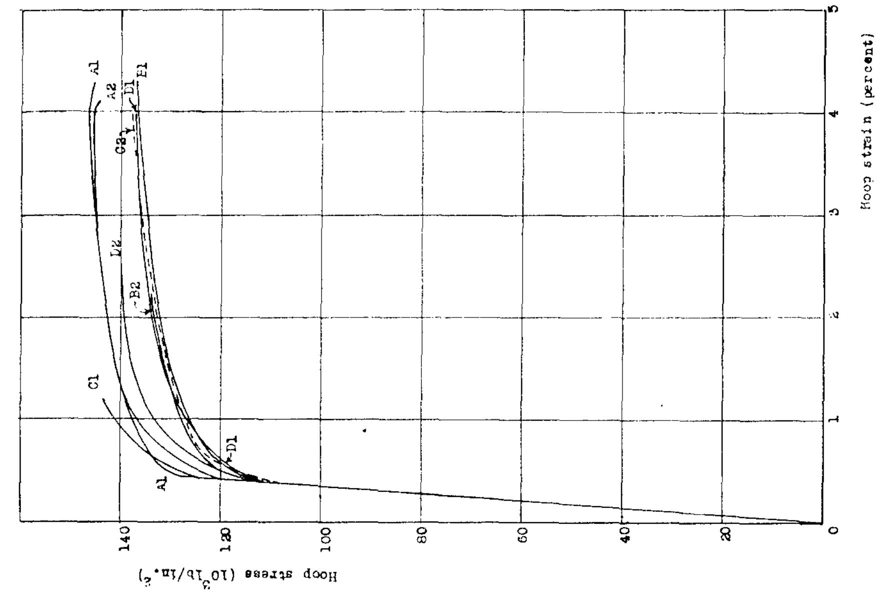


Fig. 11 Stress vs. strain for static uniaxial specimens taken from gun No. 2129.

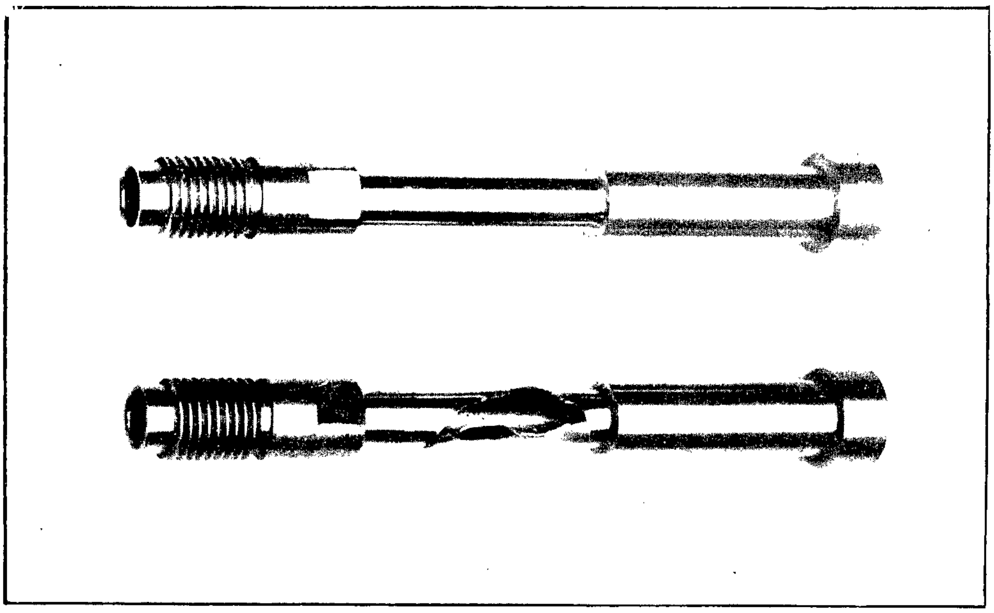


Fig. 12 Typical static uniaxial specimens.
(a) Untested specimen.
(b) Ruptured specimen.

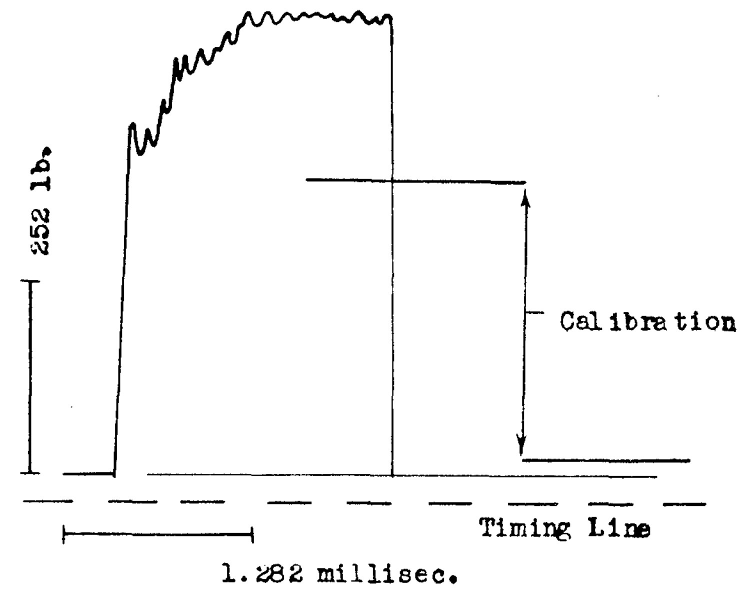


Fig. 13 Recorded force-time diagram for gun No. 2129, specimen No. D2, at a rate of strain of 42.2 in./in./sec.

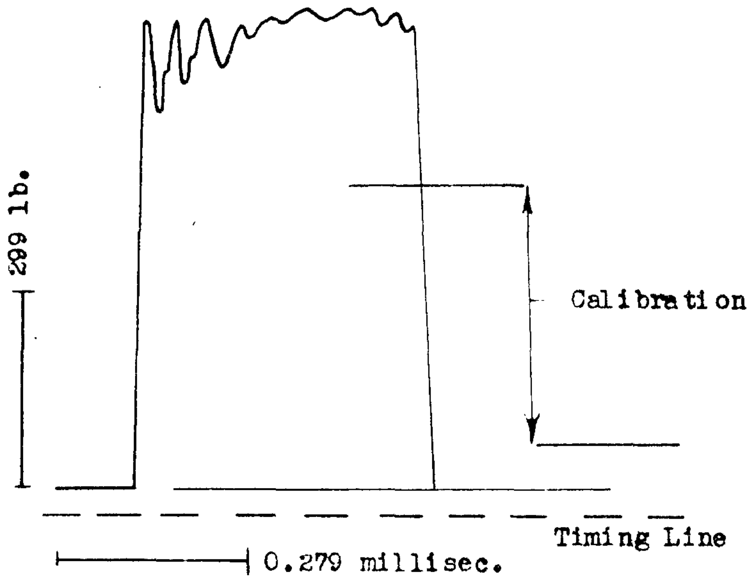
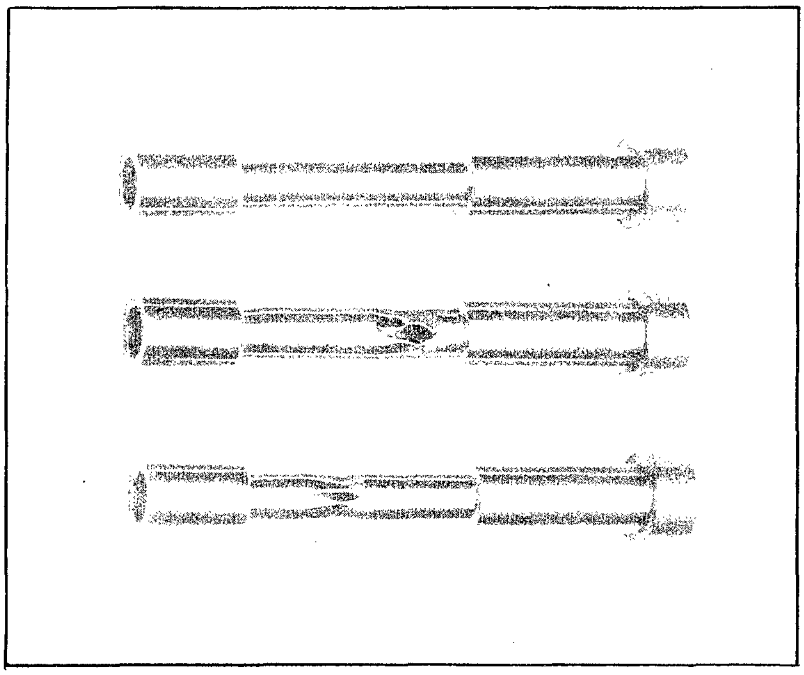


Fig. 14 Recorded force-time diagram for gun No. 2129, specimen No. A9, at a rate of strain of 98.9 in./in./sec.



(a)

(b)

(c)

Fig. 15 Typical dynamic uniaxial specimens.

(a) Untested specimen.
(b) Normally ruptured specimen.
(c) Premature failure, small plastic hoop strain.

RESTRICTED

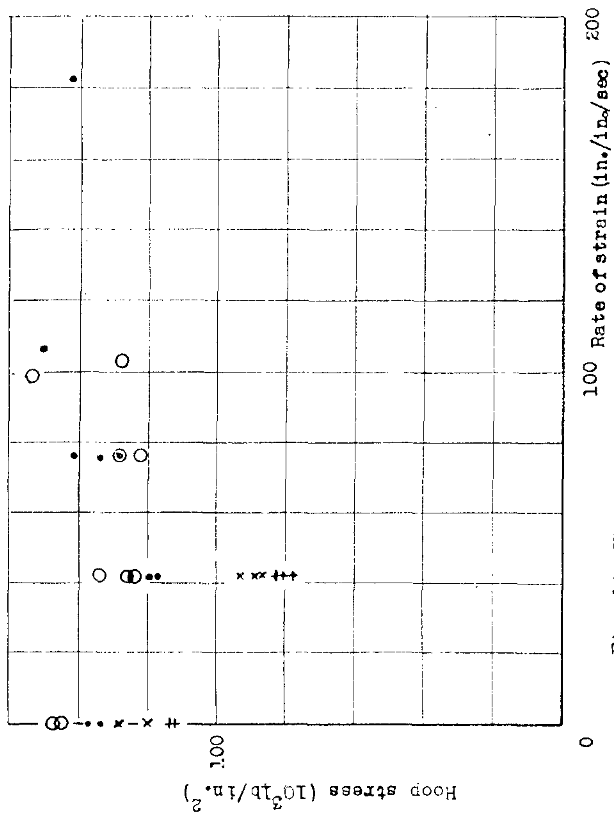


Fig. 17 Ultimate strength and proportional limit
vs. rate of strain for gun No. 2129.
Spec. A ult.str.(o),prop.lim.(x).
Spec. B ult.str.(•),prop.lim.(+).

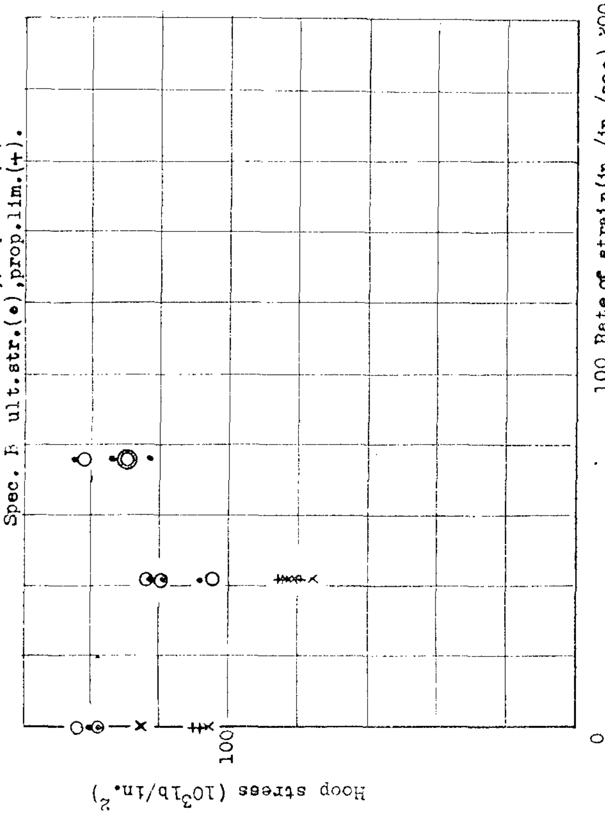


Fig. 18 Ultimate strength and proportional limit
vs. rate of strain for gun No. 2129.
Spec. C ult.str.(o),prop.lim.(x).
Spec. D ult.str.(•),prop.lim.(+).

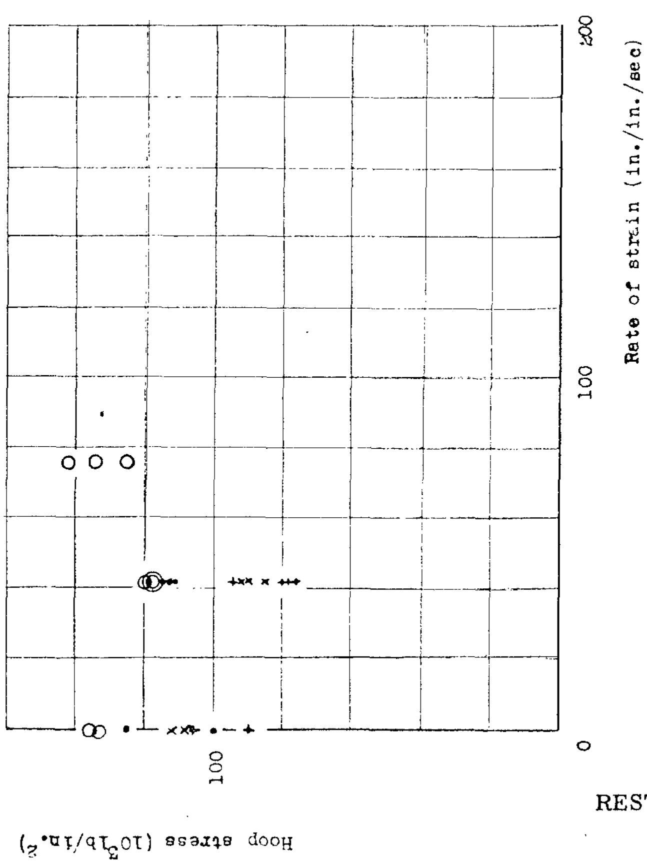


Fig. 18 Ultimate strength and proportional limit
vs. rate of strain for gun No. 351.
Spec. A ult.str.(o), prop.lim.(x).
Spec. B ult.str.(•), prop.lim.(+).
Spec. C no data obtained due to early failures.

TSDIN FORM 69 A (13 MAR 47)

RESTRICTED

P-22-2-4

ATI- 20430

ORIG. AGENCY NUMBER

O.S.R.D. 4729

REVISION

Duwez, P. E.,
Martens, H. E.,
Elmer, D. A.,
and others

AUTHOR(S)

DIVISION: Ordnance and Armament (22)
SECTION: Guns (2)
CROSS REFERENCES: Gun tubes - Rupture (47422)

AMER. TITLE: Progress report on behavior of metals under dynamic conditions. Application of pure strain rate tests to an investigation of two 76 mm gun tubes

FORG'N. TITLE:

ORIGINATING AGENCY: O.S.R.D., N.D.R.C., Div. 18, Washington, D. C.

TRANSLATION:

COUNTRY	LANGUAGE	FORG'N.CLASS	U. S.CLASS.	DATE	PAGES	ILLUS.	FEATURES
U.S.	Eng.		Restr.	Feb'45	32		photos, tables, diagr, graphs

ABSTRACT

An investigation was conducted on the static and dynamic tensile properties of specimens from two 76 mm gun tubes, previously ruptured by HE shell detonation in the bore. One tube fragmented badly while the other exhibited a ductile fracture. Rupture of some of the specimens occurred with very low maximum uniform strain. Static tensile and Izod impact tests failed to reveal any difference in the gun tubes. The test results are discussed in relation to the influence of strain rate on the properties of each material and the effect of metallographic structure on the results.

T-2, HQ., AIR MATERIEL COMMAND

AIR TECHNICAL INDEX
RESTRICTED

WRIGHT FIELD, OHIO, USAAF

WF-O-21 MAR 47 22,500