SOME PHYSICAL PROPERTIES OF A NUMBER OF PROPOSED CONSTRUCTIONS OF MATERIALS FOR NONMETALLIC CRASH-RESISTANT AIRCRAFT FUEL TANKS

By

Richard N. Motsinger

Melvin F. Miller

Robert J Schroers

Aircraft Division

TECHNICAL DEVELOPMENT REPORT No. 220

Prepared for

CIVIL AERONAUTICS ADMINISTRATION

TECHNICAL DEVELOPMENT AND

EVALUATION CENTER

INDIANAPOLIS, INDIANA

December 1953

U S DEPARTMENT OF COMMERCE

Sinclair Weeks, Secretary

CIVIL AERONAUTICS ADMINISTRATION

F B Lee, Administrator

D M Stuart, Director, Technical Development and Evaluation Center

TABLE OF CONTENTS

This is a technical information report and does not necessarily represent CAA policy in all respects

SOME PHYSICAL PROPERTIES OF A NUMBER OF PROPOSED CONSTRUCTIONS OF MATERIALS FOR NONMETALLIC CRASH-RESISTANT AIRCRAFT FUEL TANKS

SUMMARY

Tests have been conducted at the Technical Development and Evaluation Center of the Civil Aeronautics Administration to determine the strength, elongation, and energy-absorbing properties of 32 materials, including rubber and rubber-impregnated nylon and cotton fabrics These test results aid in the selection, for further evaluation under simulated crash tests, of materials which are believed to possess the most favorable properties for use in the fabrication of crash-resistant, bladder type fuel tanks for aircraft

The results of the tests indicate that two types of laminated materials possess, for their weight, greater load-carrying and energy-absorbing abilities than any of the other types tested to date The more satisfactory materials are (1) a three-ply, square-woven, mediumweight, nylon fabric with a rubber liner and with the plies laminated on the bias, and (2) a four-ply, nylon, tire-cord fabric which is resin-treated and which has a rubber liner and has the plies laminated on the bias These types of materials can be made with various weights of fabric or cords to obtain any strength which may be required

A material composed of a greater number of plies of a fabric with the plies uniformly distributed on the bias and having smaller cords appears to be better than a material composed of a lesser number of plies of fabric with the plies uniformly distributed on the bias and having larger cords The strength of the adhesive holding the plies of a fabric together appears to be an important factor in the ability of a material to demonstrate the ultimate strength of its fabric

Materials composed of nylon fabrics possess strength and energy-absorbing properties which are superior to those found in materials composed of cotton fabrics A homogenous rubber material which was tested possesses very good energy-absorption properties but is extremely poor in load-carrying ability

The strength properties of the materials tested were not affected appreciably by rupture times which varied from 0 05 to 3 0 seconds

INTRODUCTION

The Technical Development and Evaluation Center of the Civil Aeronautics Administration is engaged in a program to develop for aircraft crash-resistant fuel tanks which will help prevent the occurrence of destructive fires during aircraft accidents and crashes of the type in which the occupants would normally be expected to survive the crash impact

The initial phase of the investigation involved the testing of full-scale fuel tanks under simulated crash conditions This investigation indicated, among other things, that flexible-bladder type tanks which possess sufficient strength and/or energy-absorbing properties to resist rupture while the surrounding structure begins to disintegrate offer good possibilities as a reasonable and practical solution to the problem [1]

The present investigation was undertaken to evaluate the properties of some available bladder-cell materials and to determine the particular materials which appear to possess the best properties for the intended purpose This report summarizes the results of these evaluation tests, and the data presented herein consitutes a basis for selecting the bladder-cell materials to be used in the forthcoming impact tests Thirty-two materials or combinations of materials were tested to determine the best composite fuel-cell material

The terms "bladder cell," "fuel cell," "bladder type fuel tanks," and equivalent expressions as used in this report are intended to denote a nonmetallic, self-sealing or not self-sealing, more or less flexible type of fuel-cell construction which is removable from the aircraft They may apply to bladder type fuel tanks which are complete in themselves or to removable jackets or boots inside of which the cell actually containing the fuel might be encased

The terms "material," "bladder-cell material," "fuel-tank material," and equivalent expressions denote a nonmetallic ingredient material or combinations of such materials which are either arranged in layers or built up of plies, which in themselves may be combinations of materials, to form a composite material These terms are usually synonymous with "test specimen"

BASIC CONSIDERATIONS OF THE PROBLEM

In the case where the aircraft structure surrounding a bladder type of fuel tank is so damaged during an actual aircraft crash by impact with some external object that openings are created in the structure, the bladder tank must remain intact and must prevent any appreciable loss of fuel if the danger of destructive fire is to be averted The work absorbed by the bladder-cell material covering a relatively large opening (approximately eight to ten inches in diameter) in the metal structure is a function of the mass of fuel behind the opening and of the deceleration of that fuel mass during the crash impact A major consideration in achieving a crash-resistant bladder-cell tank, therefore, is the attainment of a material which is capable of absorbing the work done by the fuel in trying to escape from the tank This is done by virtue of the strength and of the elongation properties of the fuel-cell material If the opening in the metal structure is small (for example, if a metal seam opens only a fraction of an inch), very little elongation of the bladder-cell material behind the open seam can occur In this case it is believed that the strength of the bladder-cell material rather than its ability to absorb energy becomes the predominating factor

Therefore it is considered that the material which is, for its weight, capable of sustaining the greatest load, able to absorb the most energy, and in addition as tough as possible in order to minimize the danger of failure from puncturing and tearing action is the optimum material for use in the fabrication of crash-resistant, bladder type tanks

A high degree of tear and puncture resistance is considered an important quality of a crash-resistant bladder-cell material Previous impact testing of bladder-cell tanks at this Center, however, indicates that high tensile strength and high energy absorption for the least possible weight of material are the predominant considerations in selecting optimum materials for crash-resistant fuel tanks

APPARATUS AND TEST CONDITIONS

All tests were made using the large compressed-air gun which is shown in Fig 1 The gun was arranged so that circular material specimens 34½ inches in diameter could be attached to the muzzle for burst-testing See Fig 2 The compressed air for bursting the specimen or diaphragm was supplied to the gun

[1]R L Field, Melvin F Miller, and George Pigman, "An Investigation of the Crash-Fire Problems in Transport Aircraft Fuel Tanks," CAA Technical Development Report No 134, January 1951

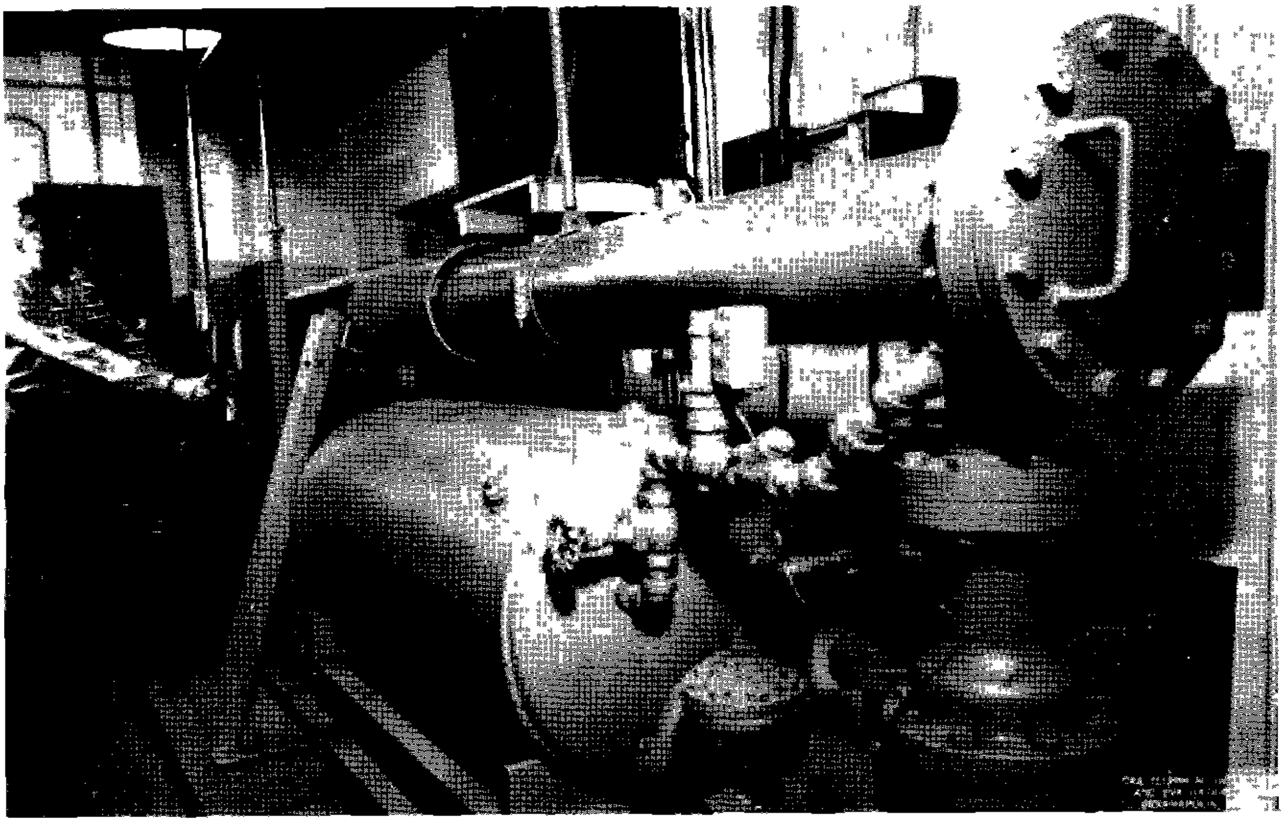


Fig 1 Compressed-Air Gun

testing See Fig 2 The compressed air for bursting the specimen or diaphragm was supplied to the gun from a reserve tank capable of withstanding 500 pounds per square inch (psi) of pressure Two valves at the reserve tank controlled the rate at which the air was supplied to the gun, and, by proper selection of the valve and of the reserve tank pressure, the time required to rupture the diaphragm could be controlled

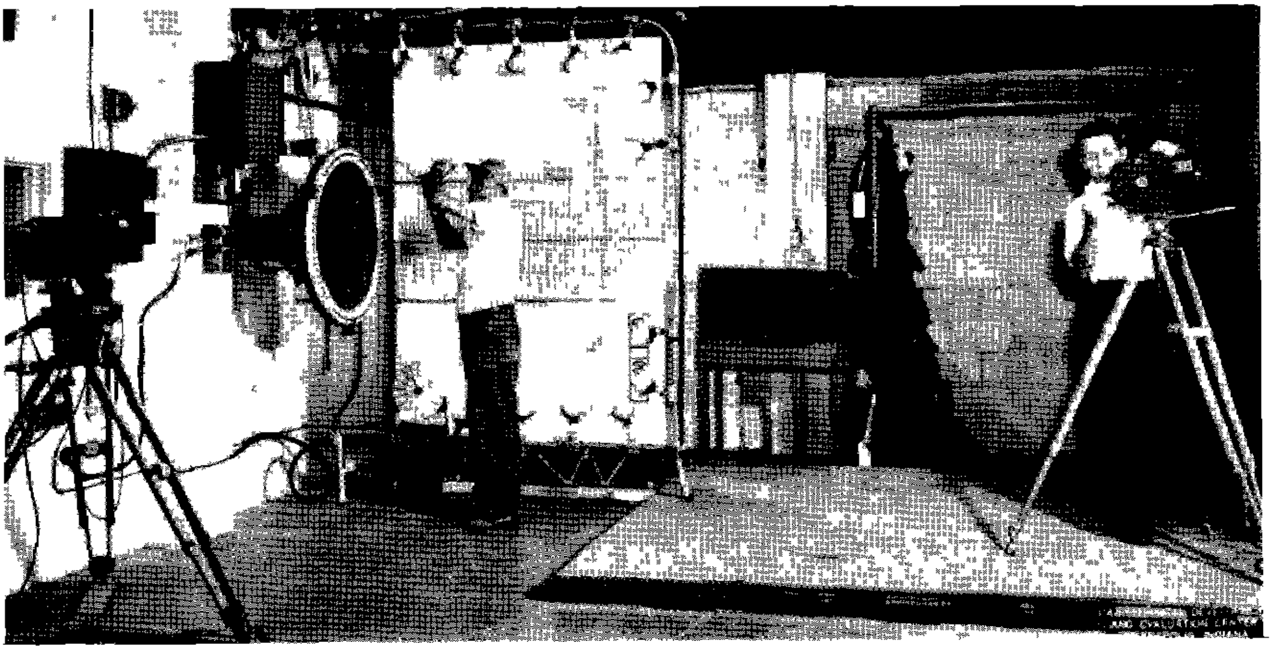


Fig 2 Test Chamber With Specimen Being Prepared for Test

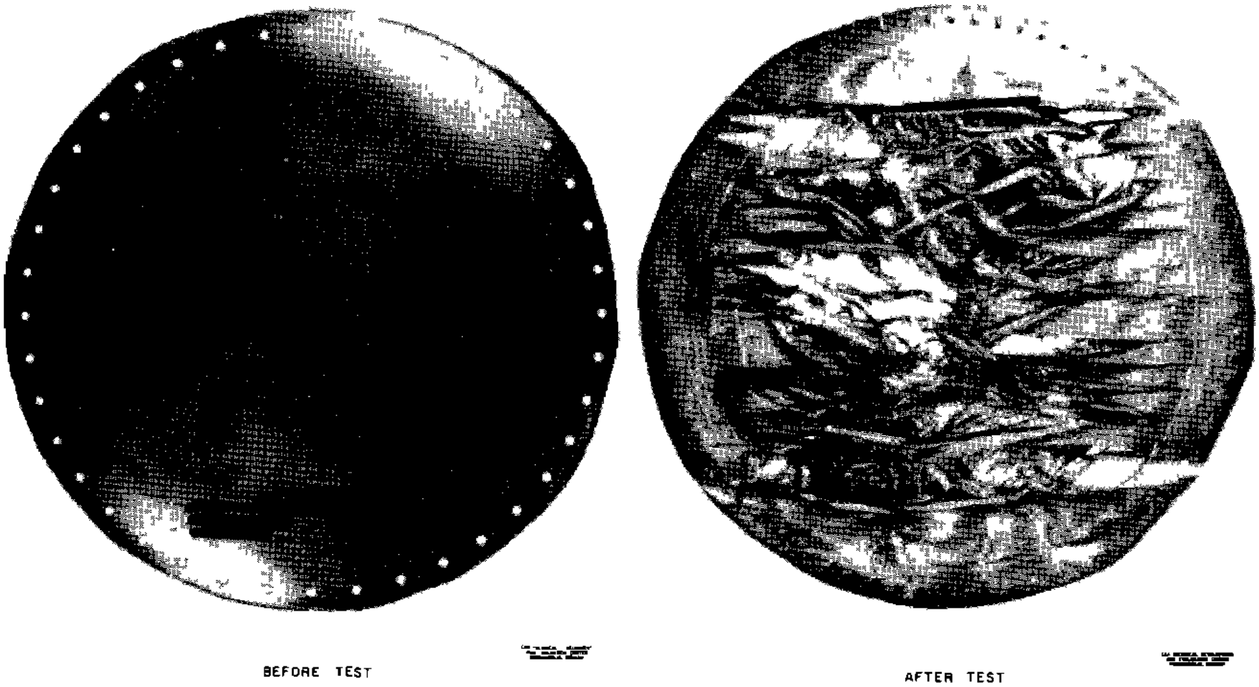


Fig 3 A Typical Specimen Before and After Testing

In these tests, omnidirectional loading of the material in a manner similar to that experienced during an actual crash is obtained

A photograph of a typical diaphragm specimen before and after testing is shown in Fig 3, and a brief description of all the specimens tested is given in Column 3 of Table I

The time history of the pressure build-up on the diaphragm is obtained by using pressure transducers, located in the gun muzzle near the test diaphragm, in conjunction with a recording oscillograph Two high-speed cameras operating at approximately 1,000 frames per second were used to record the diaphragm contour during the test Profile and oblique views of a typical specimen during the testing are shown in Fig 4 A background screen located in the field of view of the profile camera has been calibrated to provide direct readings of spherical diameter and of the percentage of elongation

The diameter of the diaphragms was arbitrarily chosen to be 34½ inches because (1) a specimen of this approximate size is necessary to allow accurate data to be taken from high-speed movie records, (2) the ability of the gun to rupture the strongest specimens requires a diaphragm of this approximate size, and (3) the specimen should be larger rather than smaller in size in order that it might contain the usual local variations in strength, elongation, weight, and so forth, inherent in fabric materials

The order of events which comprise the actual test begins with the triggering of a cam type of sequence timer The cam-timer mechanism is preset to actuate the component equipment by means of hold-in relays at the proper instant and in the following order the timing disc the high-speed cameras, the recording oscillograph, the lights for the cameras, and the gun valve

Information obtained from simulated crash tests on full-scale airplanes has shown that the duration of sharp and well-defined impact loads on the wings of aircraft is approximately 0 05 second Therefore, it was believed that the strength and elongation properties of the bladder materials should be determined by tests in which the interval of rupture is approximately 0 05 second In addition, it was desirable to determine whether there is any change in strength and elongation properties of such materials at lower rates of loading Tests were therefore arbitrarily conducted over a rupture-time range of approximately 0 05 to 3 0 seconds Rupture-time intervals in this range were controlled by the quick-opening valves in the breech of the gun and by the initial pressure in the reserve tank

The tests were conducted at ambient temperatures ranging from 60° to 80° F

ANALYSIS OF DATA

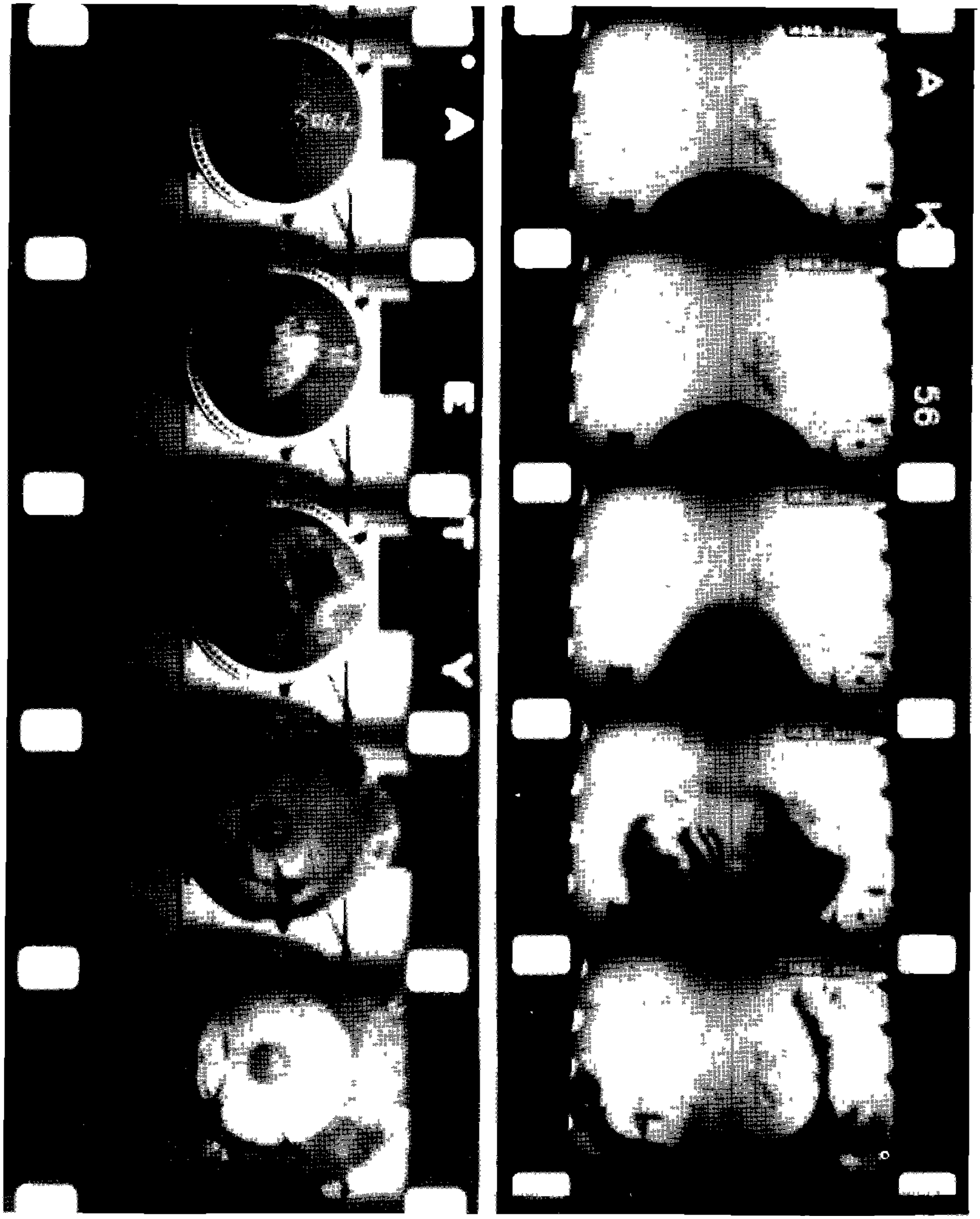
The equation which expresses the maximum tensile loads applied to the test specimens (diaphragms) on the compressed-air gun is derived by reference to Fig 5

At any section A – A having a diameter d, the force F which is due to air pressure and which is held in equilibrium by the loads in the material is expressed by

$$\frac{p \pi d^2}{4} - L_1 \pi d \cos \phi = 0$$

or

$$L_1 = \frac{p \pi d^2}{4 \pi d \cos \phi} = \frac{p d}{4 \cos \phi}$$



FRONT VIEWS PROFILE VIEWS

Fig 4 Profile and Oblique Views of a Specimen During Rupture

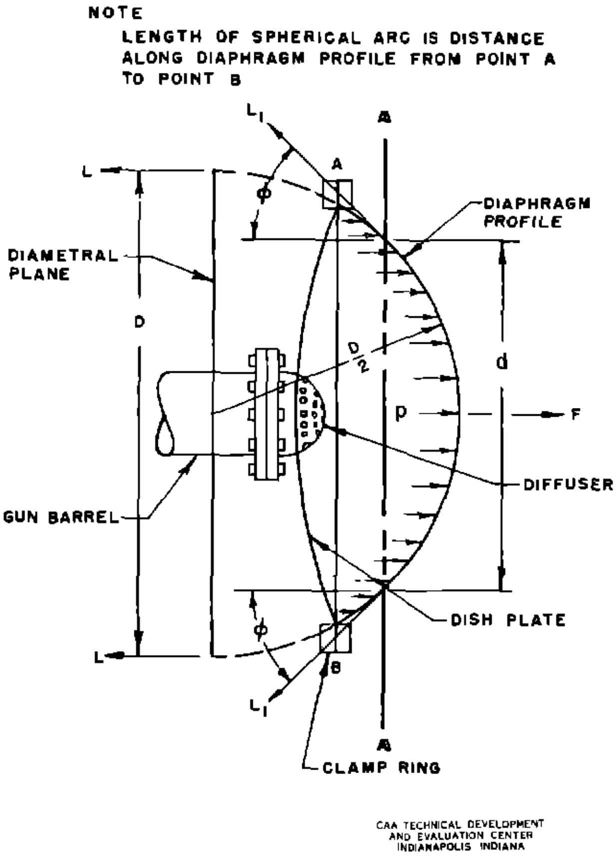


Fig 5 Tensile Load in Diaphragm

where

L_1 = the maximum tensile load which is exerted on the material and which is tangent to the test specimen at section A — A, in pounds per inch of width around the circumference,

p = air pressure in pounds per square inch,

d = the diameter in inches at section A — A,

ϕ = the angle between the line of action of the vectors L_1 and F

If the contour of the loaded diaphragm is spherical in shape, the load L_1 is the same for any section A A which is parallel to the plane of the clamp ring for any pressure p Therefore, if the contour of the diaphragm is extended to represent a semicircle having diameter D, cos ϕ becomes unity at the diametral plane and Equation (1) takes the form

$$L = \frac{pD}{4}$$

where

L = the maximum tensile load in the material in pounds per inch of width,

D = the spherical diameter

Since as nearly as can be ascertained from the high-speed photographs obtained in these tests the contours of the diaphragms are spherical arcs, Equation (2) was used for the strength calculations in this report

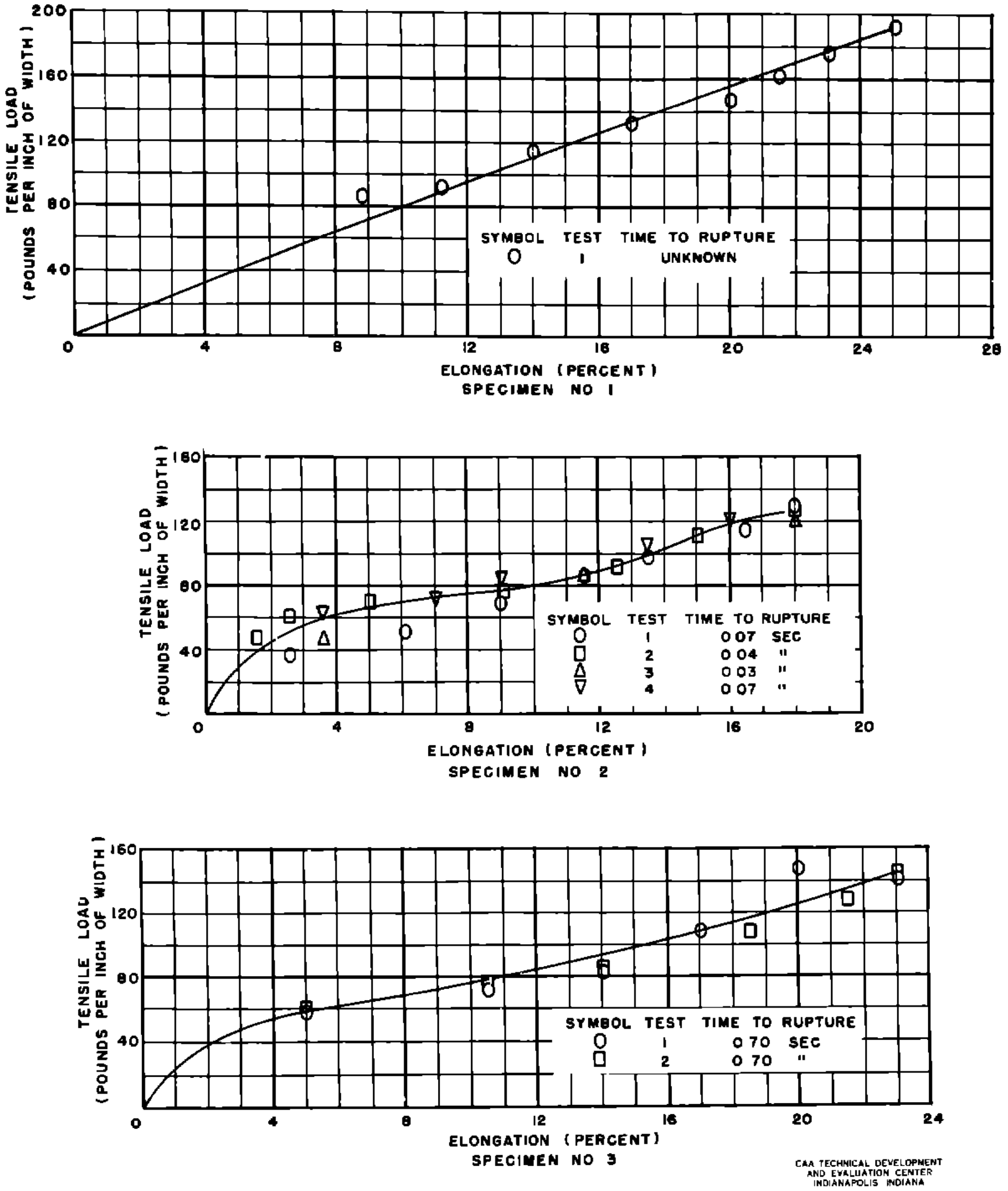
A load-versus-elongation curve for each individual test specimen of a given material was obtained by plotting the load obtained from Equation (2) against the percentage of elongation, taken directly from the movie records A number of these curves were then used to determine a mean load-versus-elongation curve for that material

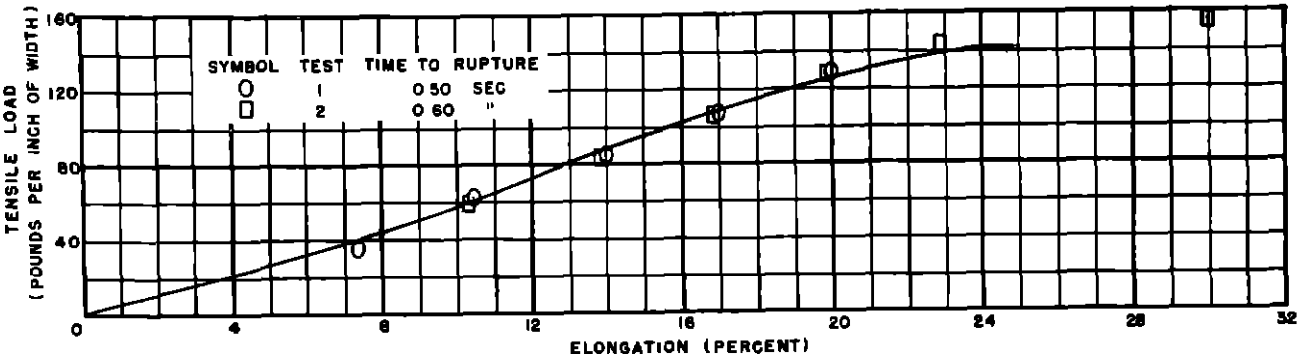
The mean load-versus-elongation curve was used to construct a mean pressure-versus-volume diagram for each type of specimen The area under the pressure-versus-volume diagram was integrated graphically and the area thus found represents the ability of the material specimen to absorb energy

RESULTS AND DISCUSSION

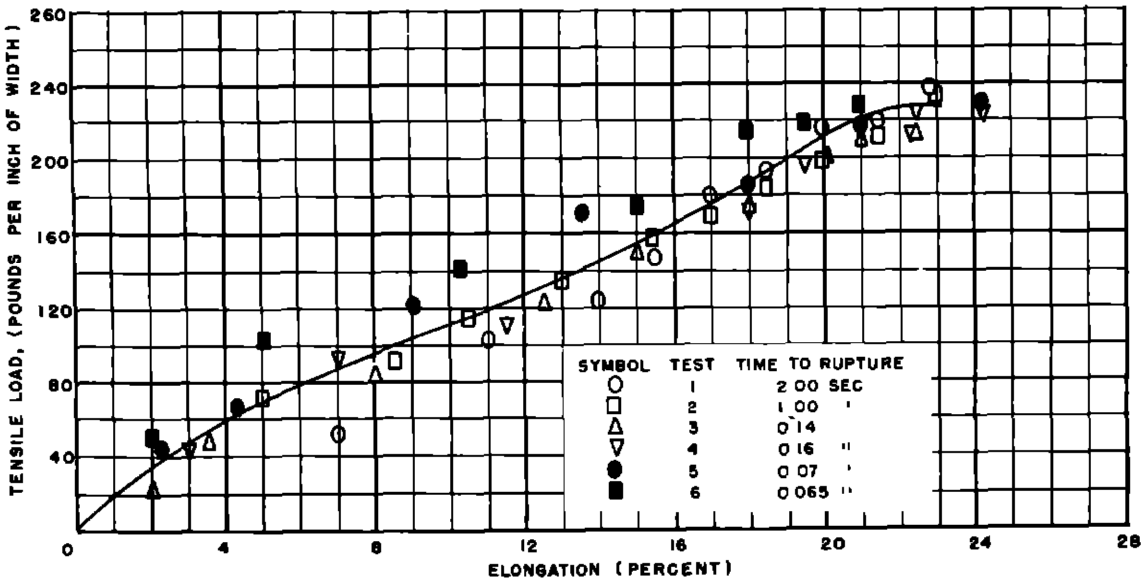
The physical properties of the materials tested are summarized in Table I The mean load-versus-elongation curves and pressure-versus-volume diagrams for the materials investigated are shown in Figs 6 and 7 The identification, a brief description, the nominal weight, and the nominal thickness of each material tested are given in Columns 1 through 7 of Table I

Fig 6 Load-Versus-Elongation Data

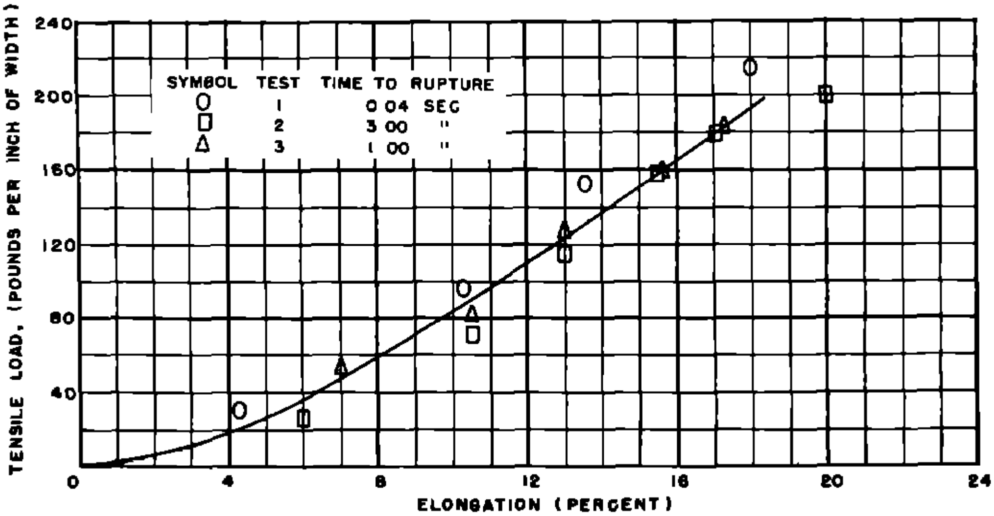




SPECIMEN NO 4

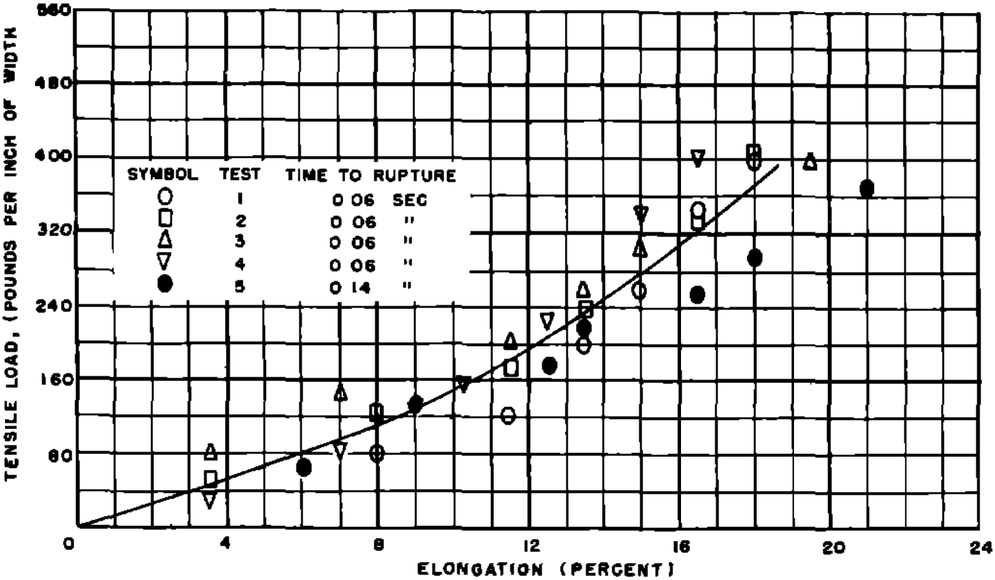


SPECIMEN NO 5

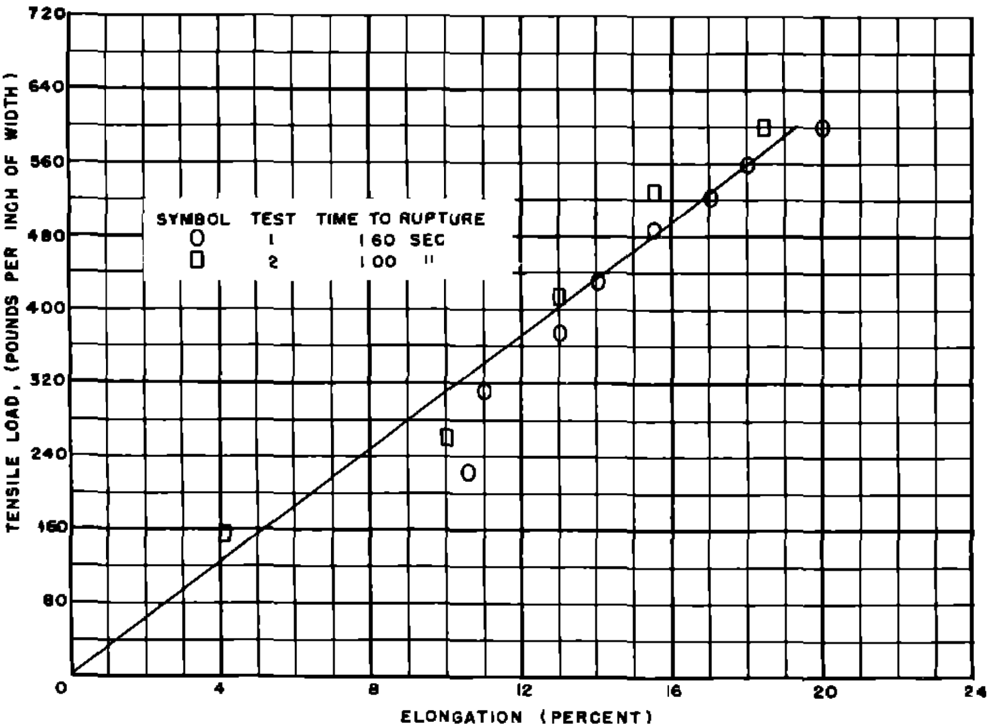


SPECIMEN NO 6

CAA TECHNICAL DEVELOPMENT
AND EVALUATION CENTER
INDIANAPOLIS INDIANA

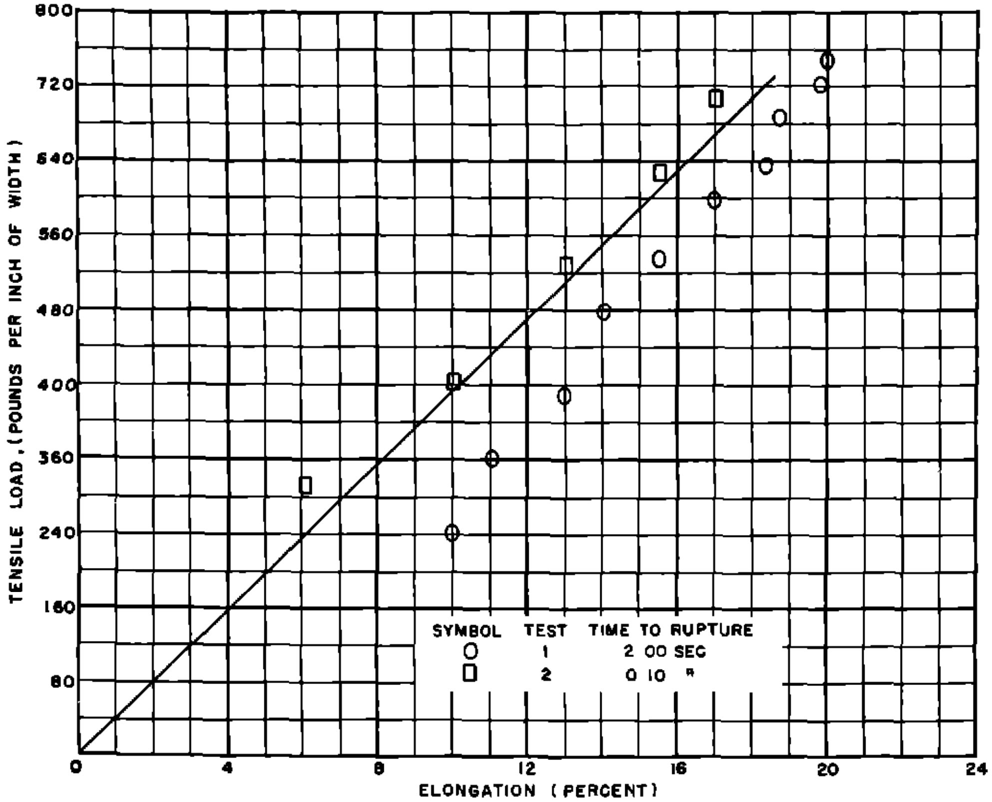


SPECIMEN NO 7

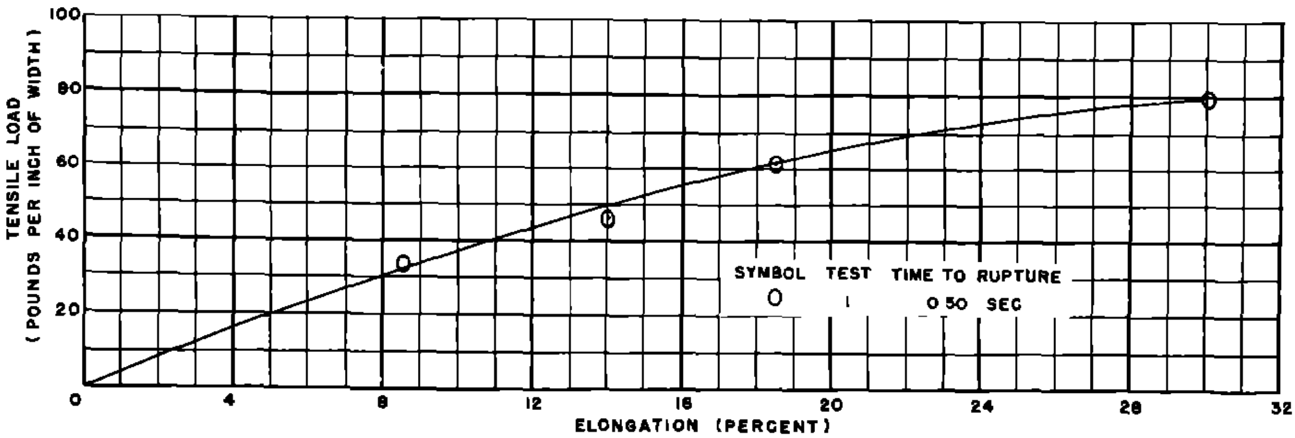


SPECIMEN NO 8

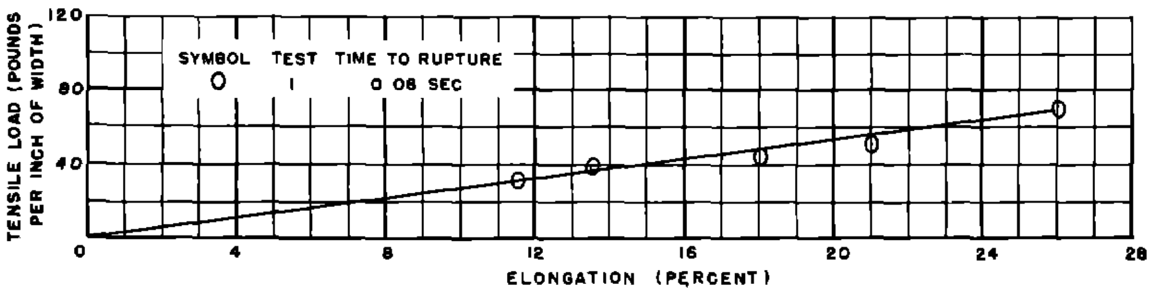
CAA TECHNICAL DEVELOPMENT
AND EVALUATION CENTER
INDIANAPOLIS INDIANA



SPECIMEN NO 9

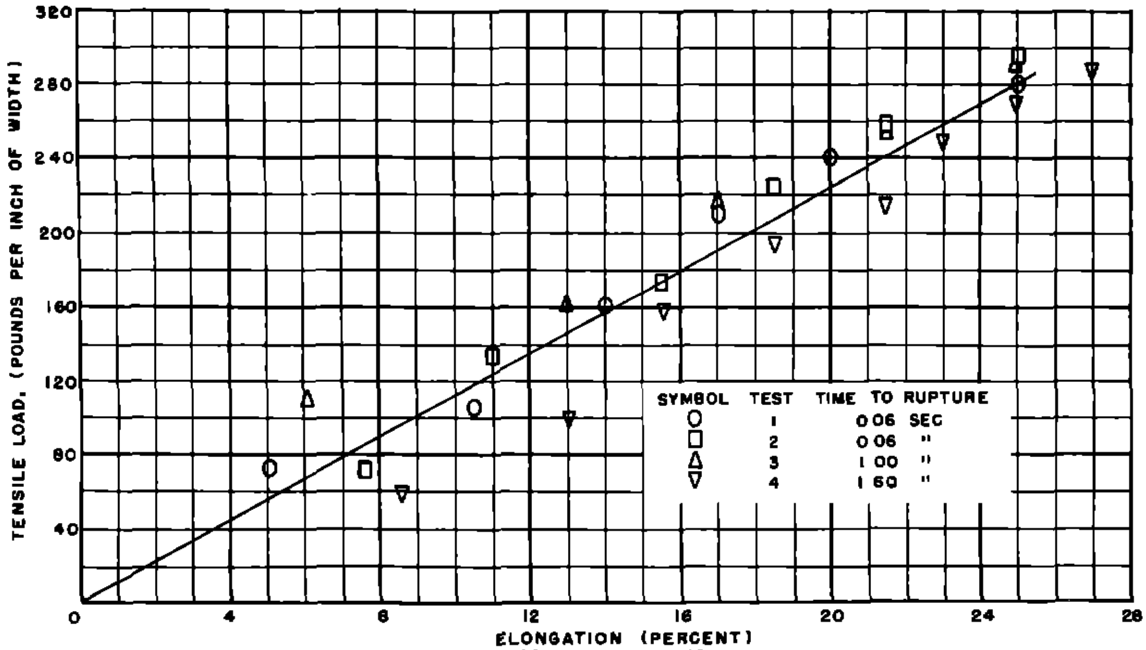


SPECIMEN NO 10

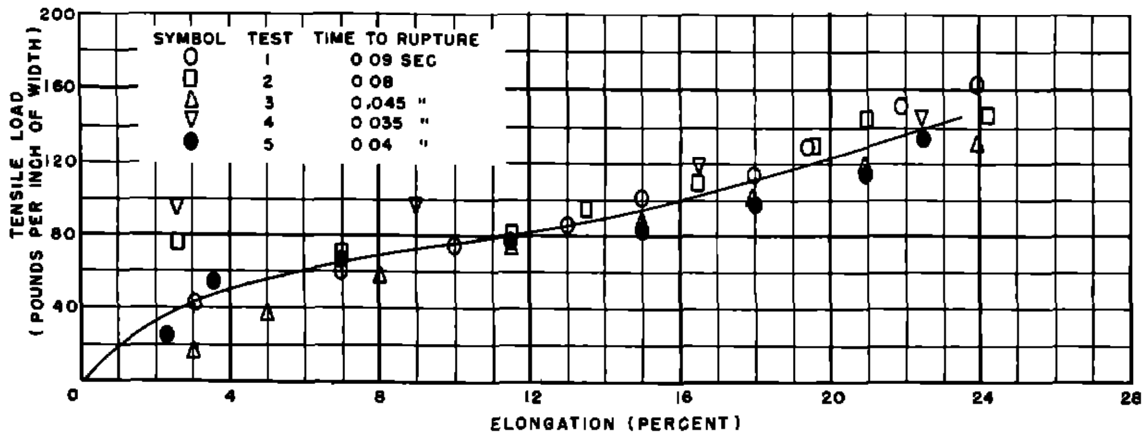


SPECIMEN NO 11

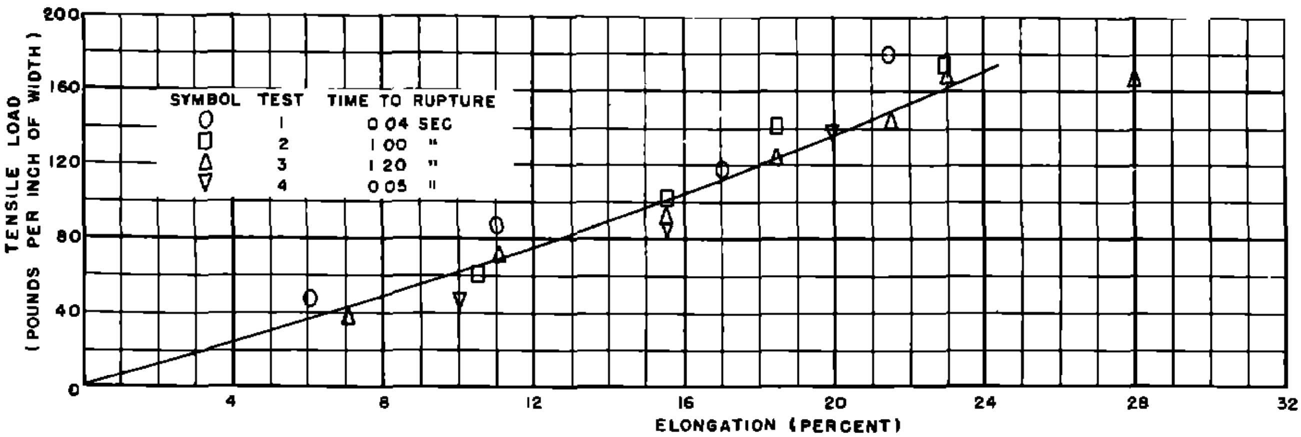
CAA TECHNICAL DEVELOPMENT AND EVALUATION CENTER INDIANAPOLIS INDIANA



SPECIMEN NO 12

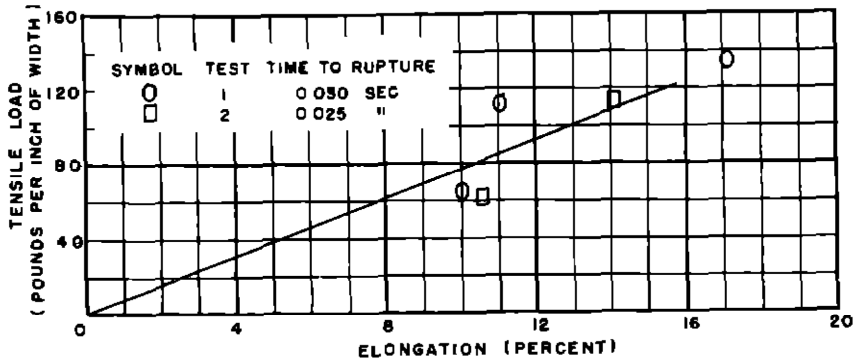


SPECIMEN NO 13

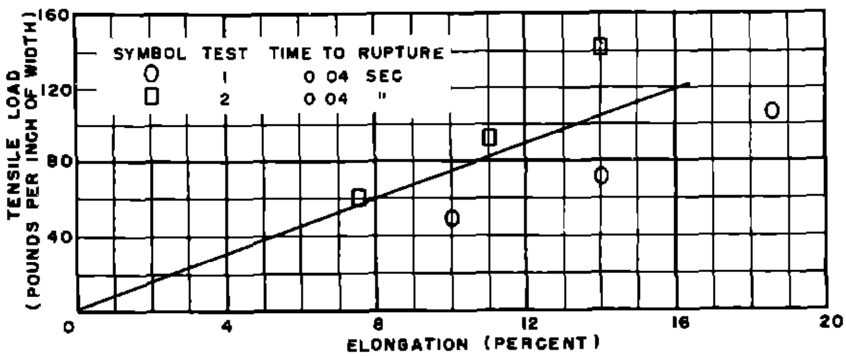


SPECIMEN NO 14

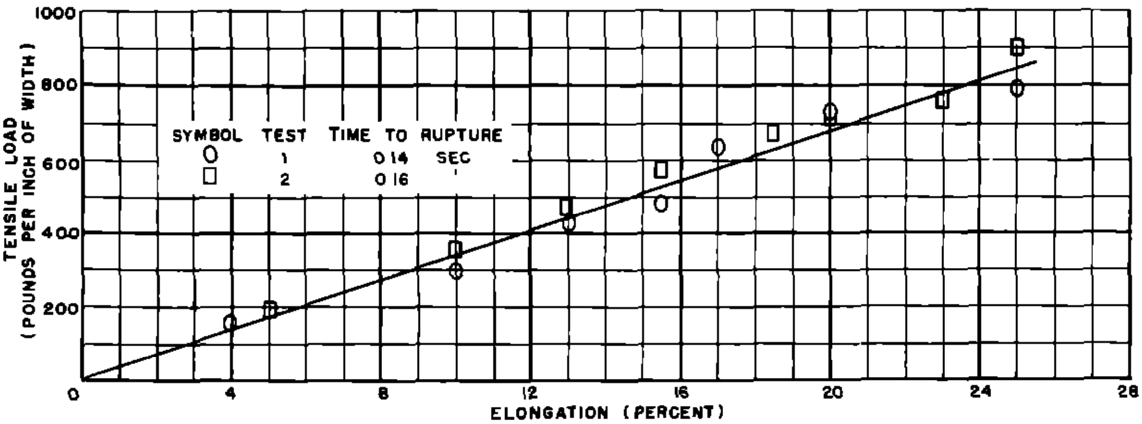
CAA TECHNICAL DEVELOPMENT
AND EVALUATION CENTER
INDIANAPOLIS INDIANA



SPECIMEN NO 15

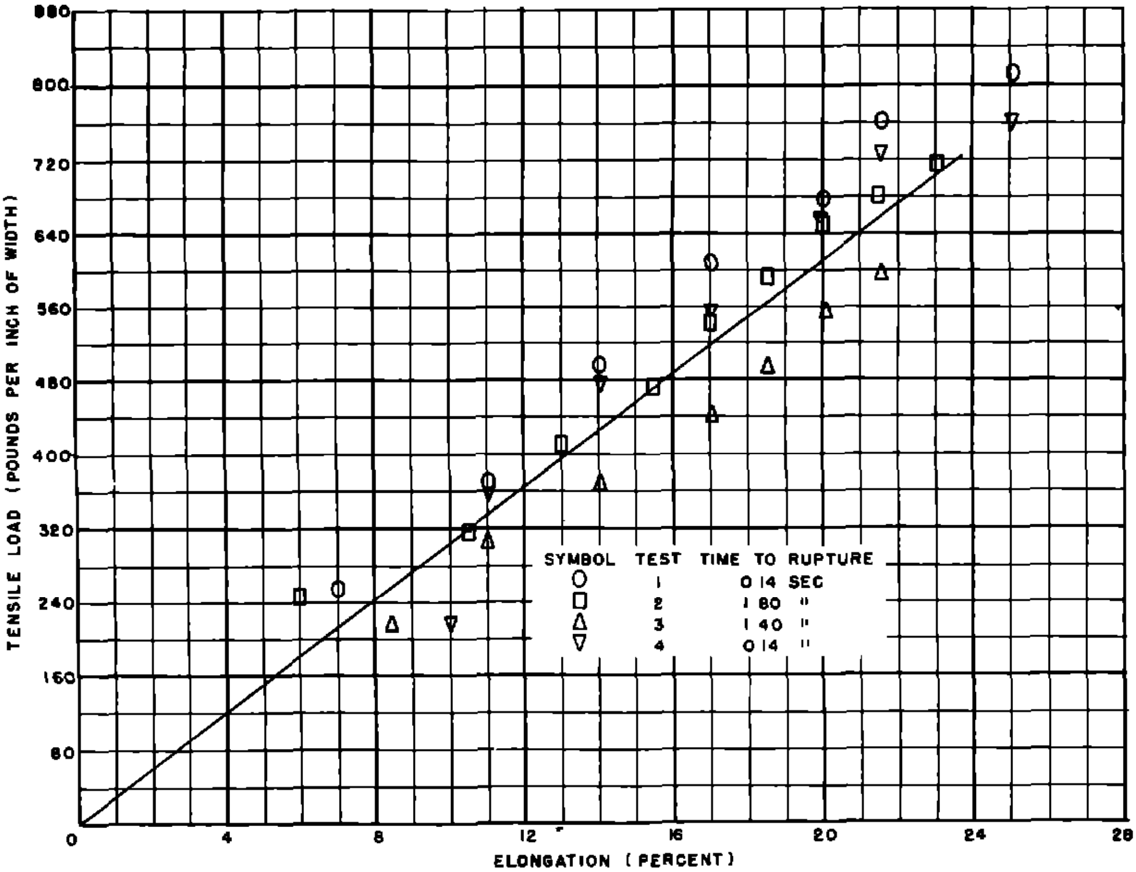


SPECIMEN NO 16

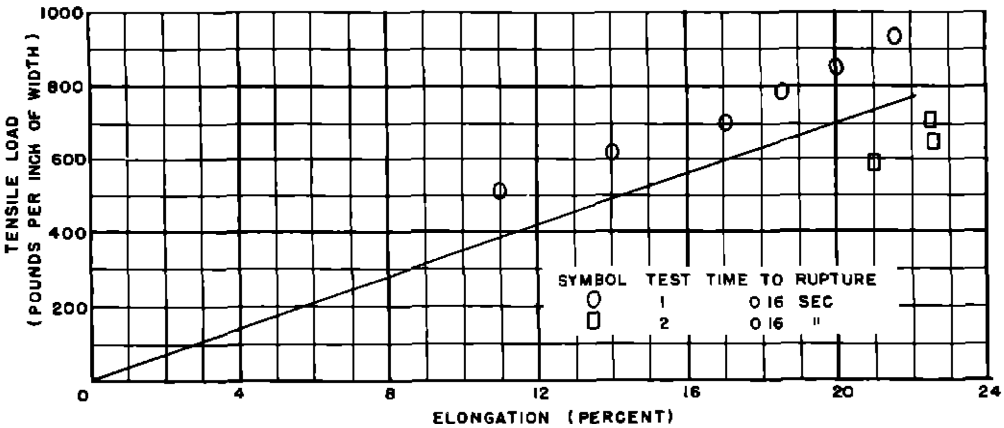


SPECIMEN NO 17

CAA TECHNICAL DEVELOPMENT AND EVALUATION CENTER INDIANAPOLIS INDIANA

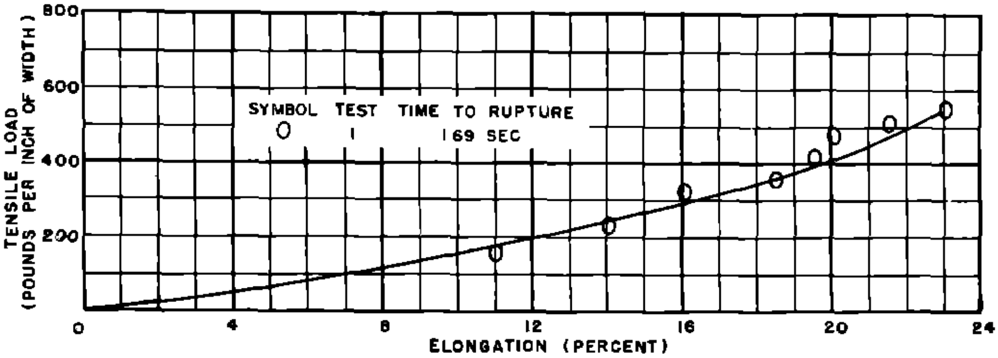


SPECIMEN NO, 18

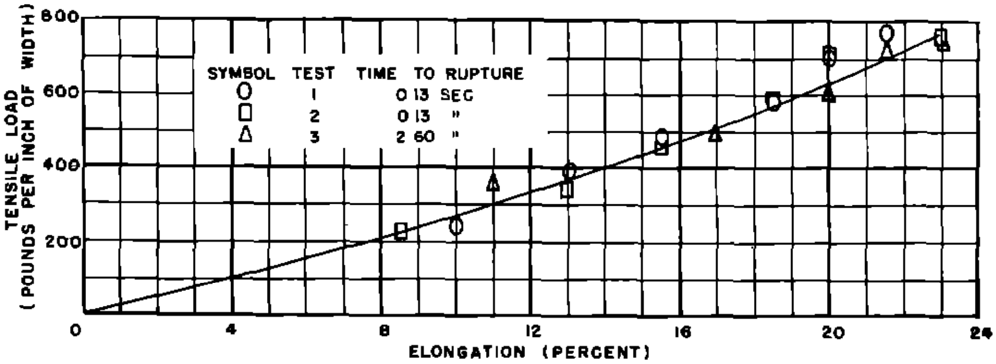


SPECIMEN NO 19

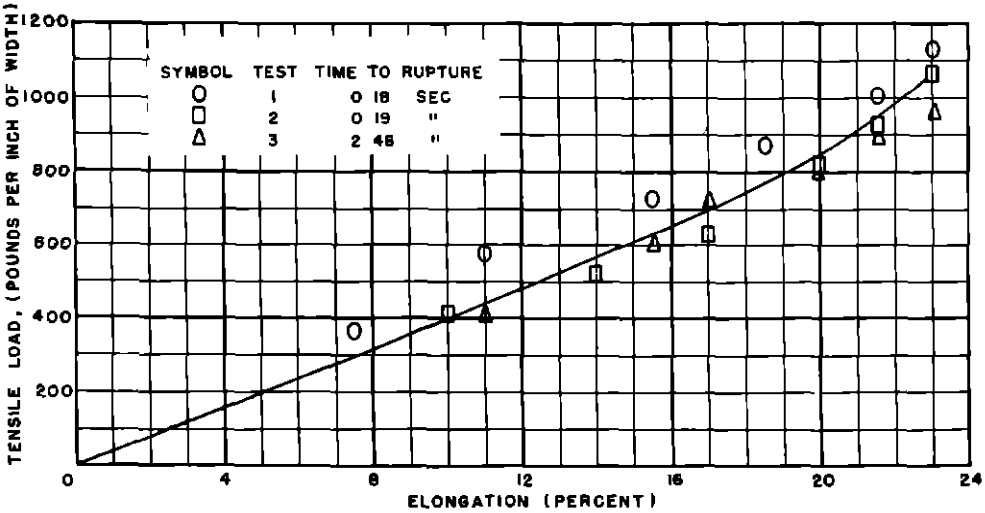
CAA TECHNICAL DEVELOPMENT
AND EVALUATION CENTER
INDIANAPOLIS INDIANA



SPECIMEN NO 20

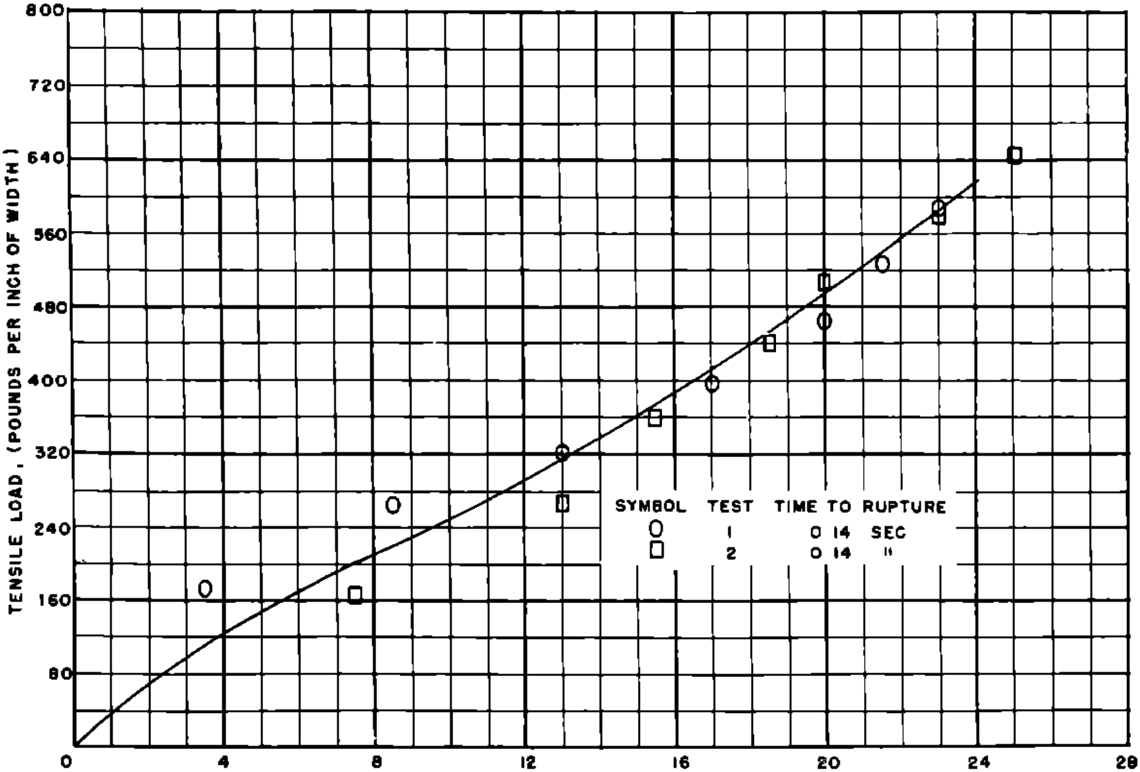


SPECIMEN NO 21

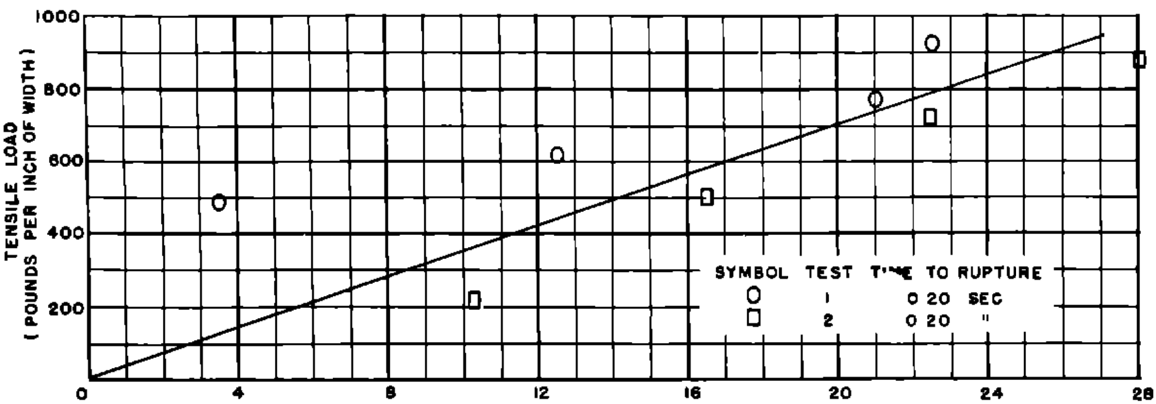


SPECIMEN NO 22

CAA TECHNICAL DEVELOPMENT
AND EVALUATION CENTER
INDIANAPOLIS INDIANA

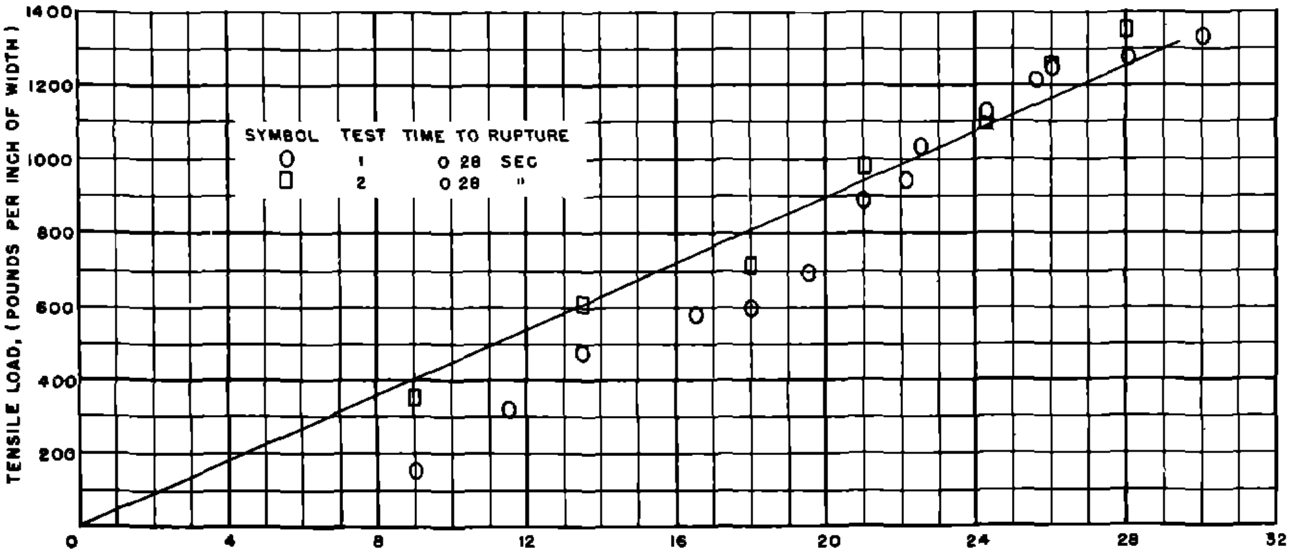


ELONGATION (PERCENT)
SPECIMEN NO 23

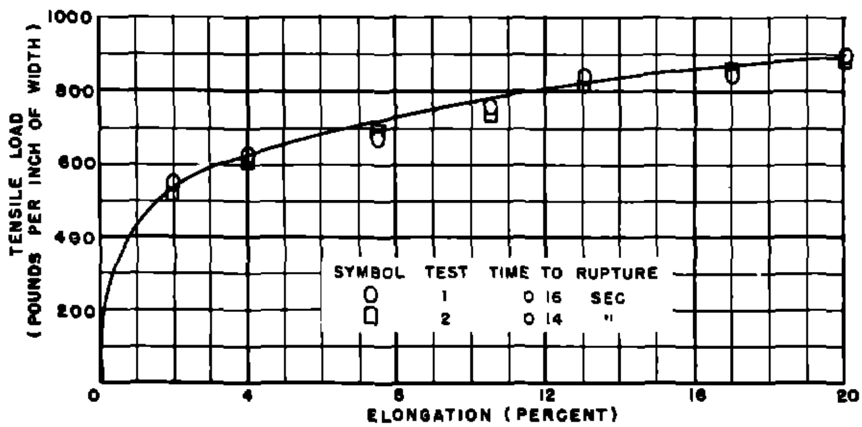


ELONGATION (PERCENT)
SPECIMEN NO 24

CAA TECHNICAL DEVELOPMENT
AND EVALUATION CENTER
INDIANAPOLIS INDIANA

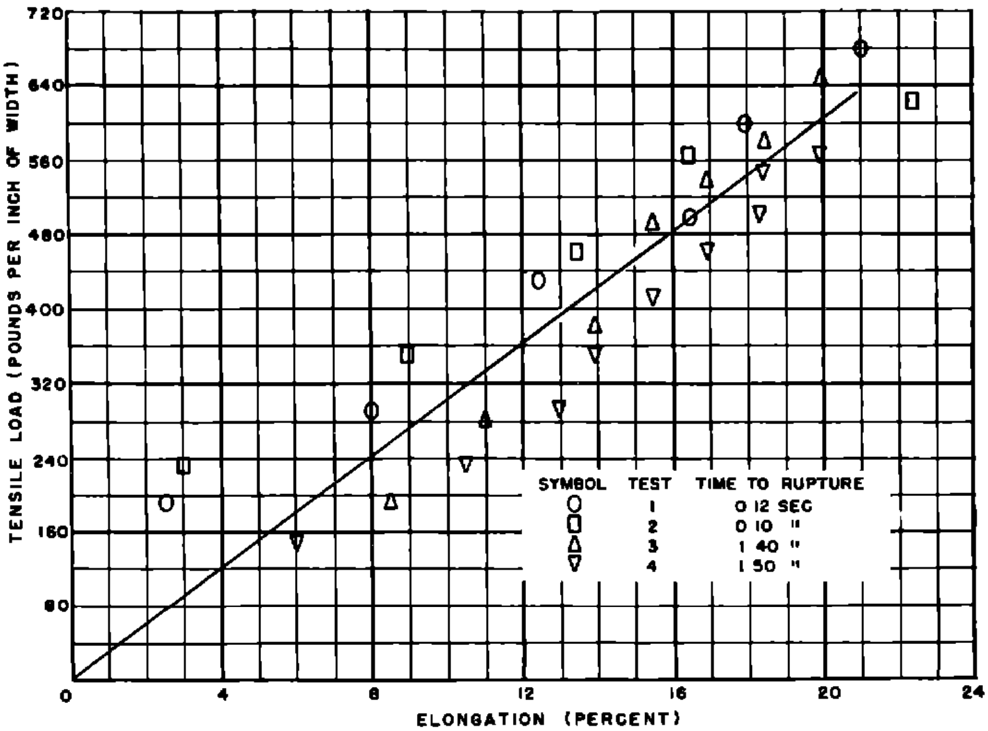


SPECIMEN NO 25

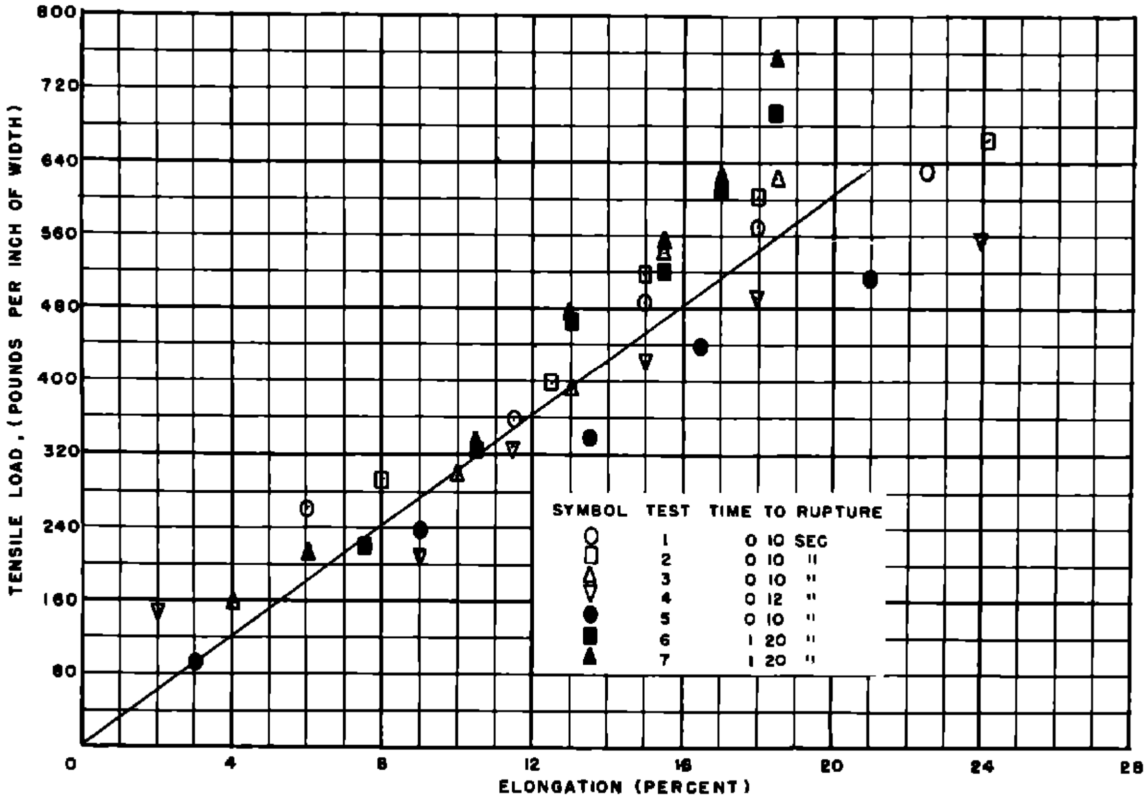


SPECIMEN NO 26

CAA TECHNICAL DEVELOPMENT AND EVALUATION CENTER INDIANAPOLIS INDIANA

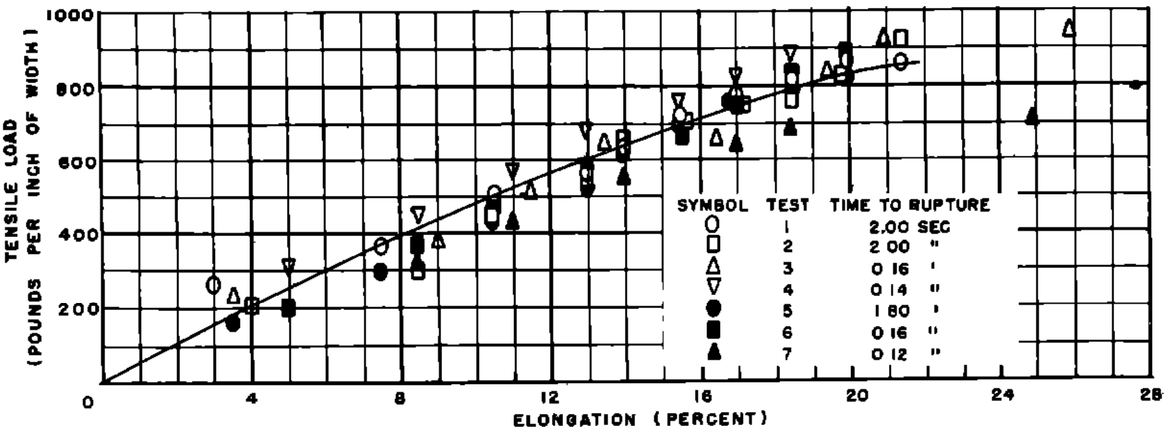


SPECIMEN NO 27

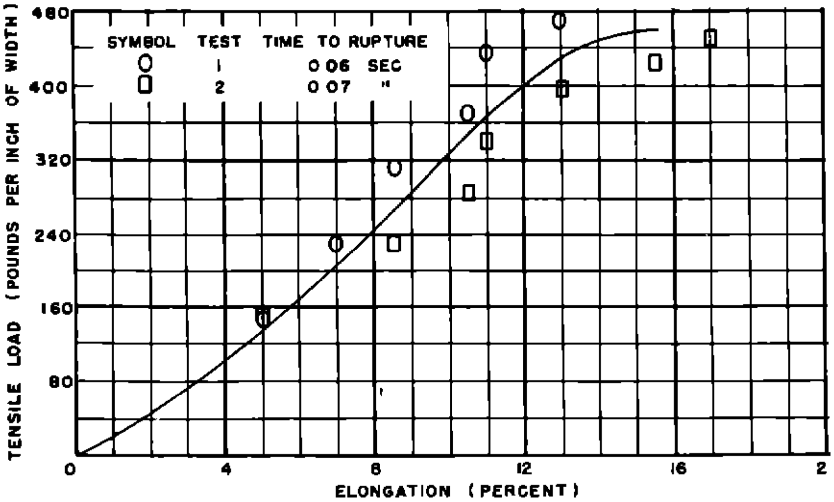


SPECIMEN NO 28

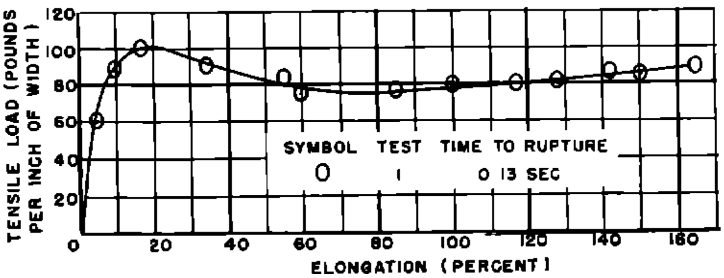
CAA TECHNICAL DEVELOPMENT AND EVALUATION CENTER INDIANAPOLIS INDIANA



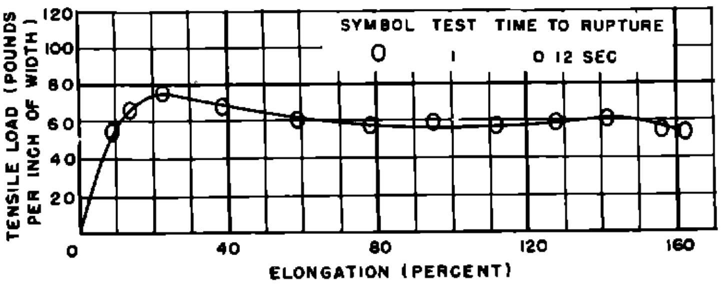
SPECIMEN NO 29



SPECIMEN NO 30



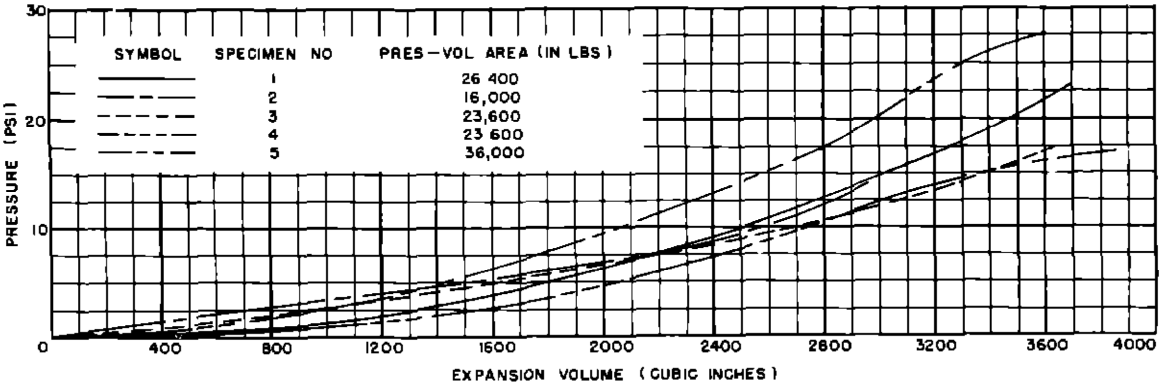
SPECIMEN NO 31

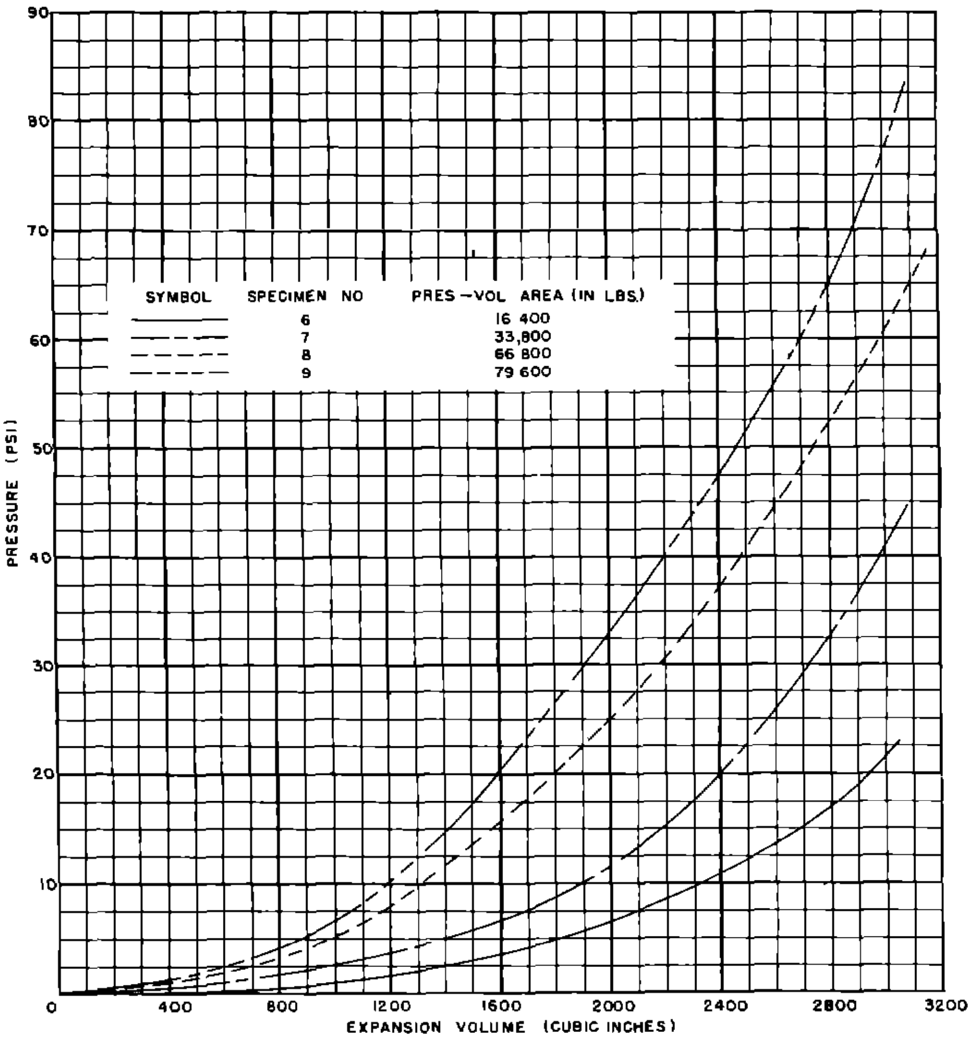


SPECIMEN NO 32

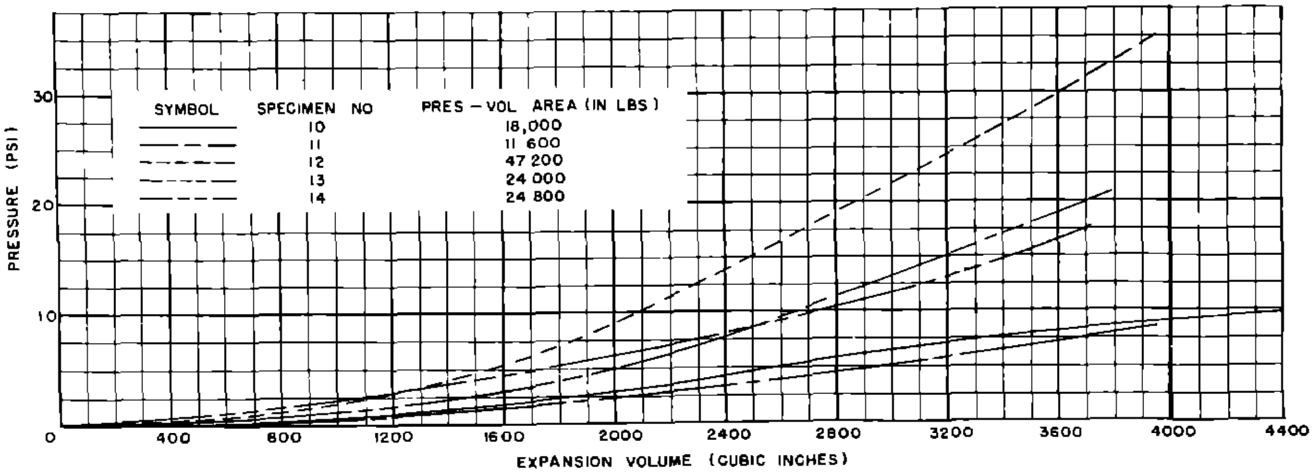
CAA TECHNICAL DEVELOPMENT AND EVALUATION CENTER INDIANAPOLIS INDIANA

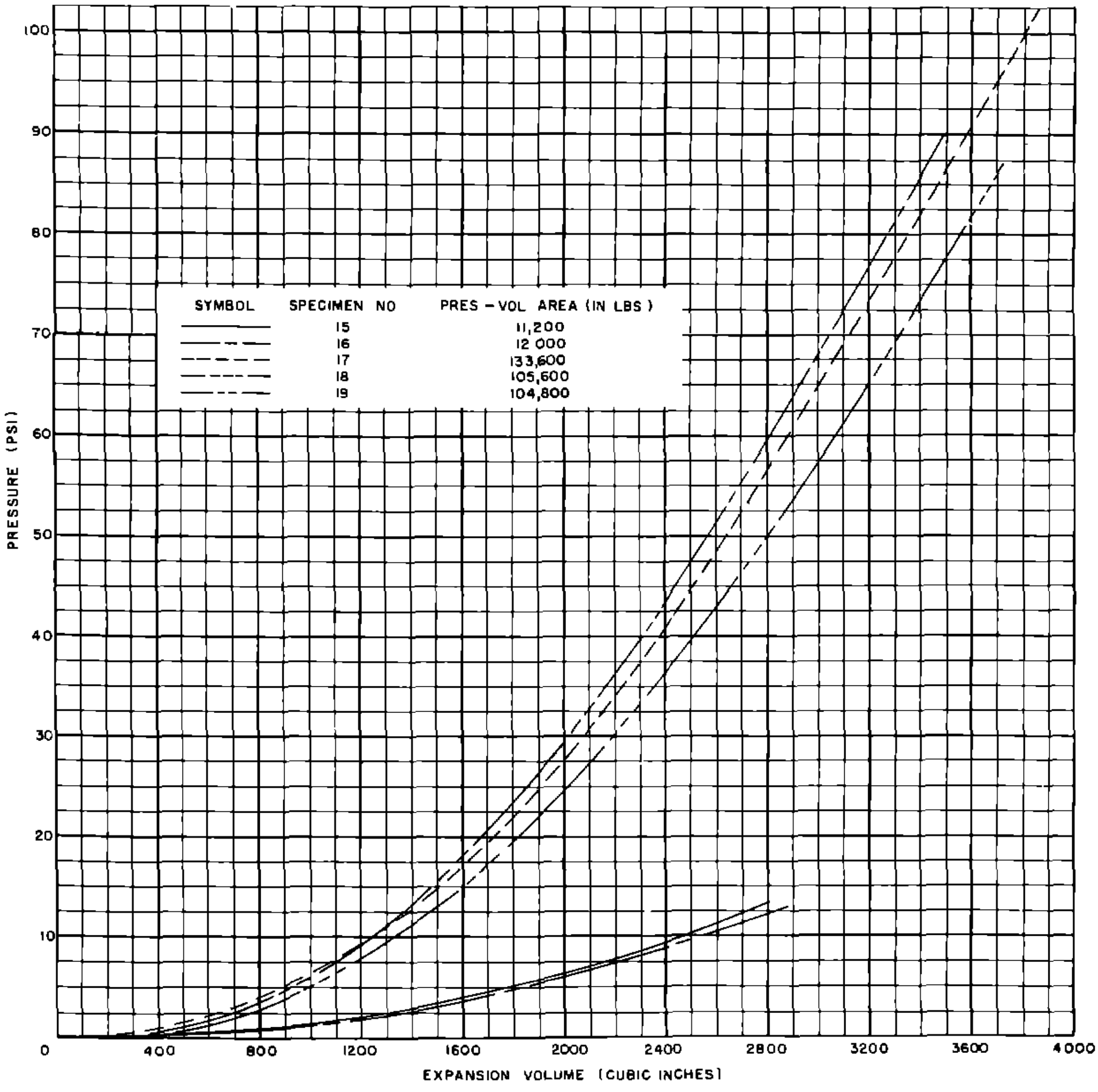
Fig 7 Pressure-Versus-Volume Data

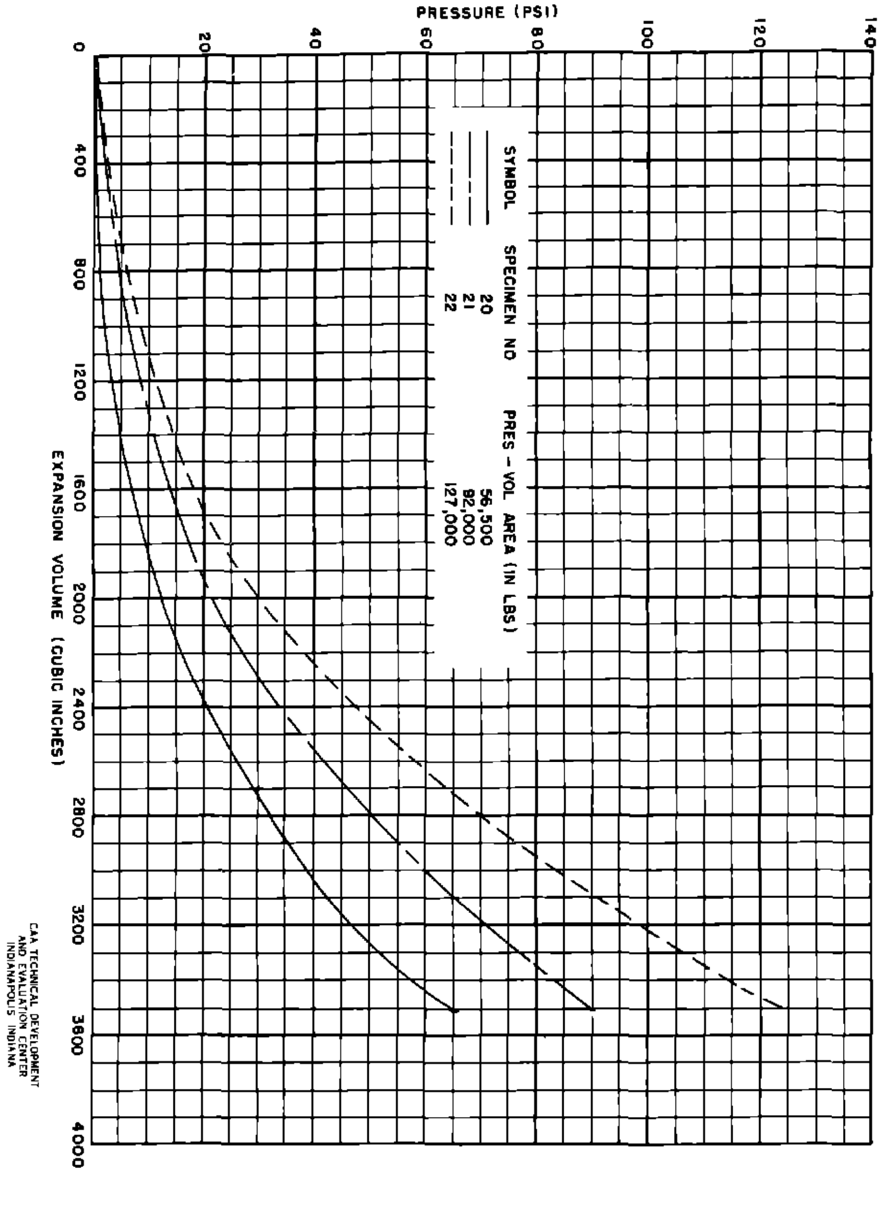


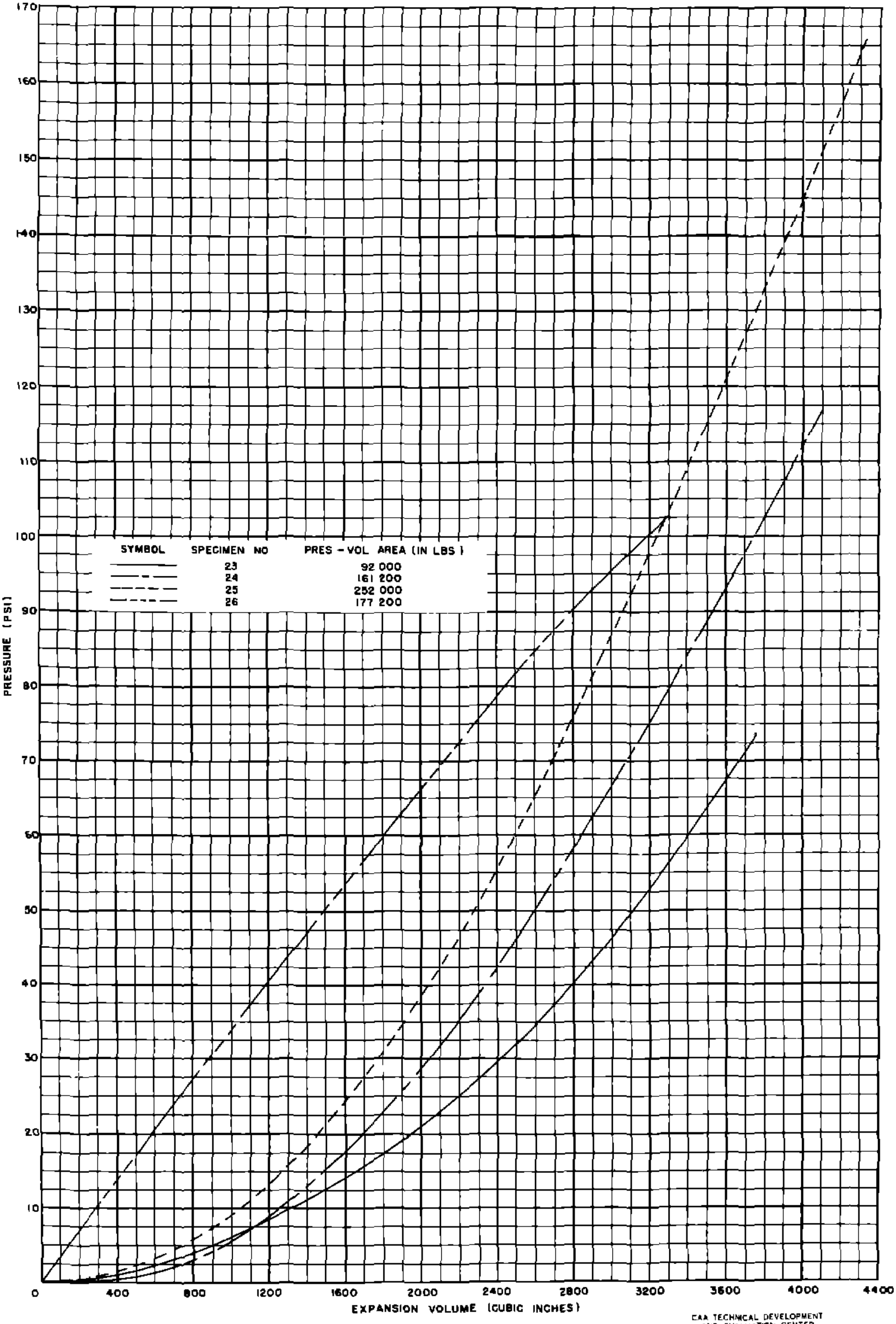


CAA TECHNICAL DEVELOPMENT AND EVALUATION CENTER INDIANAPOLIS INDIANA

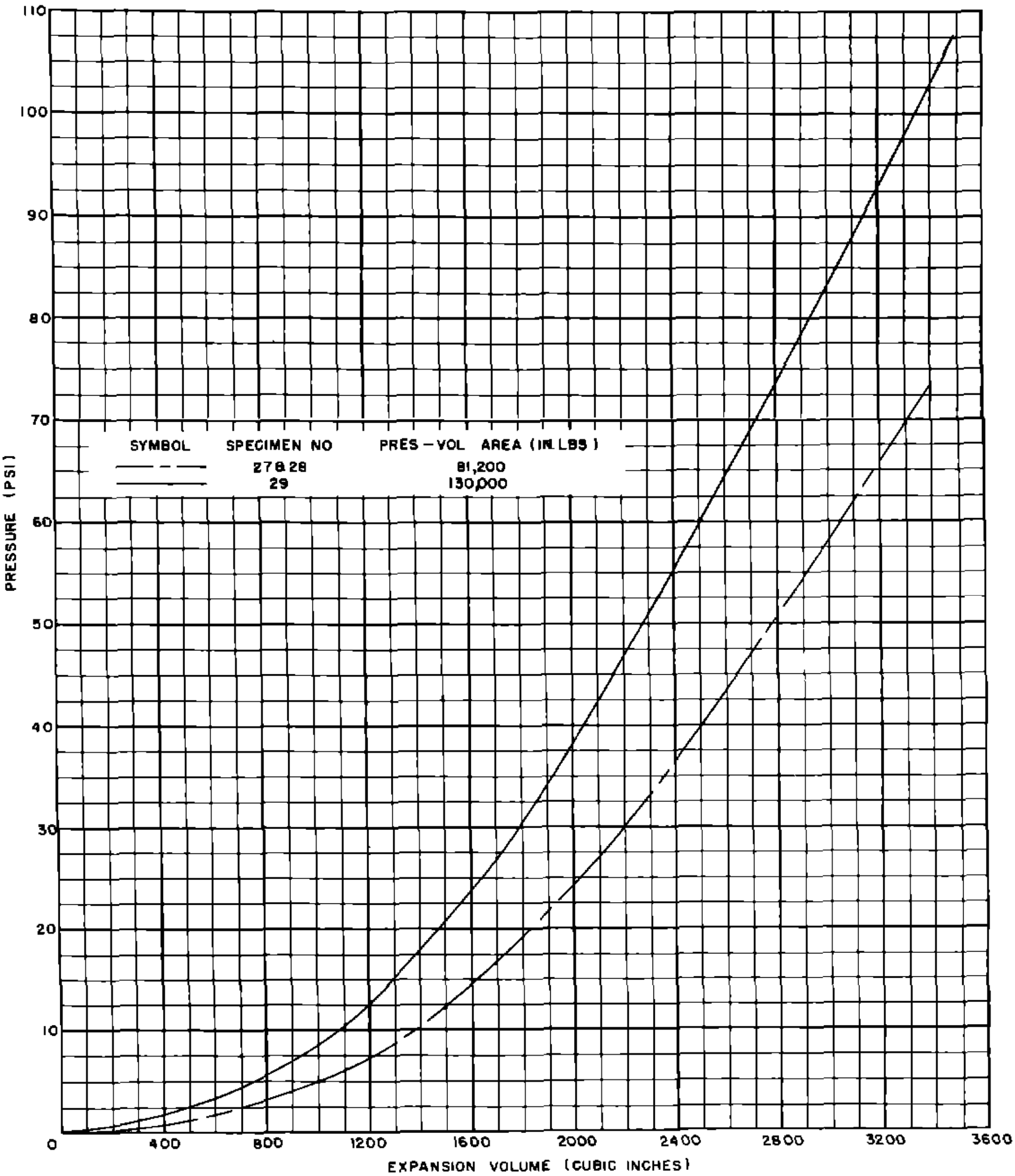

SYMBOL
SPECIMEN NO
PRES – VOL AREA (IN LBS)
10 18,000
11 11 600
12 47 200
13 24 000
14 24 800
PRESSURE (PSI)
EXPANSION VOLUME (CUBIC INCHES)


SYMBOL
SPECIMEN NO
PRES – VOL AREA (IN LBS)
15 11,200
16 12 000
17 133,600
18 105,600
19 104,800
PRESSURE (PSI)
EXPANSION VOLUME (CUBIC INCHES)

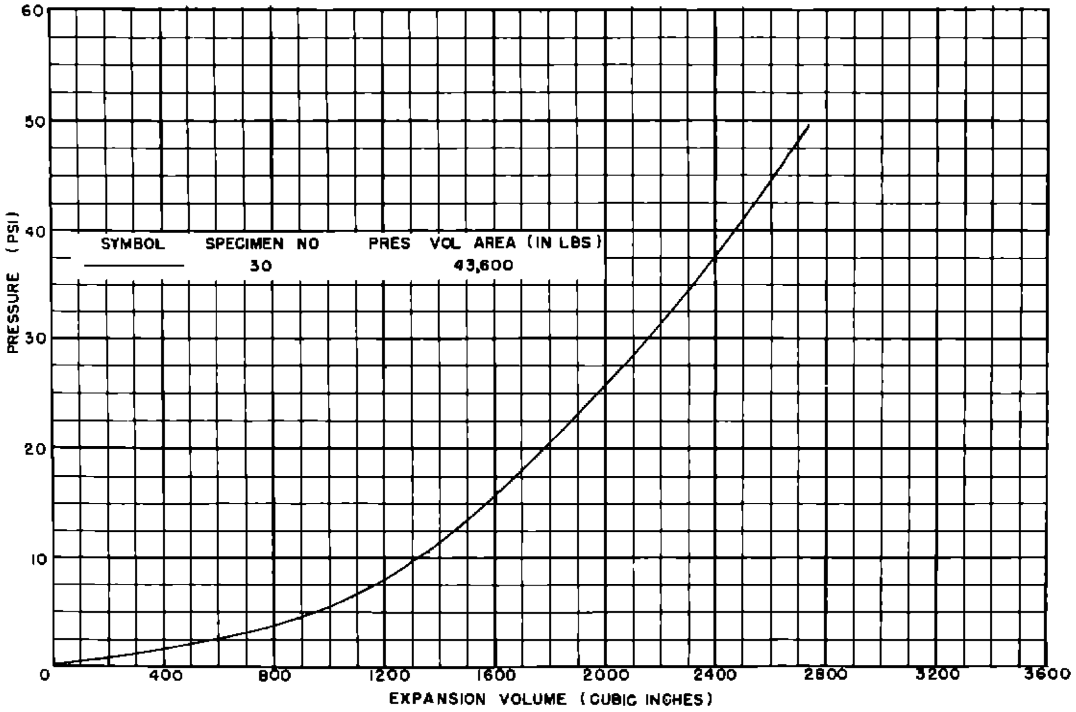

PRESSURE (PSI)
0
20
40
60
80
100
120
140
SYMBOL
SPECIMEN NO
PRES - VOL AREA (IN LBS)
20
21
22
56,500
92,000
127,000
0
400
800
1200
1600
2000
2400
2800
3200
3600
4000
EXPANSION VOLUME (CUBIC INCHES)
CAA TECHNICAL DEVELOPMENT
AND EVALUATION CENTER
INDIANAPOLIS INDIANA

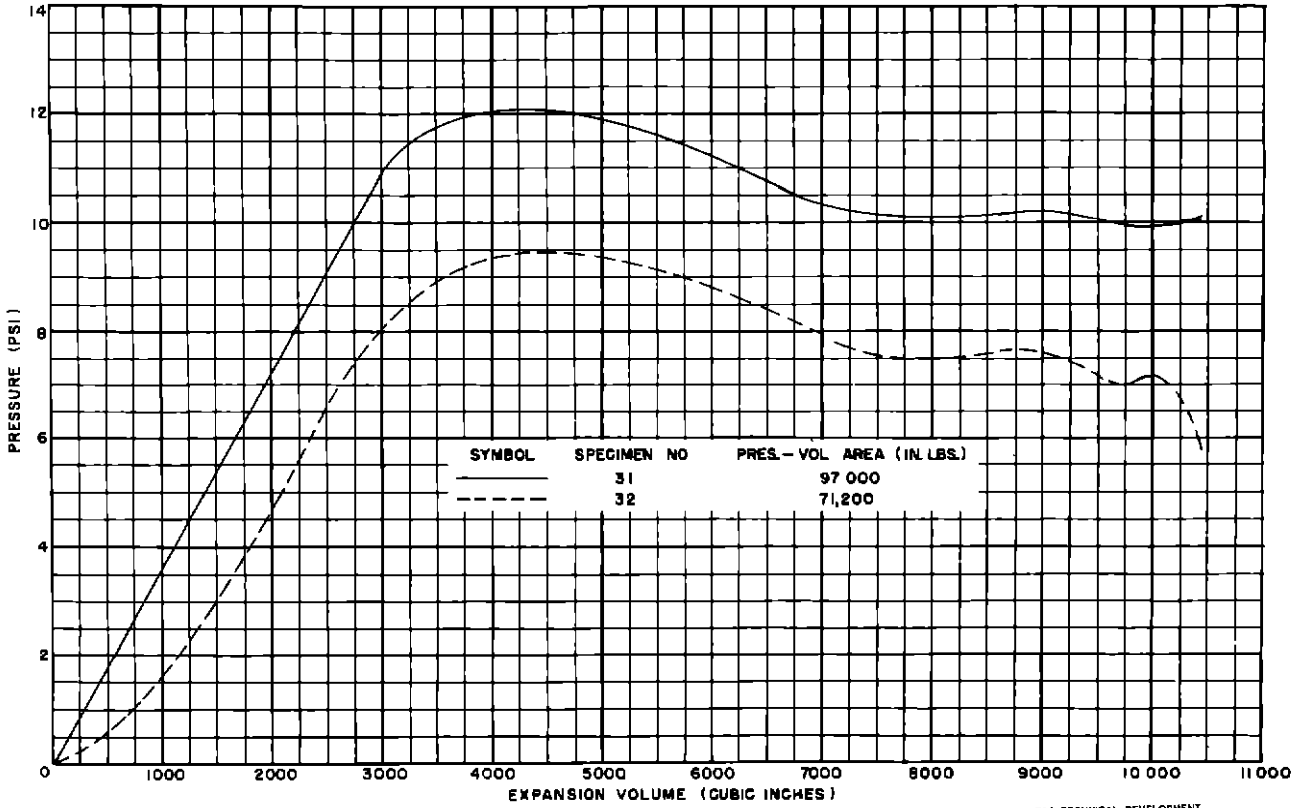


CAA TECHNICAL DEVELOPMENT
AND EVALUATION CENTER
INDIANAPOLIS INDIANA



CAA TECHNICAL DEVELOPMENT
AND EVALUATION CENTER
INDIANAPOLIS INDIANA





CAA TECHNICAL DEVELOPMENT AND EVALUATION CENTER INDIANAPOLIS INDIANA

TABLE I

TEST RESULTS

(1) Speci m n No	(2) Manu- f ture	(3) De ription of Bladder Material	(4) Nominal W ght of Composite Material: Expe i mental (lb/sq ft)	(5) Nominal W ght of Composite Material: Manufac turer s Specifi ations (lb/sq ft)	(6) Nominal Thickness of Composite Material: Experi mental (inches)	(7) Nominal Thickness of Composite Material: Manufa turer s Spe ifi- ations (inches)	(8) Ten ile Strength of Composite Mate ial (lb/in)	(9) Weight of Fabric Only: Colm 4 minus weight of rubber coating adhesive etc (lb/sq ft)	(10) Ratio of Strength of Composite Material to W ight of Composite Material: Colm 8 / Colm 4	(11) Ratio of Strength of Composite Material to Weight of Fabric Only: Colm 8 / Colm 9	(12) Ar a Under Pre sure Volume Diagram (Work) (in lb)	(13) Ratio of Are Und r Pr ure Volum Diagram to Weight of Composite Material: Colm 12 / 4 75 x Colm 4	(14) Ratio of Are Und r Pr ure Volum Diagram to Weight of F b i Only: Colm 12 / 4 75 x Colm 9	(15) Maximum Elongation (per cent)	(16) Number of T sts Determining Mean Load Versus-Elongation Cu
1	G	Two ply pla n woven nylon fab i Buna N coated	0 185	0 150	0 032	0 026	190	0 029	1 030	6 550	26 400	30 000	218 000	25 0	1
2	U	Two ply qua woven l ghtweight nylon fabric with thin ubbe oating	0 132	0 132	0 022	0 024	128	0 027	969	4 741	16 000	25 500	124 600	17 5	4
3	G	Two ply pla n-woven nylon fabri Buna N oated and with a Bun N inne ply	0 369	0 290	0 068	0 052	145	0 029	392	5 000	23 600	13 485	97 650	23 0	2
4	G	Two ply plain woven nylon fab c nylon coated	0 081	0 100	0 018	0 018	140	0 029	1 728	4 828	23 600	36 400	170 000	25 0	2
5	U	Two ply squar woven medium to l ghtweight nylon fabric w th a thin rubber line	0 186	0 150	0 029	0 028	230	0 055	1 236	4 181	36 000	40 700	137 800	23 0	6
6	U	Squar -woven mediumweight nylon fabrics with ubbe l ners Pl laminated on the bias except the two-ply material laminated at 90 (1-ply)	0 124	0 099	0 022	0 021	198	0 036	1 596	5 500	16 400	27 840	95 660	18 3	3
7	U	(2-ply)	0 258	0 199	0 041	0 044	394	0 072	1 527	5 472	33 800	27 590	98 580	18 6	5
8	U	(3 ply)	0.308	0 299	0 058	0 067	600	0 108	1 948	5 555	66 800	45 650	129 880	19 3	2
9	U	(4 ply)	0.470	0 399	0 082	0 090	730	0 144	1 553	5 069	79 600	35 660	116 080	18 5	2
10	G	One ply plain-woven nylon fabric Buna N oated and with a Buna N nner ply	0 318	None	0 055	0 037	79	0 015	248	5 266	18,000	11 920	252 000	30 0	1
11	G	One-ply plain-woven nylon fab Buna N coated and with a Buna N inner ply	0 290	0 210	0 050	0 037	70	0 015	241	4 666	11 600	8,467	162 400	26 0	1
12	U	One ply mediumwe ght quare woven nylon fabric with rubber oating	0 295	0 301	0 046	0 049	287	0 055	972	5 218	47 200	33 690	180 210	25 5	4
13	U	One ply squar wov n med um to lightweight nylon fabric with thin rubber coating	0 136	0 150	0 027	0 024	146	0 027	1 073	5 407	24 000	37 150	186 600	23 5	5
14	U	One ply qu woven extra lightweight No 5200 nylon fabric laminated at 90 to one ply lightweight No 5147 nylon fab with thin ubbe oating	0 142	0 120	0 022	0 024	173	0 041	1 218	4 219	24 800	36 000	127 020	24 3	4
15	G	One ply plain woven otton fab i Buna-N oated and with a Buna N inner ply	0 501	0 410	0 085	0 076	120	0 081	239	1 481	11 200	4 705	29 030	15 5	2
16	G	One ply plain woven cotton fabri Buna N coated and with a Buna N inne ply	0 395	0 320	0 065	0 062	120	0 081	304	1 481	12 000	6 400	31 110	16 2	2
17	G	Nylon tire cordewith Buna-N Pli s laminated on the bia (2 ply)	0 475	0 450	0 090	0 096	368	0 110	774	3 349	133 600	14 181	61 236	21 0	2
18	G	(3 ply)	0 607	0 580	0 117	0 129	720	0 165	1 185	4 363	105 600	36 666	134 400	23 7	4
19	G	(4 ply)	0 739	0 710	0 140	0 162	770	0 220	1 290	3 500	104 800	29 857	100 000	22 0	2
20	G	Nylon tir ord with Buna N Plies laminated on the bias (2 ply)	0 495	0 450	0 087	0 096	550	0 110	1 111	5 000	56 500	24 042	108 000	23 0	1
21	G	(3-ply)	0 635	0 580	0 115	0 129	760	0 165	1 196	4 600	92 000	30 560	117 000	23 0	3
22	G	(4-ply)	0 823	0 710	0 149	0 162	1 050	0 220	1 278	4 770	127 000	32 489	122 000	21 0	2
23	G	Nylon tire cord resin-treated and with rubber liners Pl s laminated on the bias (2 ply)	0.448	0 510	0 083	0 100	615	0 110	1 372	5 590	92 000	43 192	175 630	24 0	2
24	G	(3 ply)	0 581	0 660	0 110	0 136	940	0 165	1 610	5 690	161 200	58,405	205 160	27 0	3
25	G	(4-ply)	0 739	0 810	0 135	0 170	1 310	0 220	1 770	5 950	252 000	71 790	240 540	29 3	3
26	G	(5 ply)	0 844	0 960	0 169	0 206	900	0 275	1 060	3 270	177 200	44 189	135 310	20 0	2
27	U	Two ply ti ord No 5193/58 with rubber liner No 3048 Plies lam nated on the bias	0 395	0 320	0 068	0 065	630	0 156	1 594	4 038	81 200	43 280	109 300	20 9	4
28	U	Two-ply tir ord No 5193/58 laminated at 90 to ach other to rubber liner No 3048, and to t d tock No 3062	0 748	0 720	0 120	0 130	630	0 156	840	4,038	81 200	22 850	109 300	20 8	7
29	U	Self sealing onstruction two layers of rubber and three pl e of nylon ti o d laminated on the bias	1 290	1 170	0 215	0.230	860	0 234	666	3 675	130 000	21 210	116 600	21 8	7
30	L	A high g ade of leathe alled Indian Tan	0 594	None	0 123	0 125	460	None	774	None	43 600	15 460	None	15 0	2
31	R-O	A homogeneous rubbe material with ve y lightweight nylon me h loos ly bonded to the outer surface	0 334	Non	0 052	None	101	None	302	None	97 000	61 000	None	165 0	1
32	F-O	A homogeneous ubbe material with a very lightweight nylon me h loo ly bonded to the oute urfa e	0 295	None	0 049	None	75	None	254	None	71 200	50 700	Non	163 0	1

=G Goodyea Ti and Rubber Company
U = United States Rubbe Company
L Leather
R-O Marston Exc lsio Ltd supplied through the ou te y of the Ministry of Supply Gr at Britain
F-O Firep oof Tanks Ltd supplied through the courtesy of the Ministry of Supply Great Britain

The tensile strength of the various materials, given in Column 8, was determined from the test results by use of Equation (2) These results indicate that the tensile strengths of the test materials vary from 60 to 1,310 pounds for a strip of material one inch wide

Column 9 gives the weight of the fabric, that is, the weight of the material which for all practical purposes carries the tensile load specified in Column 8 Rubber coating materials are considered to contribute very little to the over-all tensile strength of the composite material

A comparison of tensile strength without a consideration of the material weight is believed to be of little value Therefore, the tensile strength has been divided by the weight of the composite material, and this ratio is presented in Column 10 Values of this ratio range from 239 to 1,948 The materials with the highest ratio are, for their weight, capable of carrying the greatest load Of the materials tested, specimens Nos 4, 8, and 25 are shown to be superior with respect to load-carrying ability Specimen No 8 is best with a ratio of 1,948, while specimens Nos 25 and 4 follow with ratios of 1 770 and 1,726, respectively

Column 11 refers to the same type of information for the material as does Column 10, except that this information applies only to the fabric in the composite material The results in Column 10 show that nylon fabric is better than cotton fabric (specimens Nos 15 and 16)

Data on the ability of the various materials to absorb energy (Column 12) were obtained by measuring the area under the pressure-versus-volume diagrams of Fig 7 The energy absorption data shown in this column are for the approximately 1,362 square inches of material which is exposed by the inside diameter of the clamp ring of the compressed-air gun

Column 13 shows the ability of the composite materials to absorb energy with respect to their weight Specimens Nos 8, 23, 25, 26, 27, 31, and 32 appear better in this respect than other materials tested

Column 14 indicates the ability of the fabric in the composite materials to absorb energy with respect to the fabric weight. The data in this column show that nylon fabric is superior in this respect to cotton fabric

Column 15 gives the percentage of elongation demonstrated by the specimens in the tests The ability to elongate is shown to be greatest for specimens Nos 31 and 32 These materials elongated approximately 165 per cent, while the majority of other materials elongated between 20 and 30 per cent

An evaluation of the better materials mentioned in the foregoing indicates that specimens Nos 8 and 25 appear to possess the best crash-resistant properties Specimen No 8 has a numerical factor of 1,948, representing its ability to sustain load in relation to its weight, and it has a numerical factor of 45,650, representing its ability to absorb energy in relation to its weight Specimen No 25 has a numerical factor of 1,770, representing its ability to sustain load in relation to its weight, and it has a numerical factor of 71,790, representing its ability to absorb energy in relation to its weight Specimen No 8 is somewhat more efficient than specimen No 25 in its ability to sustain load while specimen No 25 is more efficient than specimen No 8 in its ability to absorb energy

Although specimen No 31 is highly efficient in its ability to absorb energy, its efficiency in carrying load is extremely low Because of this deficiency, the material is not considered to possess optimum crash-resistant properties

Column 16 gives the number of tests that have been conducted to determine the mean load-versus-elongation curve for each material In some instances, the number of available samples of the material tested was limited In others, the malfunctioning of the test equipment invalidated the results of specific tests It was therefore not possible to determine the characteristics of all of the materials by averaging the results of a number of tests

The need for averaging test results to provide properly for the inherent nonuniformity of such materials is recognized However, the listing of characteristics which have been determined from only one test is believed significant In such cases, divergence limits can be assumed to be of the same order of magnitude as those exhibited by other materials It will be noted that the materials which were evaluated on the basis of one test were not outstanding

CONCLUSIONS

The results of the tests conducted to determine which bladder materials should be expected to have good crash-resistant properties indicate that two types of laminated materials possess, for their weight, greater load-carrying and energy-absorbing abilities than any of the other types tested These two materials are (1) a three-ply, square-woven, mediumweight, nylon fabric with a rubber liner and with the plies laminated on the bias, and (2) a four-ply, nylon, tire-cord fabric which is resin-treated and which has a rubber liner and has the plies laminated on the bias These types of materials can be made with various weights of fabric or cords to obtain any strength which may be required

A material composed of a greater number of plies of a fabric with the plies uniformly distributed on the bias and having smaller cords appears to be better than a material composed of a lesser number of plies of fabric with the plies uniformly distributed on the bias and having larger cords The strength of the adhesive holding the plies of fabric together appears to be an important factor in the ability of a material to demonstrate the ultimate strength of its fabric

Materials composed of nylon fabrics possess strength and energy-absorbing properties which are superior to those found in materials composed of cotton fabrics A homogeneous rubber material tested has very good energy-absorption properties but is extremely poor in load-carrying ability

The strength properties of the materials tested were not appreciably affected by rupture times varying from 0 05 to 3 0 seconds

ACKNOWLEDGMENT

Acknowledgment is made to Goodyear Tire and Rubber Company, Research Division, Akron, Ohio, and to the United States Rubber Company, Fuel Cell Division, Mishawaka Indiana, which companies have through very close technical co-operation with this Center and through submittal of the bulk of materials for the tests made this study possible

An expression of appreciation is also extended to the Air Registration Board, Ministry of Supply, Great Britain, which has shown much interest in this work, has extended most helpful comments on the test program, and has, through the co-operation of Marston Excelsior Ltd , and Fireproof Tanks Ltd , submitted some materials for tests

GPO 804258 — 1