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Part III

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INVESTIGATION OF THE HIGH SPEED IMPACT BEHAVIOR OF FIBROUS MATERIALS

PART III. IMPACT CHARACTERISTICS OF PARACHUTE MATERIALS

TECHNICAL DOCUMENTARY REPORT NO. WADD-TR-60-5II, Part III
May 1963

AF Materials Laboratory
Aeronautical Systems Division
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio

Project No. 8151, Task No. 815103

(Prepared under Contract No. AF33(616)-7627 by Fabric Research
Laboratories, Dedham, Massachusetts; Robert J. Coskren and
Chauncey C. Chu, Authors)

NO OTS

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FOREWORD

This report was prepared by Fabric Research Laboratories, Inc. under USAF Contract No. AF 33(616)-7627. (This contract was initiated under Project 8151, "Special Weapons Decelerators Studies", Task 815103, "Materials Development and Characteristics Peculiar to Special Weapons Aerodynamic Decelerator Systems".) The work was administered under the direction of the Non-Metallic Materials Division, A.F. Materials Laboratory, with Mr. Jack H. Ross and Capt. C.O. Little, Jr. acting as project engineers.

This report covers work conducted from February 1962 to June 1963.

ABSTRACT

The impact studies initiated earlier (WADD TR 60-511, Part I) have been continued. Various HT-1 webbings, ribbons, and overlap splices have been tested on the ASD High Impact Testing Machine and evaluated for energy absorbing capability.

All HT-1 samples showed significant energy losses at the three speed levels studied when compared with values obtained from slow speed tests. Maximum energy losses for HT-1 materials of 80-85 percent of the static value were found at the 700 feet per second impact level. The one nylon sample studied did not indicate as great a loss at this highest impact speed. Results obtained generally substantiate earlier findings that the less complex the geometrical structure of the HT-1 materials, then the less severe will be the energy losses at these high rates of loading. It appears that the energy losses noted can be primarily attributed to the particular types of HT-1 webbing studied. It could be possible through proper structural geometry to raise the energy absorption level of HT-1 material to that of nylon and also to have the added thermal stability which HT-1 fiber is known to provide.

Further studies of HT-1 and other potential parachute materials at these impact speeds is recommended in order to thoroughly characterize their behavior. Slow-speed tensile properties are not necessarily a reflection of the material's response to dynamic loading at very high strain rates.

This technical report has been reviewed and is approved.



C. A. WILLIS, Chief
Fibrous Materials Branch
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I. INTRODUCTION

The work performed during the present program is a continuation of studies initiated in November 1960 under the subject contract. The earlier results have been reported in WADD Technical Report 60-511, Part II dated February 1962. One of the primary conclusions drawn from that work was that certain parachute components made from HT-1 fiber were seriously deficient in energy absorbing capability when impacted at high strain rates. Specifically, when such materials were impacted at speeds in excess of 500 feet per second their energy absorption diminished in some cases to less than 20 percent of the value determined from a static test. Studies with individual HT-1 yarns conducted recently on another program at FRL indicate that its lateral critical velocity (the point where its energy absorbing potential approaches zero) is in excess of 1000 feet per second. Since this level is considerably higher than that contemplated for the parachute components it must be that HT-1 is particularly sensitive to structural geometry. There are, however, indications that certain structures are more efficient than others in this regard and that it may be possible, through changes in webbing design, to obtain HT-1 materials whose energy absorbing characteristics are equivalent or superior to those made from nylon.

The samples selected by ASD and submitted for study were as follows:

1. Control Samples

- a. Nylon Webbing, Phoenix Trimming WN1538X (3000 lbs. breaking strength)
- b. HT-1 Webbing, similar to Phoenix Trimming WN1509X (10,000 lbs breaking strength)
- c. HT-1 Webbing, similar to Phoenix Trimming WN1512 (6000 lbs. breaking strength)
- d. HT-1 Webbing, similar to Phoenix Trimming WN1538X (3000 lbs. breaking strength)
- e. HT-1 Ribbon, similar to Class E, Type II, MIL-T-5608 (1000 lbs. breaking strength)
- f. HT-1 Ribbon, similar to Class E, Type III, MIL-T-5608 (2000 lbs. breaking strength)
- g. HT-1 Ribbon, similar to Class E, Type V, MIL-T-5608 (3000 lbs. breaking strength)

2. Overlap Splices

- a. Nylon, WN1538X
- b. HT-1 Similar to WN1509X, 8 inch overlap, 4 pt. 6 cord
- c. HT-1 Similar to WN1512, 8 inch overlap, 3 pt. 6 cord
- d. HT-1 Similar to WN1538X, 8 inch overlap, 3 pt. 6 cord

Each of the above samples was evaluated on an Instron Tester at 70°F and 65% R.H. Load-Elongation diagrams were obtained and the static energy absorbed to rupture calculated from the area under the curves. The materials were then subjected to impact by free-flying projectiles travelling at speeds of approximately 250, 500 and 750 feet per second. The impact energy was calculated and compared to that obtained from the Instron test.

II. EQUIPMENT AND EXPERIMENTAL TECHNIQUE

The ASD Impact Test Machine used in this work was designed and constructed by FRL under Air Force Contract Number AF33(616)-6321. A report on this activity has been prepared and is available as WADD TR60-511, Part I. A schematic diagram of the system is given in Figure 1.

Reviewing briefly, a specimen folded in the shape of a "V" is fastened to the rear of Pendulum #1. A missile whose mass can be varied from 0.5 to 10 pounds is propelled from the helium operated gun, through an opening in the first pendulum, striking and rupturing the sample. The deflection of Pendulum #1 resulting from the impact can be measured. After breaking the specimen, the projectile enters and is contained in Pendulum #2. The deflection of this pendulum can also be recorded. A high speed, multiple flash lamp can be used to illuminate the impact area so that multi-image photographs can be taken if desired.

Knowing the period and displacement of the second pendulum, the residual velocity of the missile can be calculated. Similarly, knowing the period and displacement of the first pendulum, the loss in missile velocity as a result of specimen rupture can be determined. Having measured the residual velocity and the velocity loss it is possible to determine the striking velocity from a summation of the two known quantities. Impact energy absorption can then be calculated knowing the mass of the missile and its initial and final velocities.

$$E = \frac{1}{2} m (V_1^2 - V_2^2)$$

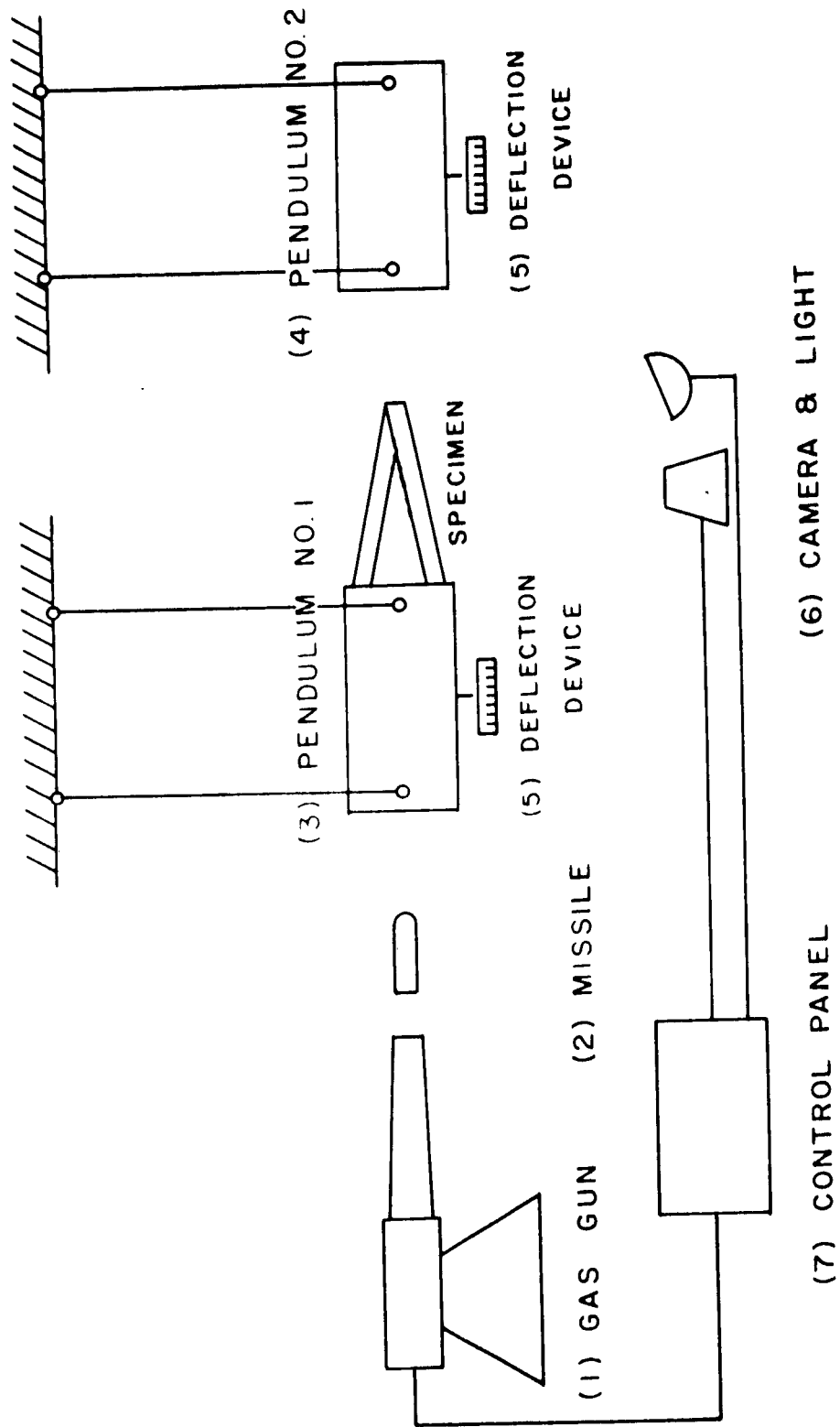


FIGURE 1. SCHEMATIC DIAGRAM OF IMPACT TESTING MACHINE

where

E is the total energy absorbed in rupturing the specimen

m is the mass of the projectile

V_1 is the projectile striking velocity

V_2 is the projectile residual velocity

In the case of the jointed specimens one joint was contained on each leg of the "V" for symmetry with the missile striking a length of control webbing between the joints. This technique and all others employed during the current program were identical with those used during the initial phase of the work. It is recommended that WADD Technical Report 60-511, Part II be reviewed for a more comprehensive description of the experimental techniques and data analysis employed.

Slow speed tensile testing was performed on an Instron Tensile Tester at a crosshead speed of 2 inches per minute. All static energies, as determined from the area under the stress-strain curve, were normalized to a 56 inch effective gage length which was approximately that used for all impact test specimens.

III. DISCUSSION OF RESULTS

A. Slow Speed Tensile Testing of Webbing, Ribbons, and Splices

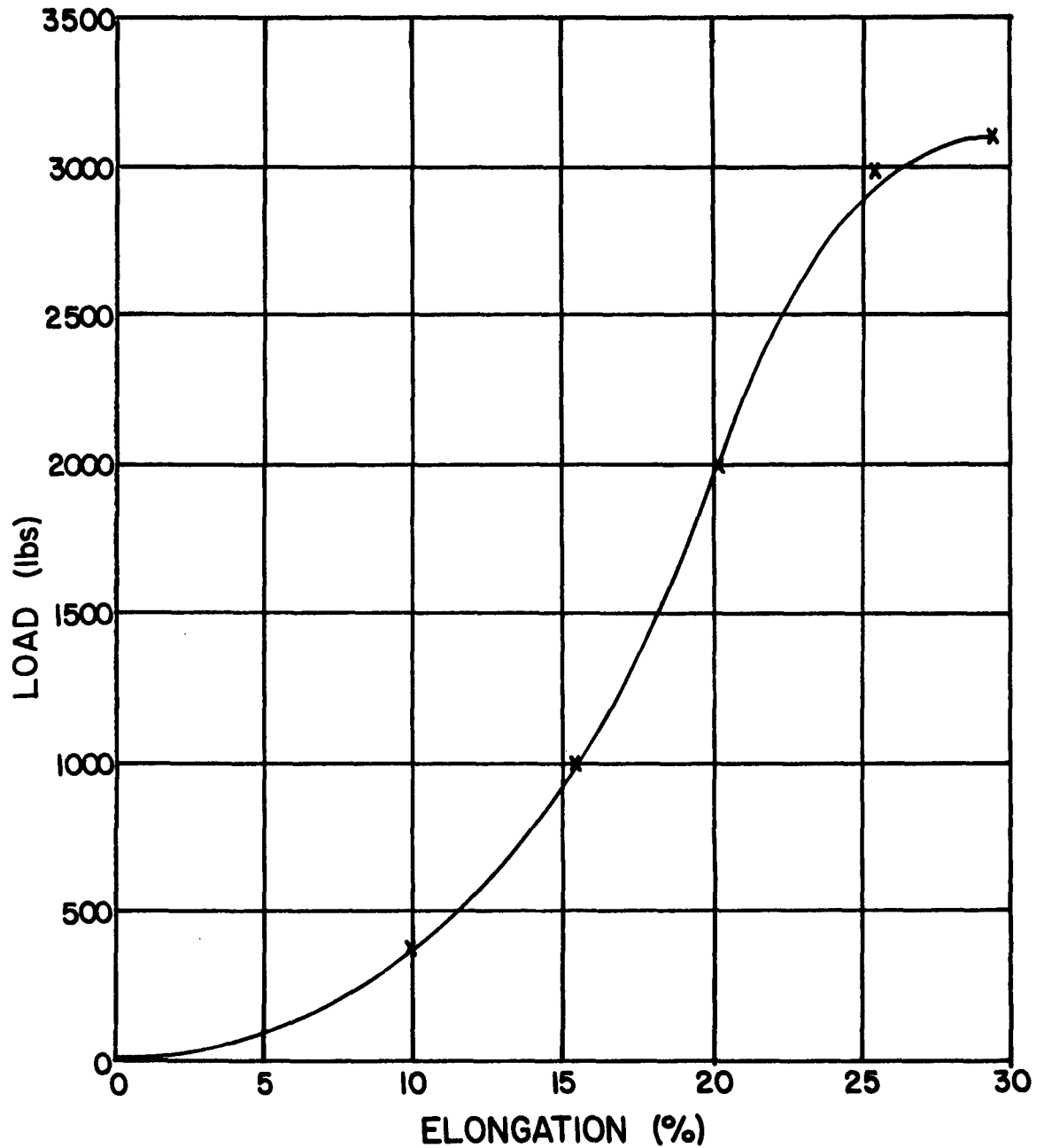
In order to evaluate the impact behavior of the various materials it is first necessary to determine their static or slow-speed tensile properties. Each of the samples was tested on an Instron Tensile Tester at a jaw speed of two inches per minute. A summary of the rupture strengths and elongations is given in Table I. Additionally, complete load-elongation diagrams are presented in Figures 2-12. The work done to rupture the samples can be obtained by measuring the area under the stress-strain curve. In calculating the rupture energies of the samples containing splices the effective gage length used was that of the control webbing plus the additional 5 inches of free gage length required due to the splices.

It is apparent from Table I that the presence of a splice results in approximately a 10-15 percent loss in static breaking strength. The rupture elongations of the splices, however, are considerably below that of the webbings, resulting in an overall loss in static energy absorption capacity of 40 to 50 percent between the control webbings and the same samples containing an 8 inch overlap splice. This loss in energy absorption is primarily a result of the lowering of extensibility of the spliced sample. The rupture elongation as measured from an Instron test is a combination of the extensibilities of the splice itself, which is practically zero, and the control webbing which is in the order of 25 percent. When these two extensions are combined into one test a general reduction in overall sample extension results. In all spliced -sample static tests the failure occurred at the joint, that is, at the beginning of the stitching between the two lapped pieces of webbing. This type of behavior is quite common in as much as the stitched portion represents the weakest link in the system, the maximum efficiency being only 70-80 percent. The stitching acts as a clamp which contributes toward failure at this point. As will be shown shortly, this is not the case in the impact test.

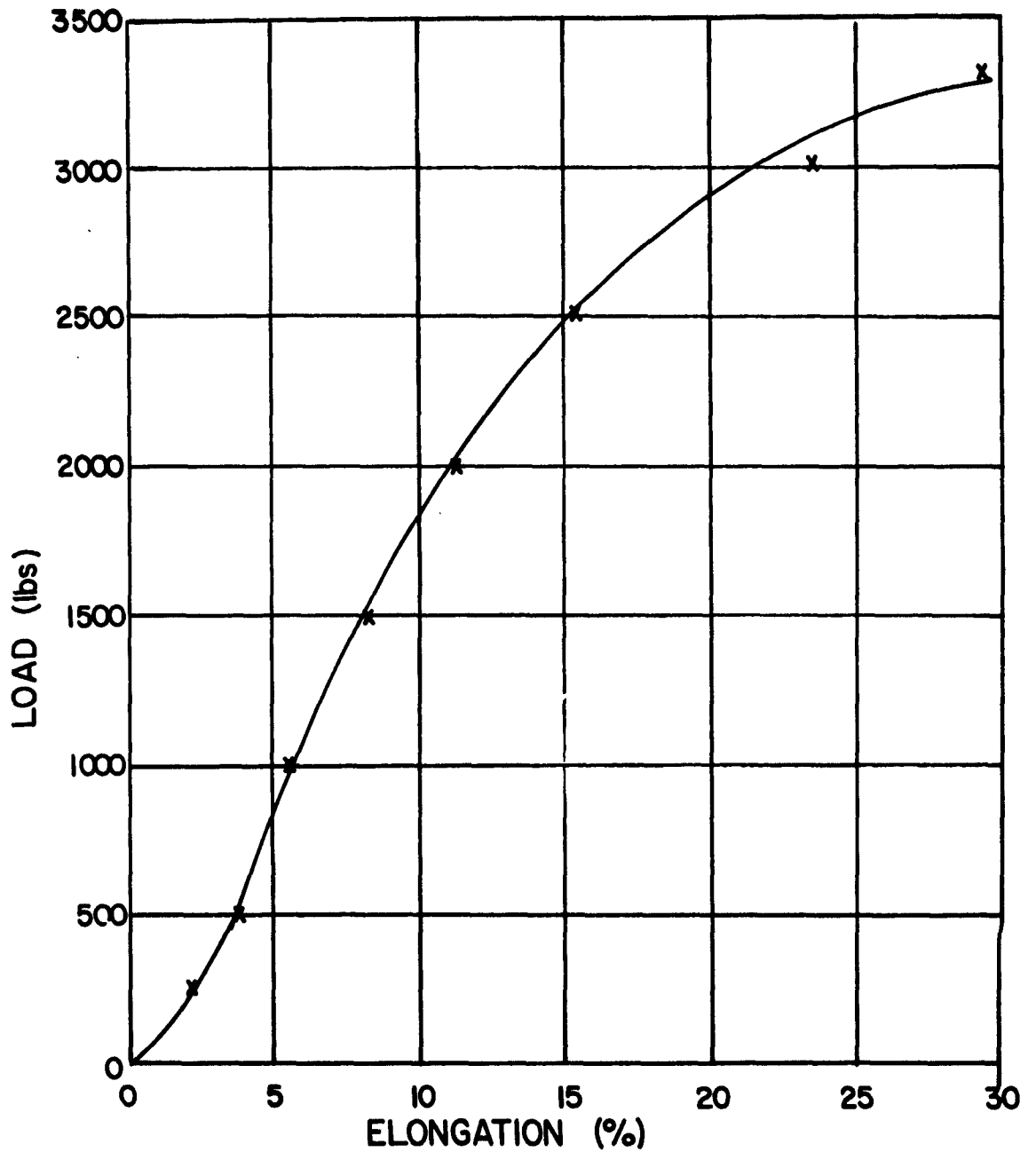
TABLE I

RUPTURE STRENGTH AND ELONGATION OF VARIOUS PARACHUTE COMPONENTS TESTED AT
70°F and 65% R.H. ON AN INSTRON TENSILE TESTER (CROSSHEAD SPEED 2"/MIN)

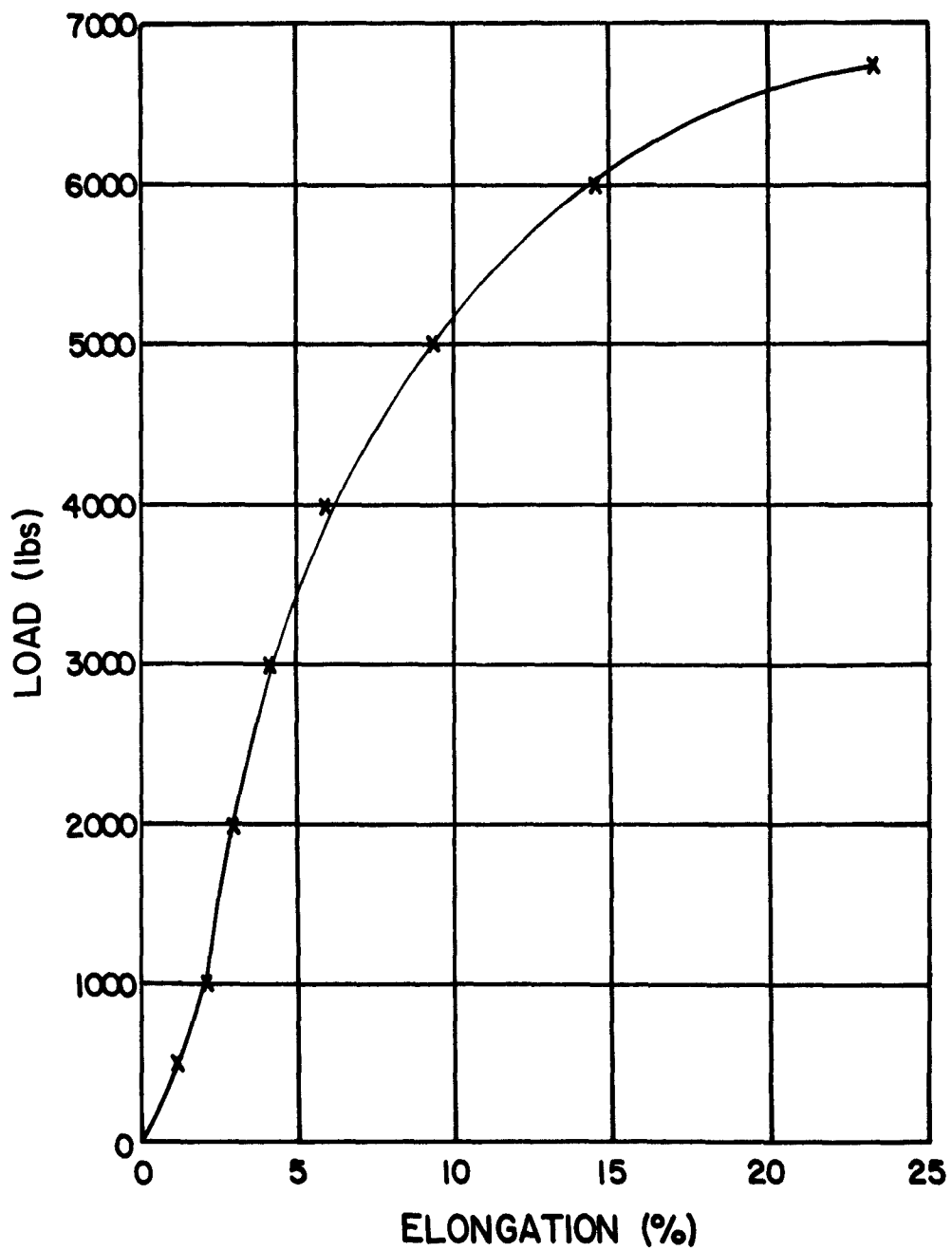
	<u>Rupture Strength (lbs)</u>	<u>Rupture Elongation (</u>
A. <u>Control Webbing</u>		
WN1538X Nylon	3066	29.4
WN1538X HT-1	3312	29.3
WN1512 HT-1	6726	23.2
WN1509X HT-1	10,362	23.4
B. <u>Control Ribbons</u>		
HT-1 Class E, Type II	1183	21.9
HT-1 Class E, Type III	2000	24.7
HT-1 Class E, Type V	3250	24.5
C. <u>8" Overlap Splices</u>		
WN1538X Nylon	2975	19.6
WN1538X HT-1	2888	16.0
WN1512 HT-1	5867	10.9
WN1509X HT-1	8800	10.5



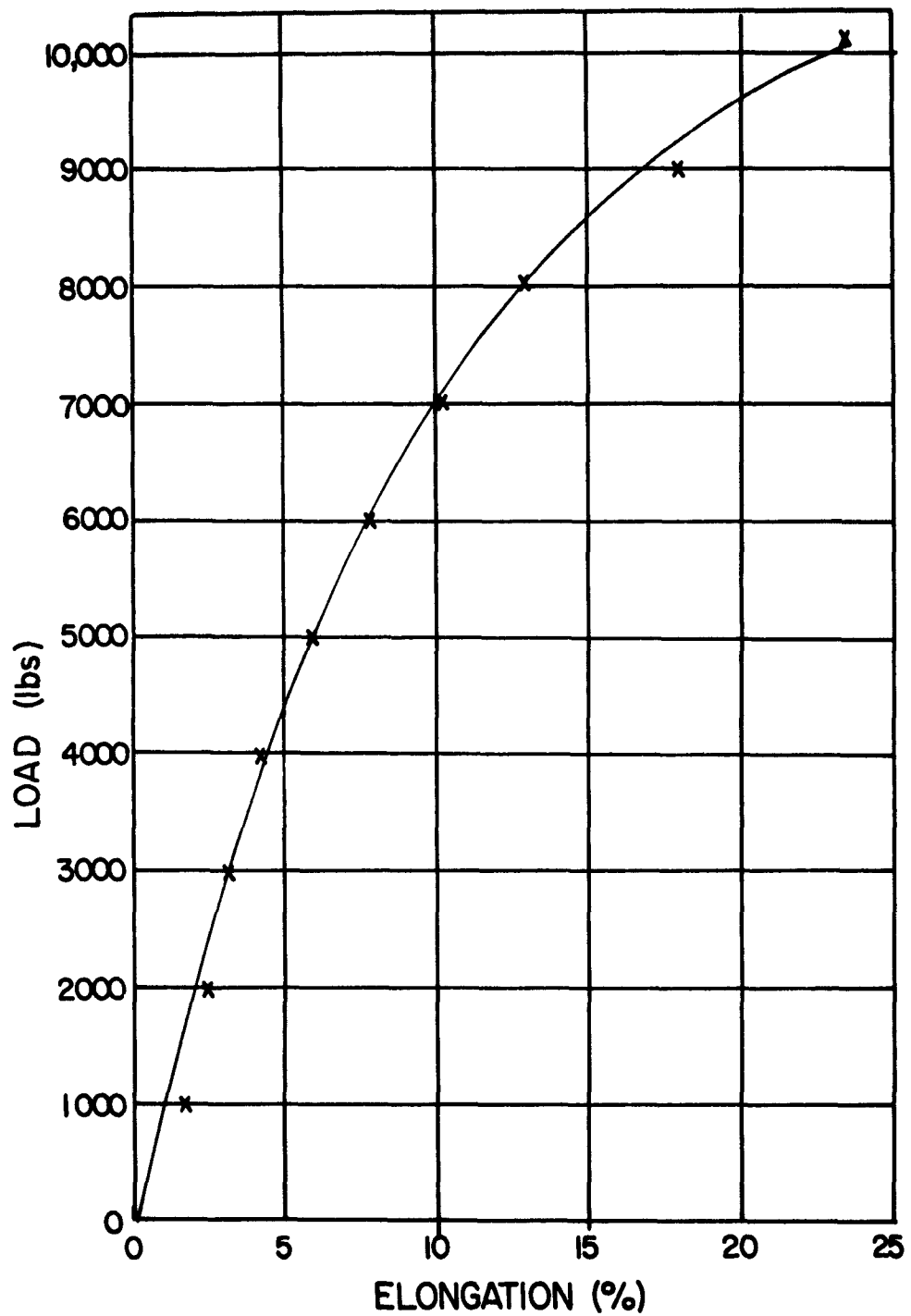
**FIGURE 2. SLOW-SPEED LOAD-ELONGATION DIAGRAM
FOR 1538X NYLON WEBBING.**



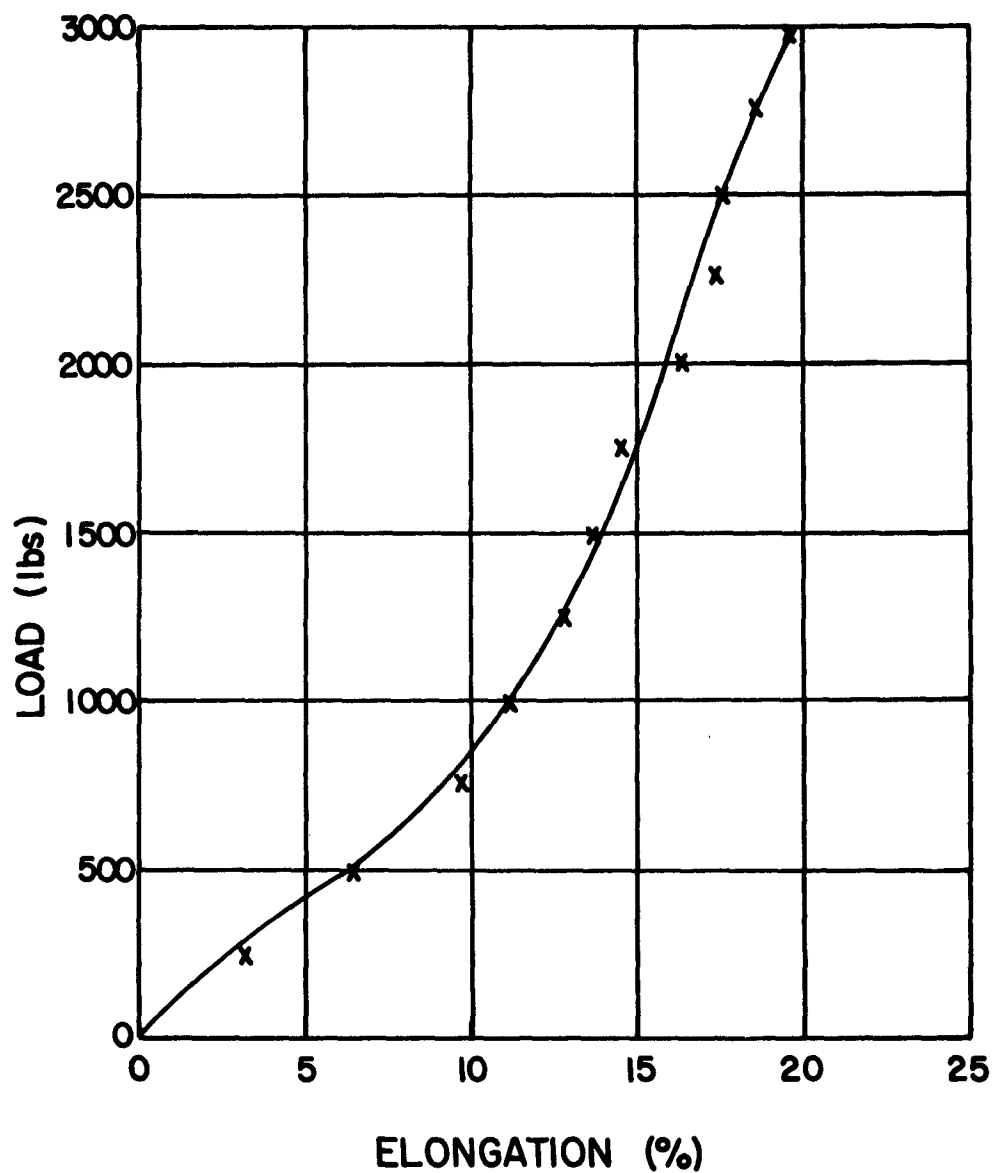
**FIGURE 3. SLOW-SPEED LOAD-ELONGATION DIAGRAM
FOR 1538X HT-1 WEBBING.**



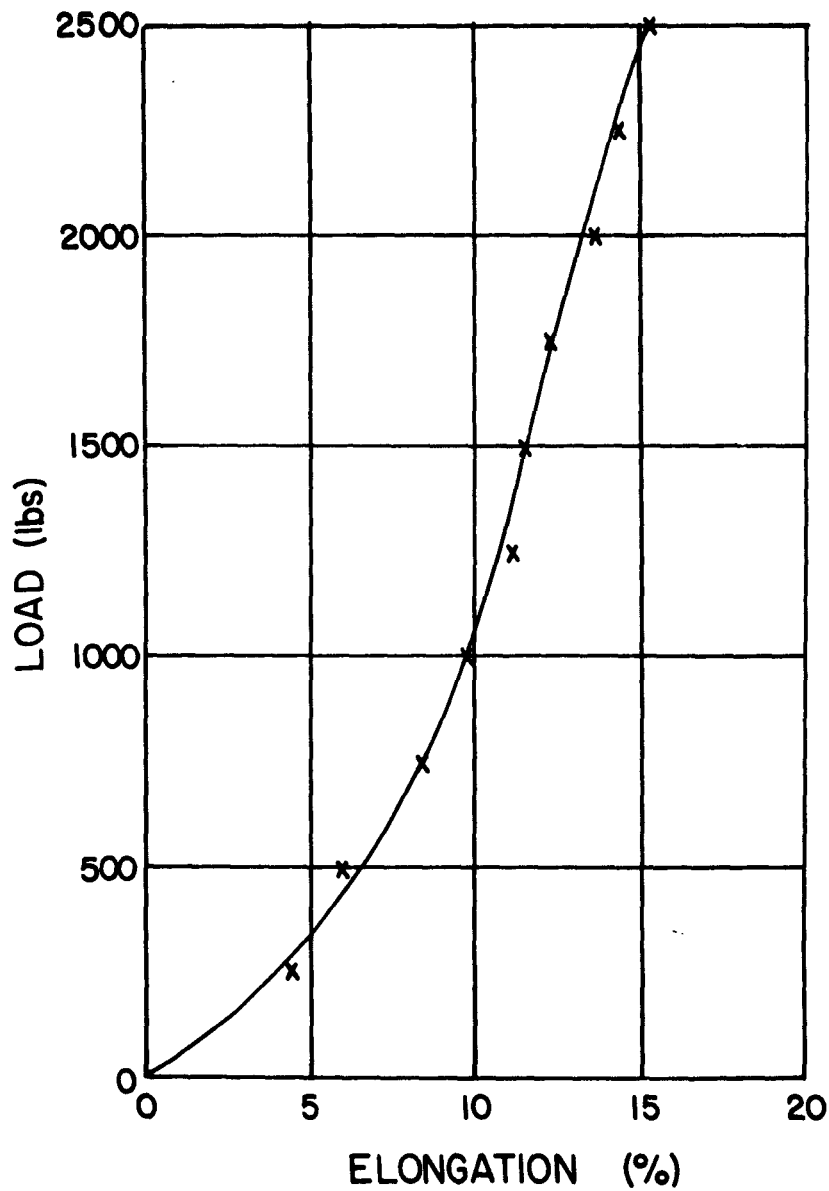
**FIGURE 4. SLOW-SPEED LOAD-ELONGATION DIAGRAM
FOR 1512 HT-1 WEBBING.**



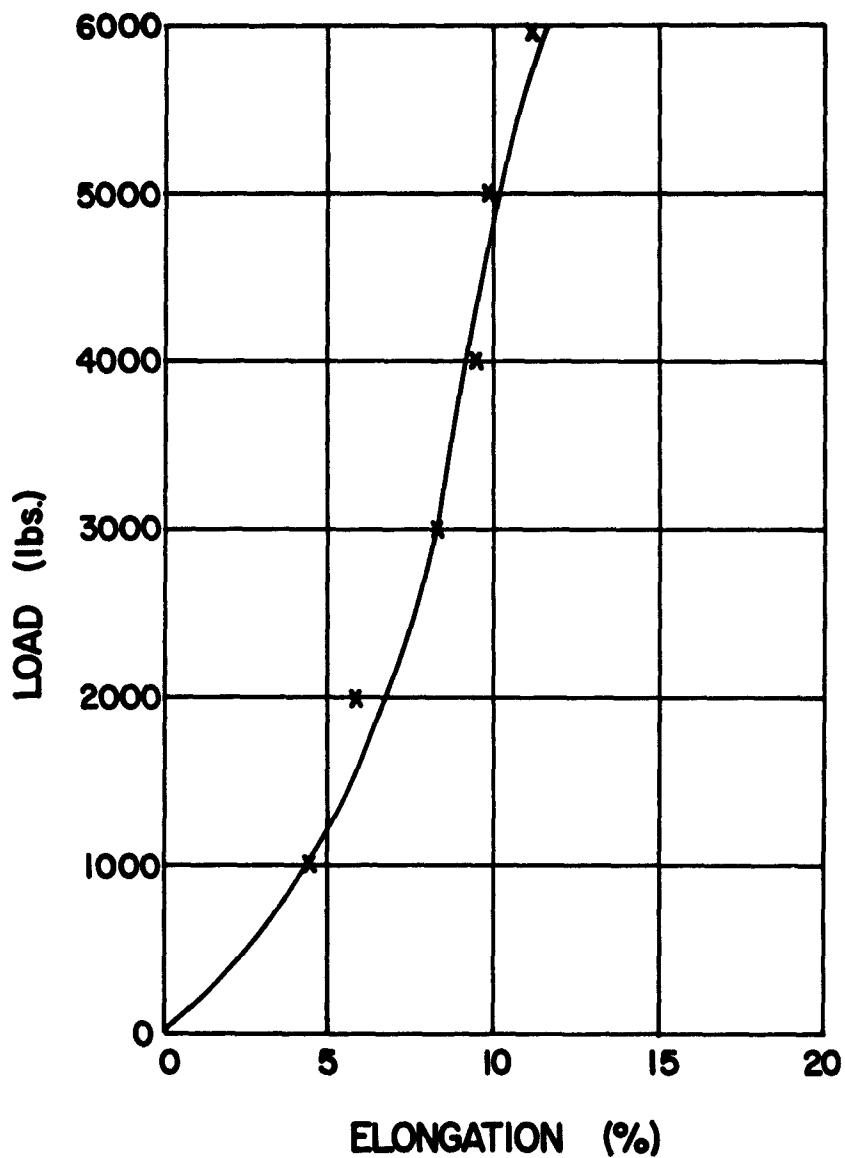
**FIGURE 5. SLOW-SPEED LOAD-ELONGATION DIAGRAM
FOR 1509X HT-1 WEBBING.**



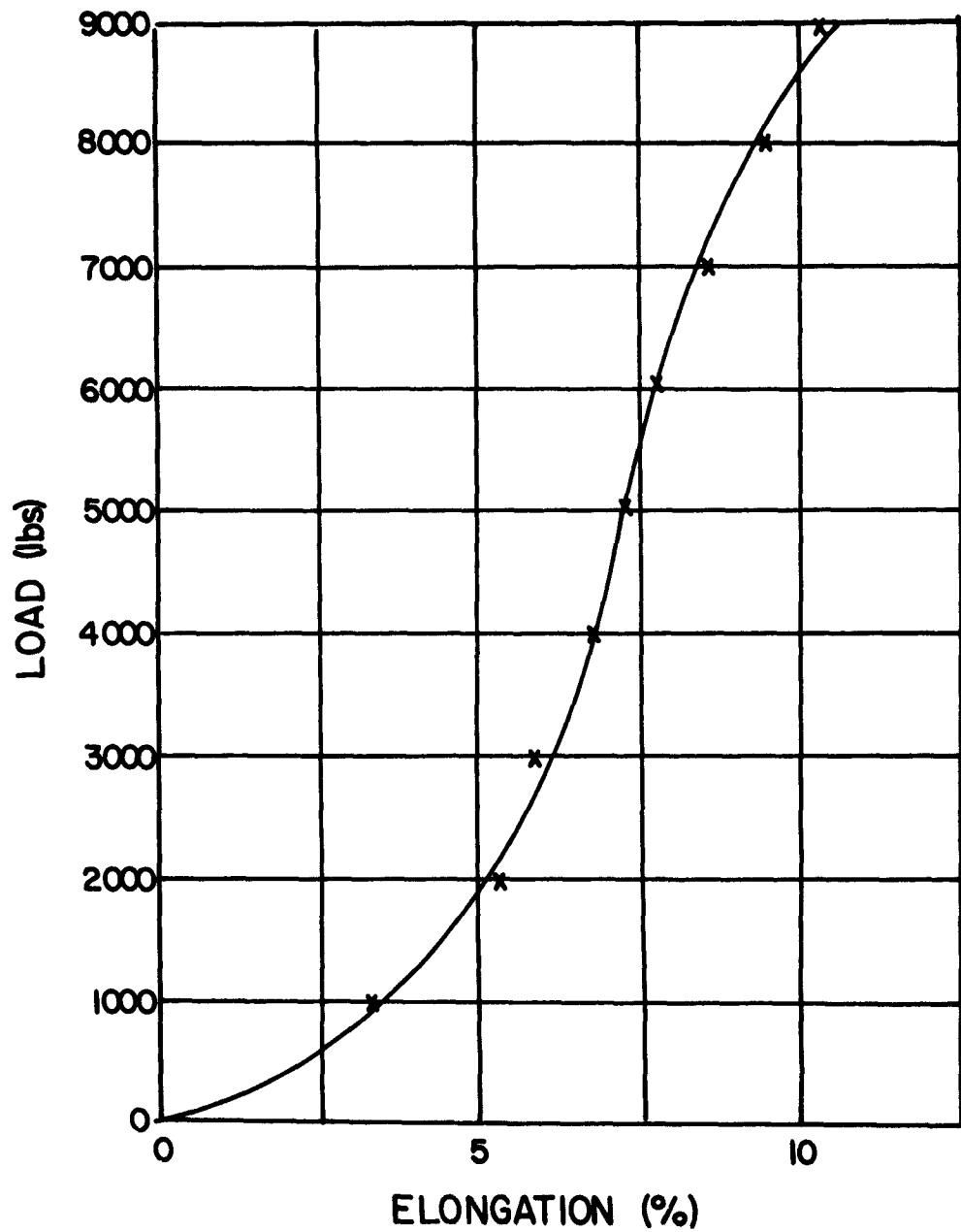
**FIGURE 6. SLOW-SPEED LOAD-ELONGATION DIAGRAM
FOR 1538X NYLON WEBBING CONTAINING
8 INCH OVERLAP SPLICE.**



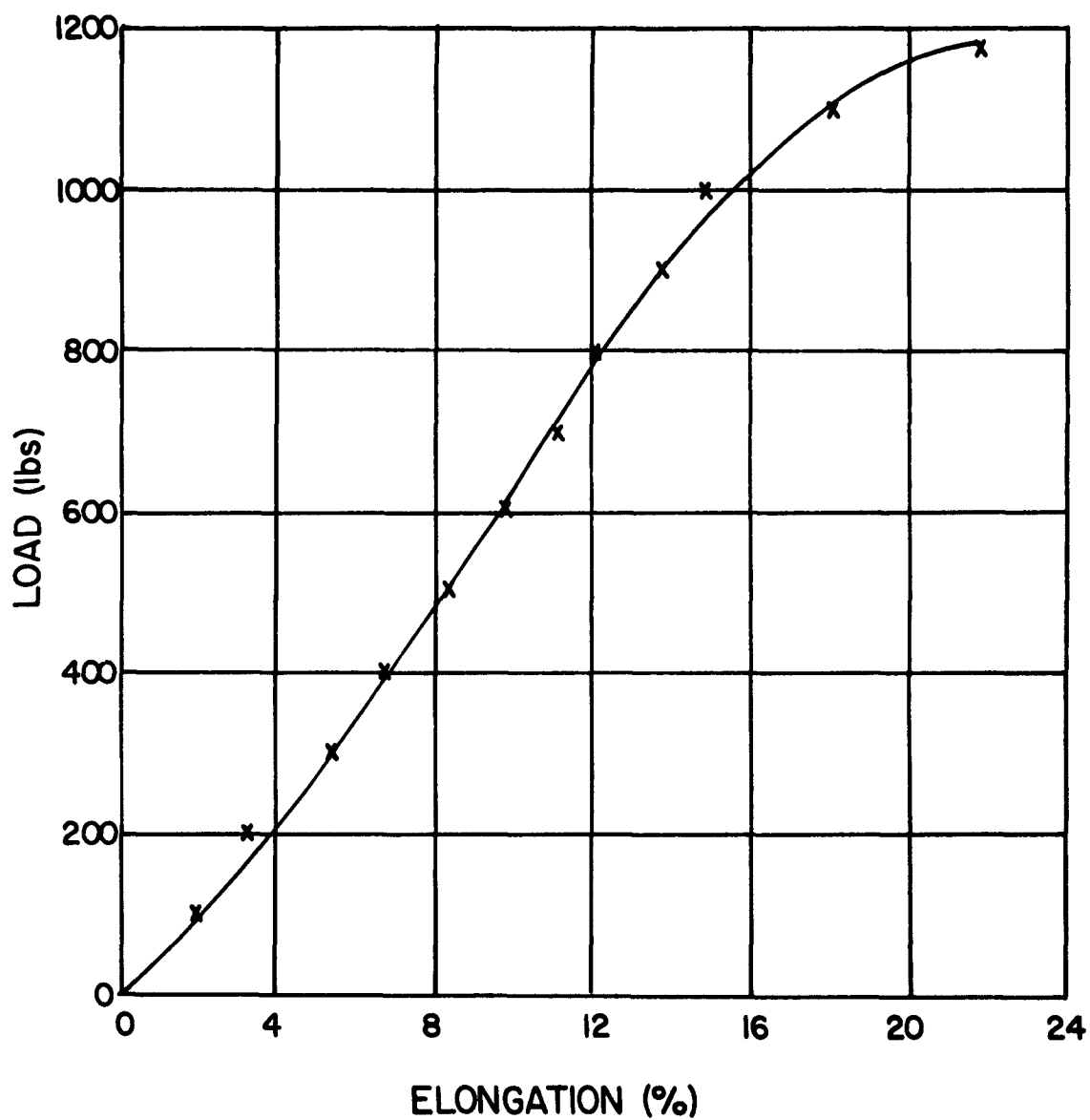
**FIGURE 7. SLOW-SPEED LOAD-ELONGATION DIAGRAM
FOR 1538X HT-I WEBBING CONTAINING
8 INCH OVERLAP SPLICE.**



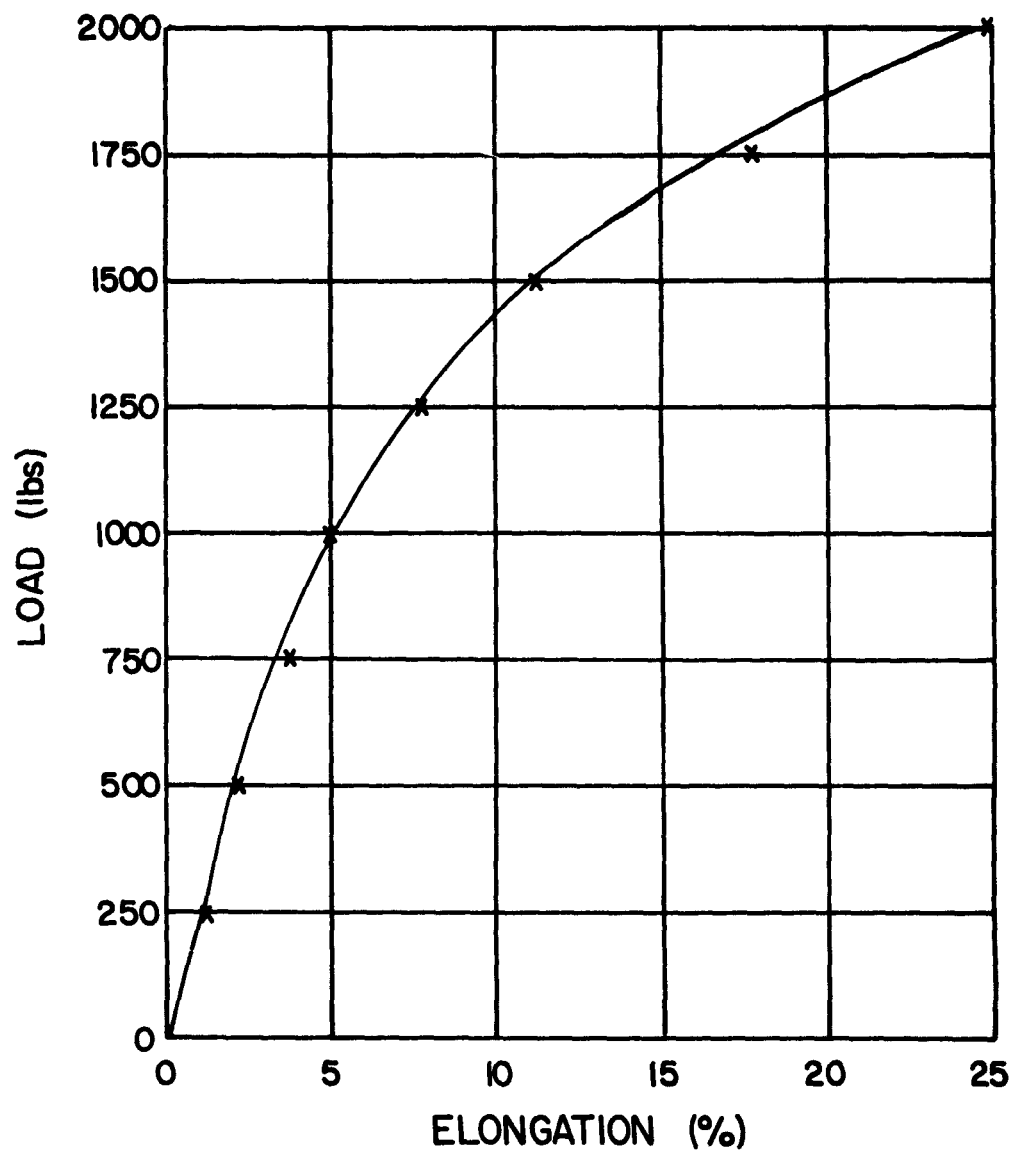
**FIGURE 8. SLOW-SPEED LOAD-ELONGATION DIAGRAM
FOR 1512 HT-1 WEBBING CONTAINING
8 INCH OVERLAP SPLICE.**



**FIGURE 9. SLOW-SPEED LOAD-ELONGATION DIAGRAM
FOR 1509X HT-1 WEBBING CONTAINING
8 INCH OVERLAP SPLICE.**



**FIGURE 10. SLOW-SPEED LOAD-ELONGATION DIAGRAM
CLASS E, TYPE II, HT-I RIBBON.**



**FIGURE II. SLOW-SPEED LOAD-ELONGATION DIAGRAM
FOR CLASS E, TYPE III, HT-I RIBBON.**

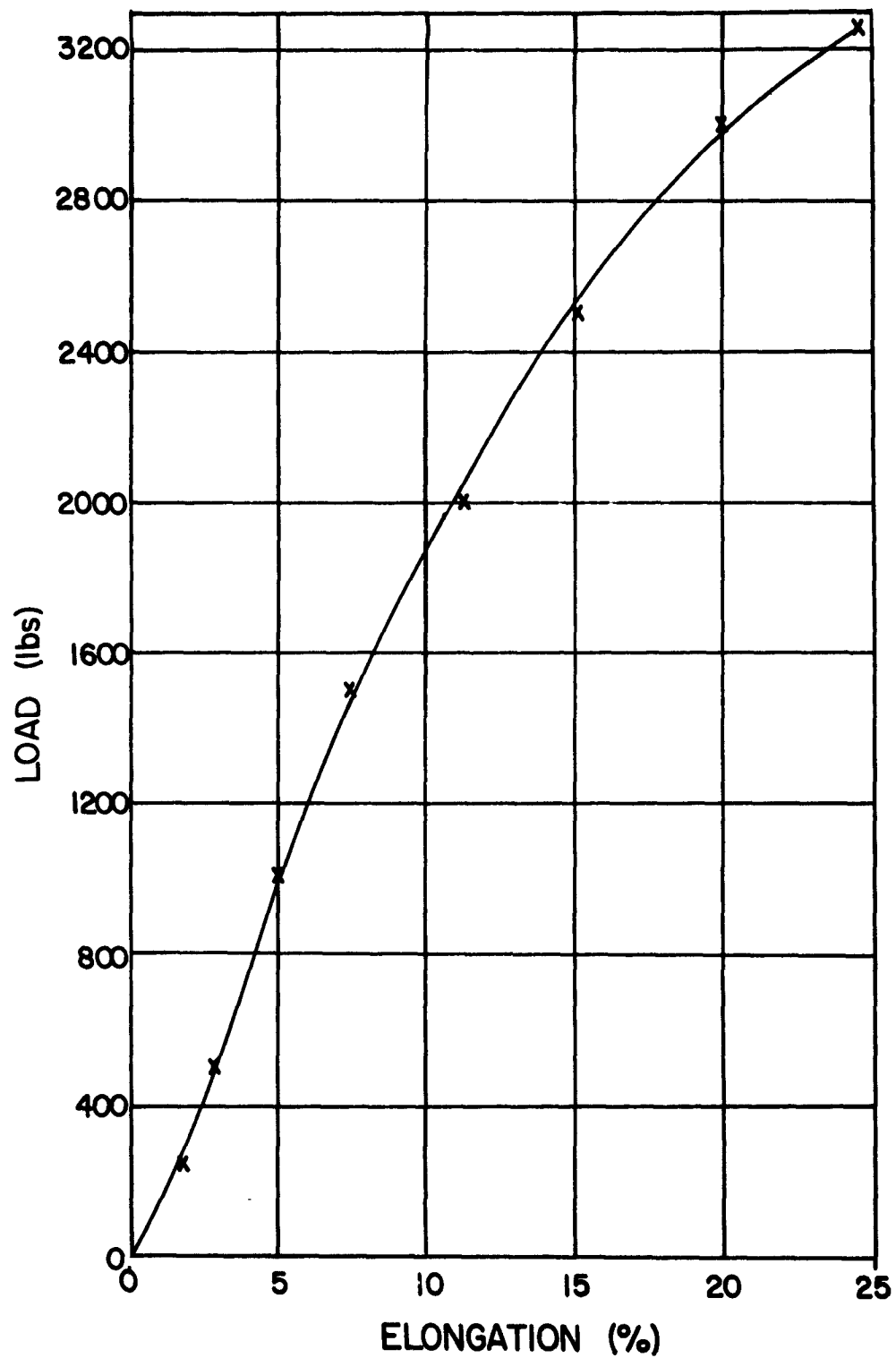


FIGURE 12. SLOW-SPEED LOAD-ELONGATION DIAGRAM
FOR CLASS E, TYPE V, HT-1 RIBBON.

B. Impact Energy Measurements on Webbing, Ribbons and Overlap Splices

Having established the slow-speed tensile behavior of the various items, the next step was determination of their impact energy absorption capabilities. Several specimens of each material were tested on the ASD High Speed Impact Test Machine using techniques described earlier in this report and elsewhere. The results of the work are given in Table II. The data is presented as a comparison between the static energy as calculated from the Instron Load-Elongation diagrams and the impact energy as measured from the change in missile velocity occurring as a result of specimen rupture. Striking velocities employed were approximately 250, 500, and 700 feet per second. It should be noted that in Table II the total energy absorbed by the sample due to the impact is recorded. This value is made up of strain, kinetic energy of the moving webbing, and thermal energy resulting from the impact. No attempt has been made to break down this total into the three individual components. This is believed to be the reason why, in some cases, the impact energy may appear to rise as the striking velocity is raised. At 500 feet per second, for example, when the samples fail at the capstan grips there apparently is considerably more heat development than at 250 and 700 feet per second. Furthermore, when the specimen fails at the grip, the entire length of unbroken specimen (almost 3 feet) is carried forward by the missile and develops kinetic energy which contributes to missile deceleration. For example, a 3 foot length of Type 1509 webbing travelling at 500 feet per second develops a kinetic energy of almost 2000 foot pounds. For this reason it will be noted in Table II that for each sample at each velocity level there is a notation as to where the majority of specimen failures occurred. It is apparent that at 700 feet per second most failures occur at the point of impact whereas at 250 feet per second there is a general randomness of failure, some being at the missile and others on the capstan grips.

Several conclusions can be drawn from the results shown in Table II. First, comparing the 1538X nylon webbing with 1538X HT-1, it appears that the HT-1 is comparable or even somewhat superior to nylon at both 250 and 500 feet per second. At 700 feet per second, however, the HT-1 is significantly poorer than the nylon. This is true with both the Control webbings and the overlap splices made therefrom.

The other two HT-1 Control webbings, 1512 and 1509X exhibit a similar loss in energy absorption capability at 700 feet per second. The 1509X shows less decay than does the 1512. However, the total loss at 700 feet per second is almost 80% of static for both.

Another interesting comparison is between the Control webbings and the three HT-1 Ribbons. The webbings are 3/4" to 1" wide whereas the ribbons are all 2" wide. Generally the translation of static energy to impact at 700 feet per second is better with the 2" ribbons than with the webbings. As can be noted from the notations of where failure occurred, some capstan grip failures occur with the ribbons at 700 feet per second whereas all webbing failures occurred at the point of impact. This reflects the ability of the ribbon to propagate stress away from the point of impact better than the more tightly woven webbings. A similar result was observed during the previous program. This capability for stress propagation observed with the thinner, wider structures should be borne in mind by the parachute designer in order to make maximum use of the HT-1 fiber. Since HT-1 yarn has a lateral critical velocity in excess of 1000 feet per second it should be possible by proper webbing design to obtain relatively high impact energy absorption at the velocity levels under consideration.

TABLE II

COMPARISON BETWEEN IMPACT AND SLOW-SPEED ENERGY ABSORPTION OF VARIOUS PARACHUTE COMPONENTS*

(All values normalized to 56 inch effective gage length)

	STATIC ENERGY 2"/min ft-lbs	IMPACT ENERGY(ft.lbs)		
		At 250 ft/sec.	At 500 ft/sec.	At 700 ft/sec.
A. <u>Control Webbings</u>				
WN1538X Nylon	1557	973 (2C)	1028 (2C)	1255 (M)
WN1538X HT-1	2352	1182 (M&2C)	1298 (2C)	488 (M)
WN1512 HT-1	4674	1766 (2C)	2457 (2C)	746 (M)
WN1509 HT-1	5435	3770 (C)	5277 (2C)	1149 (M)
B. <u>Control Ribbons</u>				
HT-1 Class E, Type II	798	282 (M&2C)	281 (2C)	298 (M&2C)
HT-1 Class E, Type III	1536	408 (M)	584 (M&2C)	864 (M&2C)
HT-1 Class E, Type V	1999	973 (M&2C)	830 (2C)	1367 (M)
C. <u>8" Overlap Splices</u>				
WN1538X Nylon	1403	896 (M&C)	908 (C)	838 (M&J)
WN1538X HT-1	1445	1035 (J)	1204 (2C)	659 (M)
WN1512 HT-1	2619	1591 (M)	2750 (2C)	834 (M)
WN1509X HT-1	3308	4180 (C)	5123 (C)	1278 (M)

*Letters in parenthesis indicate where majority of impact failures occurred.

(C = on one capstan, 2C = on two capstans, M = at missile, J = at Joint)

Comparing the Control webbings with the webbings containing 8 inch overlap splices, several important points should be noted. The first is that there is no significant loss in performance between the HT-1 Controls and the overlaps made therefrom under impact loading. This is apparently due to stress wave propagation effects which in most cases result in a failure either at the point of impact or at the capstan grips. In the case of the slow-speed Instron test, failure always occurs at the splice resulting in an apparent drop in energy absorption of 40 to 50 percent. At only one impact speed and on only one webbing (1538X HT-1) did the majority of failures occur at a joint. This again is important to the parachute designer who, being aware of this high degree of impact efficiency of the splice, need not over-design his webbings when it becomes necessary to use overlap splices of the type studied. Again, however, the spliced HT-1 webbings exhibited a great loss in energy absorption potential at impact speeds of 700 feet per second.

IV. CONCLUSIONS

Several important conclusions can be drawn from the results of the work performed during the current program:

1. At 250-500 feet per second impact energy absorption potential of HT-1 Control webbings is generally 50-60 percent of the energy as measured by the area under their slow speed stress-strain curves.
2. At 250-500 feet per second the impact energy absorption potential of HT-1 webbings containing 8 inch overlap splices is generally 60-100 percent of that measured from the Instron Test of the same webbings containing overlap splices.
3. At 700 feet per second the HT-1 Control webbings have only 15-20 percent of their slow-speed energy absorbing capability.
4. At 700 feet per second the HT-1 webbings containing 8 inch splices have only 30-50 percent of their slow-speed energy absorption.
5. Thin, wide HT-1 ribbons appear to be more effective than thick, narrow HT-1 webbings in maintaining energy absorbing potential at 700 feet per second.
6. HT-1 webbing is superior to nylon (1538X) at 250 and 500 feet per second but is inferior at the 700 feet per second impact level.

V. RECOMMENDATIONS FOR FUTURE WORK

As a result of the studies conducted during the present program certain areas of future work can be suggested:

1. Further Study of HT-1 Structural Effects

HT-1 is felt to be an important and useful fiber for certain parachute applications due to its improved heat stability. In order to utilize more fully this advantage it is important to make better use of its energy absorbing potential at high speeds. The current work has shown that HT-1 is particularly susceptible to variations in fabric geometry, especially at impact velocities approaching Mach 0.6. Further studies of geometrical effects should be made in order to improve upon the impact energy characteristics of the high strength HT-1 webbings. For example, it now appears that loosely woven HT-1 structures which allow for greater transmission of the transient impact stresses and strains can result in marked improvements in impact energy absorption capabilities for this material.

2. Impact Studies of Other Recently Developed Materials

As new polymers are developed it is important that their characterization include not only static or slow-speed performance but their response to shock loading as well. HT-1 has been an example of how a material can possess excellent properties when tested at a low strain rate but which can be extremely poor when tested at a much higher rate. Undoubtedly other materials, such as polybenzimidazole, are under development which, while showing improvements in one particular aspect of performance, may be entirely unsatisfactory in regard to high speed impact behavior. If a potential application is one where high strain rates may be encountered in service then the "new" material must be evaluated at these strain rates in order to more completely characterize its response.

3. Additional Equipment

In the previous program efforts were made to obtain impact load-extension curves for various materials. This approach is, of course, necessary if a comprehensive insight into the tensile behavior of various materials at high rates of loading is to be obtained. The results of the work showed that, due to limitations imposed by the present measuring system, additional equipment is necessary if a detailed study of the tensile behavior is to be made.

One of the simplest improvements is the addition of more light flashes to the E.G.&G. Multiflash. At the present time this device is equipped to produce only 15 light flashes during a test. Due to the rapidity of stress changes it is not possible to accurately measure the response of the material at these high strain rates with the present equipment. The addition of at least ten more pulses would make it possible to better understand the response of the materials to shock loading by extending the photography time over a longer period.

Another potential improvement, in addition to the aforementioned modifications in the E.G.&G. Multiflash is the use of a rotating drum camera for photographing the impact of the projectile on the webbing. At the present time the fifteen exposures are superimposed upon each other on one piece of 4" x 5" sheet film. While such a technique is photographically feasible it produces a multiple image print which becomes extremely difficult to analyze. By moving the film slightly between flashes it is possible to have separate exposures of the event, thereby making the photographic analysis and data reduction less confusing as well as less time consuming.

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(over)

percent of the static value were found at the 700
feet per second impact level. The one nylon sample
studied did not indicate as great a loss at this
impact speed.

Results obtained generally substantiate earlier find-
ings that the less complex the geometrical structure
of the HT-1 materials, then the less severe will be
the energy losses at these high rates of loading.

Further studies of HT-1 and other potential para-
chute materials at these impact speeds is recommended
in order to thoroughly characterize their behavior.
Slow-speed tensile properties are not necessarily a
reflection of the material's response to dynamic
loading at very high strain rates.

1. Fibrous materials
2. Parachute fabrics
1. AFSC Project 8151
- Task 815103
- II. Contract AF 33(616)-
7627
- III. Fabric Research Labs.,
Dedham, Pa.
- IV. Robert J. Coskren ,
Chauncey C. Chu
- V. Not avail fr QTS
- VI. In ASTIA collection

Unclassified Report

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- Task 815103
- II. Contract AF 33(616)-
7627
- III. Fabric Research Labs.,
Dedham, Pa.
- IV. Robert J. Coskren ,
Chauncey C. Chu
- V. Not avail fr QTS
- VI. In ASTIA collection