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PERFORMANCE CHARACTERISTICS OF PAPER HONEYCOMB CUSHIONING MATERIALS IMPACTED UNDER A HEAVY WEIGHT HIGH IMPACT SHOCK MACHINE

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FOREWORD

This report was prepared by the Lowell Technological Institute Research Foundation under U. S. Air Force Contract No. AF 18(600)-127. The contract was initiated under Project No. 6077, "Aerial Delivery Equipment", Task No. 73295, "Shock Absorbing Textiles", formerly RDO No. 612-12, "Textiles for High Speed Parachutes", and was administered under the direction of the Materials Laboratory, Directorate of Research, Wright Air Development Center, with Mr. J. H. Ross acting as project engineer.

This report covers the period of work from June 1955 to September 1955.

The test results reported relate to the performance of the materials under special test conditions. No inference is made with respect to other uses intended for them by the manufacturer either as a cushioning material or otherwise.

ABSTRACT

Dynamic tests with respect to the energy absorption characteristics of certain paperboard honeycomb materials impacted under a heavy weight high impact shock machine show that these materials are more efficient energy absorbers at the lower limit of the imposed test conditions than other materials previously tested. They are much less effective in the higher portions of the test range.

A correlation between energy absorption and density is exhibited.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER

M. R. WHITMORE
Technical Director
Materials Laboratory
Directorate of Research

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INTRODUCTION

Cellular cushioning materials capable of being crushed in a one impact type of service offer interesting possibilities in the search for a low cost energy absorber to be used in the aerial delivery of heavy cargos.

Exploratory tests on certain paperboard honeycomb materials prompted a more complete study of their dynamic properties. Consequently, this investigation of the energy absorption characteristics of these honeycomb materials was undertaken as an extension of similar work previously conducted with respect to the dynamic testing of cushioning materials.

The test apparatus used was the same as that described in an initial report*. The test methods, range of test conditions, and method of analysis of test results are essentially those reported previously**.

* "Design and Development of a Heavy Weight High Impact Shock Machine", WADC Technical Report 54-573.

** "Performance Characteristics of Cushioning Materials Impacted Under a Heavy Weight High Impact Shock Machine", WADC Technical Report 55-229.

DESCRIPTION OF TEST SPECIMENS

The paperboard honeycomb samples tested were manufactured by the Union Bag and Paper Corporation, Hudson Falls, New York. The material was in the form of sheets composed of kraft paper honeycomb cells of hexagonal cross-section located adjacent to each other and glued at the top and bottom to a single facing of paper in each case; the material was designed to receive impact forces in a direction perpendicular to the plane of the paper facing.

In the case of the 2- and 4-inch sheets, the vertical cells were of a height equal to the thickness of the sheet. The 6-inch sheets had been fabricated by combining either a 2- and a 4-inch sheet or two 3-inch sheets. The cell cross-section in the samples tested, while all of the order of magnitude of one inch, were given a different designation (probably on the basis of density) by the manufacturer as described in Table 1. The density values presented in Table 1 were determined in the course of this work from weight and volume measurements taken for all the sheets of a particular type.

Test specimens were prepared by cutting the materials as received into circular units of 24-inch diameter (in the plane of the paper facing) with a band saw. Approximately 720 different test specimens were thus made available from the material supplied.

TEST PROCEDURE

The test conditions are summarized as follows. Circular test specimens, twenty-four inches in diameter, and of 2-, 4-, and 6-inch thicknesses were subjected to impacts by a 577-pound flat impact hammer moving at velocities in the range of 20 to 50 ft/second. Tests were conducted at three temperatures: -67°F, 70°F, and 160°F, on all except some of the 6-inch thick materials. The excepted materials were those in sufficient supply (fabricated in the same manner in each case, i.e., composed of a 2- and a 4-inch sheet or two 3-inch sheets) to permit testing at only two temperatures, rather than the three.

All specimens were subjected to one impact service. To obtain data for the required curves, the specimens were impacted at velocities from approximately 20 ft/second in ascending order in increments of approximately 2 ft/second to the point at which bottoming occurred. In all cases, testing had to be terminated at a velocity of less than 50 ft/second.

A total of 465 impacts were made; these were recorded and analyzed by the analog computer system.

Consideration was given to testing several specimens of the same material at the same velocity and then obtaining an average for the test results at that velocity. Approximately fourteen specimens were available for any one specific material under a given thickness and temperature condition. With these the complete range of 20 to 50 ft/second was to be covered.

In addition, it is difficult to control the hammer velocity precisely, thus necessitating, at times, the repeating of tests. Consequently, it was decided to forego the obtaining of an average in each case and to follow the testing procedure previously described.

Thickness measurements were made in accordance with methods reported previously. However, measurements of strain before impact under the static weight of the impact hammer were omitted because the deflections of the cushions were negligibly small --- in the order of 0.02 inch or less.

RESULTS

Graphs of Energy Per Unit Volume versus Maximum Stress and graphs of Maximum Stress versus Maximum Strain are presented in Figure 2 through 35 inclusive. Tables 2 through 12 inclusive show certain data in tabular form.

The smooth curves were drawn through or near the plotted points except for points which were considered as unrepresentative. In some cases, the plotted points deviated from the smoothened curve by an amount inconsistent with the precision of measurements. This deviation was as much as 25%. It is presumed to be caused by an inherent variability in the test specimens due to a certain lack of uniformity associated with the process of manufacture. Visual observation shows a difference in the cell size in different portions of the same specimen. It is a matter of conjecture as to how representative a specimen is of the whole population. Another factor to be considered is the uniformity of the adhesive process by which the cells are glued to the facing on the upper and lower surfaces of each sheet. This is important since the cushion no doubt presents different characteristics depending on whether the cells bend over prematurely or stand on end during the impact. Since the spurious points were disregarded in drawing the smooth curves, the results are more indicative of an infinite population.

The Energy Per Unit Volume - Maximum Stress curves for the honeycomb materials of 6-inch thickness at the temperature of 70°F are compared in Figure 1. Several points of interest are indicated by a study of this diagram. Values of maximum stress are lower at 20 ft/second for these honeycomb materials than for any of the materials tested in our previous investigation.

The parts of the curves wherein the slope is the greatest, that is, wherein a change in energy produces the smallest change in maximum stress, lie near or before the energy value corresponding to a velocity of 20 ft/second. At the higher values of energy per unit volume, the paperboard honeycomb materials lose their effectiveness. In no case was it considered safe to impact the 6-inch materials with the hammer at the maximum entry energy of 100 inch-pounds per cubic inch or with a hammer velocity of 50 ft/second. (During the test operations the impact hammer suffered serious mechanical damage necessitating shutdown of the test facility for repairs; this was caused partly by the failure of the cushioning materials under the stringent test conditions imposed by this and the previous investigations.)

There is a marked correlation between the performance and the density of the materials. At the higher values of maximum stress, 500 psi as an example, as you proceed upward along the vertical at increasing values of energy, it may be seen that the curves progressively intercepted are those of materials of increasing density.

From an inspection of the curves for Materials Nos. UB-3-24 and UB-3-33, it appears that the materials fabricated from the 2- and 4-inch sheets are the better energy absorbers. In the case of Materials Nos. UB-1-24 and UB-1-33, this is true only at the higher velocities.

The effect of temperature on the performance of the materials is not obvious. An explanation of the differences between the curves at different temperatures is complicated by the statistical problems imposed by the considered variability of the specimens.

The general shape of the acceleration-time curves for the impacts recorded during these tests was dependent upon the magnitude of the kinetic energy of the impact hammer at entry. At the low velocities, the acceleration-time curve was broad and flat. At the higher velocities, the impacts were characterized by a sharp and high-valued pulse typical of a severe impact. No initial or entry pulse was recorded at the time the impact hammer first made contact with the specimen. If such a pulse did exist, its frequency was greater than the frequency of response of the analog computer system.

TABLE 1

IDENTIFICATION CODE FOR PAPERBOARD HONEYCOMB MATERIALS

Material No.	Manufacturer's Code	Specimen Thickness (inches)	Cell Height (inches)	Density (lbs/cu ft)
UB-1	UB-1-EDF	2 or 4	Equal to specimen thickness	2.15
UB-1-24	UB-1-EDF	6	One layer 2, the other 4	2.15
UB-1-33	UB-1-EDF	6	Both layers 3	2.15
UB-2	UB-2-EDF	2 or 4	Equal to specimen thickness	1.88
UB-2-33	UB-2-EDF	6	Both layers 3	1.88
UB-3	UB-3-EDF	2 or 4	Equal to specimen thickness	3.03
UB-3-24	UB-3-EDF	6	One layer 2, the other 4	3.03
UB-3-33	UB-3-EDF	6	Both layers 3	3.03
UB-5	UB-5-EDF	2 or 4	Equal to specimen thickness	1.65
UB-5-24	UB-5-EDF	6	One layer 2, the other 4	1.65
UB-6	UB-6-EDF	2 or 4	Equal to specimen thickness	2.07
UB-6-24	UB-6-EDF	6	One layer 2, the other 4	2.07

TABLE 2

SUMMARY OF RESULTS - NOMINAL THICKNESS: 6 in. - ENTRY VELOCITY: 40 ft/sec

Material No.	Temperature (^{o}F)	Maximum Stress (psi)	Maximum Strain During Impact (in./in.)	Strain After Impact (1.28 psi load) (in./in.)	Resilience (%)
UB-1-24	-67	700	0.95	0.86	16
	70	590	0.97	0.84	20
	160	-	-	-	-
UB-1-33	-67	-	-	-	-
	70	710	0.95	0.84	14
	160	710	0.98	0.70	17
UB-2-33	-67	-	-	-	-
	70	-	-	-	-
	160	-	-	-	-
UB-3-24	-67	130	0.78	0.59	5
	70	160	0.83	0.55	11
	160	270	0.92	0.72	11
UB-3-33	-67	120	0.79	0.70	9
	70	270	0.92	0.75	10
	160	-	-	-	-
UB-5-24	-67	-	-	-	-
	70	-	-	-	-
	160	-	-	-	-
UB-6-24	-67	-	-	-	-
	70	-	-	-	-
	160	-	-	-	-

TABLE 3

SUMMARY OF RESULTS - NOMINAL THICKNESS: 6 in. - ENTRY VELOCITY: 35 ft/sec

Material No.	Temperature (°F)	Maximum Stress (psi)	Maximum Strain During Impact (in./in.)	Strain After Impact (1.28 psi load) (in./in.)	Resilience (%)
UB-1-24	(-67	200	0.88	0.84	10
	(70	300	0.95	0.82	13
	(160	-	-	-	-
UB-1-33	(-67	280	0.92	0.84	10
	(70	270	0.92	0.82	11
	(160	345	0.95	0.82	13
UB-2-33	(-67	-	-	-	-
	(70	-	-	-	-
	(160	-	-	-	-
UB-3-24	(-67	100	0.70	0.53	5
	(70	110	0.77	0.56	7
	(160	150	0.87	0.52	7
UB-3-33	(-67	100	0.76	0.55	5
	(70	125	0.83	0.72	13
	(160	-	-	-	-
UB-5-24	(-67	-	-	-	-
	(70	-	-	-	-
	(160	-	-	-	-
UB-6-24	(-67	520	0.98	0.88	9
	(70	360	0.97	0.86	19
	(160	545	0.98	0.86	22

TABLE 4

SUMMARY OF RESULTS - NOMINAL THICKNESS: 6 in. - ENTRY VELOCITY: 30 ft/sec

Material No.	Temperature (°F)	Maximum Stress (psi)	Maximum Strain During Impact (in./in.)	Strain After Impact (1.28 psi load) (in./in.)	Resilience (%)
UB-1-24	(-67	80	0.69	0.67	5
	(70	140	0.89	0.80	11
	(160	-	-	-	-
UB-1-33	(-67	100	0.86	0.78	6
	(70	130	0.87	0.78	11
	(160	140	0.90	0.75	7
UB-2-33	(-67	420	0.97	0.86	8
	(70	280	0.95	0.87	16
	(160	360	0.98	0.89	15
UB-3-24	(-67	90	0.64	0.39	3
	(70	75	0.64	0.44	7
	(160	95	0.81	0.50	7
UB-3-33	(-67	90	0.72	0.40	2
	(70	90	0.68	0.62	7
	(160	-	-	-	-
UB-5-24	(-67	-	-	-	-
	(70	630	0.98	0.92	19
	(160	-	-	-	-
UB-6-24	(-67	115	0.90	0.83	11
	(70	150	0.95	0.81	11
	(160	200	0.91	0.81	14

TABLE 5

SUMMARY OF RESULTS - NOMINAL THICKNESS: 6 in. - ENTRY VELOCITY: 25 ft/sec

Material No.	Temperature (°F)	Maximum Stress (psi)	Maximum Strain During Impact (in./in.)	Strain After Impact (1.28 psi load) (in./in.)	Resilience (%)
UB-1-24	(-67	65	0.54	0.50	4
	(70	75	0.78	0.54	5
	(160	-	-	-	-
UB-1-33	(-67	55	0.48	0.44	14
	(70	75	0.81	0.72	7
	(160	80	0.86	0.72	7
UB-2-33	(-67	130	0.91	0.87	11
	(70	70	0.92	0.79	5
	(160	130	0.95	0.81	9
UB-3-24	(-67	85	0.56	0.30	18
	(70	80	0.64	0.37	8
	(160	65	0.72	0.37	7
UB-3-33	(-67	85	0.71	0.38	2
	(70	75	0.77	0.41	7
	(160	-	-	-	-
UB-5-24	(-67	520	0.99	0.95	16
	(70	210	0.96	0.92	15
	(160	300	0.98	0.84	7
UB-6-24	(-67	65	0.82	0.80	5
	(70	60	0.86	0.78	9
	(160	85	0.84	0.58	7

TABLE 6

SUMMARY OF RESULTS - NOMINAL THICKNESS: 6 in. - ENTRY VELOCITY: 20 ft/sec

Material No.	Temperature (°F)	Maximum Stress (psi)	Maximum Strain During Impact (in./in.)	Strain After Impact (1.28 psi load) (in./in.)	Resilience (%)
UB-1-24	(-67	60	0.40	0.31	4
	(70	50	0.60	0.39	5
	(160	-	-	-	-
UB-1-33	(-67	50	0.34	0.26	13
	(70	45	0.70	0.34	5
	(160	45	0.80	0.72	5
UB-2-33	(-67	40	0.80	0.64	5
	(70	25	0.85	0.60	3
	(160	40	0.80	0.72	2
UB-3-24	(-67	55	0.60	0.17	6
	(70	65	0.38	0.26	7
	(160	85	0.79	0.26	4
UB-3-33	(-67	70	0.64	0.19	1
	(70	80	0.54	0.27	3
	(160	-	-	-	-
UB-5-24	(-67	65	0.91	0.82	2
	(70	50	0.90	0.84	6
	(160	45	0.85	0.81	8
UB-6-24	(-67	50	0.50	0.40	1
	(70	30	0.58	0.56	4
	(160	50	0.66	0.56	9

TABLE 7

SUMMARY OF RESULTS - NOMINAL THICKNESS: 4 in. - ENTRY VELOCITY: 35 ft/sec

Material No.	Temperature (^{o}F)	Maximum Stress (psi)	Maximum Strain During Impact (in./in.)	Strain After Impact (1.28 psi load) (in./in.)	Resilience (%)
UB-1	(-67	655	0.99	0.84	16
	(70	-	-	-	-
	(160	-	-	-	-
UB-2	(-67	-	-	-	-
	(70	-	-	-	-
	(160	-	-	-	-
UB-3	(-67	160	0.85	0.70	7
	(70	240	0.94	0.80	13
	(160	390	0.96	0.75	14
UB-5	(-67	-	-	-	-
	(70	-	-	-	-
	(160	-	-	-	-
UB-6	(-67	-	-	-	-
	(70	-	-	-	-
	(160	-	-	-	-

TABLE 8

SUMMARY OF RESULTS - NOMINAL THICKNESS: 4 in. - ENTRY VELOCITY: 30 ft/sec

Material No.	Temperature (°F)	Maximum Stress (psi)	Maximum Strain During Impact (in./in.)	Strain After Impact (1.28 psi load) (in./in.)	Resilience (%)
	(-67	320	0.96	0.83	13
UB-1	(70	310	0.97	0.84	14
	(160	390	0.98	0.90	13
	(-67	810	0.99	0.89	18
UB-2	(70	730	0.97	0.88	14
	(160	640	0.99	0.88	17
	(-67	90	0.75	0.55	5
UB-3	(70	100	0.76	0.65	4
	(160	150	0.87	0.80	14
	(-67	-	-	-	-
UB-5	(70	-	-	-	-
	(160	-	-	-	-
	(-67	-	-	-	-
UB-6	(70	-	-	-	-
	(160	-	-	-	-

TABLE 9

SUMMARY OF RESULTS - NOMINAL THICKNESS: 4 in. - ENTRY VELOCITY: 25 ft/sec

Material No.	Temperature (^oF)	Maximum Stress (psi)	Maximum Strain During Impact (in./in.)	Strain After Impact (1.28 psi load) (in./in.)	Resilience (%)
UB-1	(-67	105	0.89	0.76	5
	(70	95	0.83	0.70	11
	(160	145	0.94	0.76	11
UB-2	(-67	320	0.97	0.88	17
	(70	320	0.95	0.85	13
	(160	320	0.99	0.88	13
UB-3	(-67	80	0.64	0.47	3
	(70	80	0.64	0.42	5
	(160	90	0.87	0.85	11
UB-5	(-67	-	-	-	-
	(70	-	-	-	-
	(160	-	-	-	-
UB-6	(-67	190	0.95	0.83	8
	(70	140	0.89	0.53	1
	(160	180	0.95	0.87	3

TABLE 10

SUMMARY OF RESULTS - NOMINAL THICKNESS: 4 in. - ENTRY VELOCITY: 20 ft/sec

Material No.	Temperature (°F)	Maximum Stress (psi)	Maximum Strain During Impact (in./in.)	Strain After Impact (1.28 psi load) (in./in.)	Resilience (%)
UB-1	(-67	50	0.46	0.31	3
	(70	50	0.71	0.62	6
	(160	45	0.67	0.65	5
UB-2	(-67	60	0.72	0.69	12
	(70	70	0.83	0.80	4
	(160	120	0.91	0.83	13
UB-3	(-67	75	0.59	0.58	14
	(70	60	0.36	0.35	4
	(160	75	0.63	0.36	6
UB-5	(-67	125	0.95	0.90	12
	(70	100	0.89	0.87	9
	(160	130	0.95	0.90	11
UB-6	(-67	80	0.82	0.54	5
	(70	60	0.80	0.69	3
	(160	55	0.86	0.68	3

TABLE 11

SUMMARY OF RESULTS - NOMINAL THICKNESS: 2 in. - ENTRY VELOCITY: 25 ft/sec

Material No.	Temperature (°F)	Maximum Stress (psi)	Maximum Strain During Impact (in./in.)	Strain After Impact (1.28 psi load) (in./in.)	Resilience (%)
UB-1	-67	430	0.98	0.78	11
	70	480	0.95	0.80	16
	160	460	0.99	0.75	12
UB-2	-67	-	-	-	-
	70	660	0.99	0.89	19
	160	-	-	-	-
UB-3	-67	150	0.84	0.39	7
	70	310	0.93	0.69	17
	160	490	0.97	0.74	19
UB-5	-67	-	-	-	-
	70	-	-	-	-
	160	-	-	-	-
UB-6	-67	-	-	-	-
	70	-	-	-	-
	160	-	-	-	-

TABLE 12

SUMMARY OF RESULTS - NOMINAL THICKNESS: 2 in. - ENTRY VELOCITY: 20 ft/sec

Material No.	Temperature (°F)	Maximum Stress (psi)	Maximum Strain During Impact (in./in.)	Strain After Impact (1.28 psi load) (in./in.)	Resilience (%)
	(-67	160	0.89	0.72	7
UB-1	(70	140	0.85	0.66	9
	(160	200	0.90	0.75	14
	(-67	270	0.96	0.85	11
UB-2	(70	230	0.93	0.83	13
	(160	370	0.98	0.83	18
	(-67	90	0.60	0.60	3
UB-3	(70	120	0.80	0.47	11
	(160	140	0.90	0.50	13
	(-67	420	0.98	0.91	15
UB-5	(70	400	0.98	0.91	19
	(160	440	0.99	0.88	16
	(-67	200	0.98	0.81	13
UB-6	(70	280	0.95	0.85	16
	(160	300	0.97	0.85	22

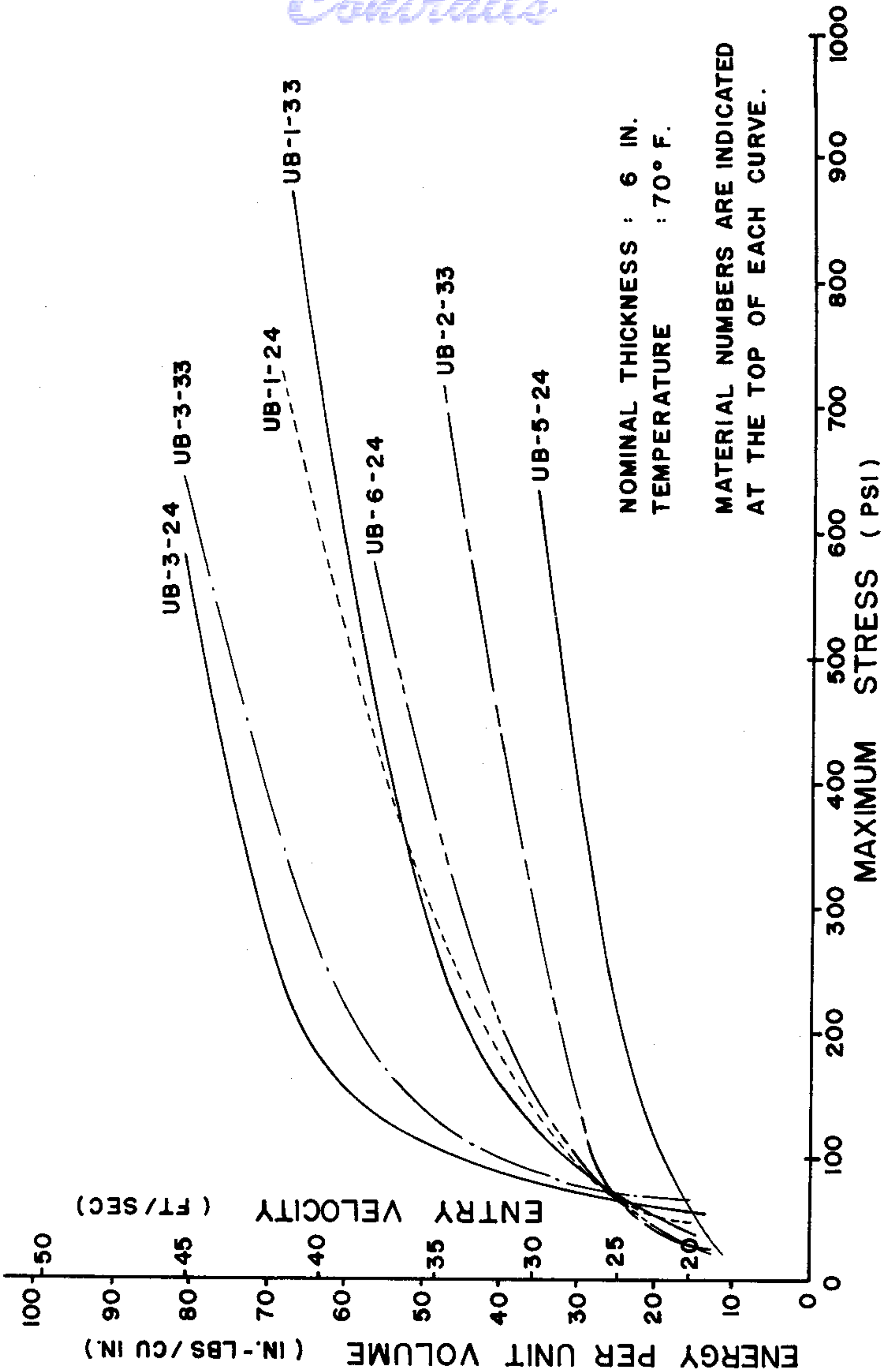

FIGURE 1 COMPARISON OF THE ENERGY PER UNIT VOLUME - MAXIMUM STRESS CURVES FOR PAPERBOARD HONEYCOMB MATERIALS

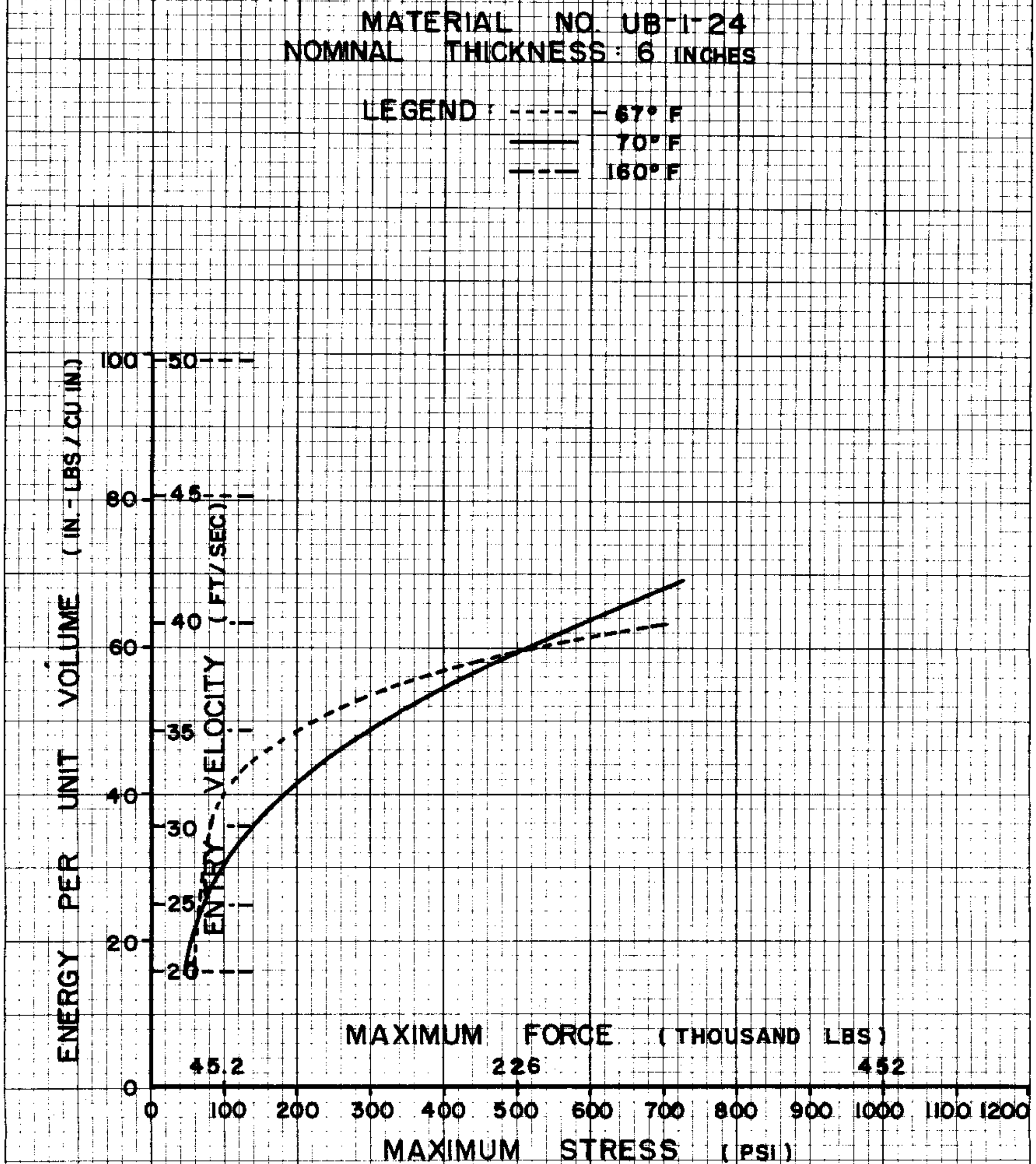

FIGURE 2 ENERGY PER UNIT VOLUME - MAXIMUM STRESS CURVE FOR 6 INCHES OF MATERIAL NO. UB-1-24

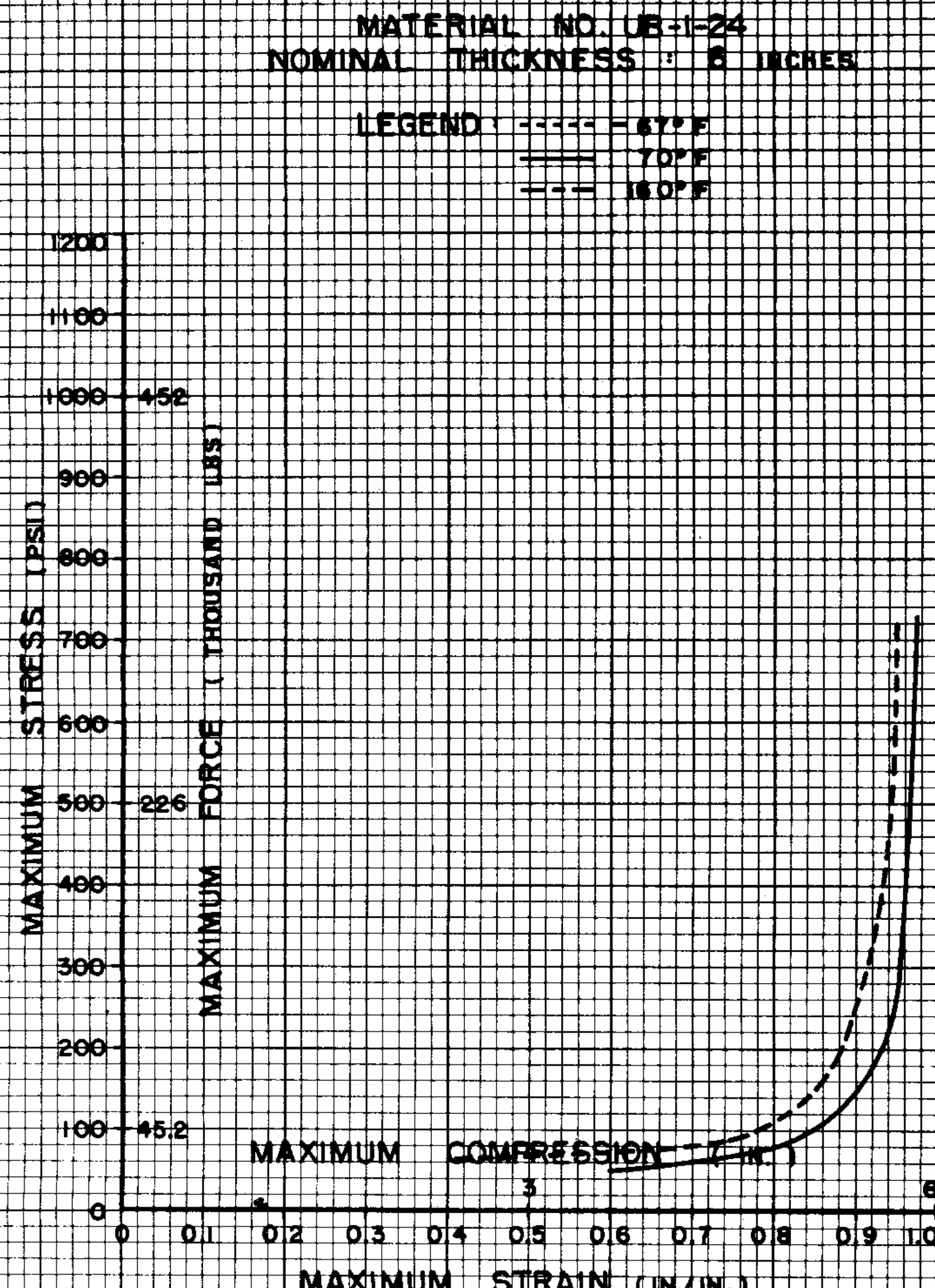

FIGURE 3. MAXIMUM STRESS - MAXIMUM STRAIN CURVE FOR 6 INCHES OF MATERIAL NO. UB-1-24

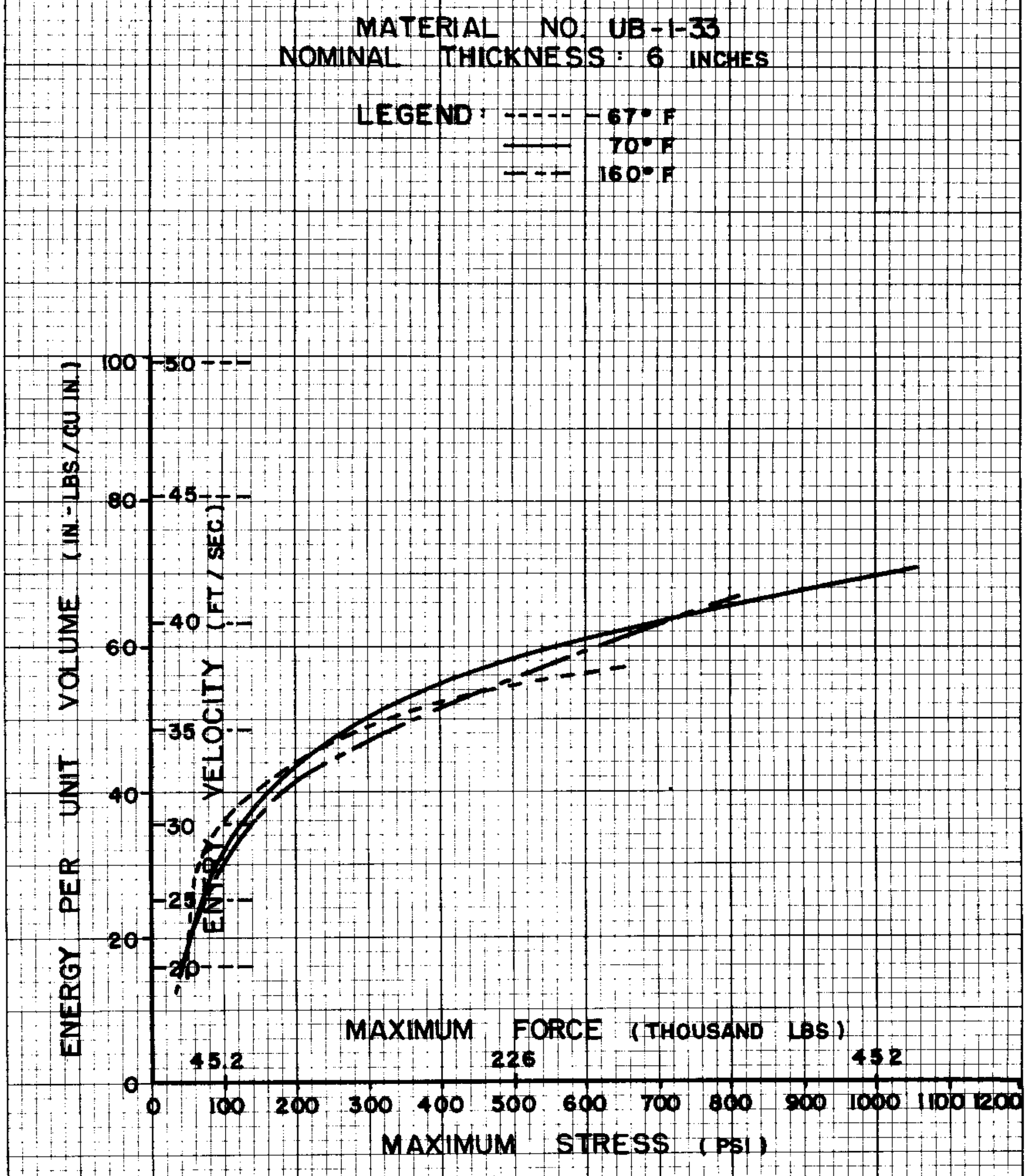

FIGURE 4 ENERGY PER UNIT VOLUME - MAXIMUM STRESS CURVE FOR 6 INCHES OF MATERIAL NO. UB-1-33

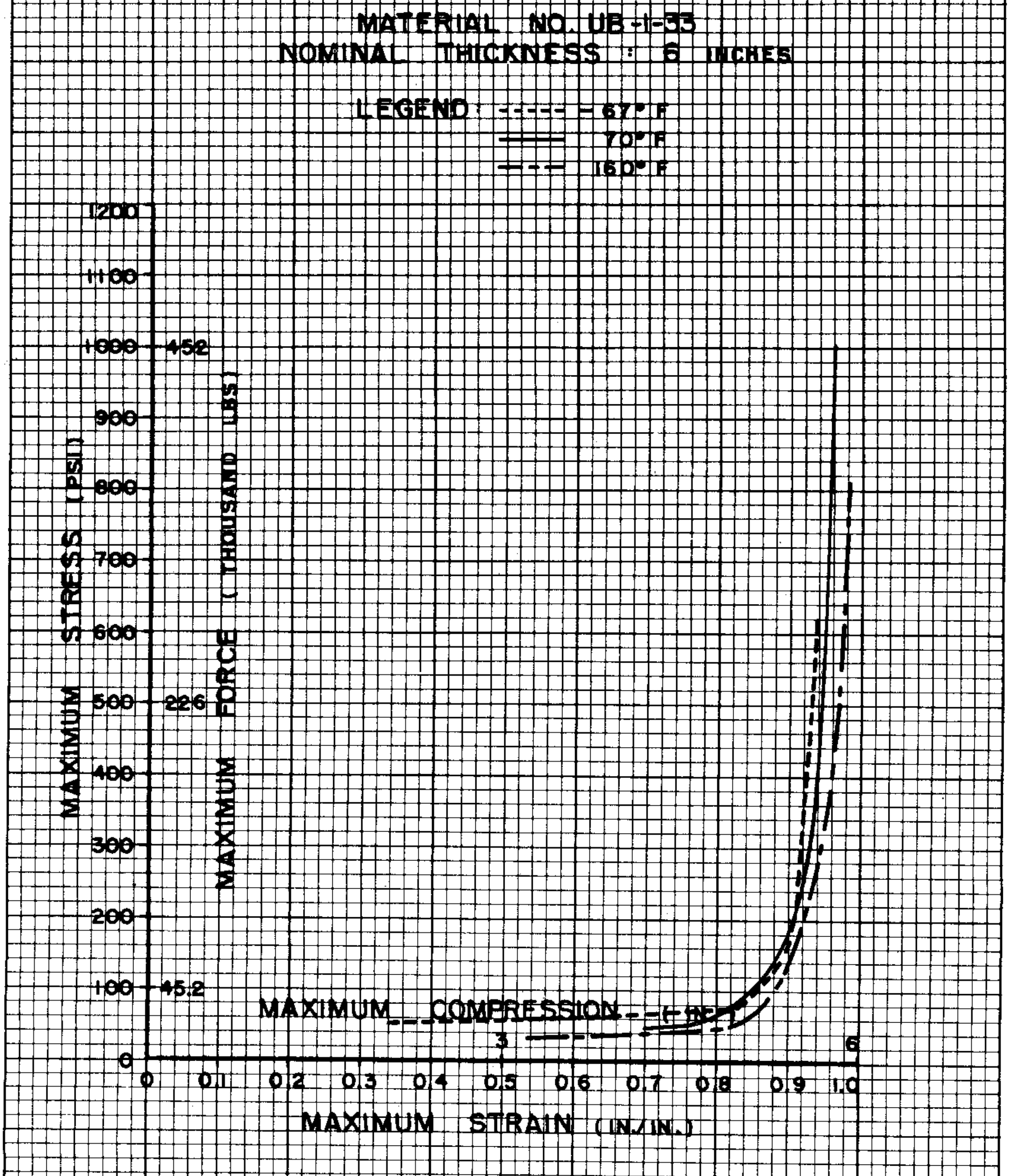

FIGURE 5 . MAXIMUM STRESS - MAXIMUM STRAIN CURVE FOR 6 INCHES OF MATERIAL No. UB-1-33

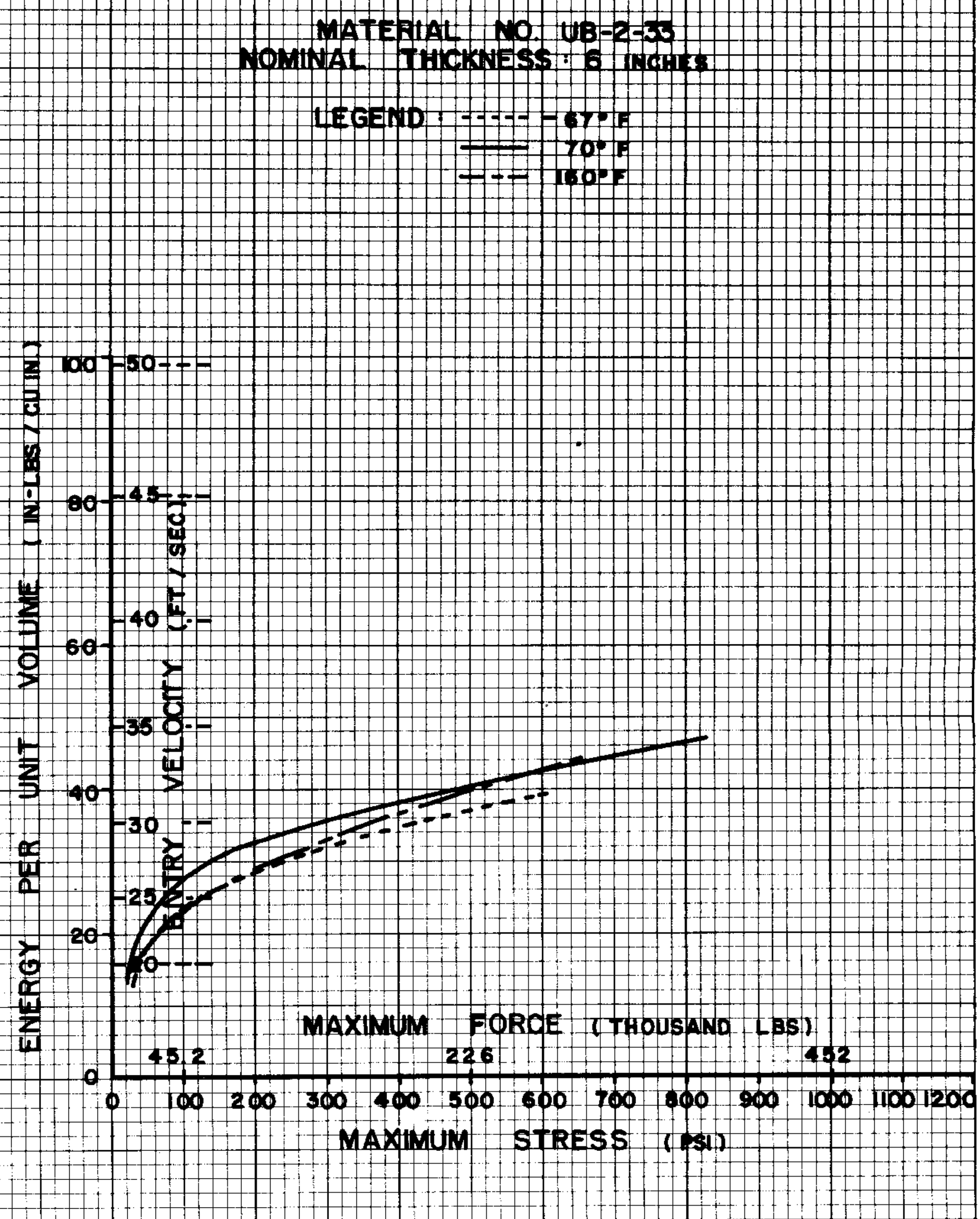

FIGURE 6 ENERGY PER UNIT VOLUME - MAXIMUM STRESS CURVE FOR 6 INCHES OF MATERIAL No. UB-2-33

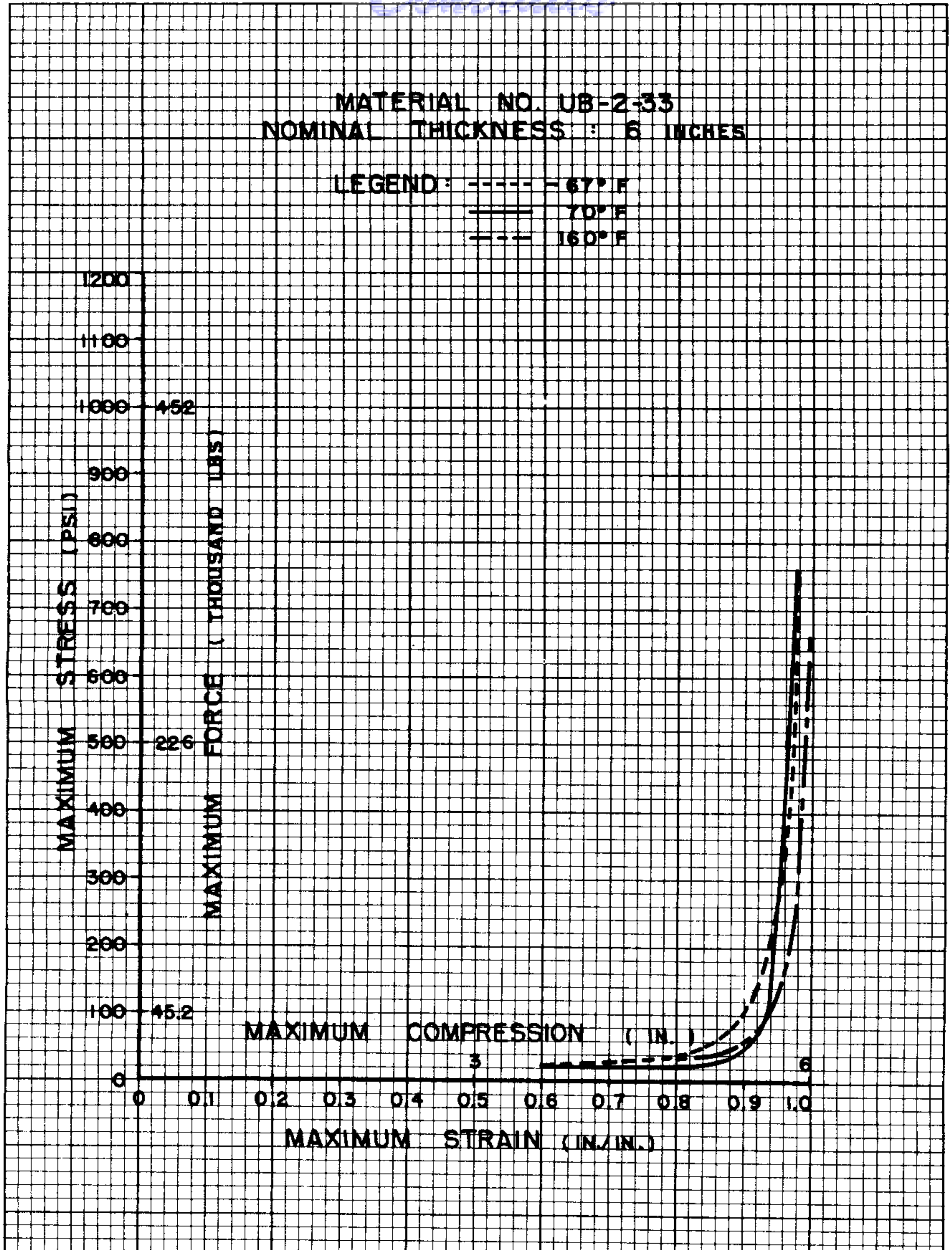

FIGURE 7. MAXIMUM STRESS - MAXIMUM STRAIN CURVE FOR 6 INCHES OF MATERIAL No. UB-2-33

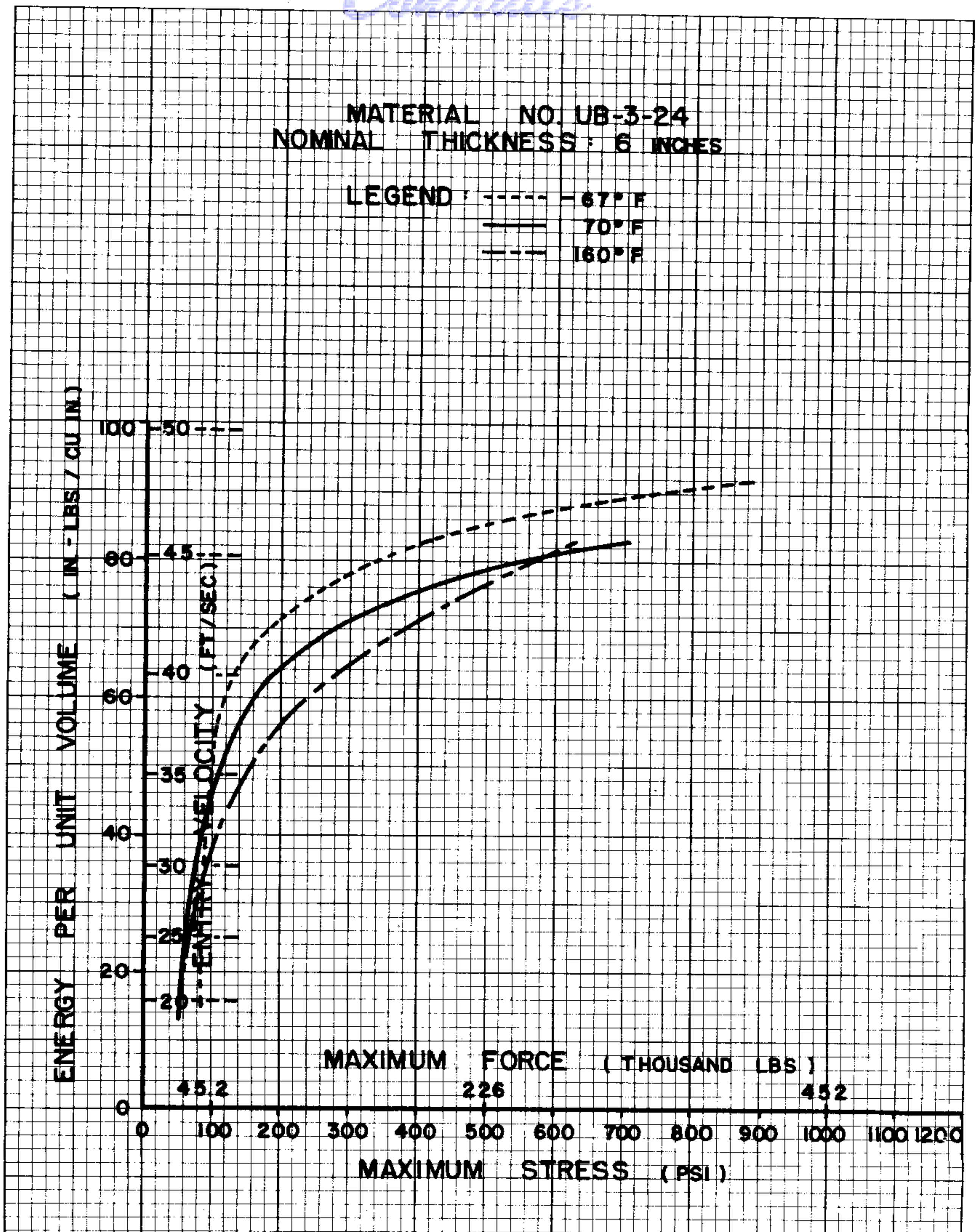

FIGURE 8 ENERGY PER UNIT VOLUME - MAXIMUM STRESS CURVE FOR 6 INCHES OF MATERIAL No. UB-3-24

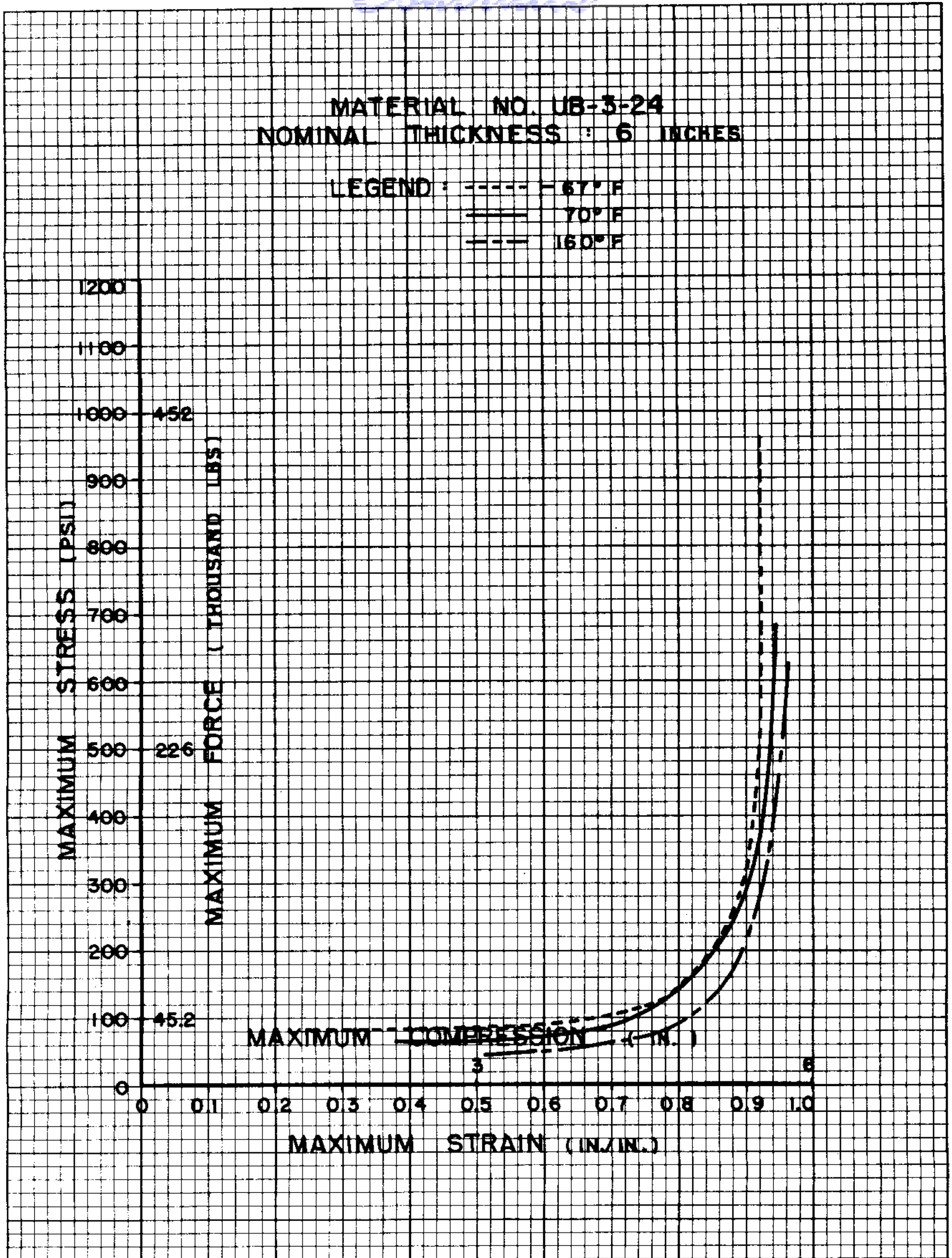

FIGURE 9. MAXIMUM STRESS - MAXIMUM STRAIN CURVE FOR 6 INCHES OF MATERIAL No. UB-3-24

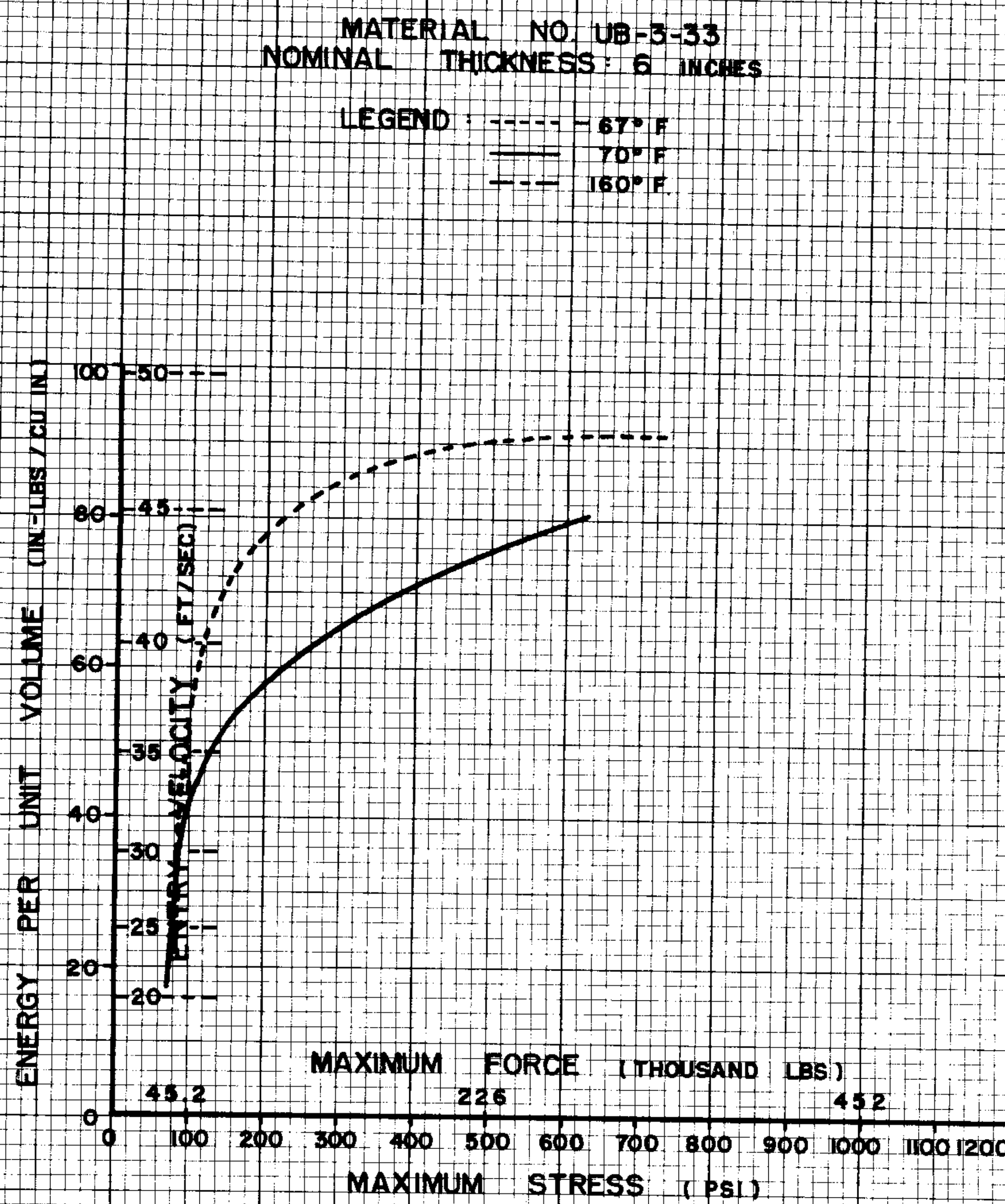

FIGURE 10 ENERGY PER UNIT VOLUME - MAXIMUM STRESS CURVE FOR 6 INCHES OF MATERIAL No. UB-3-33

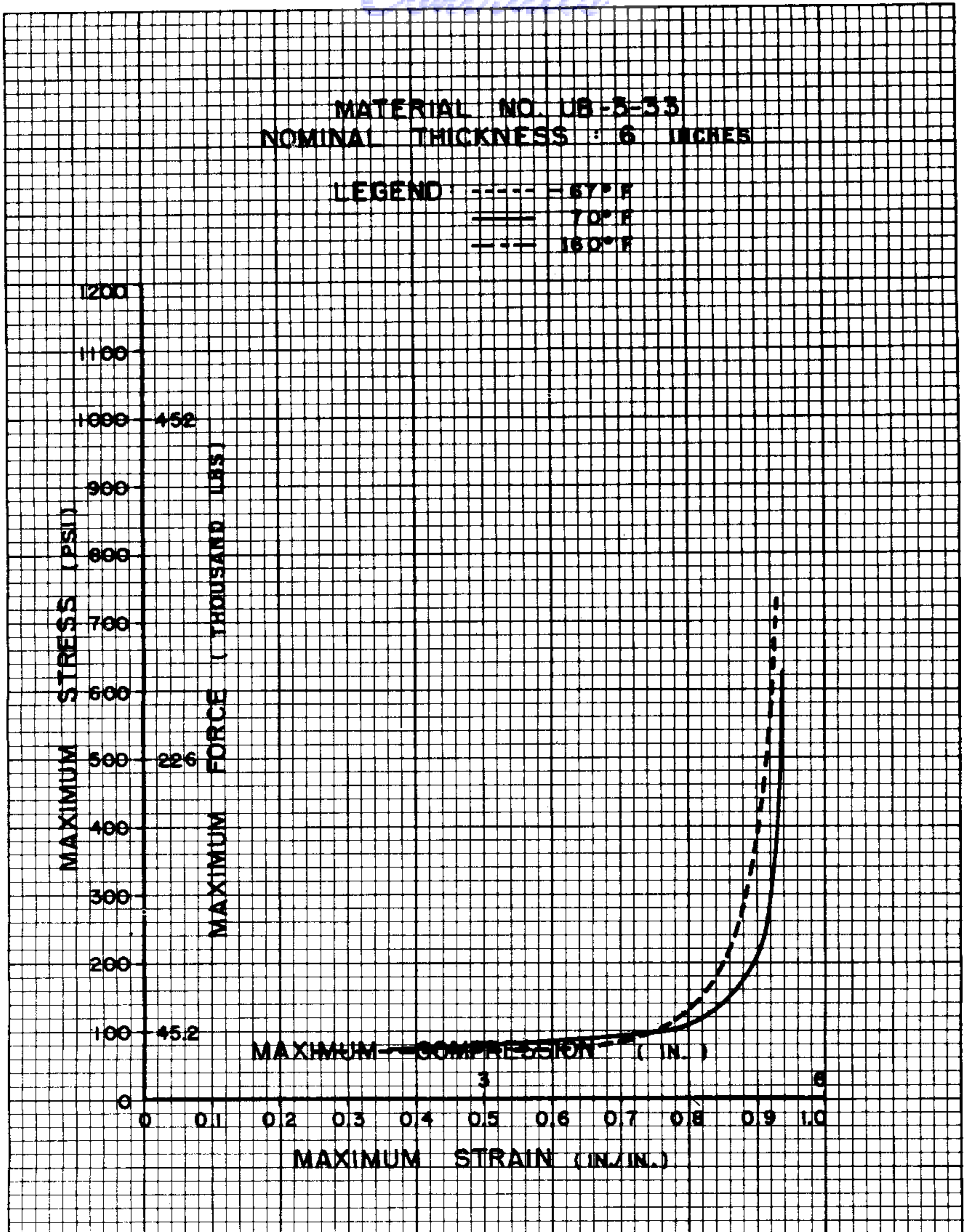

FIGURE 11 . MAXIMUM STRESS - MAXIMUM STRAIN CURVE FOR 6 INCHES OF MATERIAL No. UB-3-33

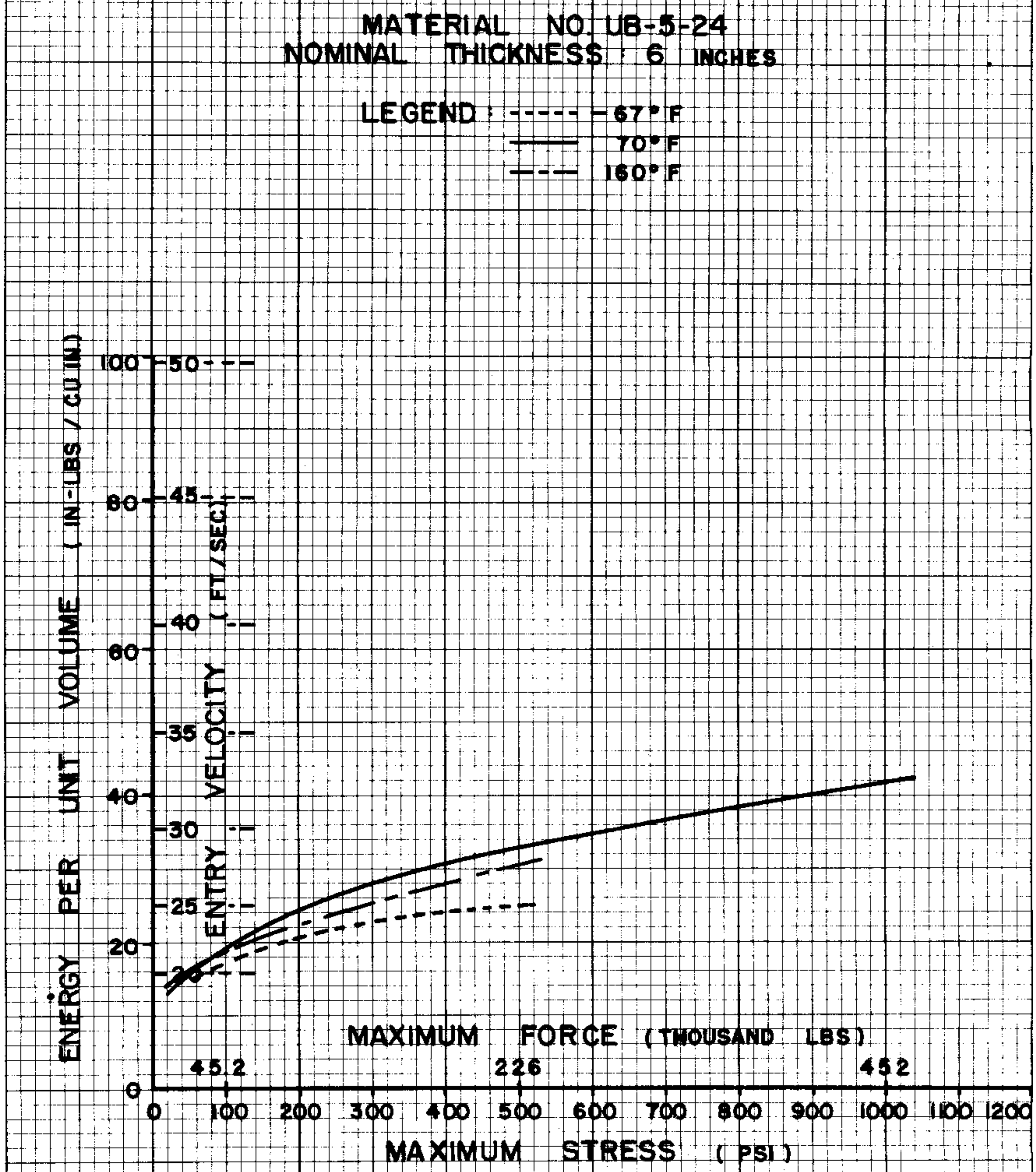

FIGURE 12 ENERGY PER UNIT VOLUME - MAXIMUM STRESS CURVE FOR 6 INCHES OF MATERIAL No. UB-5-24

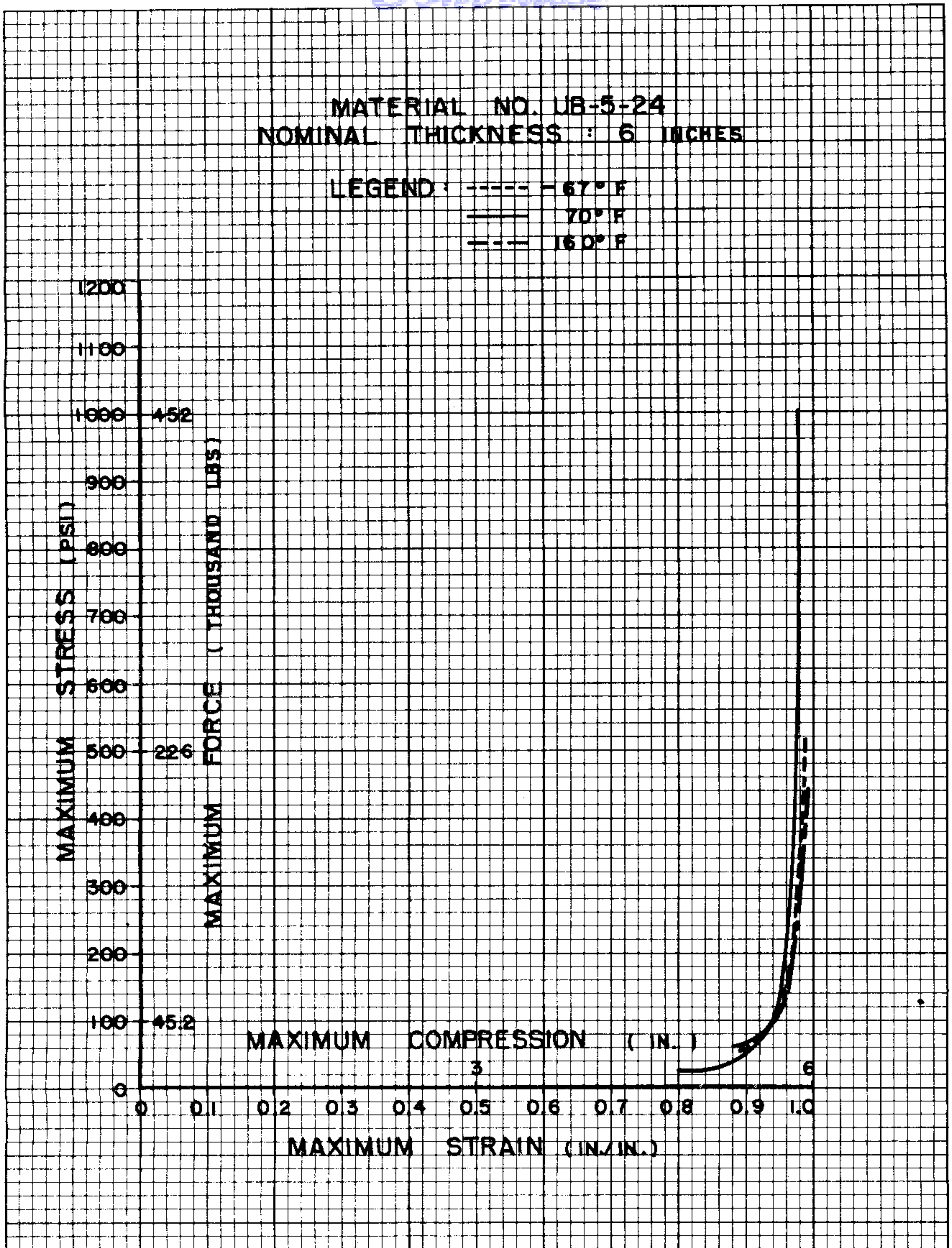

FIGURE 13. MAXIMUM STRESS - MAXIMUM STRAIN CURVE FOR 6 INCHES OF MATERIAL No. UB-5-24

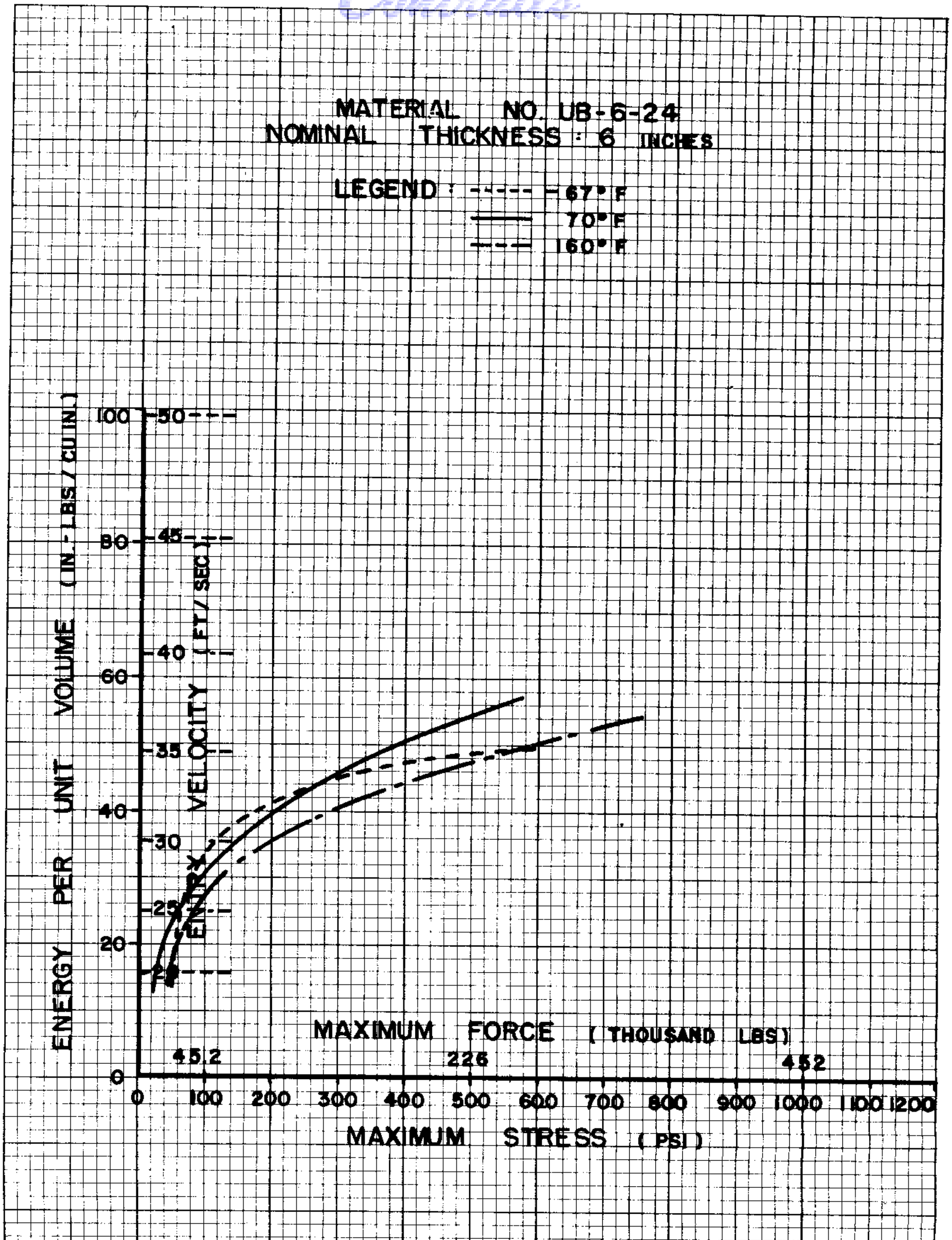

FIGURE 14 ENERGY PER UNIT VOLUME - MAXIMUM STRESS CURVE FOR 6 INCHES OF MATERIAL No. UB-6-24

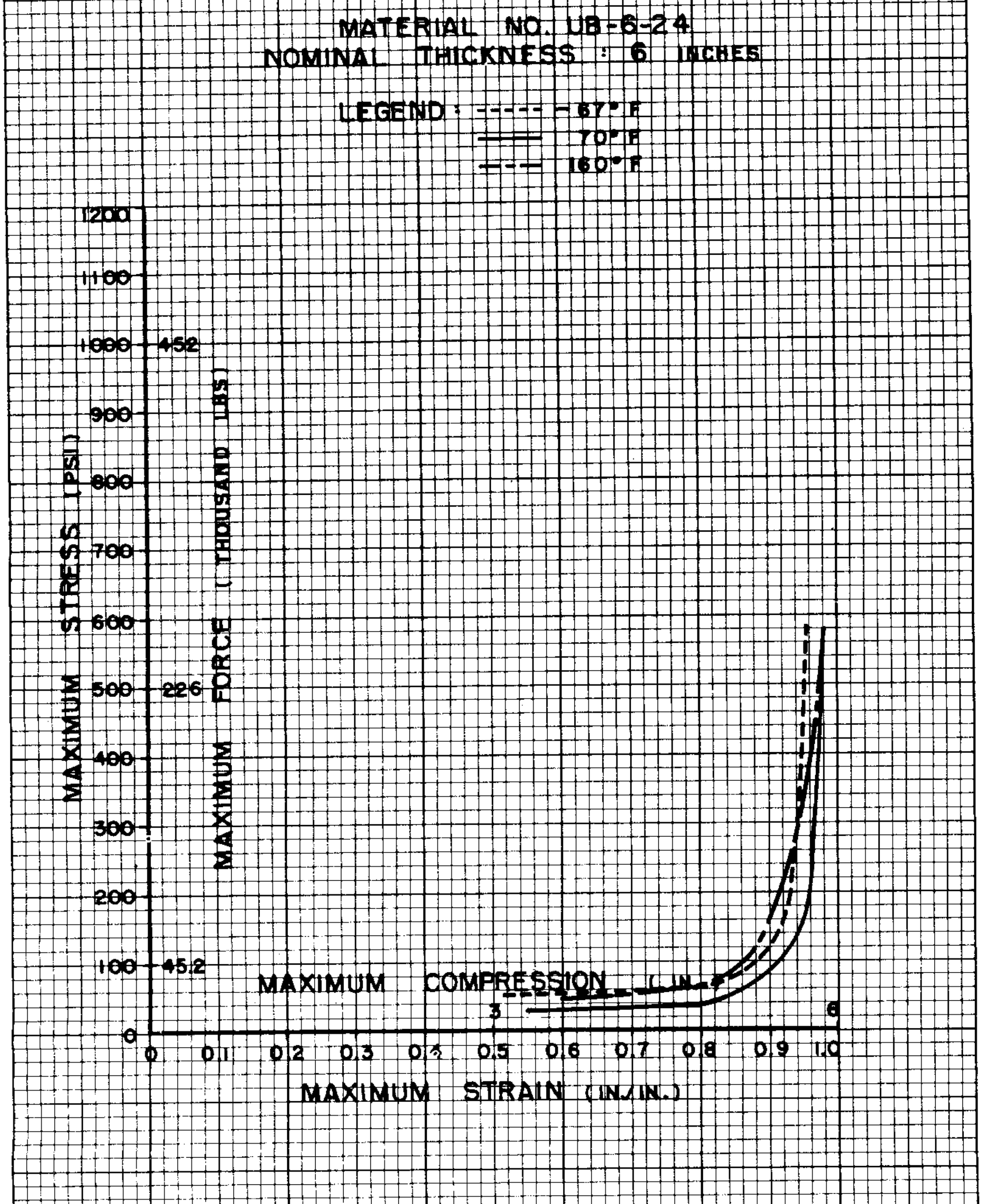

FIGURE 15 . MAXIMUM STRESS - MAXIMUM STRAIN CURVE FOR 6 INCHES OF MATERIAL No. UB-6-24

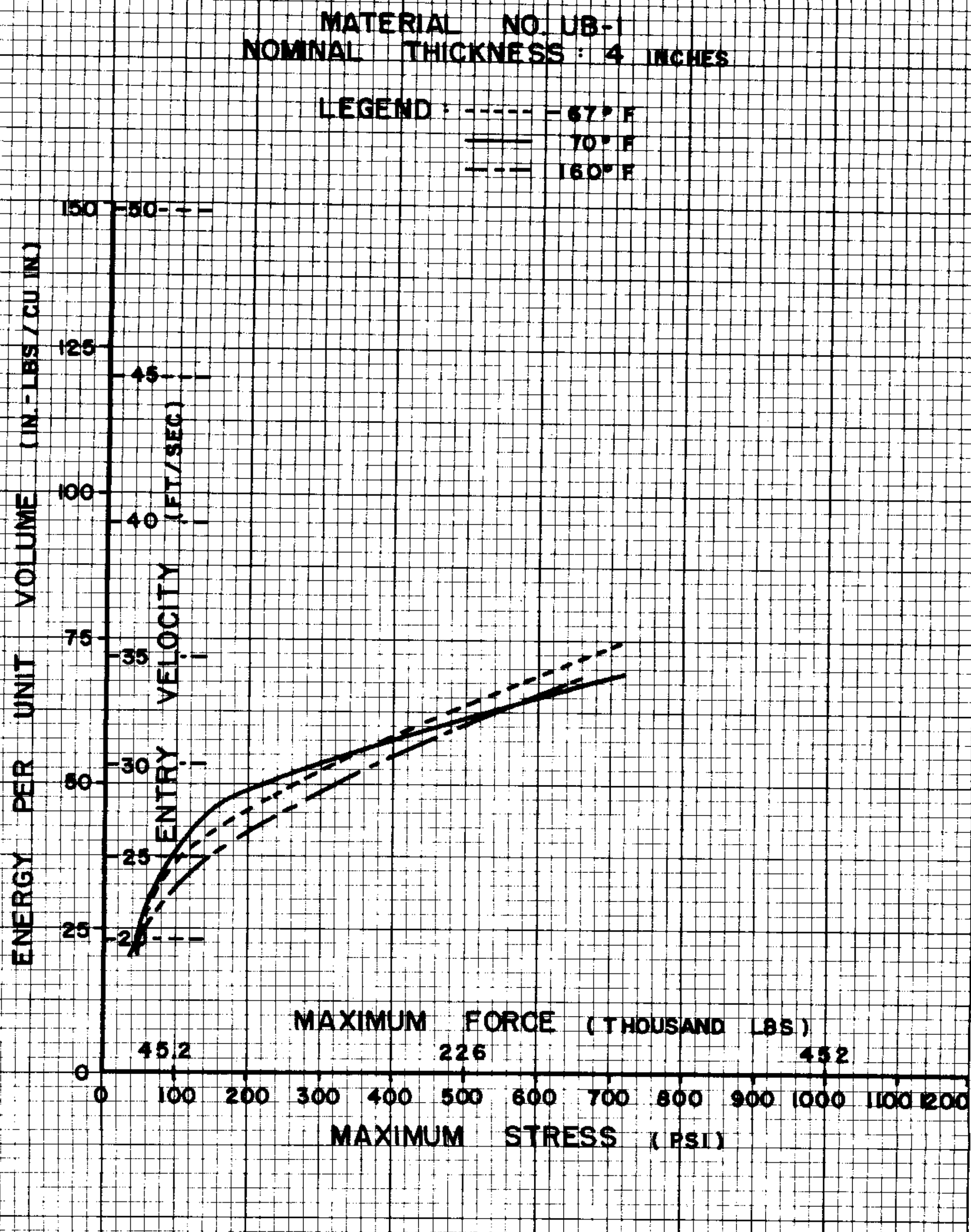

FIGURE 16 ENERGY PER UNIT VOLUME - MAXIMUM STRESS CURVE FOR 4 INCHES OF MATERIAL No. UB-1

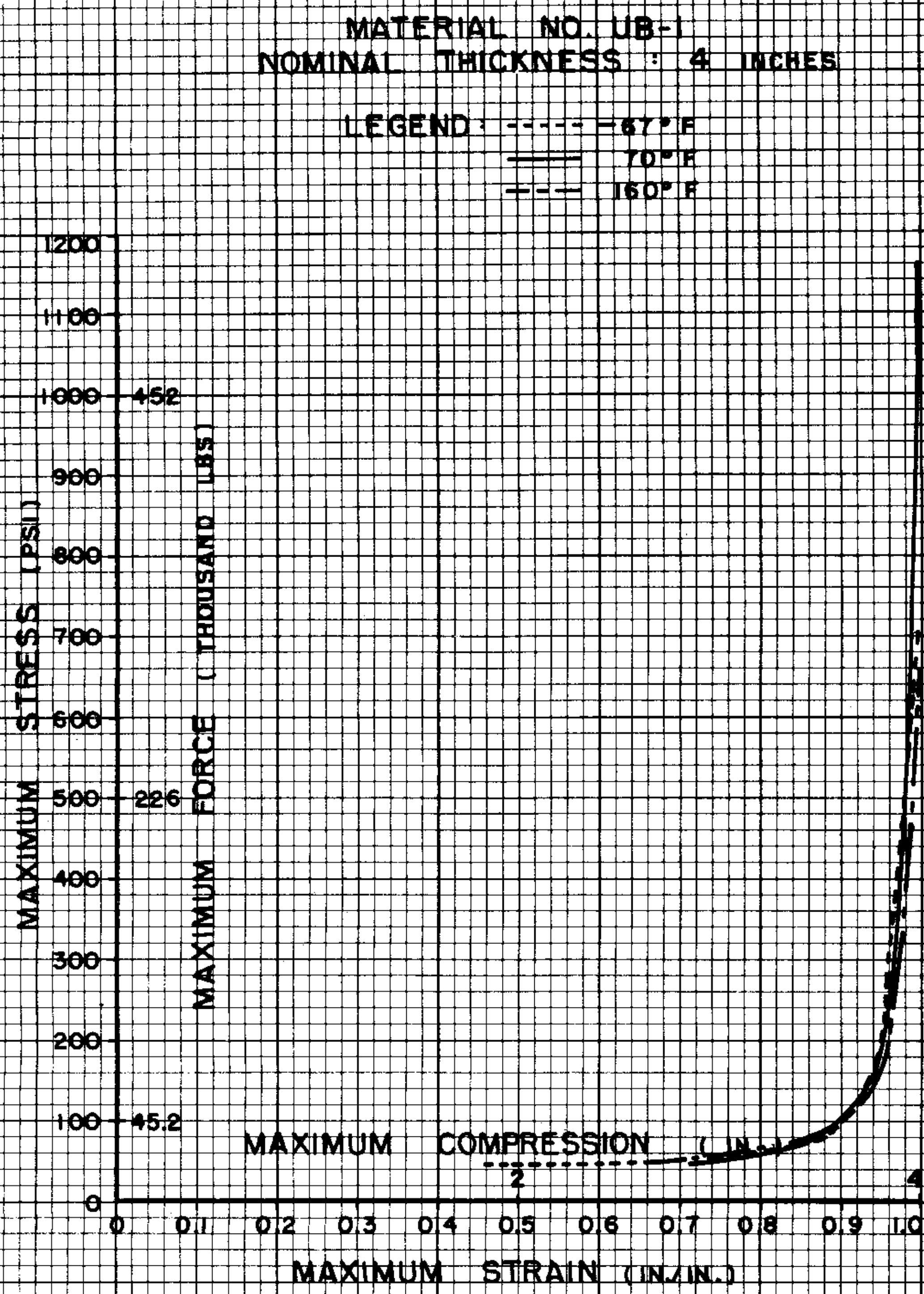

FIGURE 17 . MAXIMUM STRESS - MAXIMUM STRAIN CURVE FOR 4 INCHES OF MATERIAL NO. UB-1

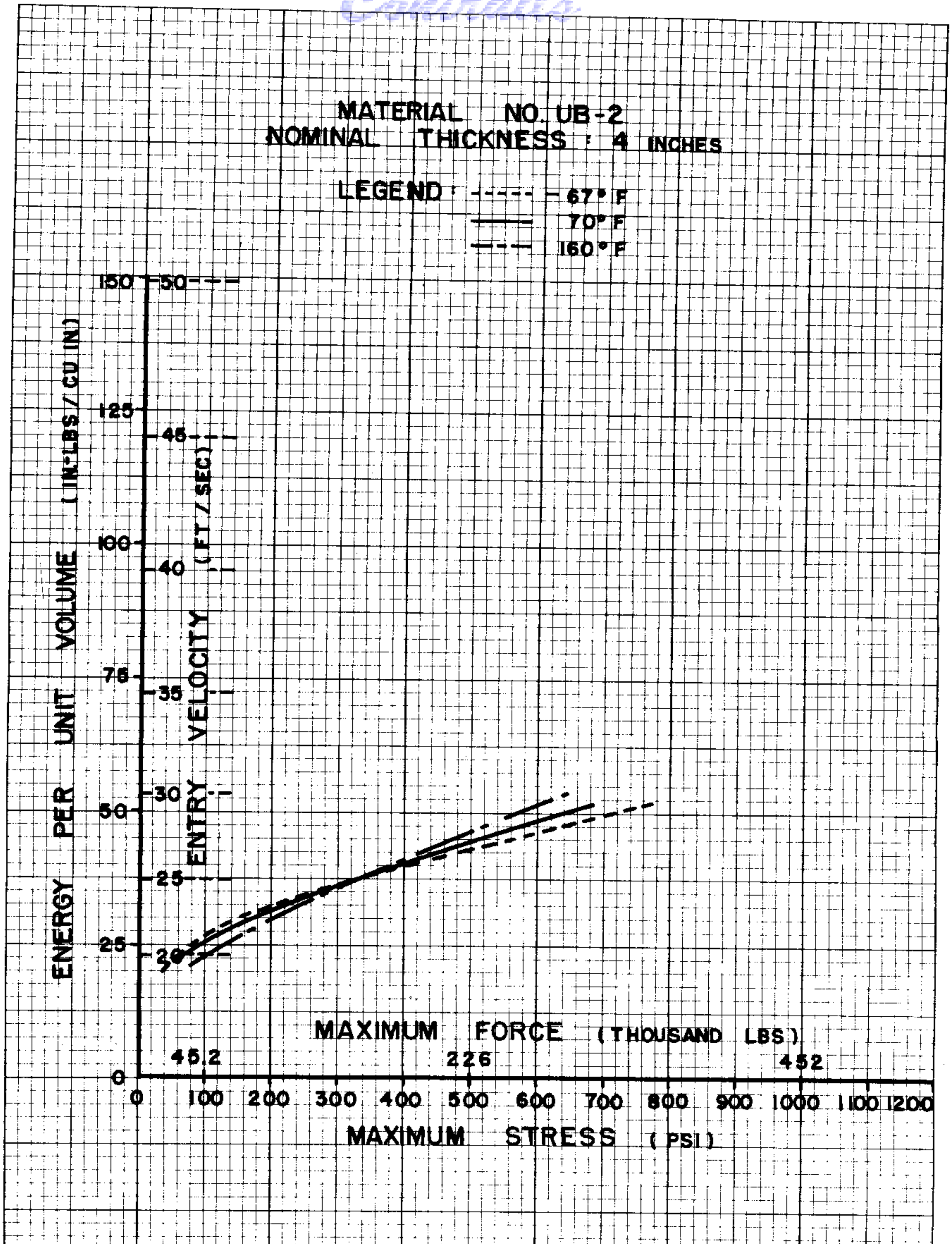

FIGURE 18 ENERGY PER UNIT VOLUME - MAXIMUM STRESS CURVE FOR 4 INCHES OF MATERIAL No. UB-2

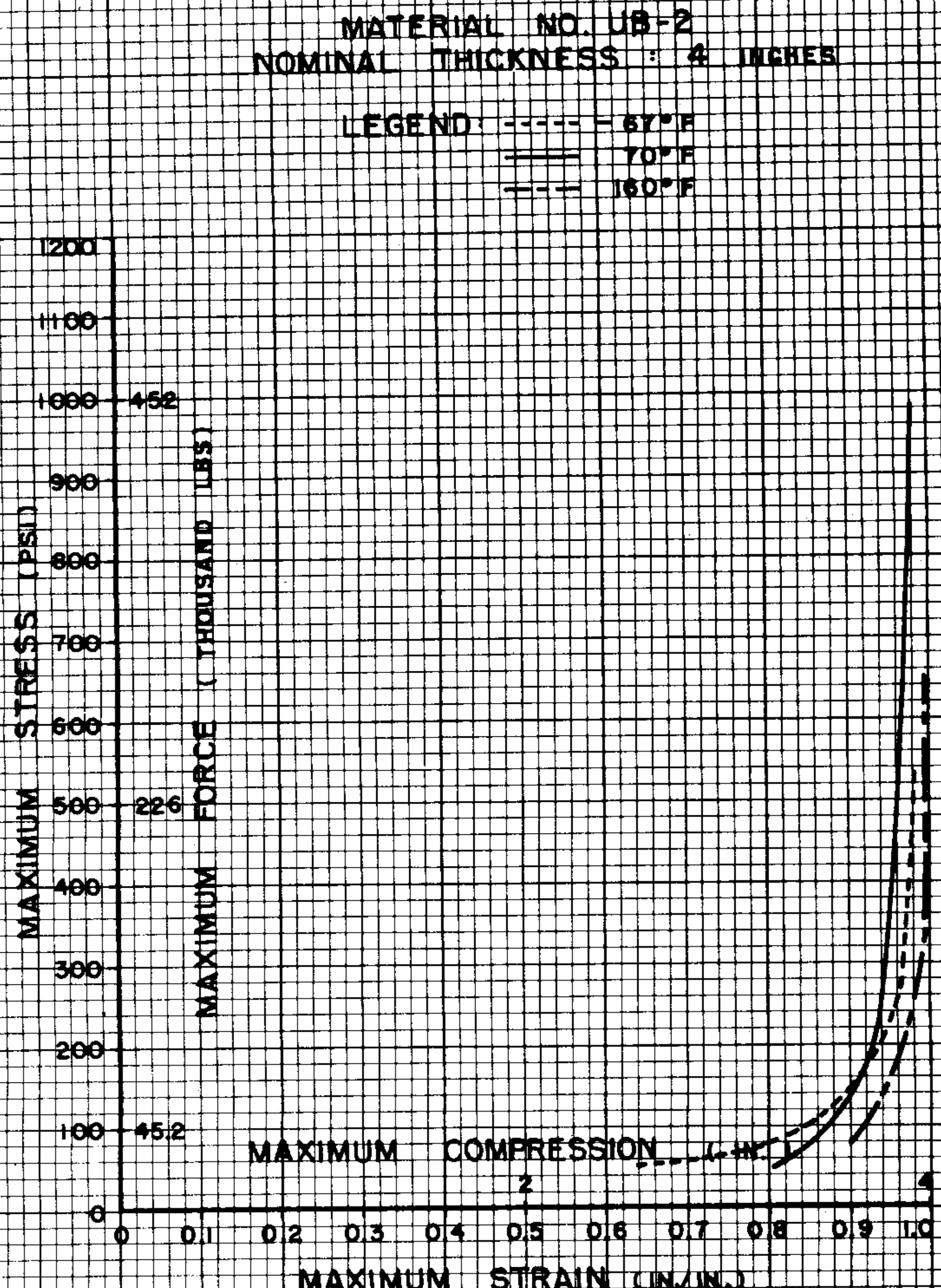

FIGURE 19. MAXIMUM STRESS - MAXIMUM STRAIN CURVE FOR 4 INCHES OF MATERIAL No. UB-2

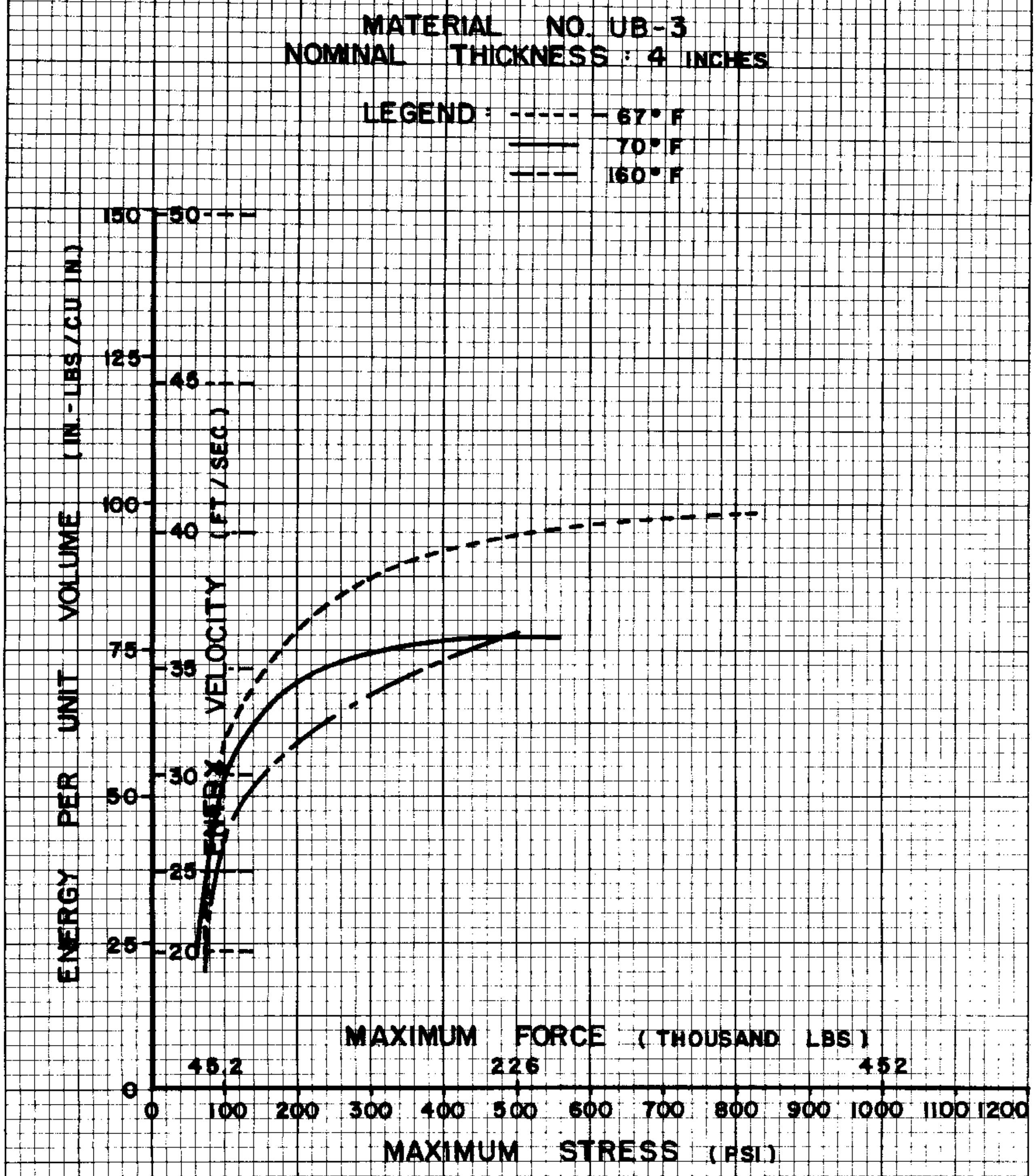

FIGURE 20 ENERGY PER UNIT VOLUME - MAXIMUM STRESS CURVE FOR 4 INCHES OF MATERIAL No. UB-3

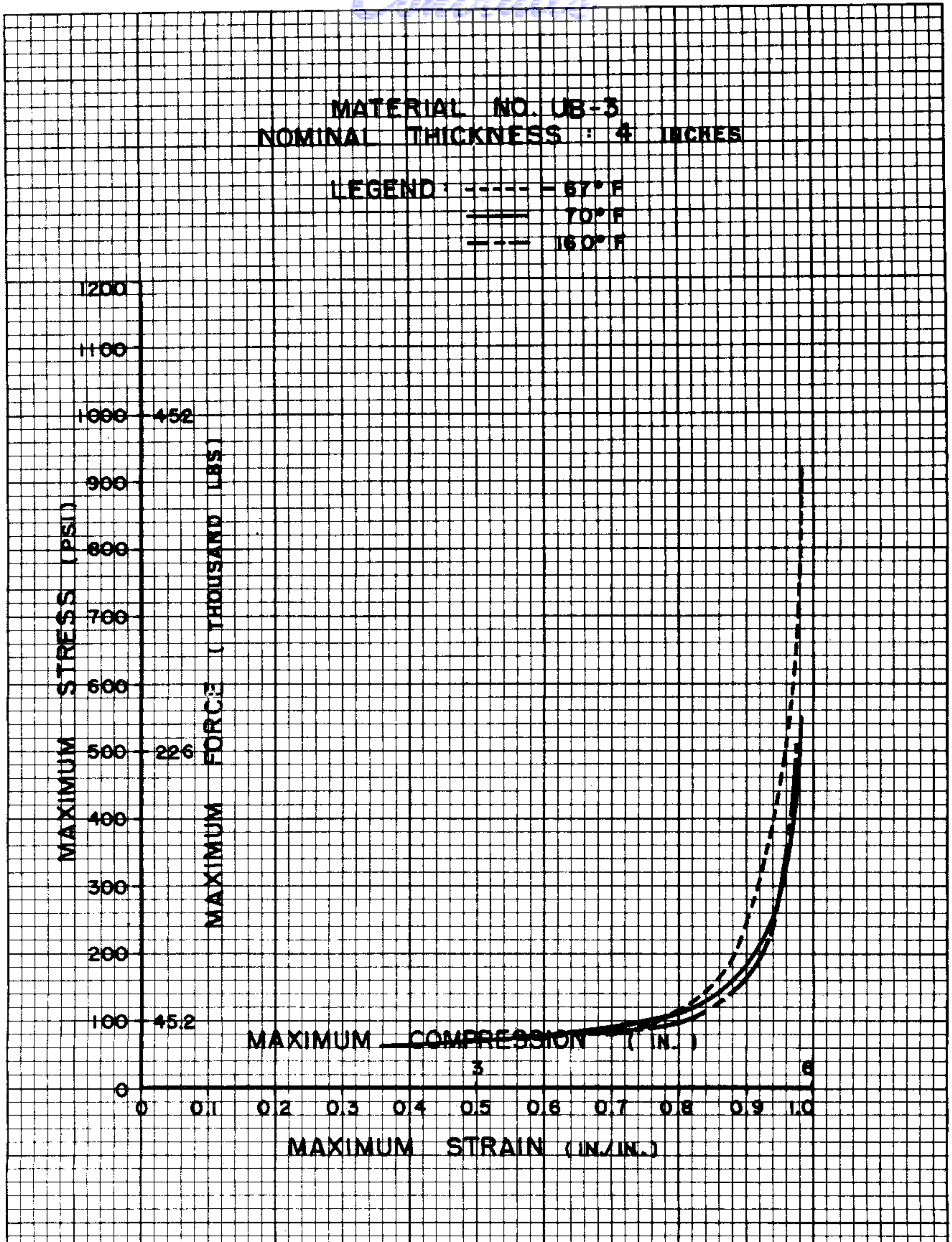

FIGURE 21 . MAXIMUM STRESS - MAXIMUM STRAIN CURVE FOR 4 INCHES OF MATERIAL No. UB-3

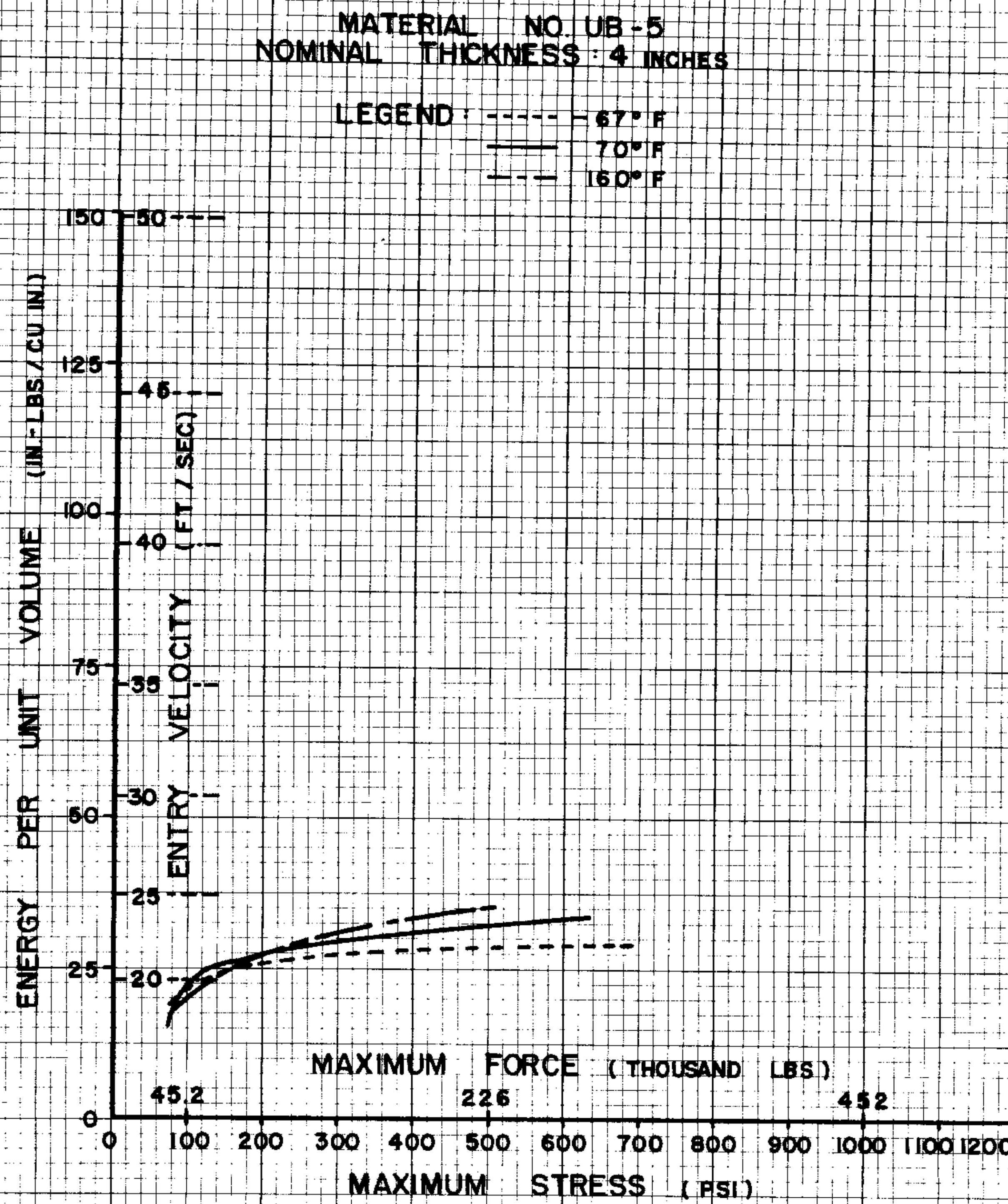

FIGURE 22 ENERGY PER UNIT VOLUME - MAXIMUM STRESS CURVE FOR 4 INCHES OF MATERIAL No. UB-5

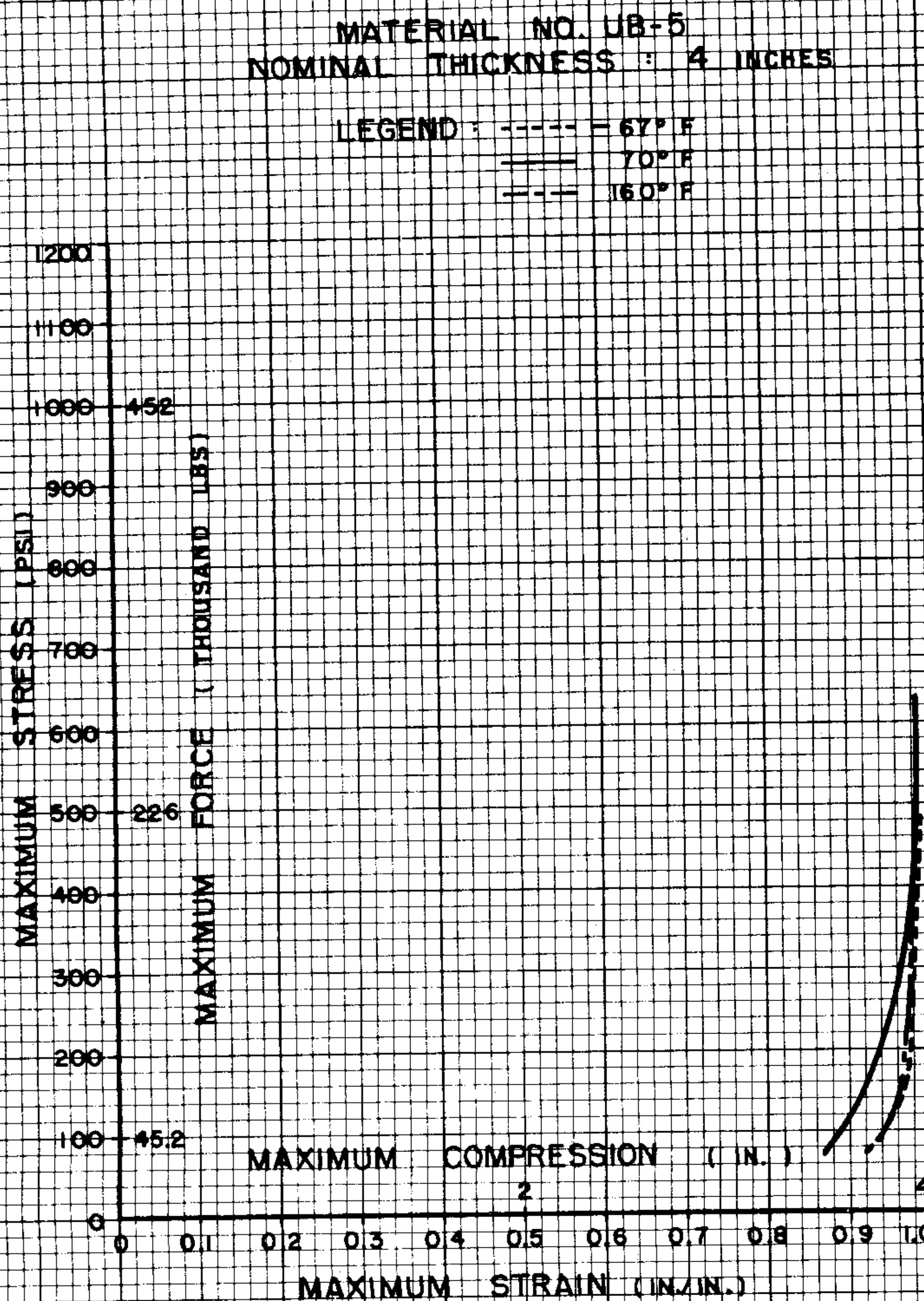

FIGURE 23. MAXIMUM STRESS - MAXIMUM STRAIN CURVE FOR 4 INCHES OF MATERIAL No. UB-5

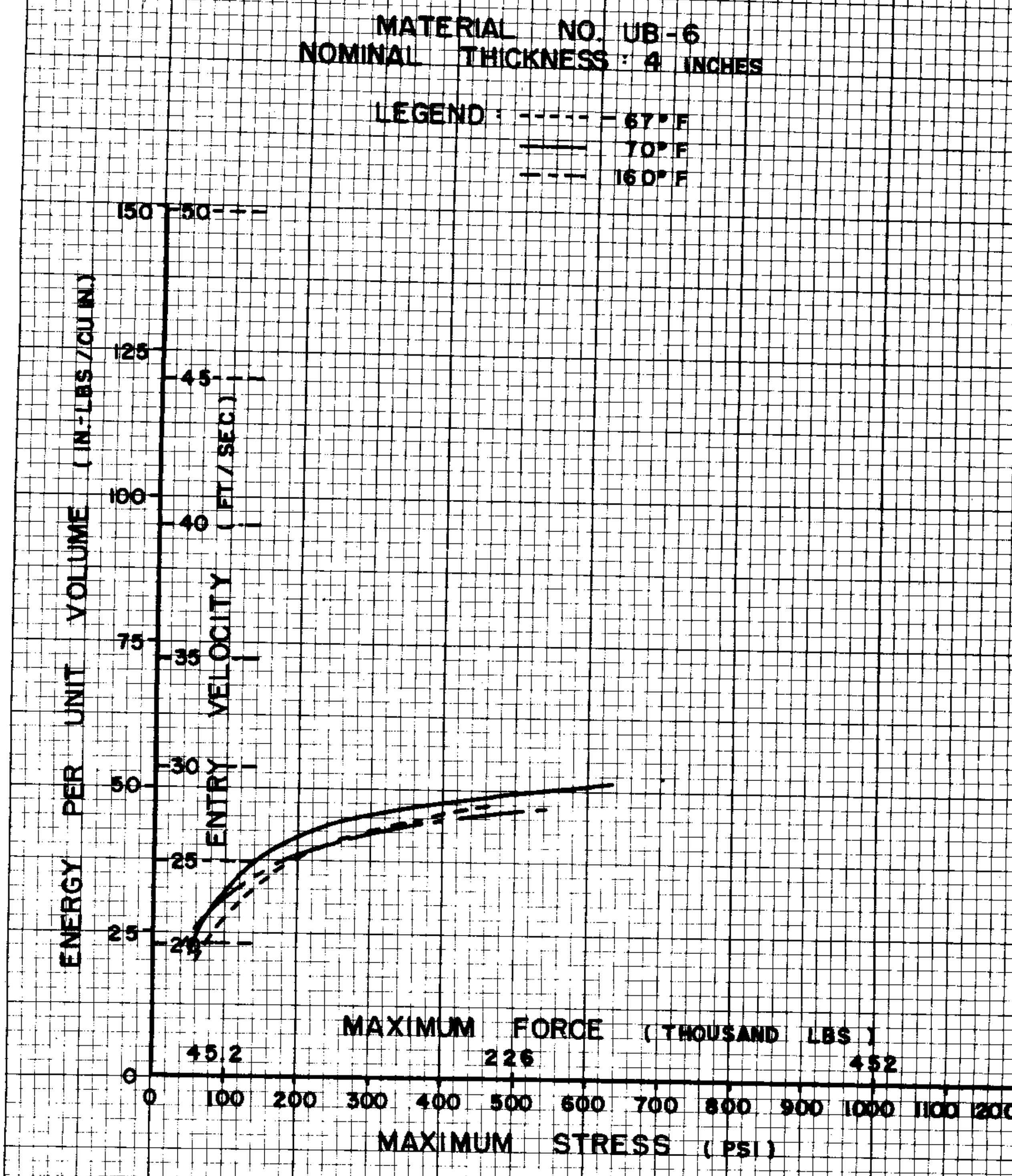

FIGURE 24 ENERGY PER UNIT VOLUME - MAXIMUM STRESS CURVE FOR 4 INCHES OF MATERIAL No. UB-6

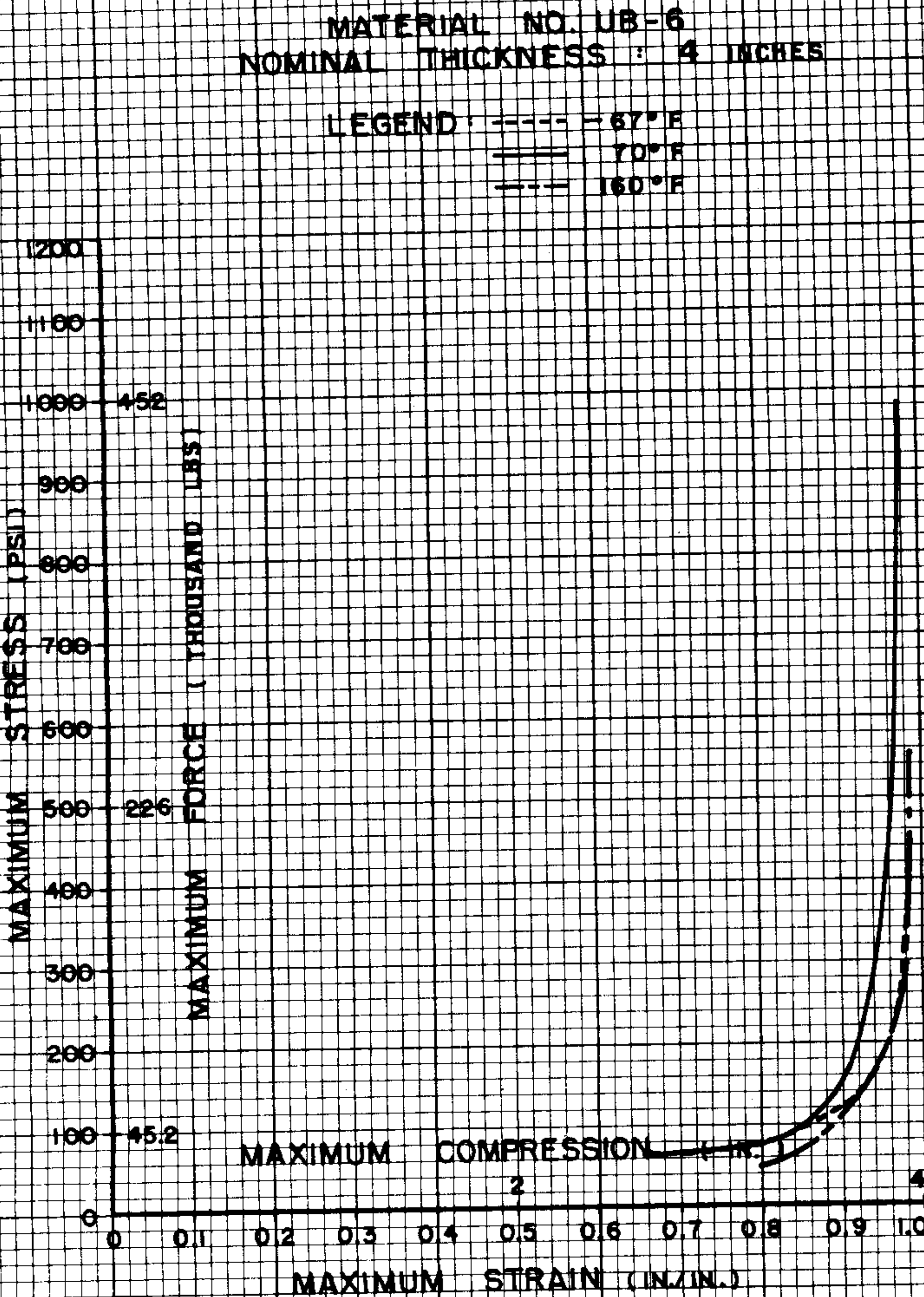

FIGURE 25 . MAXIMUM STRESS - MAXIMUM STRAIN CURVE FOR 4 INCHES OF MATERIAL No. UB-6

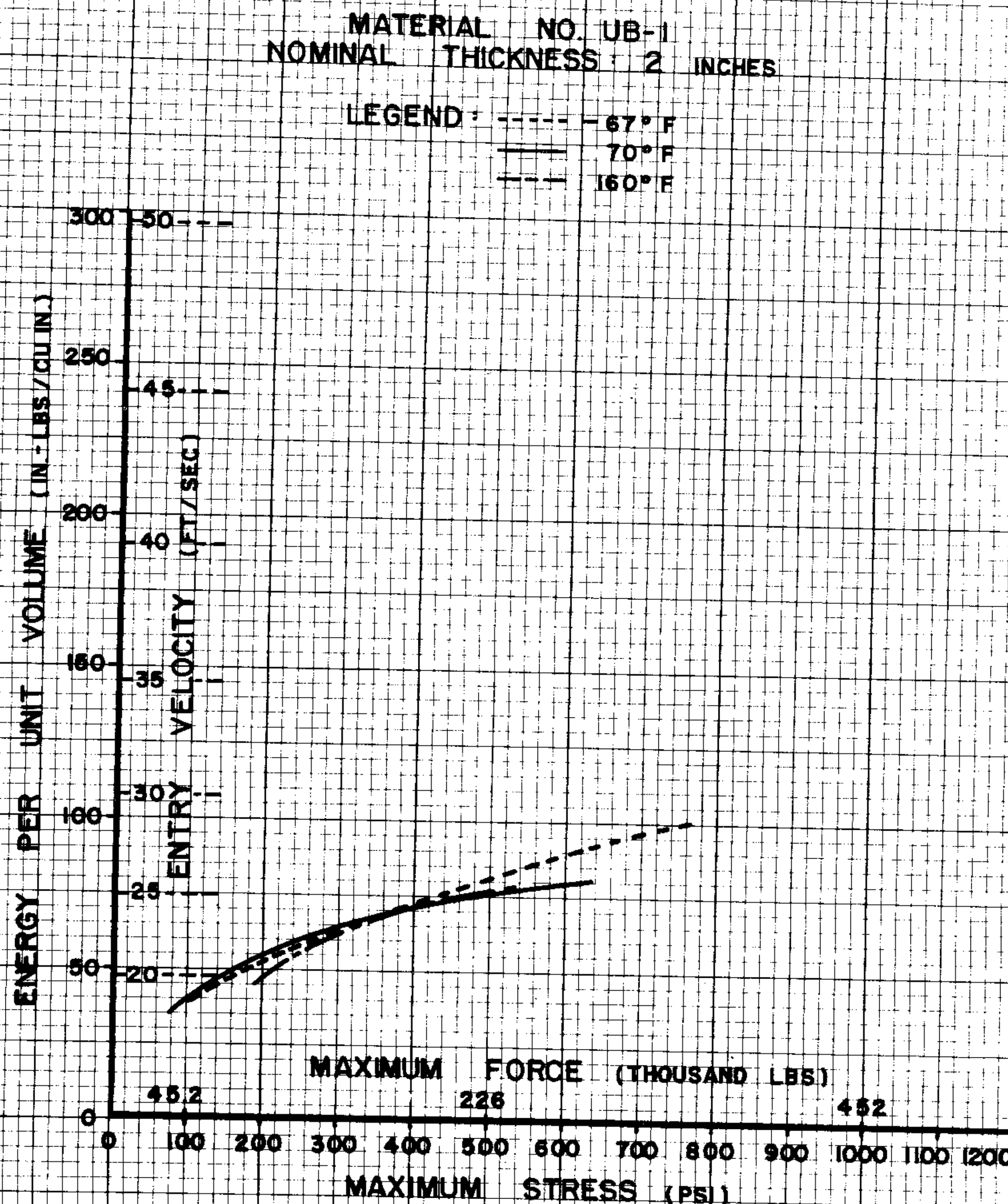

FIGURE 26 ENERGY PER UNIT VOLUME - MAXIMUM STRESS CURVE FOR 2 INCHES OF MATERIAL No. UB-1

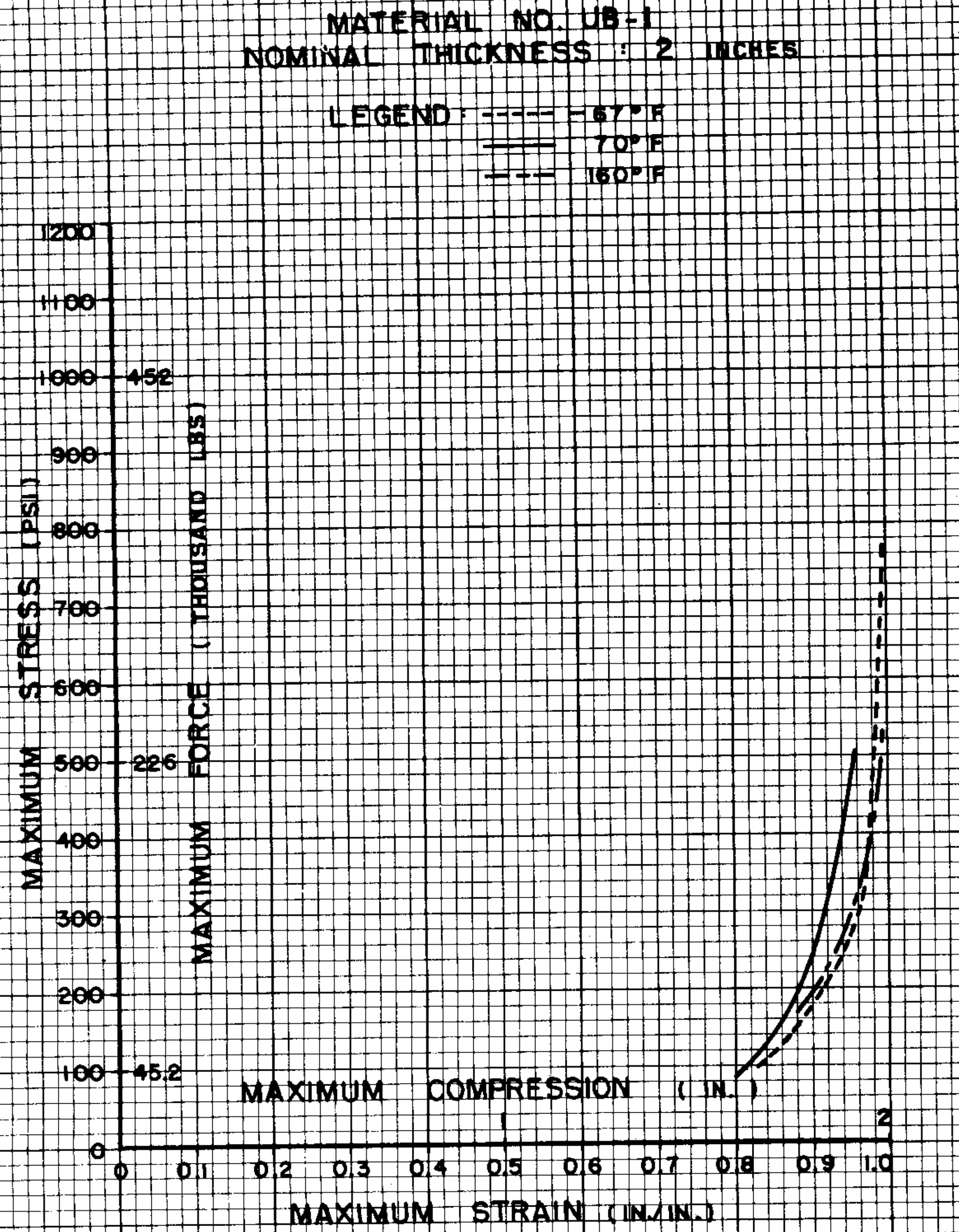

FIGURE 27. MAXIMUM STRESS - MAXIMUM STRAIN CURVE FOR 2 INCHES OF MATERIAL No. UB-1

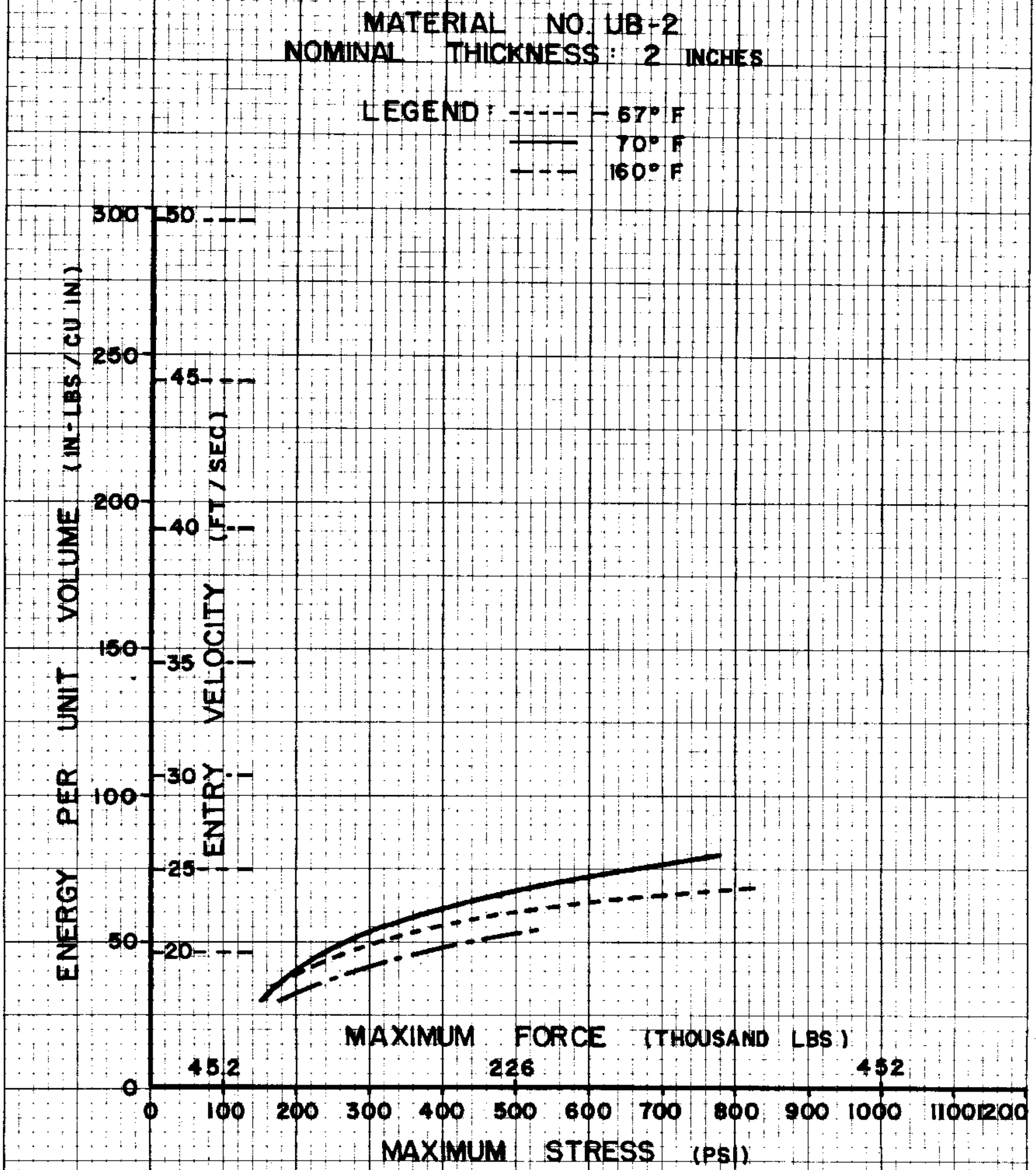

FIGURE 28 ENERGY PER UNIT VOLUME - MAXIMUM STRESS CURVE FOR 2 INCHES OF MATERIAL No. UB-2

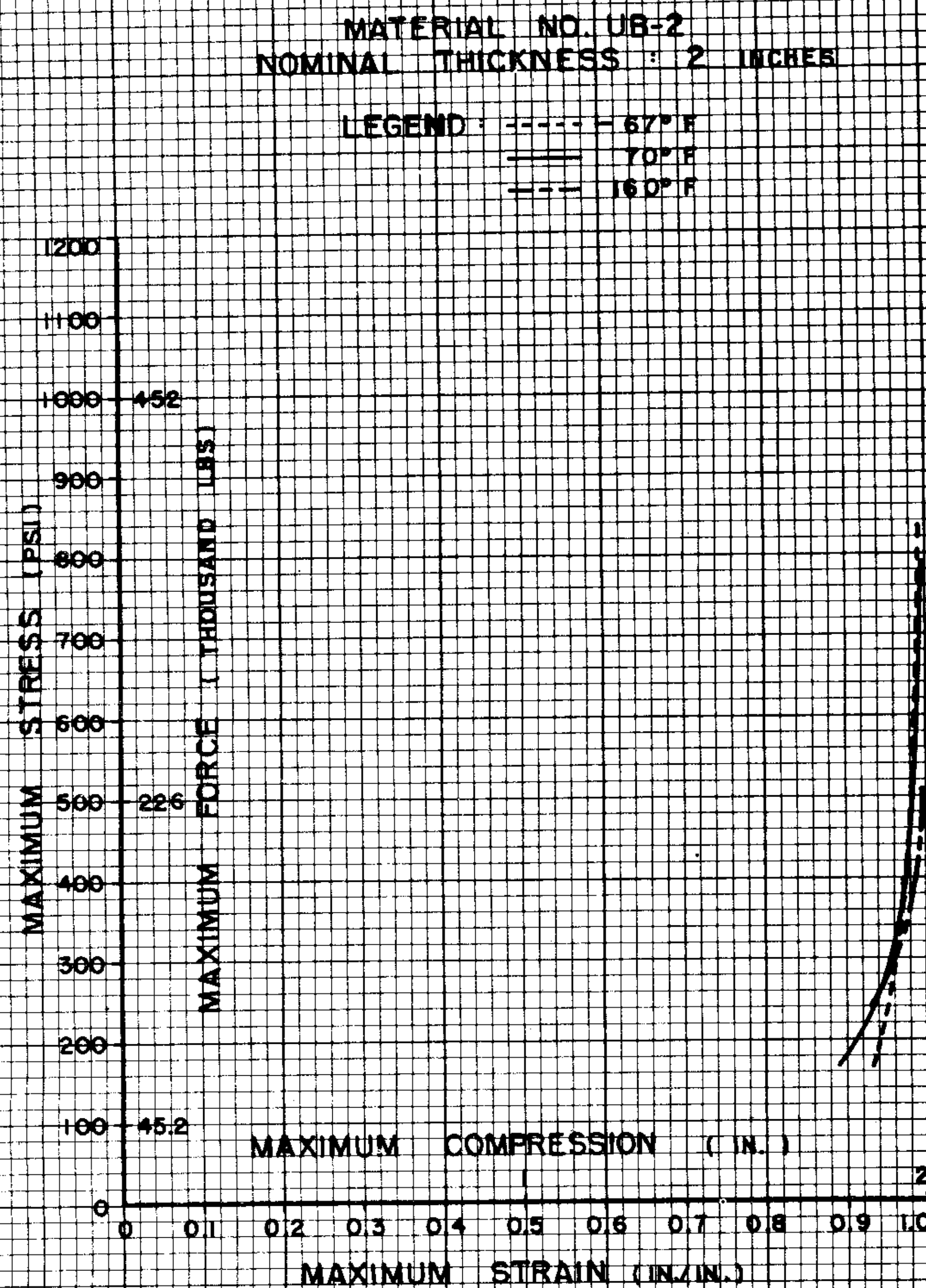

FIGURE 29. MAXIMUM STRESS - MAXIMUM STRAIN CURVE FOR 2 INCHES OF MATERIAL No. UB-2

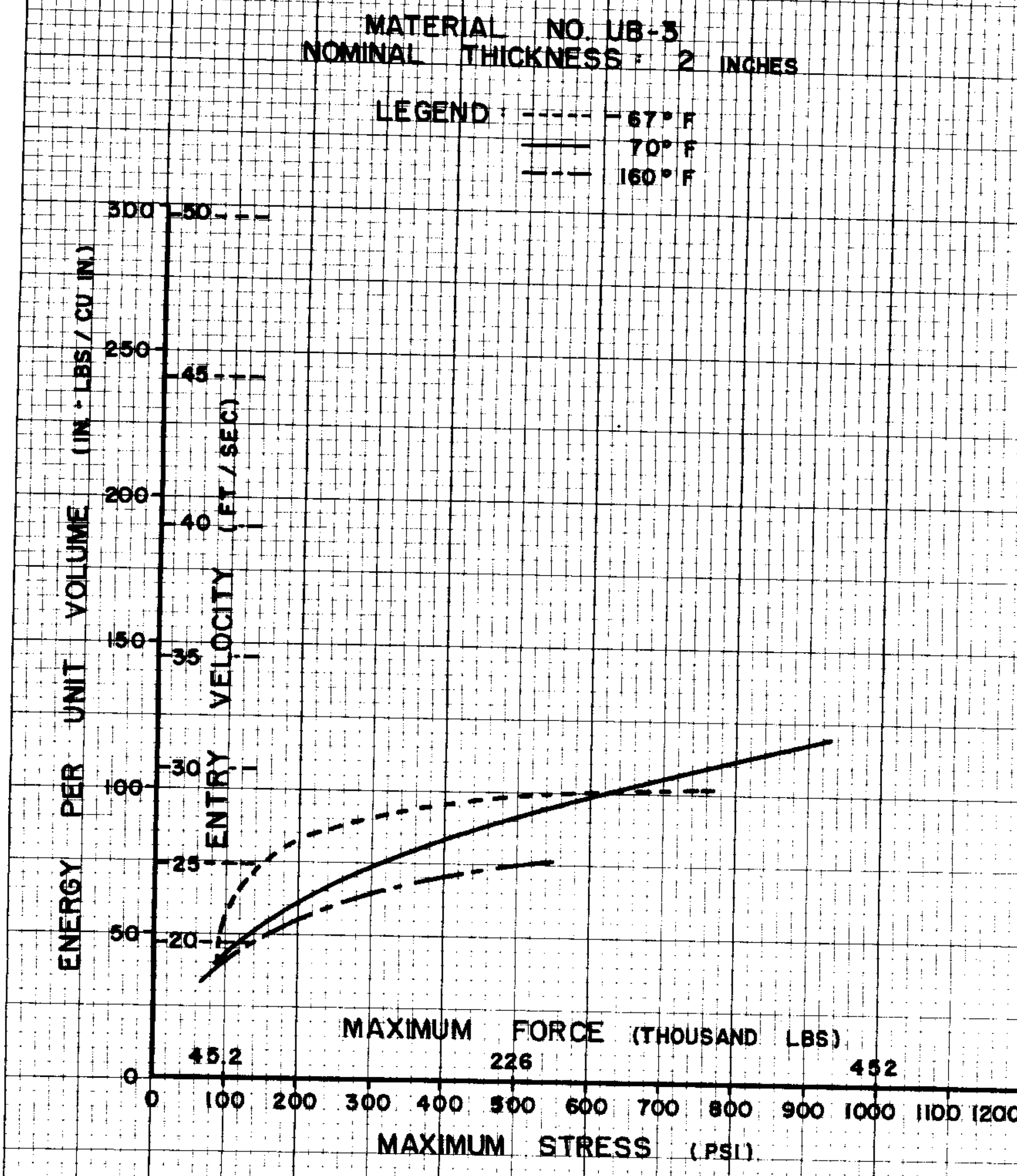

FIGURE 30 ENERGY PER UNIT VOLUME - MAXIMUM STRESS CURVE FOR 2 INCHES OF MATERIAL No. UB-3

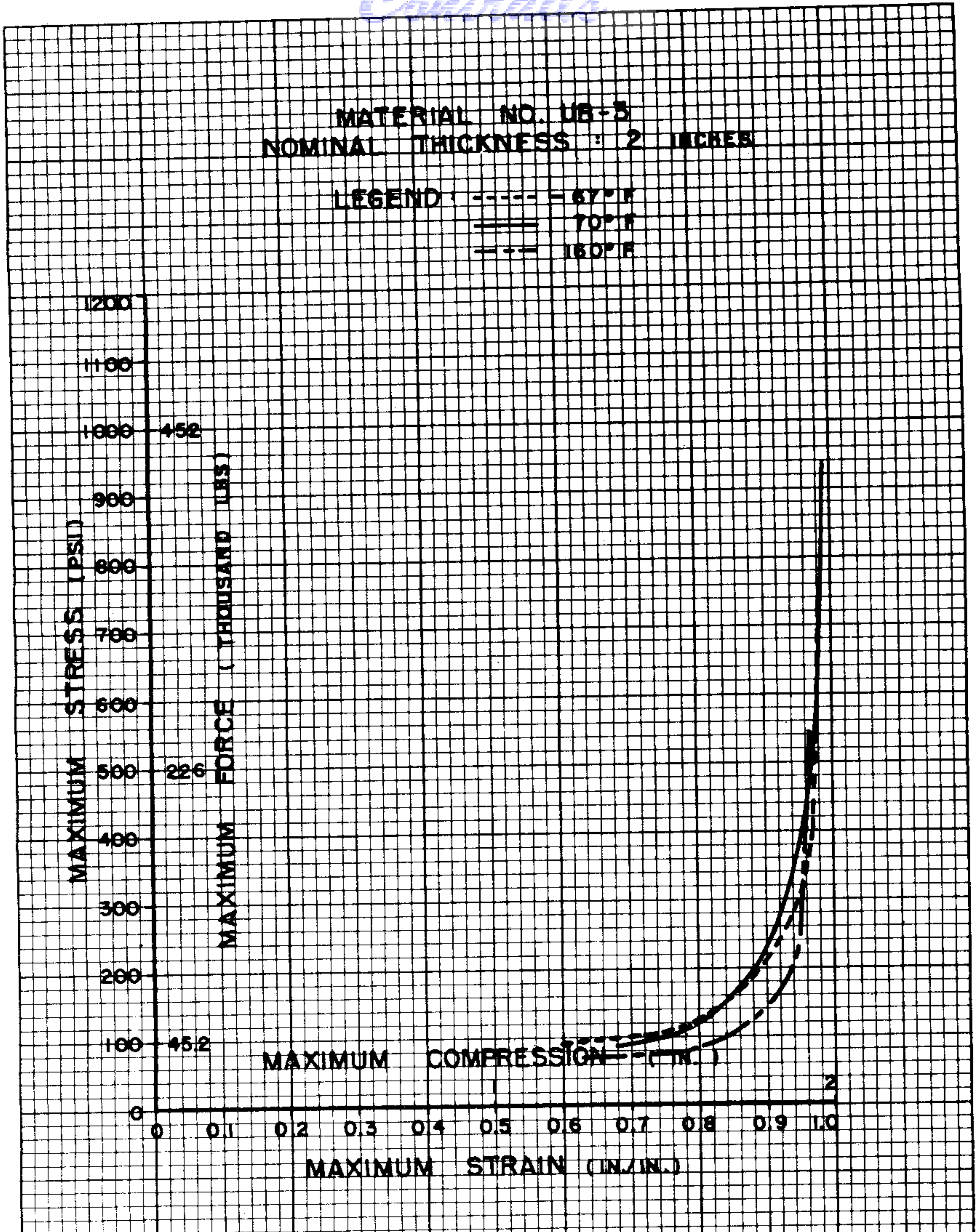

FIGURE 31 . MAXIMUM STRESS - MAXIMUM STRAIN CURVE FOR 2 INCHES OF MATERIAL No. UB-3

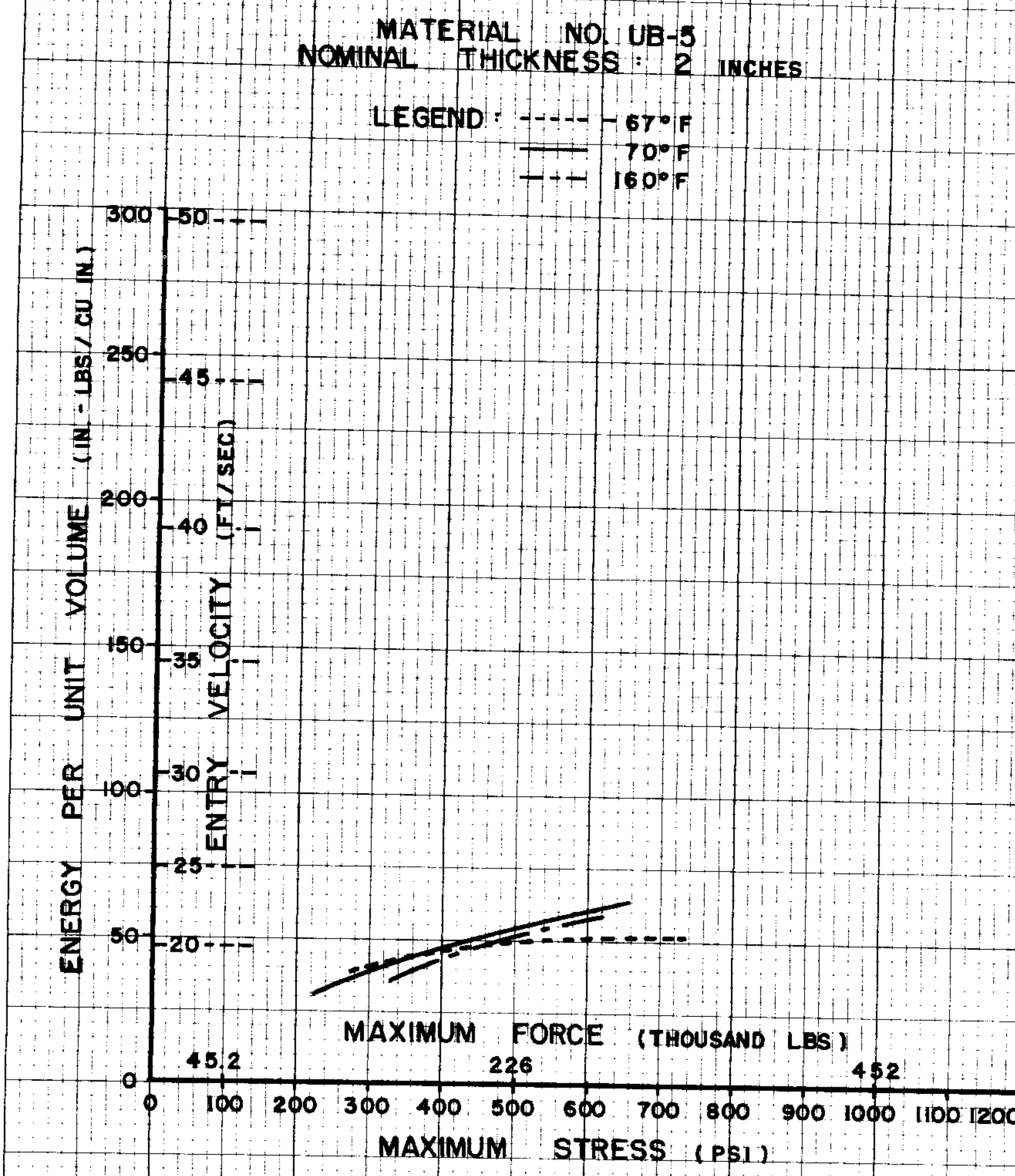

FIGURE 32 ENERGY PER UNIT VOLUME - MAXIMUM STRESS CURVE FOR 2 INCHES OF MATERIAL No.UB-5

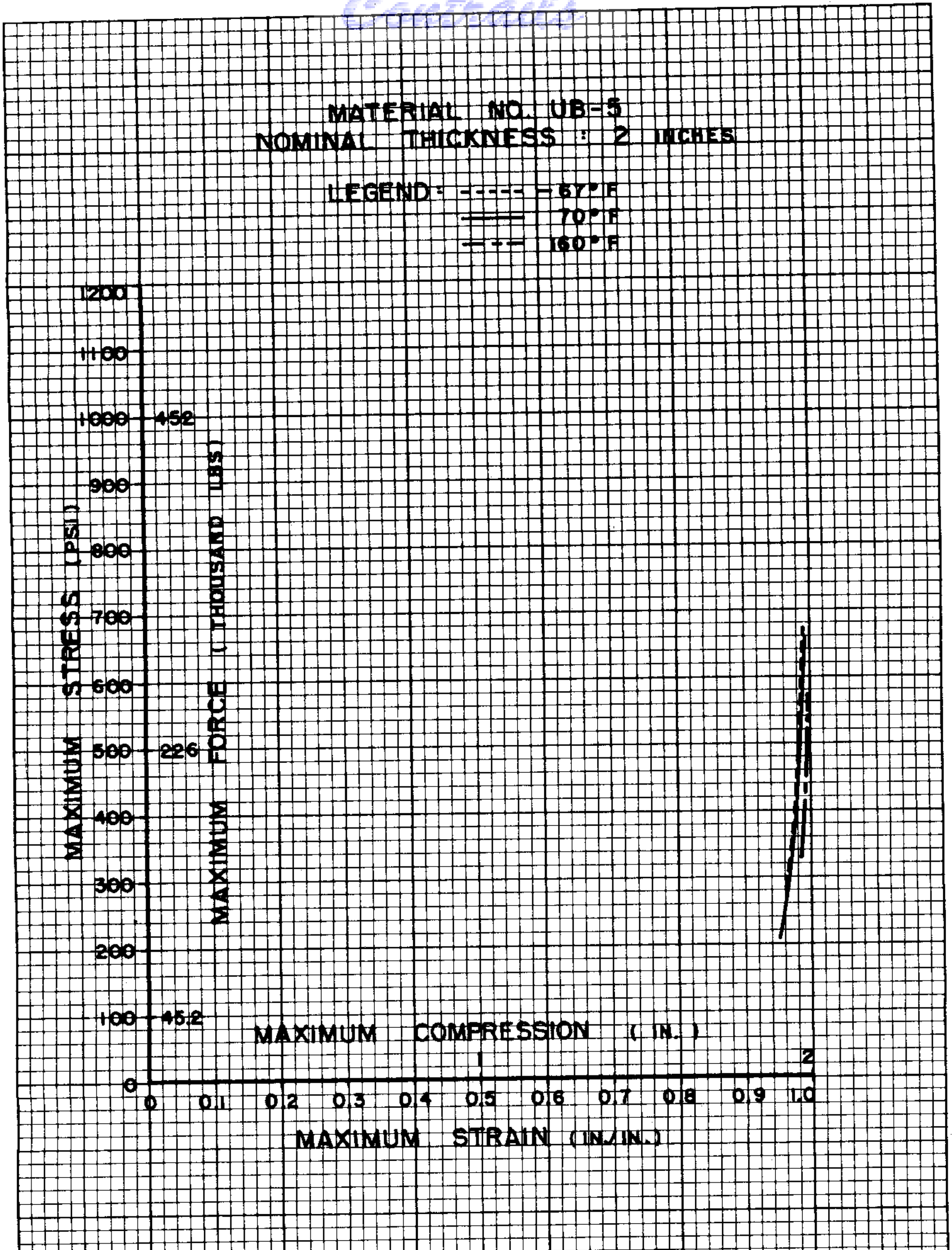

FIGURE 33. MAXIMUM STRESS - MAXIMUM STRAIN CURVE FOR 2 INCHES OF MATERIAL No. UB-5

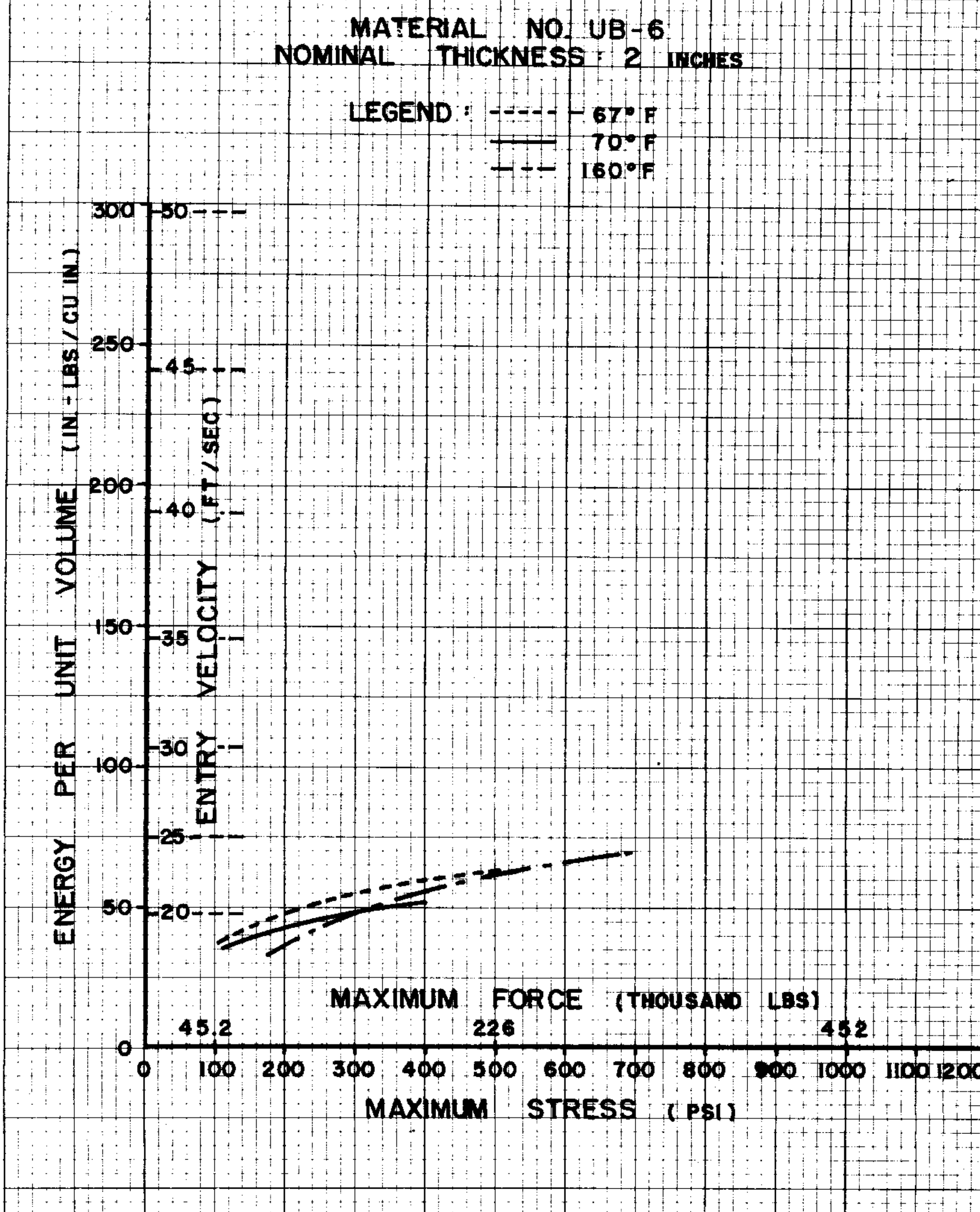

FIGURE 34 ENERGY PER UNIT VOLUME - MAXIMUM STRESS CURVE FOR 2 INCHES OF MATERIAL No. UB-6

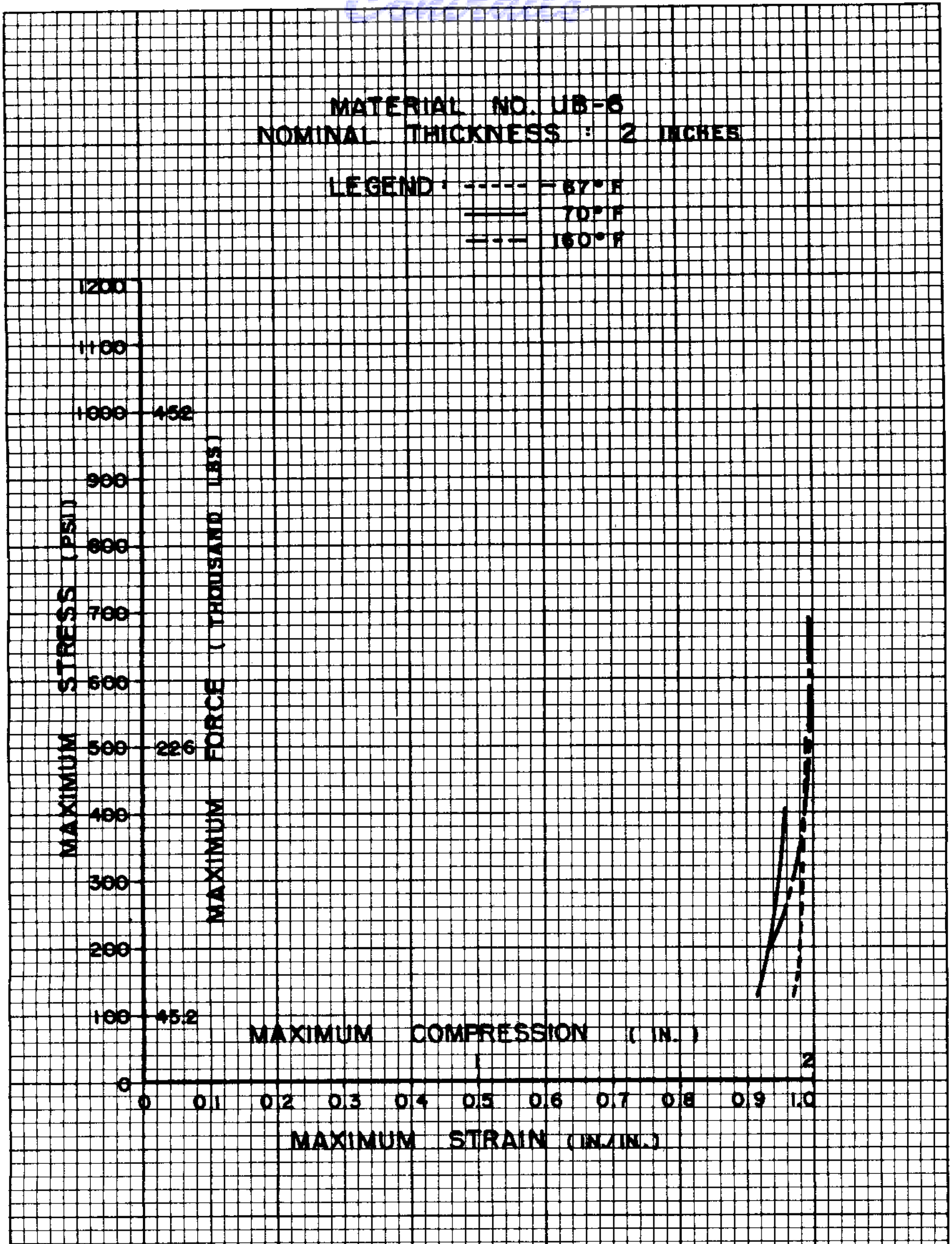

FIGURE 35. MAXIMUM STRESS - MAXIMUM STRAIN CURVE FOR 2 INCHES OF MATERIAL No. UB-6