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General Chemistry Technical Note No. 61: New Developments in Plastic Bonded Explosives

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E. James

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GENERAL CHEMISTRY TECHNICAL NOTE NO. 61

"New Developments in Plastic Bonded Explosives"

K. Scribner and E. James

INTRODUCTION

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Two new explosives are under development at LRL which show considerable promise as replacements for PBX 9404 (and also PBX 9010). Three primary considerations have guided us in the development of these explosives; compared to PBX 9404 we have sought

(1) a significant decrease in sensitivity,

(2) a substantial gain in mechanical properties, and

(3) as little loss in energy and detonation velocity as possible.

While testing is not complete on these materials, and probably won't be for quite some time, sufficient information is available to warrant a complete status report at this time. An index of the topics covered herein is:

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I. FORMULATIONS AND RAW MATERIALS

The first of these PBX's is designated LX-03-0 and has the general formulation (given in weight per cent):

70% HMX
20% DATB (2,4-diamino-1,3,5-trinitrobenzene)*
10% Viton A

The HMX used in this PBX is of 98% purity and coarse granulation, defined in specification MIL-H-45444A as Class A, Grade II. The DATB, for which specifications have not yet been written, is of ~95% purity and has an average particle size of 10-20μ. The Viton is a commercial fluoro elastomer produced by E. I. Du Pont De Nemours Co., and has the following elemental analysis, based on weight %:

Fluorine	63.6%
Carbon	34.5%
Hydrogen	1.9%

The other PBX, designated as LX-04-0, has the formula:

HMX	85%
Viton A	15%

The HMX used in LX-04-0 is of 98% purity and fine granulation, defined in specification MIL-H-45444A as Class F, Grade II.

2. MOLDING POWDER

Over a ton of molding powder has been prepared at Site 300 and at the Holston Ordnance Plant. There is sufficient evidence to say that a dust-free molding powder with a bulk density of at least 0.85 gm/cc can be manufactured. Although some difficulty has been encountered in controlling the compositions of these products, it appears that the Viton content can be controlled to ±0.3% in either PBX, and the DATB in the LX-03-0 to ±0.8%.

*Correction: Was 2,5-diamino.

3. EXPLOSIVE PERFORMANCE

3.1 Energy and Detonation Velcoity

The performance of LX-03-0 and LX-04-0 relative to PBX 9404 has been measured in the cylinder test. In addition, double-ended Kinglet experiments have been fired with both PBX 9404 and LX-03-0. PBX 9404 delivered 124 megabar-cc to the Kinglet pit, whereas LX-03-0 delivered 119 megabar-cc. Lyric 2D hydrodynamic calculations best agree with these experiments when the "adjusted $\mathcal{E}_o$" γ-law equations of state given in Table I are used.

Table I

"Adjusted $\mathcal{E}_o$" γ-Law Equations of State

Explosive	Loading Density (gms/cc)	Detonation Velocity (mm/μsec)	$\mathcal{E}_o$ (megabar cc/cc)
PBX 9404	1.835	8.78	0.074
LX-04-0	1.865	8.48	0.071
LX-03-0	1.850	8.40	0.067

3.2 Detonator Pickup

J. Stroud of Weapons Division reports that LX-03-0 and LX-04-0 are being tested for initiation by the 1E-26 detonator using a wave shape shot at Mound Laboratories. The shot design is one which is used routinely for the evaluation of each lot of 1E-26 detonators (normally fired with PBX 9404). Preliminary results indicate both materials "pick-up" reproducibly, and are $\sim$6 shakes slower than PBX 9404.

4. SENSITIVITY

Quite a few different sensitivity tests have been run on both LX-03-0 and LX-04-0. The results, particularly of the larger scale tests, show clearly that both materials are less sensitive than PBX 9404. Both of these new PBX's have now been qualified as LRL Standard-1 (see section 8).

4.1 Drop Hammer

A number of drop weight impact tests using ERL Type 12 tools have been run. The data from a typical group test is reproduced in Table II. The results of this small scale test can be interpreted only to the extent of saying that the new materials are likely to be somewhere between PBX 9404 and composition B-3 in sensitivity.

Table II

Drop Weight Impact Machine

	With Sandpaper		Without Sandpaper		With 30 Mesh SS Screen	
Explosive	h_{50} (cm)	σ (log units)	h_{50} (cm)	σ (log units)	h_{50} (cm)	σ (log units)
PBX 9404-03	32.8	0.07	42.1	0.28	32.8	0.13
LX-03-0	49.1	0.10	46.5	0.13	58.6	0.26
LX-04-0	50.0	0.05	36.8	0.06	39.8	0.15
Comp B-3	38.3	0.07	76.3	0.18	73.4	0.05

4.2 Susan and Large Scale Dahlgren Tests

The Susan test, in which about 1 lb. of the explosive is hurled against a steel plate in a projectile, shows both the new PBX's to be less sensitive than PBX 9404 (see Table III and Figure 1).

Table III

Susan Test

Material	Velocity (ft/sec)	Comments and Type of Reaction (Mod-I projectile)
9404-03	100-200	Violent burning to high order detonation
	over 200	High order detonation
LX-03-0	100	Dud
	150-500	Moderate to vigorous burning. No detonation.
LX-04-0	200-400	Slight reaction
	400-1000	Moderate burning
Comp B-3	250	Dud
	300-1500	Slight to moderate burning

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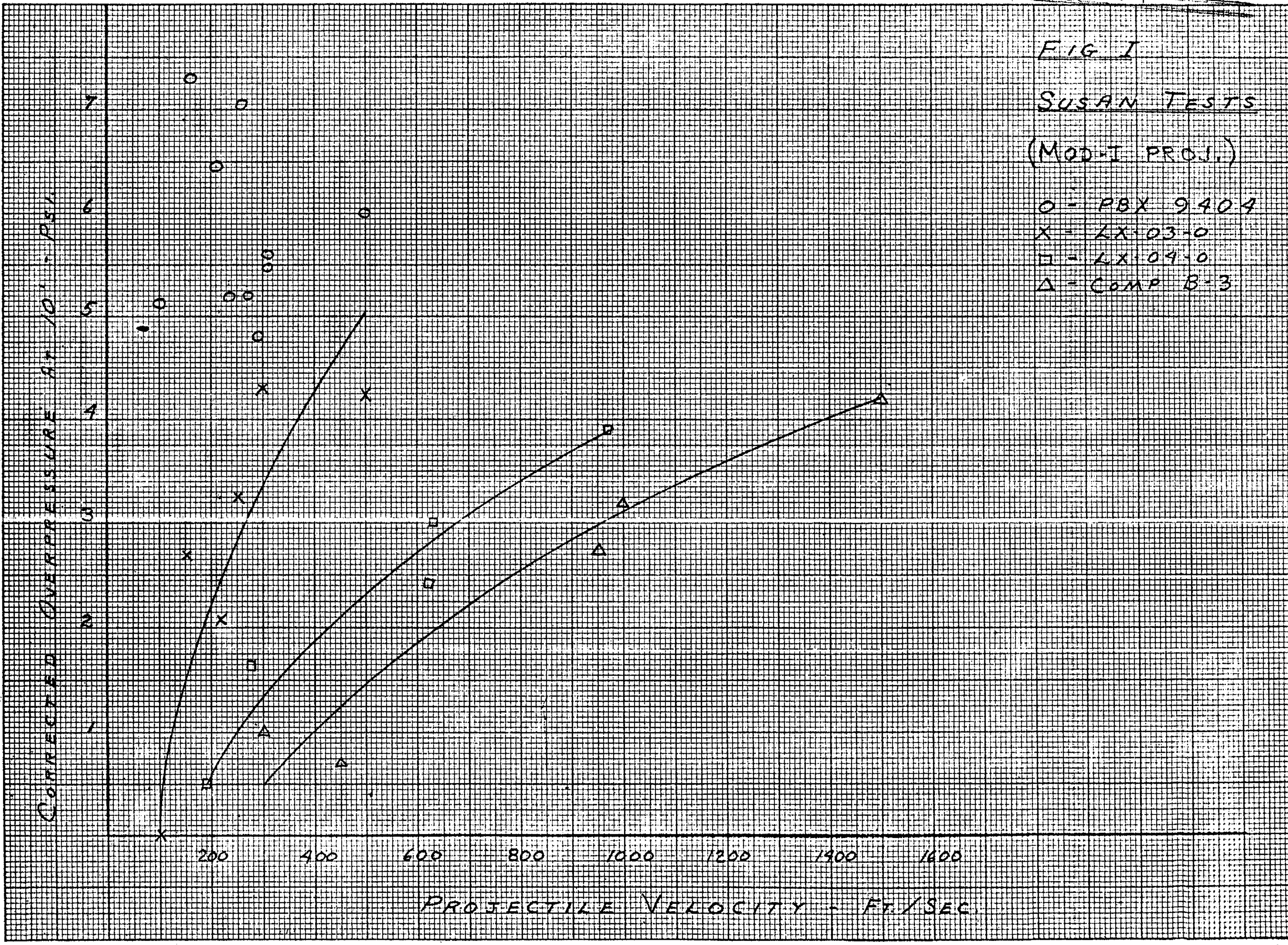

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The larger scale Dahlgren tests in which XW-42 type assemblies with an inert metal pit are hurled against concrete targets also show LX-03-0 to be somewhat less sensitive than PBX 9404 (see Table IV). LX-04-0 has not been run.

Table IV

Large Scale Dahlgren Test

Material	Velocity (ft/sec)	Reaction
PBX-9404	185	None
	215-270	Burning
	340	High order detonation
LX-03-0	200	None
	300-500	Burning
Comp B-3	700	None
	750-1650	Burning
	2150	High order detonation

4.3 Skid Test

In the Skid test, which is an adaptation of a U.K. sensitivity test, a 14" hemispherical charge weighing ~ 50 lbs. impacts a grit-coated steel plate at an angle of 45°. The A.W.R.E. has found that a combination of impact and friction can represent a serious hazard, and the Skid test which measures the susceptibility to this hazard is of importance in evaluating an explosive from the point of view of plant handling safety. The development of Skid test capability at Pantex is very recent, and since large charges are required, only a limited number of drops have been run so far. The data reported in Table V is preliminary.

Table V**

Skid Test Results (Pantex)

Material	Vertical Drop Height, ft.	Overpressure* @ ~15', psi	Remarks
PBX 9404	5	> 20	High order detonation
	3	0	Dud
LX-03-0	10	0.5	Very low order partial*
	7	0.3	" " " "
	5	0.1	" " " "
PBX 9010	3.5	> 20	High order detonation or very vigorous burn
	2.5	> 20	" " " " "
	1.5	0	Dud
LX-04-0	7	0.3	Very low order partial*
	5	0.1	" " " "
	3.5	0.0	No overpressure or light but a slight blackening of the impact area.

*About 3 gms of explosive detonated high order gives an overpressure of about 0.2-0.3 psi in this particular experimental setup.

**Table V revised December 4, 1961.

4.4 Gap Sensitivity

Gap tests have been run for us by LASL in both the 1-5/8" dia. and the 1/2" dia. sizes. The 50% initiation gaps are listed in Table VI for LX-03-0 along with comparative data for PBX 9404, PBX 9010, Comp B, and TNT. LX-04-0 has not yet been run.

Table VI

Gap Sensitivity

Material	1-5/8"d Gap (in.)	1/2"d Gap (in.)	Density (gms/cc)
9404	2.22	-	1.836
9010	2.09	.085	1.785
LX-03-0	1.95	.063	1.84
Comp B-3	1.98	.042	1.718
Comp B-Grade A	1.70	-	1.714
TNT	1.11	.010	1.62

[redacted]

4.5 LASL Drop Tower

In the LASL drop tower test a 6 pound charge is confined in a 50 pound mass of mock H.E. A steel adapter plate is attached so that on contact with the target, a 1" dia. steel cylinder is driven into the test explosive.

The analysis depends not only upon the 50% drop height, but also on the type of reaction observed.

Table VII

Large Scale LASL Drop Test

Material	50% Height	Reactions
PBX 9404	49'	High order detonations
LX-03-0	115'	Vigorous reactions but no detonations even at 150'.
Comp B-3	86'	Small reaction. Lots of H.E. recovered even on 150' drops.

LX-03-0 has a higher drop height than even Comp B-3; however, the reactions, once initiated, are generally much more violent.

LX-04-0 has not yet been run on the drop tower.

5. THERMAL STABILITY

5.1 Thermal Stability

The thermal stabilities of LX-03-0 and LX-04-0 are greater than that of 9404. On the LRL gas chromatographic system the volume of gas evolved at STP when a one gram sample is held at 120°C for 22 hours is:

for PBX 9404 - 1.40 cc
for LX-03-0 - <.05 cc
for LX-04-0 - <.05 cc

5.2 Resistance to Thermal Spikes

Measurements have been made on the decomposition rates of PBX 9404, LX-03-0, LX-04-0, and pure HMX in the temperature range of 240 to 270°C. These data have been normalized against previously conducted temperature spike experiments with PBX 9404 (using the Hangfire code). The normalization permits the calculation of the thermal stabilities of all these explosives when subjected to rapid thermal pulses (such as might be encountered in inadvertent pit hydriding).

The calculational results indicate that LX-03-0 would ignite when subjected to temperature spikes hotter than 250°C whereas, PBX 9404 and LX-04-0 require temperature spikes of 265-270°C for ignition. This order of thermal stabilities correlates with the melting points of the explosives and is due to the fact that liquid HMX decomposes some 10 times faster than solid HMX. (PBX 9404 and LX-04-0 begin to melt at approximately 270°C while LX-03-0 does so at about 247°C due to eutectic formation between HMX and DATB).

6. COMPATIBILITY

LX-03-0 has been shown to be compatible with all materials with which it has been run with the exception of iron oxides. However, its compatibility with Furane and Duco cements is borderline, and contact with these materials should be avoided if possible. The list of tested materials includes:

1. Metals - tin, iron, aluminum, copper, zinc.
2. Silastics and rubber - RTV 503, 521, 601, 5313, 5314, GE-565, 916-U, DC silastic LS-X-30274, and butyl rubber.
3. Glues - Eastman 910, Adiprene L-100 (w/MOCA), Furane, Duco cement.
4. Minerals - asbestos fiber.

Compatibility tests will be run with LX-04-0 whenever required; however, since its only components are two major components of LX-03-0, the probability is very high that it would also be compatible with any of the materials in the above list.

7. MECHANICAL PROPERTIES

7.1 Tensile Tests

Tensile tests have been run on LX-03-0 and LX-04-0 at various temperatures and for LX-03-0 at two crosshead velocities in the LRL standard tensile configuration (see Figure 2). The elongation is determined from a 1" clip gage attached to the center portion of the reduced section of the speciman.

Graphs showing the complete stress strain curves at the various temperatures are shown in Figures 3, 4 and 5.* Both materials exhibit higher tensile strengths and greater elongations than PBX 9404 at each of the temperatures tested.

A series of tensile tests was conducted on LX-03-0 in which the center of the reduced section of the specimen had been cut at an angle of 90° or 45° and then re-assembled by gluing with a 7 to 10 mil thickness of Adiprene L-100 with MOCA. On the 45° glue joint tests the rupture occurred in the explosive and the stress strain curves, Figure 6, look very much like the earlier runs on the explosive. On the 90° glue joint tests the rupture occurred at the glue joint at 165°F and 68°F and the ultimate tensile strength was only about 85% of that of the explosive. At -65°F, however, the ultimate tensile strength was the same as for the explosive. Figure 7 shows the stress strain curves for the 90° glue joint. Figures 8, 9 and 10 show typical ruptures in these specimens.

Table VIII gives the average values of the measurements made to determine the 80% secant modulus of elasticity along with some comparable data for PBX 9404 and PBX 9010.

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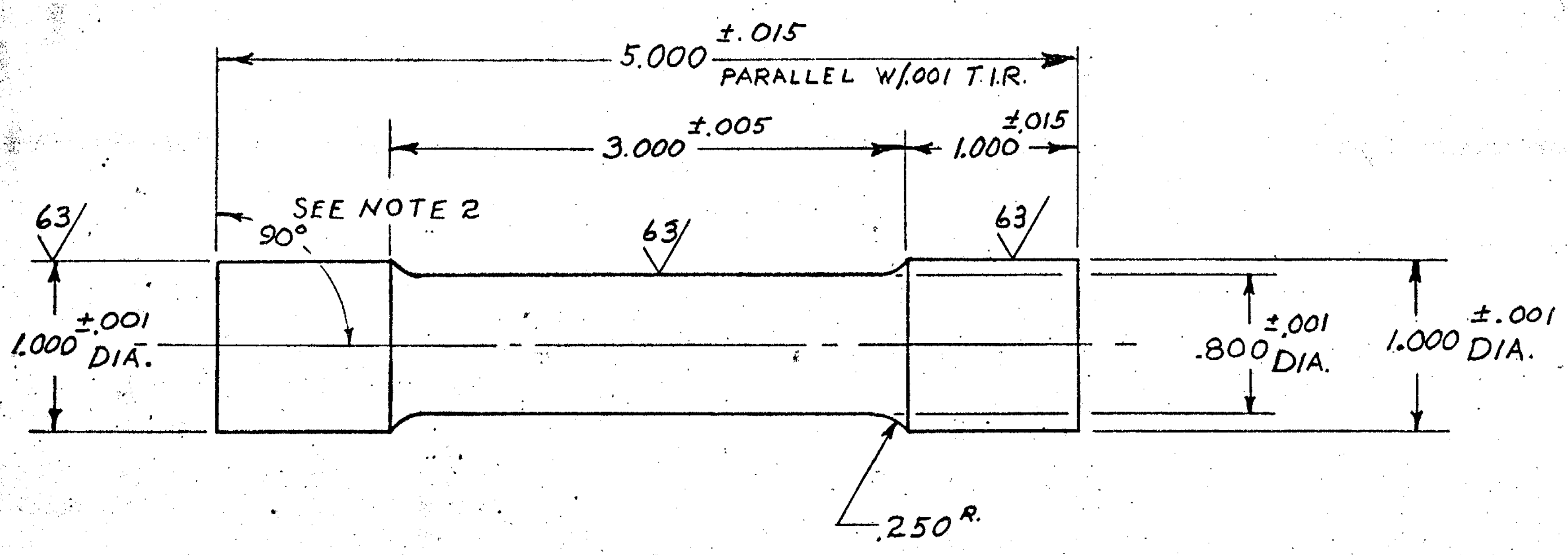
*Not all of these graphs are to the same scale.



NOTES.

1. .800 DIA & 1.000 DIA'S TO BE CONCENTRIC WITHIN .003 T.I.R.
2. TO BE PERPENDICULAR WITHIN .001 T.I.R.

TENSILE SAMPLE

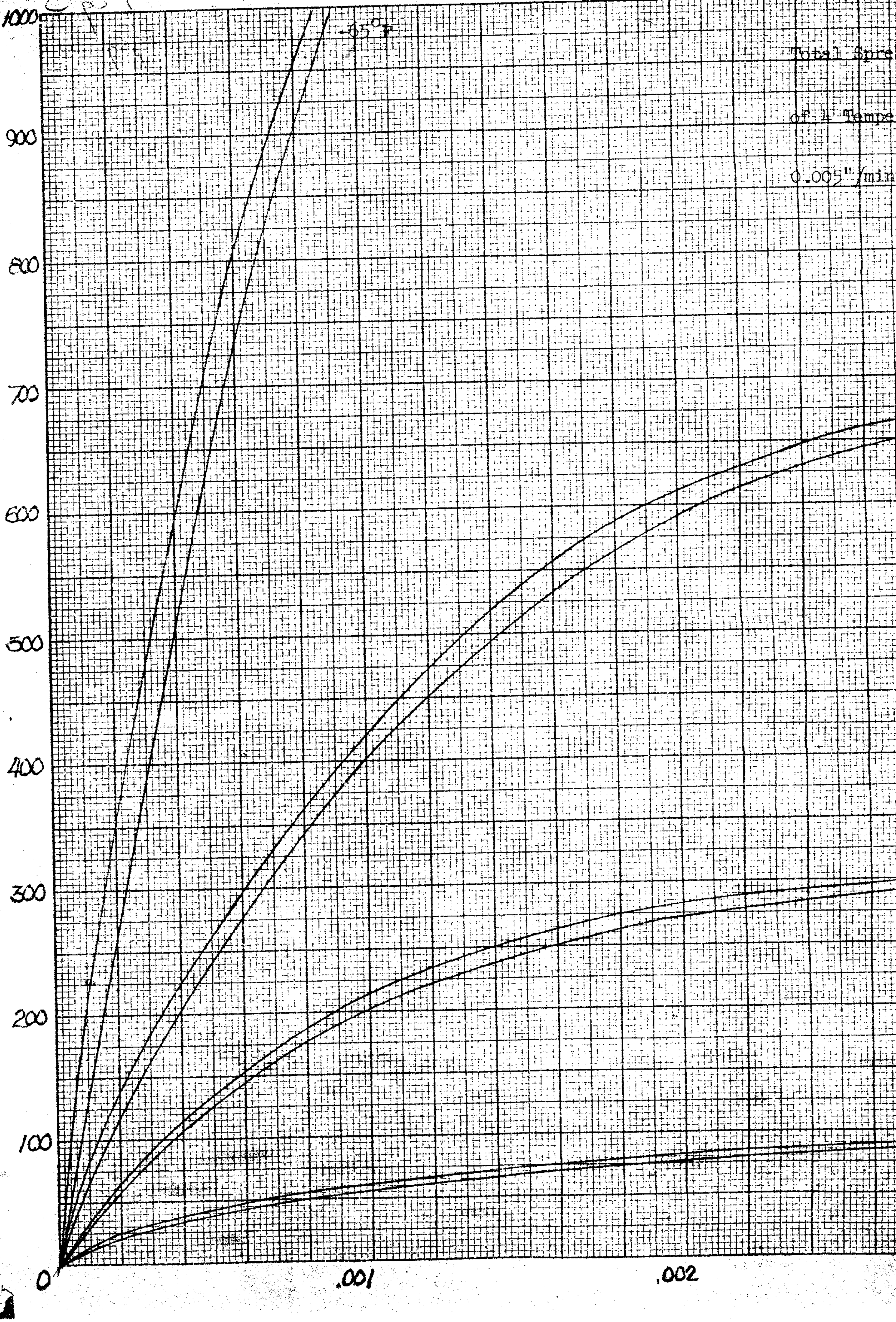
FIG #2

Tensile Te

Total Spre

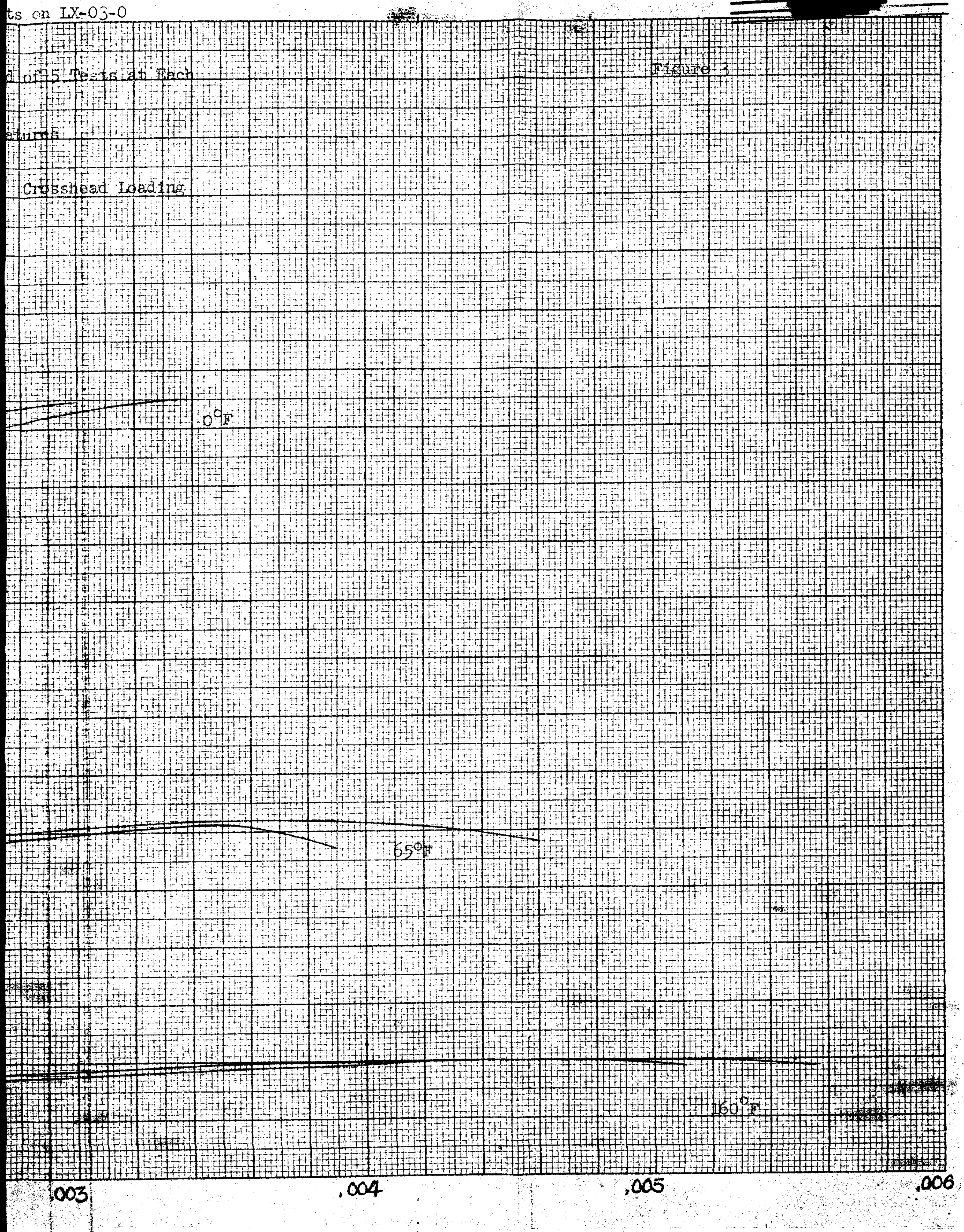
of 4 Tempe

0.005"/min

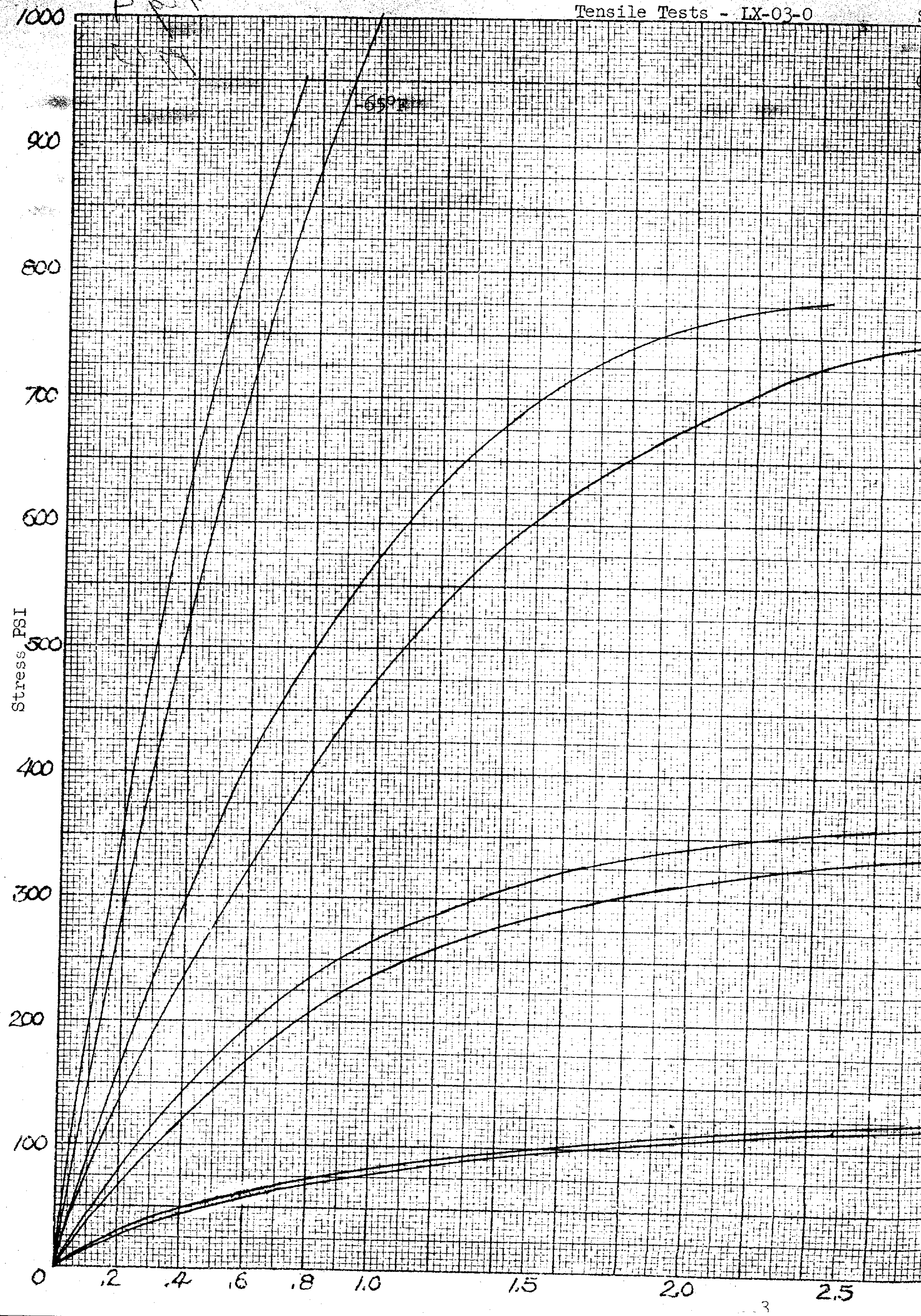


K&E 10 X 10 TO THE ½ INCH 359-11LG
KEUFFEL & ESSER CO. MADE IN U.S.A.

[redacted]


ts on LX-03-0
d of 5 Tests at Each
atures
Crosshead Loading
Figure 3
0°F
65°F
160°F
.003
.004
.005
.006

Tensile Tests - LX-03-0



359-11LG
10 X 10 TO THE 1/2 INCH
KEUFFEL & ESSER CO.
MADE IN U.S.A.

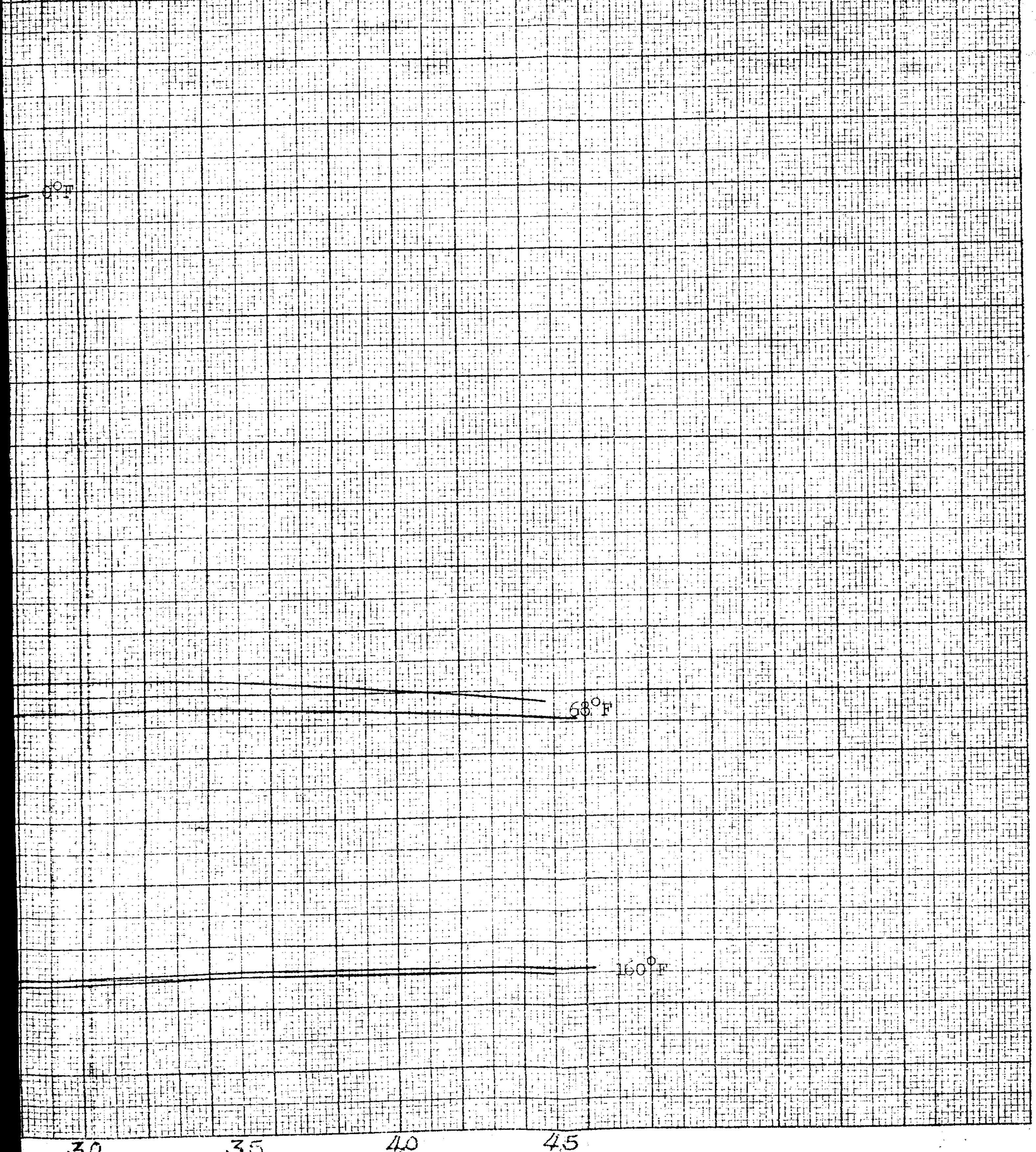
[redacted]

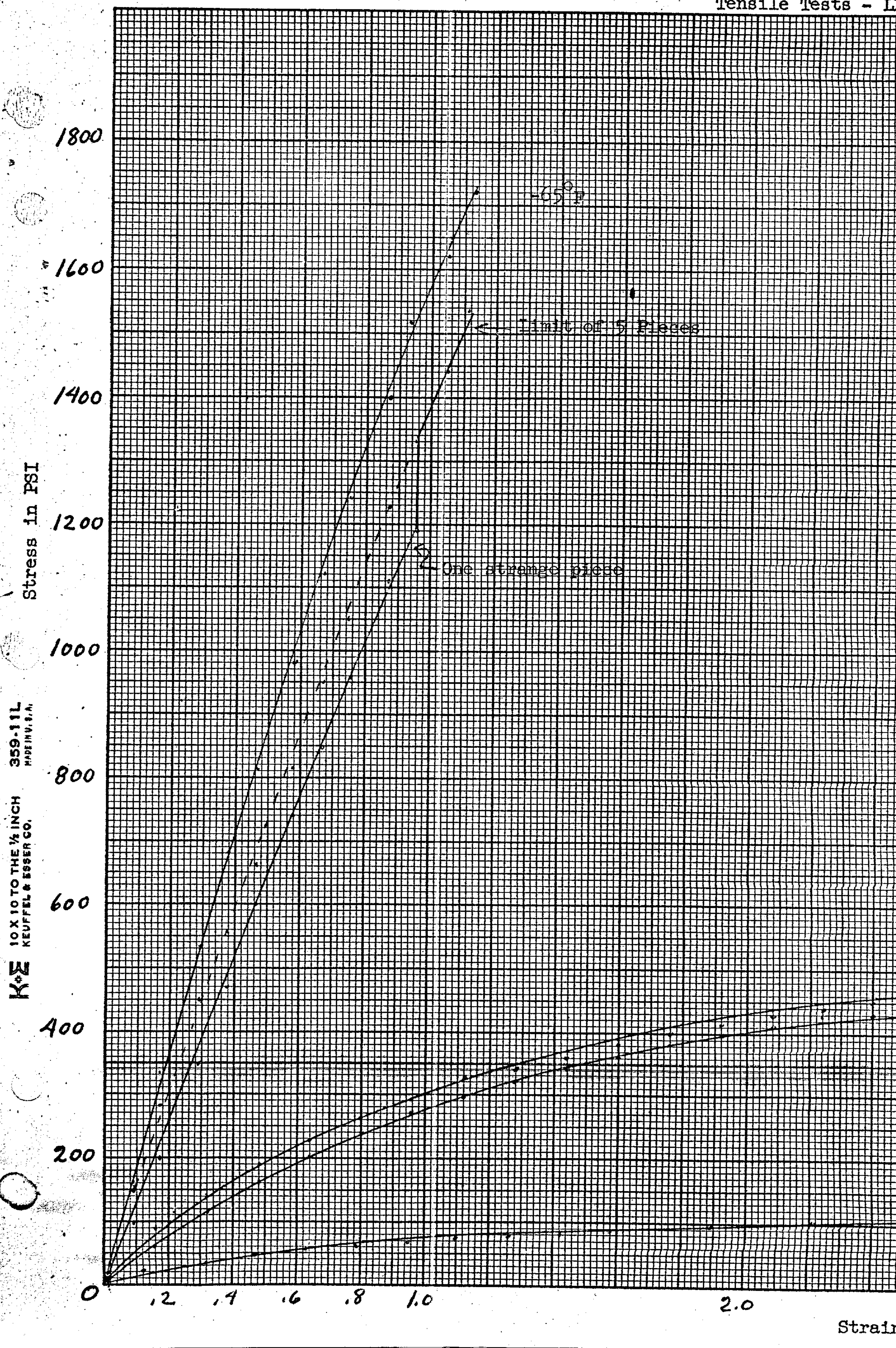
Specimen Area = 0.502" in^2

015 in/min. Crosshead Loading

Pieces at Each Temp.

Figure 4




Stress in PSI
1800
1600
1400
1200
1000
800
600
400
200
0
.2
.4
.6
.8
1.0
2.0
-65°F
<- Limit of 5 Pieces
One strange piece
Strain

04-0

STD Specimen Area = 0.502 in^2

0.005 in/min Crosshead Loading

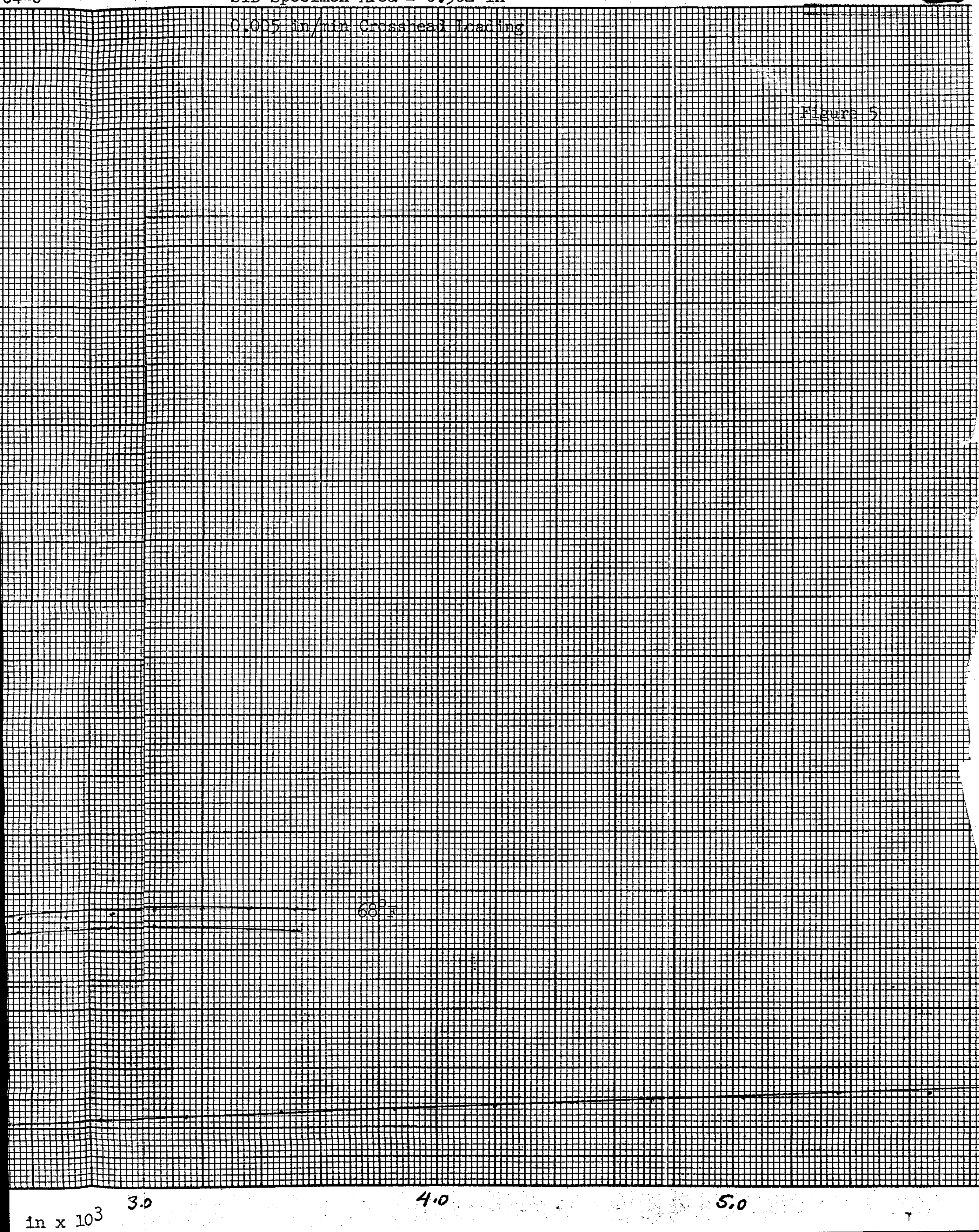
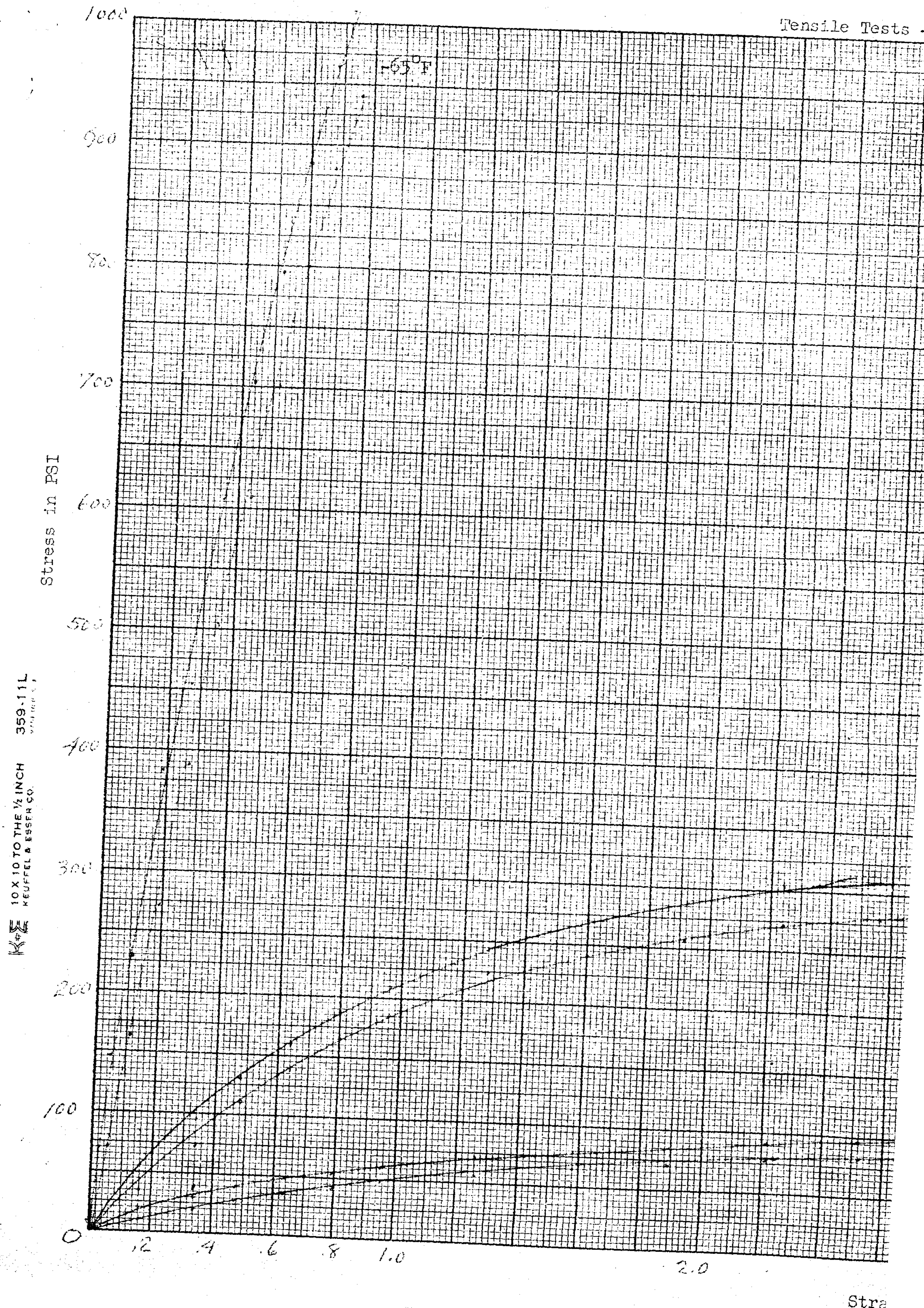


Figure 5


1000
900
800
700
600
500
400
300
200
100
0
Stress in PSI
-65°F
.2
.4
.6
.8
1.0
2.0
Stra
10 X 10 TO THE ½ INCH
KEUFFEL & ESSER CO.
359-11L

[redacted]

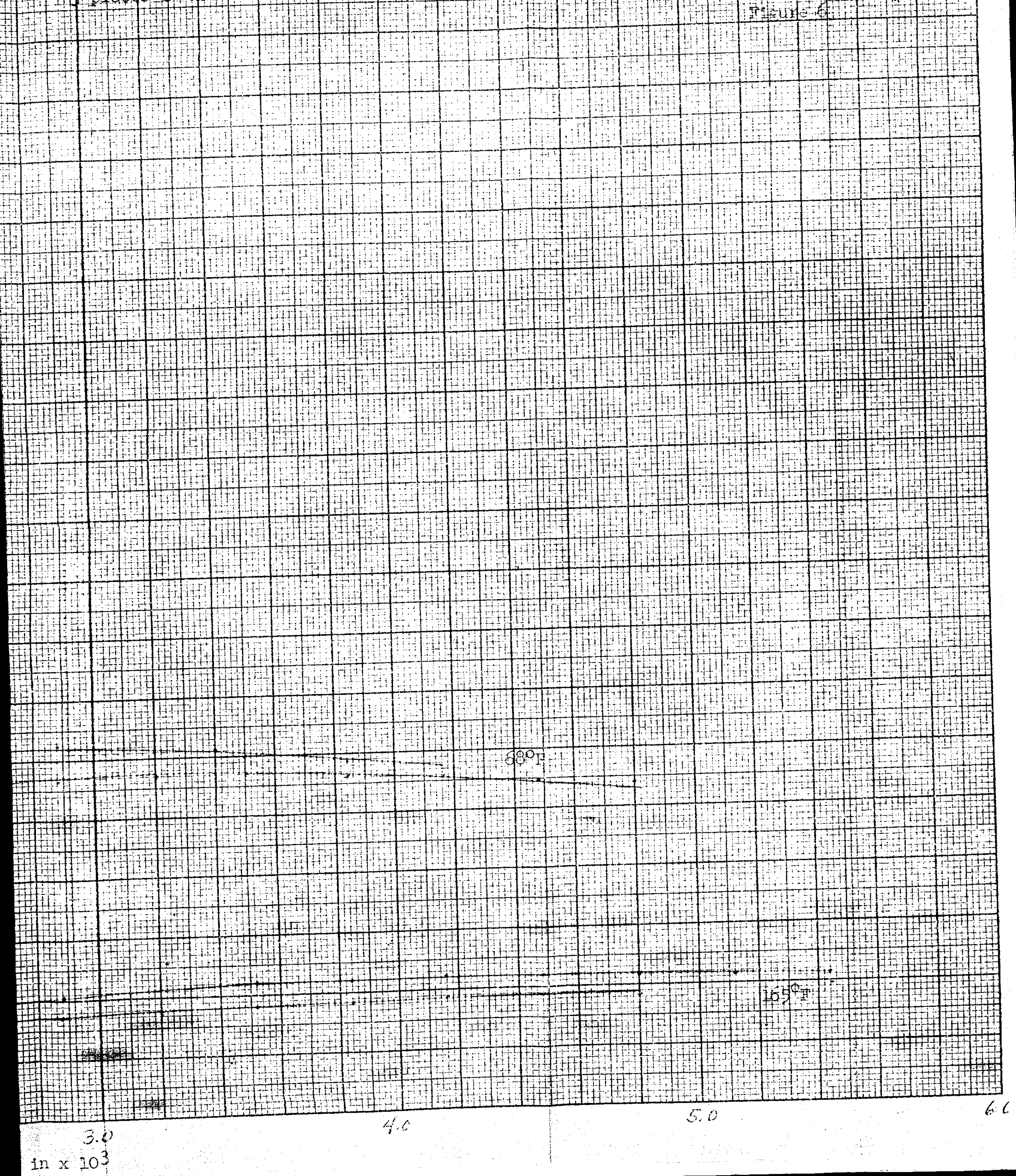
04-0 With 45° Adiprene glue joint

Std specimen area = 0.502 in²

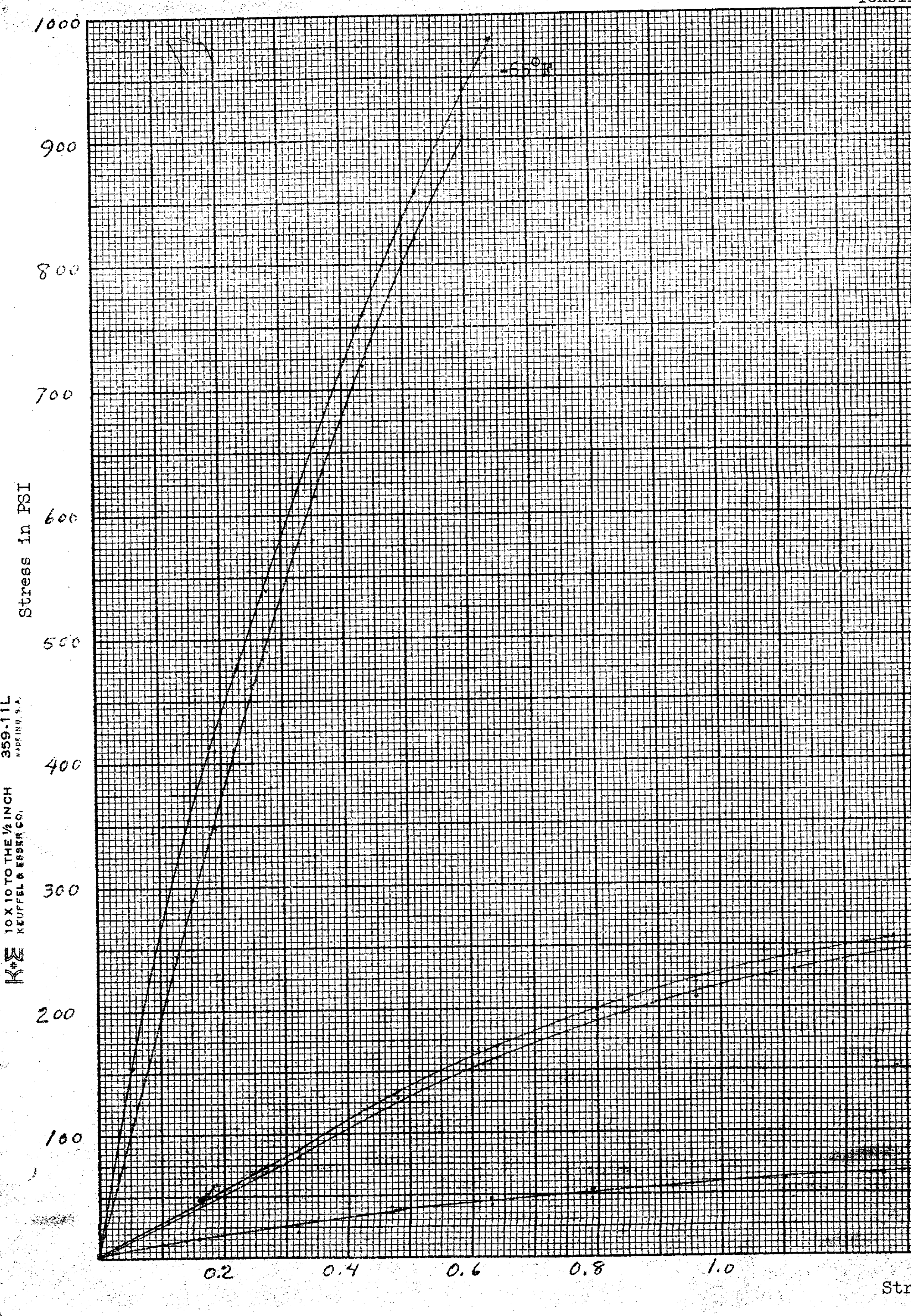
0.005 in/min Crosshead loading

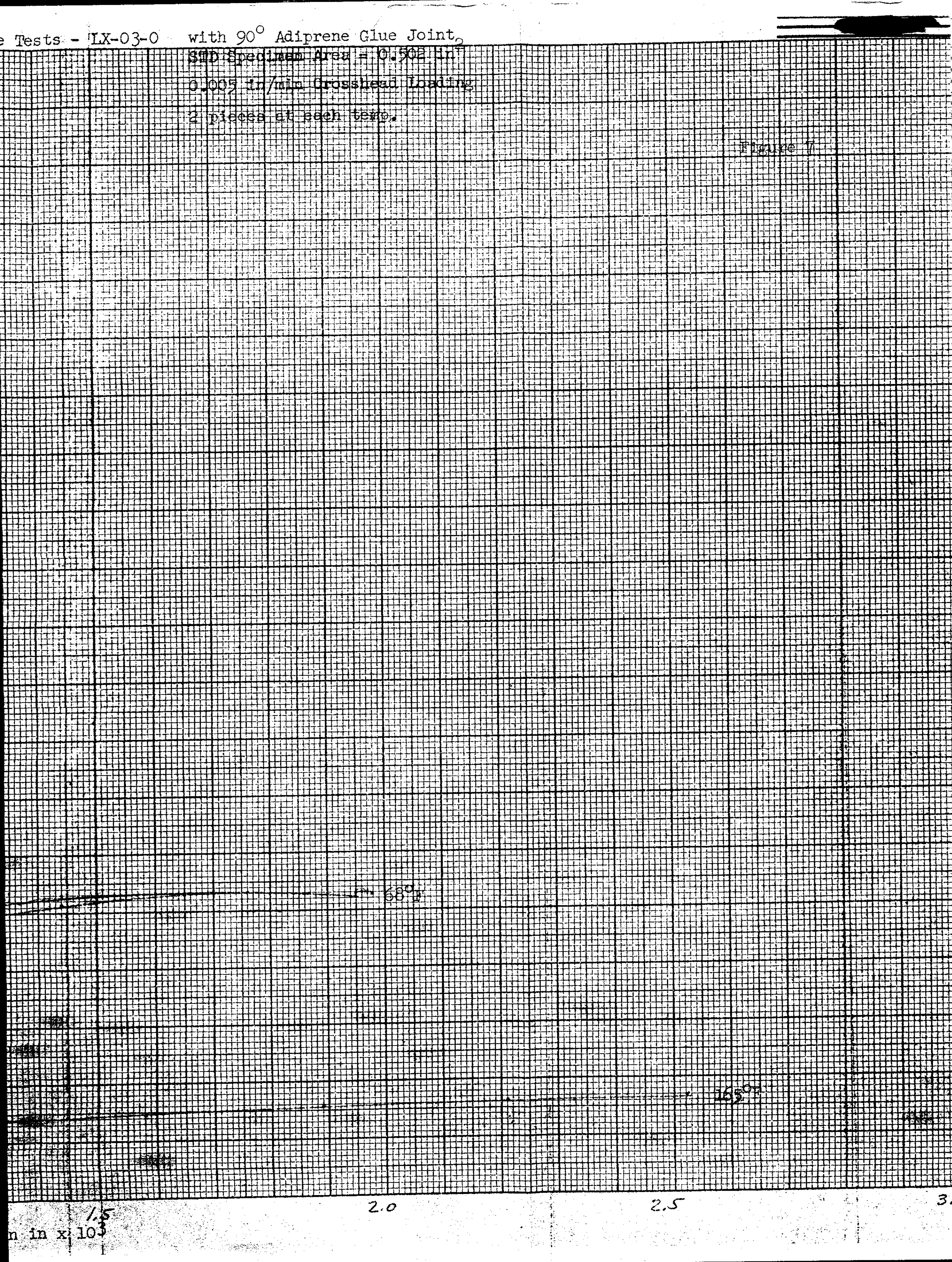
3 pieces at each temp.

Figure 6



Tensil


-65°F
1000
900
800
700
600
500
400
300
200
100
Stress in PSI
0.2
0.4
0.6
0.8
1.0
Str
K&E 10 X 10 TO THE 1/2 INCH 359-11L
KEUFFEL & ESSER CO.


[redacted]
e Tests - LX-03-0 with 90° Adiprene Glue Joint,
STD Specimen Area = 0.502 in²
0.005 in/min Crosshead Loading
2 pieces at each temp.
Figure 7
68°F
165°F
1.5
2.0
2.5
3.
n in x 10³

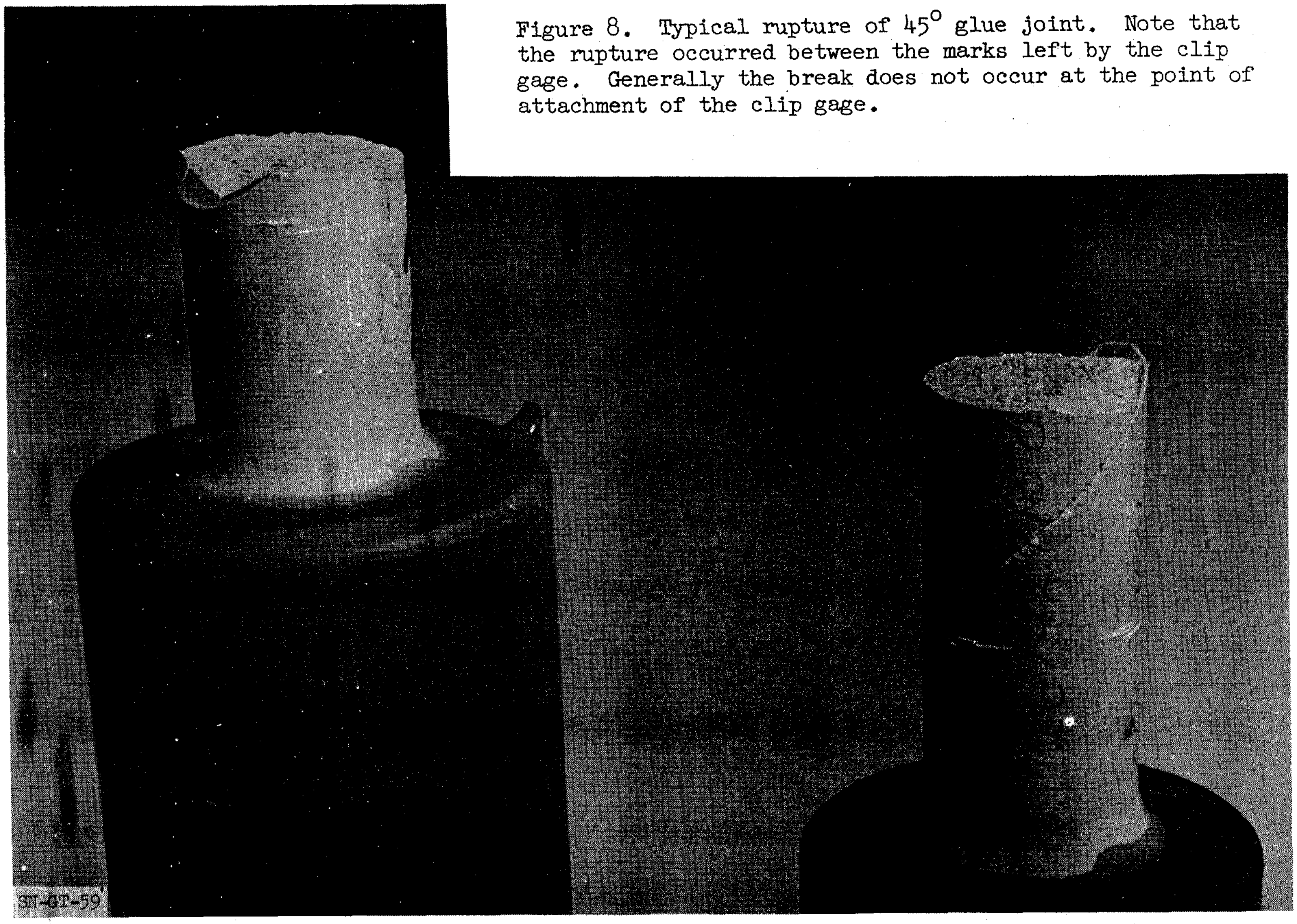


Figure 8. Typical rupture of 45° glue joint. Note that the rupture occurred between the marks left by the clip gage. Generally the break does not occur at the point of attachment of the clip gage.

Figure 9. Typical rupture of 90° glue joint specimens tested at 68°F and 165°F.

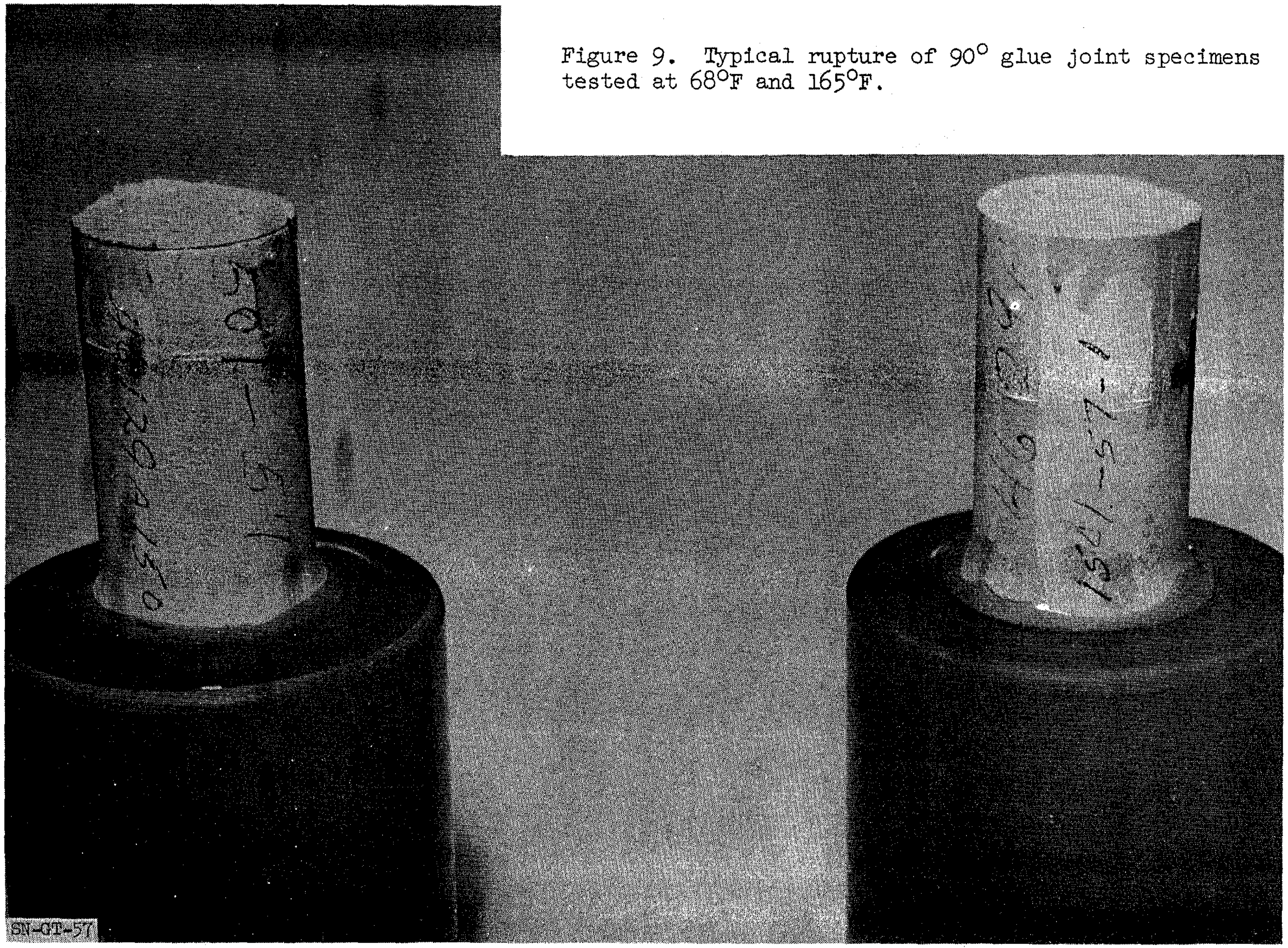


Figure 10. Rupture of 90° glue joint specimen tested at -65°F.

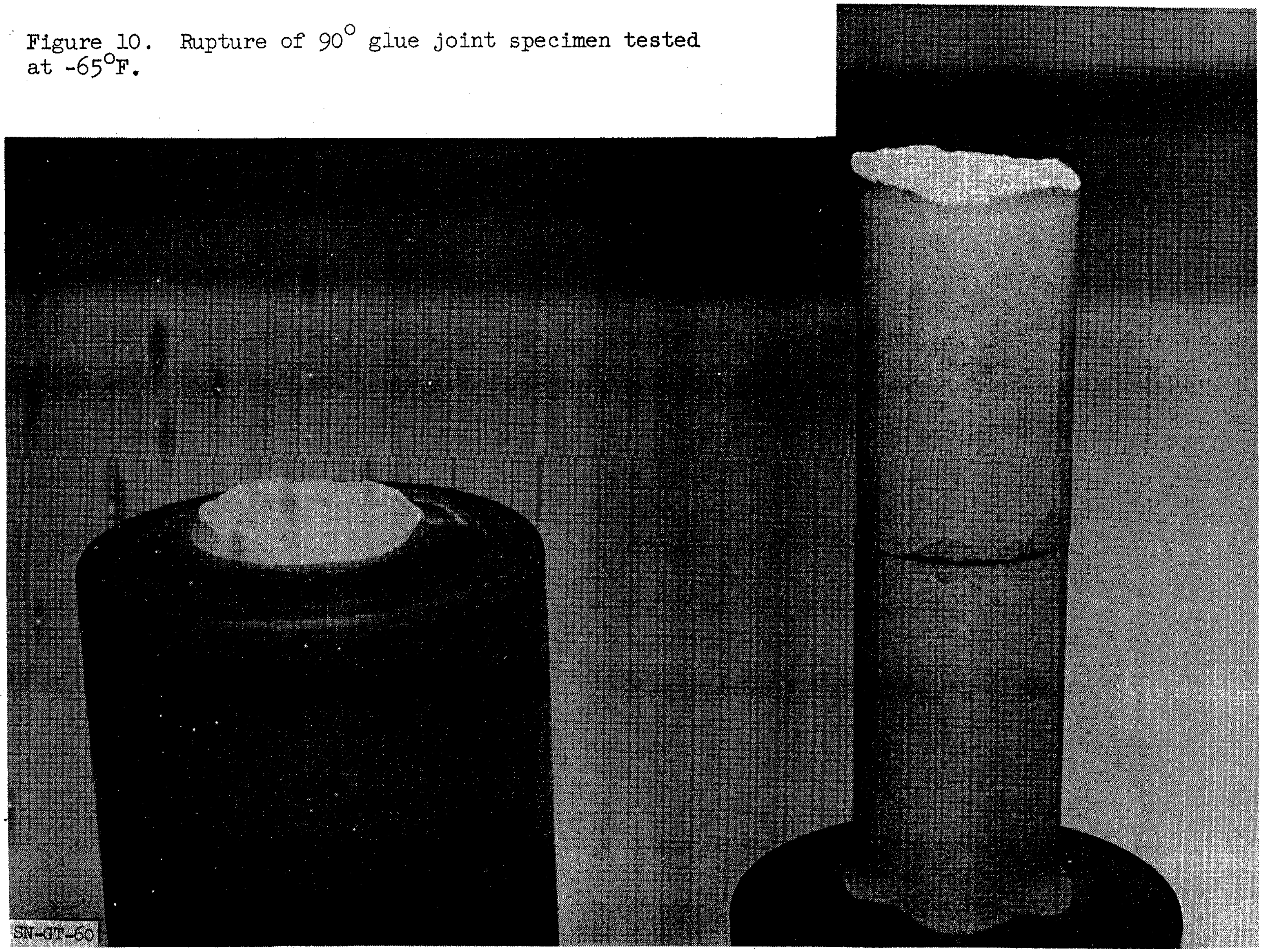


Table VIII

Tensile Tests

(LRL Standard H.E. Tensile Specimen Configuration

Cross-Head Movement - 0.005"/min except as noted)

Material	Temp °F	Ultimate psi	80% Load	Displ @ 80%	E x 10^{-5}	Density gm/cc
9404	165	40	32	.00075	0.43	1.827
Cold Pressed	70	165	132	.00132	1.0	to
	0	550	440	.00056	7.8	1.840
	-65	635	508	.00036	14.0	
9404	165	40	32	.00070	0.46	1.827
Hot Pressed	70	245	196	.00131	1.5	to
	0	725	580	.00058	10.0	1.840
	-65	650	520	.00026	20.0	
9010	165	143	114	-	-	1.77
	70	276	221	.00074	3.0	to
	0	735	588	-	-	1.79
	-65	920	736	.00052	14.1	
LX-03-0	160	99	79	.0018	0.44	1.832
	68	306	245	.0014	1.75	to
	0	661	529	.0015	3.44	1.836
	-65	950	760	.0006	12.77	
LX-04-0	165	146	117	.00332	.38	
	68	452	362	.00149	2.4	
	-65	1531	1225	.00076	15.7	
LX-03-0	165	104	83	.00208	.40	
45° glue	68	298	238	.00141	1.7	
joint	-65	978	782	.00055	14.2	
LX-03-0	165	84	67	.00131	.51	
90° glue	68	267	214	.00095	2.3	
joint	-65	943	755	.00045	17.0	
Cross Head Movement - 0.015"/min.						
LX-03-0	160	130	104	.00188	0.56	1.832
	68	347	277	.00123	2.26	to
	0	748	598	.00128	4.77	1.836
	-65	984	787	.00064	12.4	

7.2 Thermal Coefficient of Expansion of LX-03-0

Pantex has measured the thermal coefficient of expansion of LX-03-0 between -65°F and ambient temperature as 32.2×10^{-6} in/in/°F. Nine runs were made and the total spread was 1.5×10^{-6} in/in/°F.

7.3 Dimensional Stability of LX-03-0

Weapons Engineering Division has run some thermal tests on LX-03-0 in shapes similar to XW-58 configuration. Comments on the test are listed below. All assemblies had the explosive confined within RTV silastic rubber (no stress cushions).

	Cycle	Results
1.	Heat at 10°/hr. to 125°F Stabilize Cool at 10°/hr to -20°F Stabilize	No H.E. cracks. Parts remained within dimensional tolerance
2.	Cool at 10°/hr to -40°F Stabilize Heat at 10°/hr to 140°F Stabilize	No H.E. cracks. Parts remained within dimensional tolerance
3.	Cycle at 10°/hr to +70°F, to -20°F, to 120°F, to -20°F to 70°F, stabilizing at each temperature	No H.E. cracks. Parts remained within dimensional tolerance

After removal of the case in tests 2 and 3, a gap opened between the H.E. parts. Further tests are in progress to determine if this is a problem.

7.4 Dimensional Stability of LX-04-0

An extensive set of thorough tests are currently in progress, but no results are available at this time. Preliminary data on the stability of a few large hydrostatic pressings and several 2" diameter mechanical pressings stored under ambient conditions for several weeks without constraint show decreases in density of the order of 0.002 g/cc.

8. MACHINABILITY

Both LX-03-0 and LX-04-0 have been run through rigorous machining tests by Site 300 Mechanical Shops without incident. The results of these tests, which are summarized below, along with previous remote machining and the results of all of our sensitivity tests, have permitted us to reclassify both of these PBX's as LRL-Std. 1. The Std 1 classification allows us to contact machine these materials, and also permits some relaxation with respect to handling procedures.

Machining Tests

Operation

Saw	Blade speed	Feed rate		No of cuts
4 pitch blade	750-848 ft/min	5-180 in/min	Dry	45

Blade cuts clean with no loading and fairly good finish through feed rates of 40 in/min. Cutting gets rough on higher feed rate. Little or no heating of piece.

Drill	RPM	Feed rate	Depth		No of cuts
1/4" twist	480	0.005" to 0.030"/rev.	1"	Dry	19

Drill cuts freely to approximately 1/4" depth, flutes fill and hole glazes at greater depth. Piece will frequently crack out if drilled within 3/8" from edge.

Drill	RPM	Feed rate	Depth		No of cuts
1/4" twist	1520	0.015"/rev.	1"	Dry	4

Results similar to lower RPM.

Form cut	RPM	Feed rate	Depth		No of cuts
Single blade	1800	0.002" to 0.030"/rev.	1/2-1"	Wet	6

LX-04-0 loads the cutter on the low feed rate. Both materials seem to cut better at higher feed rate. No heating of either material.

Form cut	RPM	Feed rate	Depth		No of cuts
Single blade	1800	0.002" to 0.030"/rev.	1/2-1"	Dry	8

On LX-03-0 the blade did not load but the material balled up causing a rough finish. On LX-04-0 the cutter loaded at the lower feed rate but cut a very good finish with no loading at the faster rate.

No appreciable heat buildup in either material.

Fly cut	RPM	Feed rate	Width of cutter		No of cuts
6" piece	1800	0.030"/rev.	0.050" to 0.250"	Dry	4

Cuts clean with no loading of blade. No temperature rise of cutter nor part.

On machining tests and on regular machining of pieces, both materials seem easy to work and maintain good finishes with little or no chipping of parts. Generally, LX-04-0 machines better using the higher speed cuts.

9. PRESSABILITY

9.1 LX-03-0

LX-03-0, which has a theoretical density of 1.880, can be pressed to 98% of TMD under production type conditions.

A typical set of pressings from a 2" dia. mechanical press follows; in all cases the pressed parts were 2" long and the pressings were done with a vacuum of at least 300 u.

	Powder Preheat °C	Press Temp. °C	Pressure PSI	Dwell min	No. of Pieces	Avg ρ gm/cc	% TMD
1.	105	105	30,000	10	5	1.848	98.3
2.	105	105	20,000	10	5	1.842	98.0
3.	85	85	30,000	10	10	1.840	97.9
4.	105	105	30,000	3	5	1.844	98.1
5.	105	105	20,000	3	5	1.842	98.0

Some typical isostatic pressings of large pieces, ~50 lbs. that were made at Pantex are as follows:

Powder Preheat °C	Press Temp. °C	Pressure PSI	Dwell min	No. of Pieces	Machined ρ - gm/cc avg.	% TMD
106	106	20,000	10	5	1.847	98.2
106	Amb	20,000	10	2	1.829	97.3
106	Amb	16,000	10	1	1.843	98.0*

*This pressing was made in the 30" hydrostatic press while all the others were made in the 18" press in the development area. It is not uncommon to get higher density pieces from the 30" press, using lower pressures, than the densities obtained from the 18" press.

9.2 LX-04-0

Two distinct lots of LX-04-0 have been produced at Site 300, the first using Grade 1 HMX that was purified at the Site and the second using Holston's Grade II HMX. Though both of these lots can readily be pressed to 98% of the theoretical density there is a distinct difference between them. TMD for LX-04-0 is 1.899 gm/cc.

Typical mechanical pressing data for the first lot is as follows:

Powder Preheat °C	Press Temp. °C	Pressure PSI	Dwell min	No. of Pieces	Avg ρ gm/cc	% TMD
90	90	30,000	3	1	1.8622	
105	105	30,000	10	5	1.8657	

And for the second lot:

105	105	30,000	10	3	1.8779
105	105	25,000	3	9	1.8747

Isostatic pressings from the two lots tend to show the same type of a spread of densities as follows:

From the first lot of PBX

Powder Preheat °C	Press Temp. °C	Pressure PSI	Dwell min	No. of Pieces	Avg ρ gm/cc	% TMD
105	105	20,000	30	2	1.8574	
110	Amb	16,000	20	3	1.855	
And from the second lot						
105	105	20,000	10	3	1.870	
106	Amb	16,000	10	3	1.876	

Photomicrographs and screen analysis have been made on the HMX that went into each of these lots and no significant distinction can be made. We think this anomaly has no serious consequences. The nominal pressed density of LX-04-0 should settle down around 1.870 as further production experience is gained. In the meantime, we set as our pressing specification a density of 1.860 ± 0.010 gm/cc.

10. COMPARISON OF THE TWO MATERIALS

LX-04-0 came about as an outgrowth of the LX-03-0 development. Based on the evidence available today, it seems to be the equal or superior of LX-03-0 in every category. For example, LX-04-0 is less costly, more energetic, and less sensitive under conditions of crushing impact than LX-03-0. In addition, since LX-04-0 is only a 2 component system, it should be simpler to manufacture to tight specifications than LX-03-0. It is likely, therefore, that LX-03-0 will have served only as the pathway to LX-04-0, and that LX-04-0 will be the material of choice for coming LRL weapon and device systems (examples are the XW-58, and the Chickadee and Hedgehog devices). Until all the results of the intensive evaluation program now in progress are available, however, LX-03-0 will be carried along as a back-up to LX-04-0.

Presuming the material enters large scale production, LX-04-0 can be considered a good possibility as a direct substitute for either PBX 9404 or PBX 9010 in weapons now in production. The need for this might arise, for example, as a result of material compatibility problems or from new or more restrictive weapon handling requirements. Design changes associated with such a substitution could be quite minimal for Robin or Kinglet-based systems, and perhaps even Swan and Tsetse-based systems as well.

KS:EJ:vg

Distribution:

cy. 1 of 30A C. Aplin
cy. 2 of 30A W. Arnold
cy. 3 of 30A R. Batzel
cy. 4 of 30A E. Broadman
cy. 5 of 30A J. Dittig
cy. 6 of 30A G. Dorough/J. Kury
cy. 7 of 30A F. Eby
cy. 8 of 30A J. Foster
cy. 9 of 30A L. Germaine
cy. 10 of 30A C. Godfrey
cy. 11 of 30A A. Haussmann
cy. 12 of 30A C. Henry
cy. 13 of 30A J. Hulse
cy. 14 of 30A E. James/K. Scribner
cy. 15 of 30A E. James/K. Scribner
cy. 16 of 30A M. May
cy. 17 of 30A M. Martin
cy. 18 of 30A P. Moulthrop
cy. 19 of 30A R. Mullins
cy. 20 of 30A T. Perlman
cy. 21 of 30A J. Routh
cy. 22 of 30A B. Rubin
cy. 23 of 30A J. Stroud
cy. 24 of 30A I. Akst, Pantex
cy. 25 of 30A I. Akst, Pantex
cy. 26 of 30A M. Brooks/A. Popolato, LASL
cy. 27 of 30A E. Eyster, LASL
cy. 28 of 30A J. Marron, Sandia, Alb.
cy. 29 of 30A L. Smith/M. Urizar, LASL
cy. 30 of 30A B. Worden, Sandia, Liv.

Series "B" made 12/7/61

Cy 1 of 15B - M. T. Abegg, Sandia, Alb.
Cy 2 of 15B - R. Bradeen
Cy 3 of 15B - T. Carroll
Cy 4 of 15B - A. Maimoni
Cy 5 of 15B - R. Myers
Cy 6 of 15B - L. Peck
Cy 7 of 15B - K. Pister
Cy 8 of 15B - M. Ryan
Cy 9 of 15B - D. Warner
Cys 10, 11, 12, 13, 14, 15B - File

<u>Series "C" made 6/14/62</u>

Cy 1 of 2B - G. Dorough
Cy 2 of 2B - R. Craig

<u>Series "D" - 8/19/63</u>

Cy 1,2,3D - Tech. Info.

[redacted]