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The Application of Stress-Strain Analysis in Routine Control

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THE APPLICATION OF STRESS-STRAIN ANALYSIS IN ROUTINE CONTROL

by

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Abstract

Many of the empirical strength tests used for determining end use performance of a paper sheet do not give a true indication of actual sheet properties and performance. The empirical tests of burst, tear, and folding endurance were made on eighteen paper samples of different grades of papers. The fundamental tests of tensile strength, elongation, and tensile energy absorption were also made on the same samples using a stress--strain tester. The fundamental tests were used in showing deficiencies and discrepancies in the empirical test values.

The discrepancies found indicated a need for increased fundamental testing to be used in predicting the end use performance of a paper sheet in routine control work. Elongation was found to be an important fundamental property showing little significance in the empirical tests. Fundamental properties explained the reasons for one sheet being better than another sheet, but the empirical tests could not. Stress-strain testing used in conjunction with a computer could determine other fundamental properties of the sheet. Stress-strain testing appeared to be an improved approach in predicting

end use performance. The fundamental properties obtained from stress-strain testing could be used to make sheet improvements based on sound scientific reasoning.

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Introduction

Many paper strength tests are used at the present time in predicting the end use utility of the paper sheet. Most of these tests are empirical in nature and do not always indicate the actual sheet properties or accurately predict end use performance. Fundamental properties obtained from stress-strain testing should be of more value in determining actual sheet performance. Little work has been done in using stress-strain testing for predicting the end use performance of paper, partly because the relatively complex testing procedure and mathematical calculations are not compatible with routine quality control work. However, recent developments in stress-strain instrumentation and in the use of computers tend to reduce these problems. It should now be possible to develop a new philosophy of routine control directed toward obtaining more and better information from fewer tests by emphasis on the fundamentals.

This investigation was made to provide some insight into the deficiencies of several empirical tests through the correlation of test results obtained from a variety of paper grades with the more fundamental test results obtained with a stress-strain tester.

Literature Review

One of the major purposes of testing paper is to determine the end use properties of a sheet at the time of manufacture. According to Gallay (1) and Rance (2), the failure tests of burst, tear, and fold bear little relation to most end use applications or have little regard to the actual properties demanded. The tests are not only inadequate, but can often be actually misleading for both the paper maker and paper consumer. These tests can not be totally disregarded, because they are valuable in testing specific grades of paper. An example would be the burst test being used to predict the utility of a wrapping paper. In the case of the burst test being used to predict the utility of an offset printing paper, the burst test has little relationship.

Many new tests have been developed to predict better end use performance. The new test is often an attempt to simulate the end use. Most of these tests are complex and contain a combination of other more fundamental tests. A high degree of interdependence develops between the tests. If a test does give a good indication of the end use performance, the test is usually of little value to the paper maker in trying to improve quality if problems arise. The empirical test cannot explain the reason for one paper being better than another. The correction of one problem may result in the creation of other problems. A gap exists between manufacturing variables and the end use of the paper sheet.

Most of the conventional strength tests record only the ultimate rupturing strength of the paper sheet. The prerupture behavior of a paper in stress-strain is frequently of far greater value than results obtained in the failure tests. Many important properties of the paper sheet can be determined without reference to the actual rupture. The determination of elastic and inelastic limits would be examples. The degree of elongation at some given tensile load before rupture would be another example. This could be applied to a printing press when the amount of tension is known, and the amount of elongation is needed for proper register.

The load-elongation or stress-strain curve obtained with the stress-strain testers can give important prerupture properties along with fundamental rupture properties. Prerupture characteristics and behavior are important, because most papers are in use before rupture than after rupture. After failure or rupture, the sheet is of no use in most ordinary processes of usage.

Many of the conventional rupture tests measure only the stressability of a paper sheet and little or no strainability.(2) Relatively few processes exist in which the usage behavior of the paper is determined by stressability alone. Most processes use a combination of stressability and strainability. Testing paper for end use utility should include both stress and strain.

Much of the past stress-strain tester use has been performed in research and laboratory work. Past research has studied the effect of variables like specimen length, width, moisture, and rate of elongation on stress-strain testing (3,4). Other studies have concentrated on the effect of fiber characteristics and formation on the stress-strain curves (5,6,7). Attempts have been made using stress-strain testing to understand the structure and flow properties of different papers under different conditions (2,8,9). Nazzaro (10) and coworkers found that the viscoelastic properties were a better indication of the performance of laminated glassine than the conventional physical tests. For example, a glassine with high plastic flow performed better than a glassine of higher tensile strength, burst, and tear.

The stress-strain curves have been used and studied, but very few of the studies have concentrated with the curve and the fundamental properties in relation to end use properties. Rance did some work in relating the stress-strain curve to folding endurance (2). His method of testing was different than the constant rate elongation method used in this study.

Some work was done by Welsh (11) in relating the stress-strain curve to actual end use. Welsh used the area under the curve in his work. This area is called the tensile energy absorption and can be related to end use performance in terms of toughness. The stress-strain curves were compared to the bag drop test and trial shipments of bags. A good correlation was found between the tensile energy absorption and the behavior of the bags in use.

Welsh's work (11) also showed that knowledge of the whole load-elongation curve or function was necessary for a better evaluation of the paper sheet. Two papers had identical tensile strength and elongation, but had dissimilar stress-strain curves. The differences in the curves resulted in differences in tensile energy absorption. Consequently, the toughness of the two papers was different indicating that one paper would be superior in end use. This should verify the point that a comparison of tensile strength and elongation at the rupture point could tell little of how the paper would perform in a specific end usage. Knowledge and use of the entire stress-strain curve is necessary for proper end use evaluation.

Experimental Design

The experimental procedure consisted of testing paper samples for various strength properties. The strength tests of burst, tear, fold, tensile strength, elongation, and tensile energy absorption were performed on the samples. Testing was performed over a wide range of paper grades and basis weights. Papers of low filler content were used, so the tests would relate more to the fibers than to fillers or coatings.

Paper samples were obtained from two local companies. The paper grades varied from wrapping and bag paper to bond and offset printing paper. The basis weights of the papers were in the range of 24 to 66 pounds per ream (24 x 36 - 500).

The paper samples were conditioned in accordance with TAPPI Standard T 402 m-49, and tested in the same standard atmosphere. The basis weight of the samples was determined following TAPPI Standard T 410 os-68. The caliper was determined following TAPPI Standard T 411 os-68. The apparent density was calculated from the caliper and basis weight determinations.

The bursting strength of the paper was determined according to TAPPI Standard T 403 ts-63. The tearing strength tests were performed according to TAPPI Standard T 414 ts-65. The MIT type apparatus was used for determining the folding endurance following TAPPI Standard T 511 su-69.

The tensile strength, elongation, and tensile energy absorption were determined using an Instron tester following the Operating Instructions for the Instron Universal Testing Instrument, Manual 10 - 13 - IM - (B), Instron Corporation, Canton, Massachusetts, 1964. Calculations were performed using the proposed revision and expansion of TAPPI Standard T 494 su-64. A specimen width of 25 mm. and length of 100. mm. were used. The jaw separation speed was set at 2 cm/min.

The results of the testing were averaged. These averages were used in determining the correlation coefficients and regression analysis.

Discussion

Descriptions of the paper samples used in this study are presented in Table I. The averaged results of the empirical and fundamental tests appear in Tables II and III, respectively. The correlation coefficients between the empirical tests and the fundamental tests are shown in Table IV. Comparisons between the tests are shown in Figures 2-31.

Of the empirical tests, the burst test indicated the best correlations with the fundamental properties. Regression lines for the comparison of burst and tensile are drawn in Figures II and III. Even though good correlation coefficients exist between the two variables, some of the points plotted fail to appear close to the regression line. Table V gives the actual deviations from the regression lines for the tensile and burst comparisons. The reason for these deviations is due to the burst test being somewhat dependent on the elongation of the sheet. The burst test cannot distinquish between elongation and tensile. Therefore, the burst test could be misleading in predicting the actual tensile property of a paper sheet.

Although two papers have the same bursting strength, the fundamental tests may show many differences. This can be shown by a comparison of Samples 1 and 3. Sample 1 has a slightly lower burst value than Sample 3. The MD tensile of 12.65 kg. of Sample 1 is much higher than the MD tensile of Sample 3 of 9.4 kg. The CD tensile is just the opposite with 6.05 kg. for Sample 3 against 4.5 kg. for Sample 1. The TEA values follow the same trends as the tensile values. Consequently, Sample 1 would be a superior paper, if used in the machine direction, while Sample 3 would be a superior paper in cross machine direction usage. The burst test is unable to determine the direction in which the paper sheet will perform better.

The burst test correlated well with the MD TEA and fairly well with the CD TEA. The better correlation of burst with the MD TEA is due to the fact that TEA is a function of tensile and elongation. Since a sheet has more elongation in the cross machine direction than machine direction, the sheet reaches its maximum elongation in the machine direction before the cross machine direction when the diaphragm of the burst tester presses against the sheet. Therefore, the rupture will tend to be more a function of MD tensile and MD elongation rather than CD tensile and CD elongation.

Even though the elongation illustrated the best correlations with burst, the correlations were not significant. These poor correlations are shown by the poor correlation coefficients presented in Table IV and the Figure VI. Even though both coefficients are poor, the MD elongation shows signs of better correlation than the CD elongation. The CD elongation indicates very little significance in the burst test.

The tear tests indicated poorer correlations with the fundamental tests than the burst test did. The actual correlation coefficients are shown in Table IV. One of the major reasons for the poorer correlations with the tear tests is due to the differences in the rate of elongation and rupture between the tear testing and stress-strain testing. Past work in stress-strain testing has proven the rate of elongation to have a significant effect on the test results. Higher rates of elongation tend to give erroneous test results. Since the rate of tear testing is faster than the stress-strain testing, the tear test values could tend to give delusive results. Samples 12 and 14 have approximately equal tear test values, but the fundamental test values are greatly different. Sample 12 has much higher test values over Sample 14 for all of the fundamental tests. Examples 8 and 9 exhibit about the same fundamental properties, but the tear test values vary greatly. From these examples, it is evident that the tear test can give delusive test results that do not represent the actual sheet properties.

The elongation showed no significant correlation with the tear tests. Part of the poor correlation may be attributed to the speed of the tear test. The rapid rate of stress in the tear test may not give the paper or fibers much of a chance to elongate. Consequently, the tear test is another example of the failure of the important property of elongation to enter into quality control testing.

Fold showed the worst correlation with the fundamental tests of the empirical tests examined. The only indication of a slight correlation was between the MD fold and MD tensile. This correlation was probably due to the tension which was applied to the sheet during the fold test. This tension may cause some fold test results to relate more to tensile strength rather than actual folding endurance. This affect is evident in light weight papers. The tension causes the rupture rather than folding, and erroneous values of folding endurance result.

The fold test is believed to be a function of the flow properties of the paper sheet, such as the elastic and inelastic portions of a stress-strain curve. The flow properties are determined by the different shapes of the curves. These different shapes were not studied in this investigation due to the difficulty of visual analysis. If the stress-strain curve was put into a computer, the computer could quickly analyze the curve and determine other fundamental properties not presented in this study.

Samples 1 and 8 represent two papers with approximately equal fold test results. The fundamental tests show the tensile strength and TEA values of Sample 8 being twice as great as the values of Sample 1. The elongation values do not show any correlation with the folding test values.

The need for the entire stress-strain curve to be used in analysis is shown by Figure I. This figure shows two different stress-strain curves with equal TEA values. The curves are the MD stress-strain curve of Sample 16 and the CD stress-strain curve of Sample 17. Although the TEA values are equal, the tensile and elongation values are greatly different. The elongation of Sample 17 is over twice the elongation of Sample 16. The tensile is the opposite with Sample 16 having a tensile value over twice that of Sample 17. The curves exhibit different amounts of elastic and inelastic flow. Sample 17 reaches a load early in the testing and then develops elongation over a relatively small increase in stress.

Another example of the need for analysis of the entire curve is the comparison of samples 2 and 3. Both samples have equal MD tensile strengths, but the elongation and TEA values are significantly different. If only the tensile values were reported, the papers would appear to have the same characteristics. The different values of elongation and TEA indicate many differences in the properties of the papers.

Elongation is an important paper property that is not determined by the empirical strength tests. This is shown in the results by none of the empirical tests examined showing any significant correlation with the elongation values determined by stress-strain analysis. Since better correlations were found with the tensile than elongation, the empirical tests of burst, tear, and fold are more dependent on stressability than strainability. Since most end use operations involve both stress and strain, it seems absurd to neglect strain in testing for end use utility. The fundamental test of elongation should be more generally considered in determining end use performance.

Since the entire stress-strain curve would give a good indication of end use performance, a computer could be used to correlate stress-strain data and relate to end use performance. If a paper lacks some end use quality, the present empirical tests tell little of why one paper is better than another. The fundamental properties determined by stress-strain could be used to better explain the causes of poor quality. These fundamental tests could be better used to systematically make improvements, that are based on sound reasoning rather than empirical assumptions. The effects of changing a variable could be determined before the change or sheet was formed. More fundamental tests must be developed to improve predictability through scientific reasoning. Stress-strain testing is one very likely method of increasing predictability which deserves more consideration.

Past reasoning for not using stress-strain analysis has been the complex and time consuming procedure over empirical tests or the difficult mathematical calculations which are not compatible with routine control work. The introduction of computers has eliminated most of the calculations and analysis problems. Since more empirical end use tests are constantly being developed, the complexity and time required for stress-strain testing has become less of a factor. The major point is that the fundamental tests can explain the reasons for one paper being better than another, where the empirical tests cannot.

Conclusion

This investigation has shown some of the discrepancies and deficiencies in the empirical tests of burst, tear, and folding endurance. The fundamental property of elongation was found to have little significance in the empirical tests. The fundamental tests obtained from stress-strain testing were of more value in determining the actual paper properties than the empirical tests.

Stress-strain testing deserves more attention and consideration in order to improve the paper making process and end use performance predictability. The use of computers in connection with stress-strain testing could make the paper making process more controllable and predictable.

Literature Citations

1. Gallay, W., In "The Formation and Structure of Paper, The Interdependence of Paper Properties," Oxford, BPBMA, 1962, pp. 491-531.

2. Rance, H. F., The Paper-Maker and British Paper Trade Journal 117:22 (1949).

3. Anderson, O., and Sjoberg, Lars, Svensk Papperstid 36, 16 (August 31, 1953).

4. Sanborn, I.B.,and Dinz, R.F., Tappi 42 (7):588-597, (July, 1959).

5. Jentzen, C.A., Tappi 47 (7):412-418 (1964).

6. Broughton, Geoffery, Paper Industry 34 (4): 482-485 (July, 1952).

7. Tappi 34 (11):493-497 (November, 1951).

8. Anderson, O., Ivarsson, B., Nissan, A.H., Steenberg, B., Paper-Maker 118 (5):335-338 (November, 1949).

9. Brezinski, J.P., Tappi 39 (2):116-128 (1956).

10. Nazzaro, R.T., Brand, W.J., and Arnold, S.R., Tappi 39 (2):84-91 (February, 1956).

11. Welsh, Hewitt S., Modern Packaging 31 (9):221-222 (May, 1958).

12. Casey, J.P., "Pulp and Paper" 2nd ed., New York, Interscience, 1966, Vol. 3, pp. 1301-1341.

APPENDIX

Table I

Description of Samples

Sample No.	Grade	Wt. lbs.	Cal. inch/1000	Density g/cc
1	Waterleaf	27.2	3.1	0.562
2	Coating Base Stock	28.5	2.5	0.732
3	Bond	36.2	2.5	0.774
4	Wrapping Paper	36.8	3.2	0.737
5	Printing	27.8	2.3	0.776
6	Waterleaf	27.4	3.1	0.566
7	Waterleaf	24.0	3.0	0.514
8	Unbleached Kraft	61.8	4.84	0.818
9	Bleached Bag	65.8	5.84	0.723
10	Offset	36.3	3.4	0.684
11	Bond	27.3	2.4	0.730
12	Bond	34.9	2.9	0.773
13	Ledger	65.4	5.4	0.777
14	Envelope	34.7	3.5	0.637
15	Offset	38.5	4.6	0.536
16	Offset	46.3	4.5	0.659
17	Offset	43.9	3.9	0.722
18	Writing	37.0	3.2	0.743

Samples 1-9 from Brown Company

Samples 10-18 from Georgia-Pacific

Table II

Empirical Tests

Sample No.	Tear grams MD	Tear grams CD	Burst psi	Fold # double folds MD	Fold # double folds CD
1	37	49	26.1	486	181
2	33.5	44	16.9	73.3	15.7
3	34	42.5	26.9	337	496
4	51	65.5	23.3	213	61.7
5	38.5	51	22.9	384	38.4
6	32	38.5	19.0	304	53
7	29	38.5	17.4	264	44.5
8	92	108	55.3	475	203
9	166	203	50.2	786	145
10	37	36	19.6	144	42.5
11	25	29	15.2	98	46
12	34	39	20.5	78	24.4
13	98	106	39.5	69.5	50
14	32.5	36	9.3	6.9	5.4
15	66	64	29.4	120	118
16	46.5	52	24.2	115	22.4
17	42	43.5	19.2	139	38.6
18	40.5	54.5	23.2	117.3	22.7

NOTE: The values represent the averages of ten tests performed on each sample.

Table III

Fundamental Tests

Sample No.	Tensile kg/2.5 cm		Elongation %		TEA kg m/m^2	
	MD	CD	MD	CD	MD	CD
1	12.65	4.5	2.06	4.08	304	672
2	9.4	3.45	1.92	3.08	600	408
3	9.4	6.05	1.52	3.48	440	828
4	10.1	4.05	2.10	5.00	672	756
5	10.7	3.8	1.98	2.48	656	332
6	8.85	4.2	2.40	5.52	648	792
7	7.3	3.6	1.96	5.24	448	728
8	25.9	11.1	2.28	3.32	1812	1200
9	24.3	9.9	2.20	2.52	1660	1256
10	8.3	4.35	2.26	3.48	620	532
11	3.6	4.0	2.04	3.92	530	604
12	10.2	4.75	2.24	3.00	748	552
13	15.75	10.7	2.56	4.94	1376	1920
14	5.5	2.55	1.76	2.48	288	228
15	12.0	6.8	2.26	4.24	1080	1108
16	11.3	5.9	2.28	3.04	824	656
17	10.35	4.4	2.22	4.72	772	820
18	11.4	4.6	2.36	3.48	380	584

NOTE: The values represent the average of ten tests.

Table IV

Correlation Coefficients

Variables	Coefficient
Burst vs. MD Tensile	0.969
Burst vs. CD Tensile	0.947
Burst vs. MD Elongation	0.364
Burst vs. CD Elongation	-0.114
Burst vs. MD TEA	0.946
Burst vs. CD TEA	0.752
MD Tear vs. MD Tensile	0.864
MD Tear vs. CD Tensile	0.837
MD Tear vs. MD Elongation	0.364
MD Tear vs. CD Elongation	-0.175
MD Tear vs. MD TEA	0.864
MD Tear vs. CD TEA	0.715
CD Tear vs. MD Tensile	0.868
CD Tear vs. CD Tensile	0.795
CD Tear vs. MD Elongation	0.307
CD Tear vs. CD Elongation	-0.204
CD Tear vs. MD TEA	0.838
CD Tear vs. CD TEA	0.655

Table IV (cont.)

Correlation Coefficients

Variables	Coefficient
MD Fold vs. MD Tensile	0.677
MD Fold vs. CD Tensile	0.440
MD Fold vs. MD Elongation	-0.063
MD Fold vs. CD Elongation	-0.149
MD Fold vs. MD TEA	0.511
MD Fold vs. CD TEA	0.261
CD Fold vs. MD Tensile	0.275
CD Fold vs. CD Tensile	0.349
CD Fold vs. MD Elongation	-0.477
CD Fold vs. CD Elongation	-0.054
CD Fold vs. MD TEA	0.133
CD Fold vs. CD TEA	0.256

Table V

Burst vs. MD Tensile

Sample	Actual	Predicted	Deviation	% Deviation
1	26.1	27.3	-1.2	4.4
2	16.9	20.3	-3.4	16.7
3	26.9	20.3	6.6	32.4
4	23.3	21.8	1.4	6.4
5	22.9	23.1	-0.2	0.9
6	19.0	19.2	-0.2	1.0
7	17.4	15.8	1.6	10.0
8	55.3	55.8	-0.5	0.9
9	50.2	52.4	-2.1	4.0
10	19.6	18.0	1.6	8.9
11	15.2	18.6	-3.4	18.3
12	20.6	22.1	-1.5	6.8
13	39.5	34.0	5.5	16.2
14	9.3	12.0	-2.7	22.5
15	29.4	25.9	3.5	13.5
16	24.2	24.4	-0.2	0.8
17	19.2	22.4	-3.2	14.3
18	23.2	24.6	-1.4	5.7

Burst vs. CD Tensile

Sample	Actual	Predicted	Deviation	% Deviation
1	26.1	21.1	5.0	23.7
2	16.9	16.5	0.4	2.4
3	26.9	27.9	-1.0	3.6
4	23.3	19.2	4.1	21.4
5	22.9	18.1	4.8	26.5
6	19.0	19.8	-0.8	4.4
7	17.4	17.2	0.2	1.2
8	55.3	50.2	5.1	10.1
9	50.2	44.9	5.3	11.8
10	19.6	20.5	-0.9	4.4
11	15.2	18.9	-3.7	19.6
12	20.6	22.2	-1.6	7.2
13	39.5	48.4	-8.9	18.4
14	9.3	12.6	-3.3	26.2
15	29.4	31.2	-1.8	5.8
16	24.2	27.3	-3.1	11.4
17	19.2	20.7	-1.5	7.4
18	23.2	21.6	1.6	7.4

CURVES OF EQUAL TEA

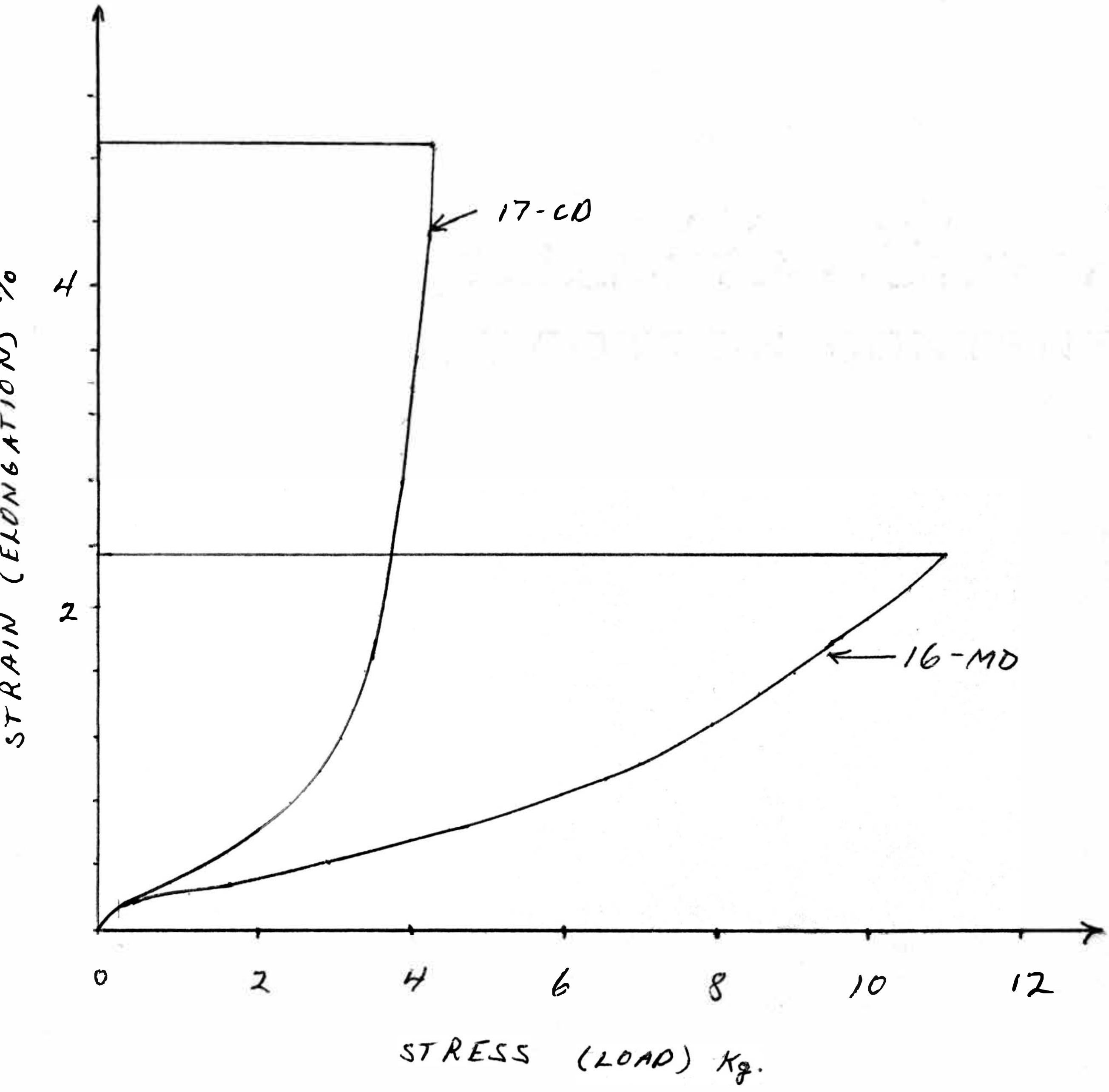


Figure 2

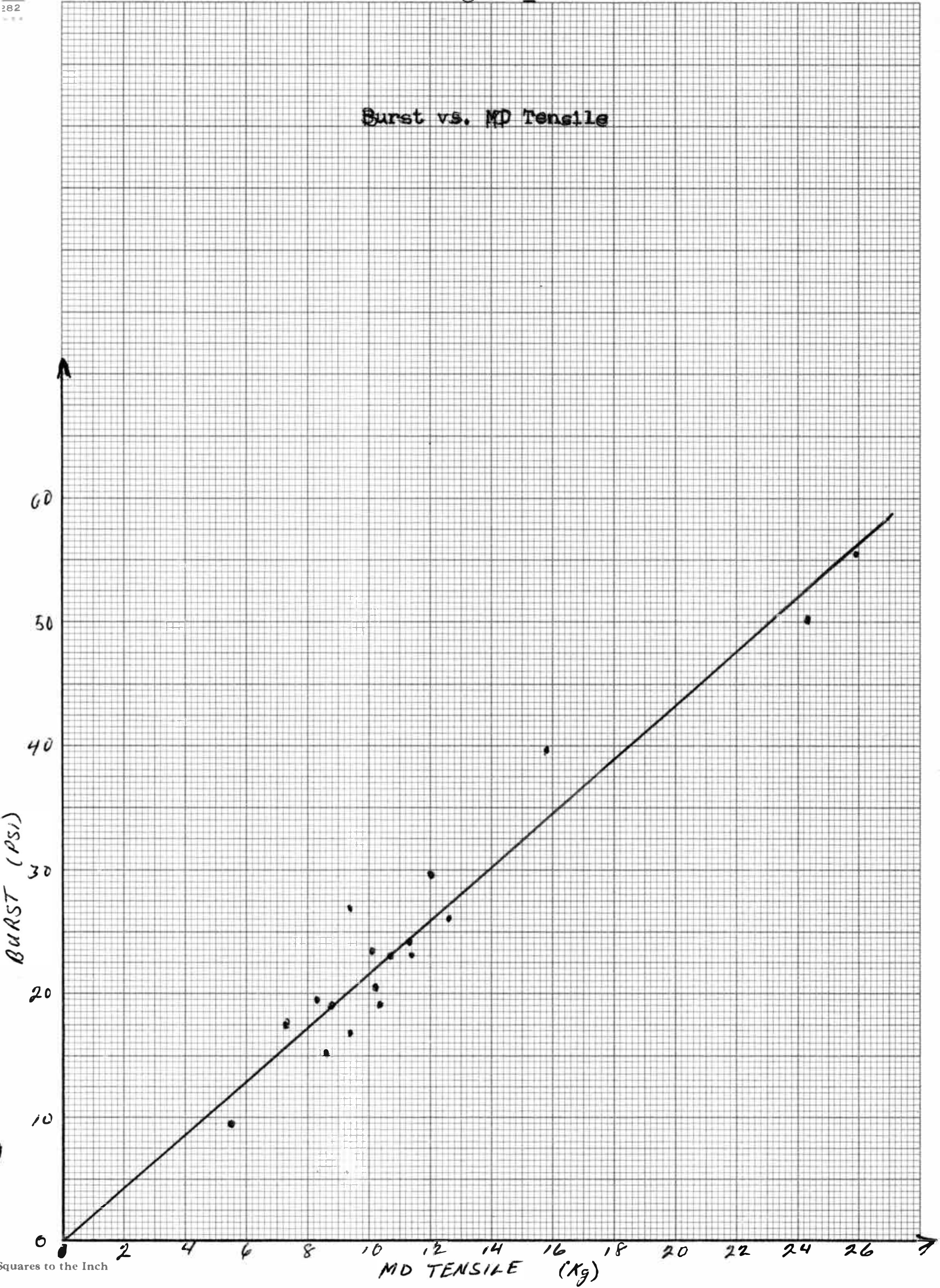

Burst vs. MD Tensile
BURST (PSI)
0
10
20
30
40
50
60
0
2
4
6
8
10
12
14
16
18
20
22
24
26
MD TENSILE (Kg)

Figure 3

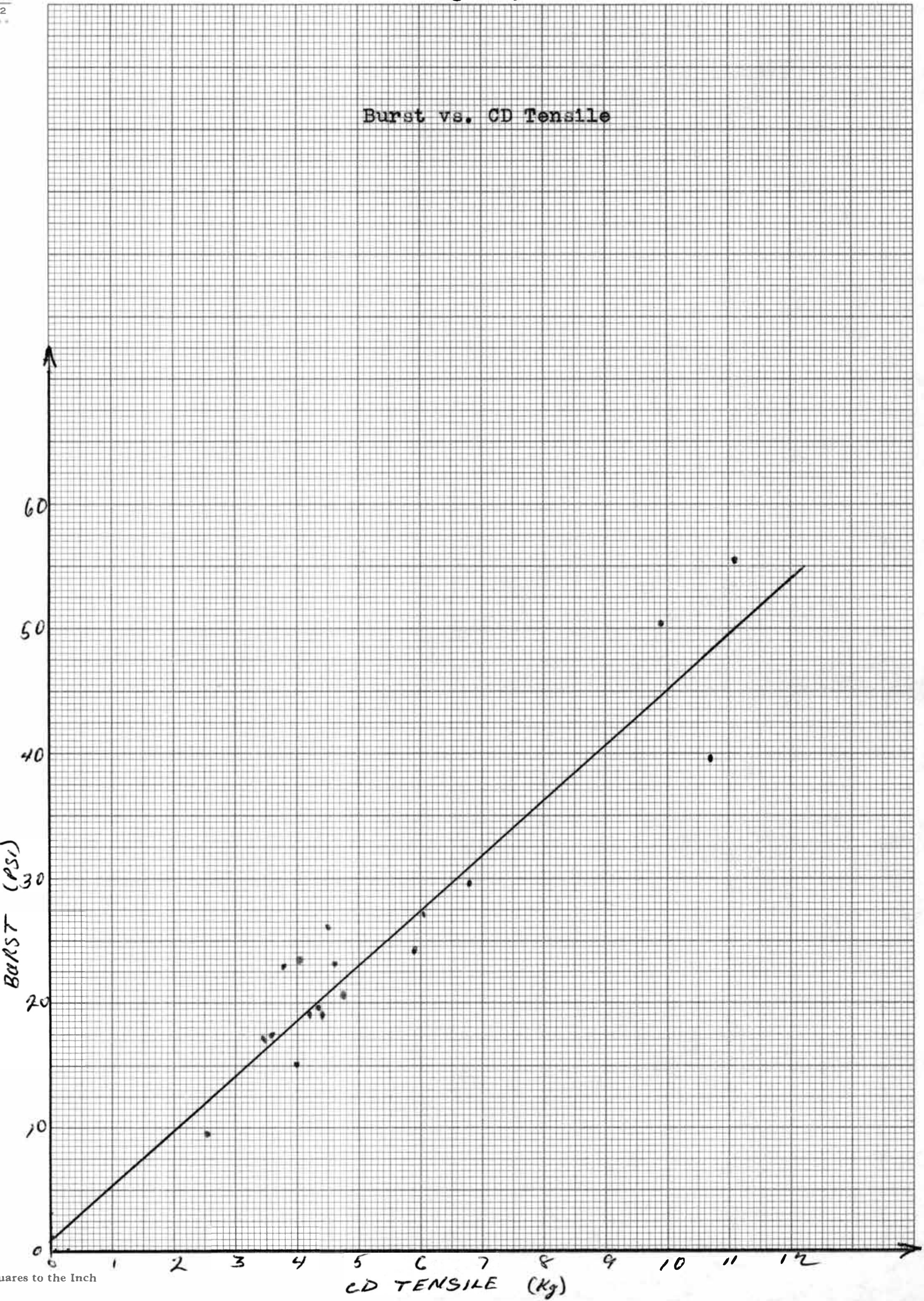
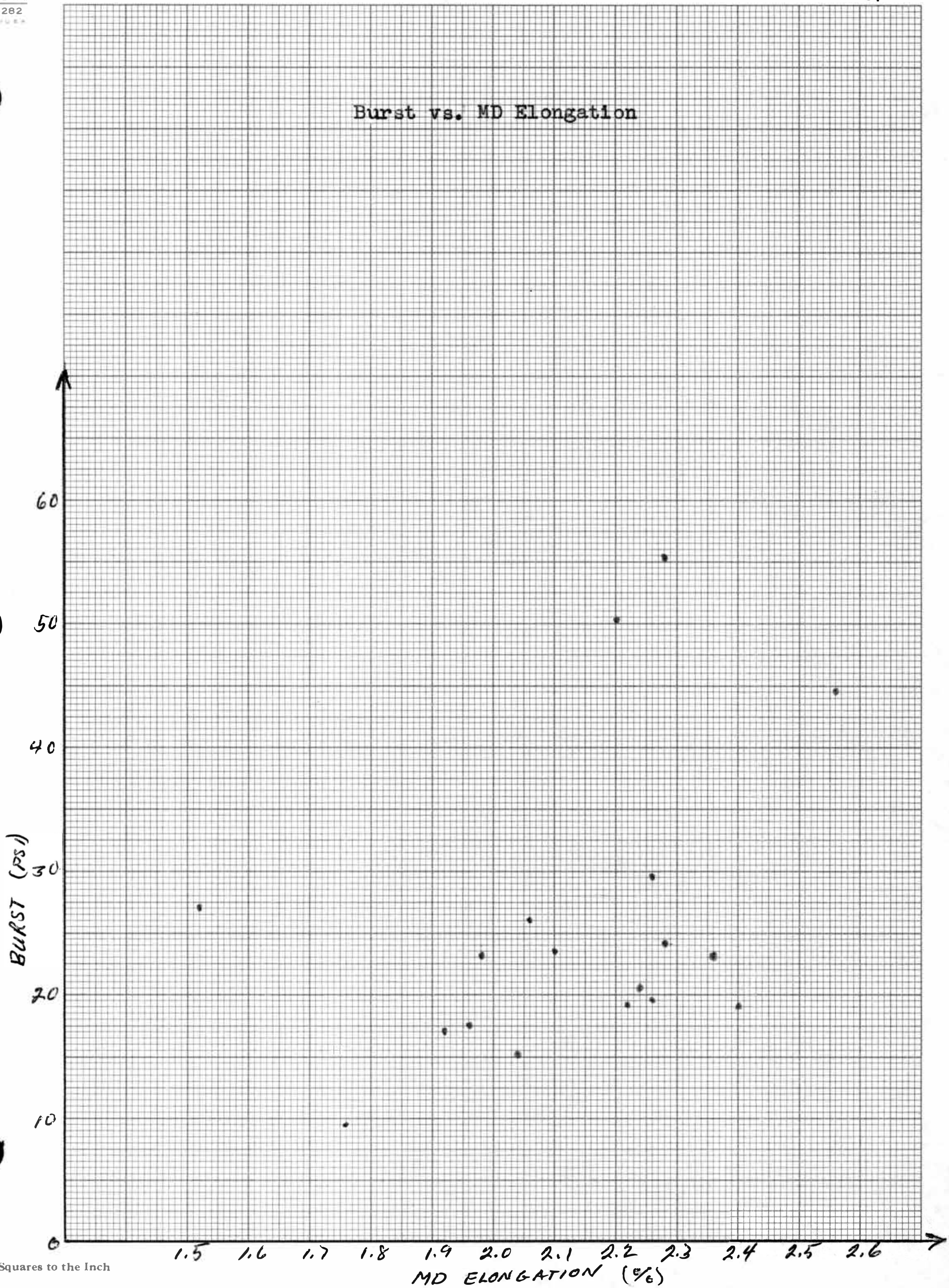

Burst vs. CD Tensile
BURST (PSI)
0
10
20
30
40
50
60
0
1
2
3
4
5
6
7
8
9
10
11
12
CD TENSILE (Kg)

Figure 4


Burst vs. MD Elongation
BURST (PSI)
60
50
40
30
20
10
0
1.5
1.6
1.7
1.8
1.9
2.0
2.1
2.2
2.3
2.4
2.5
2.6
MD ELONGATION (%)

Burst vs. CD Elongation

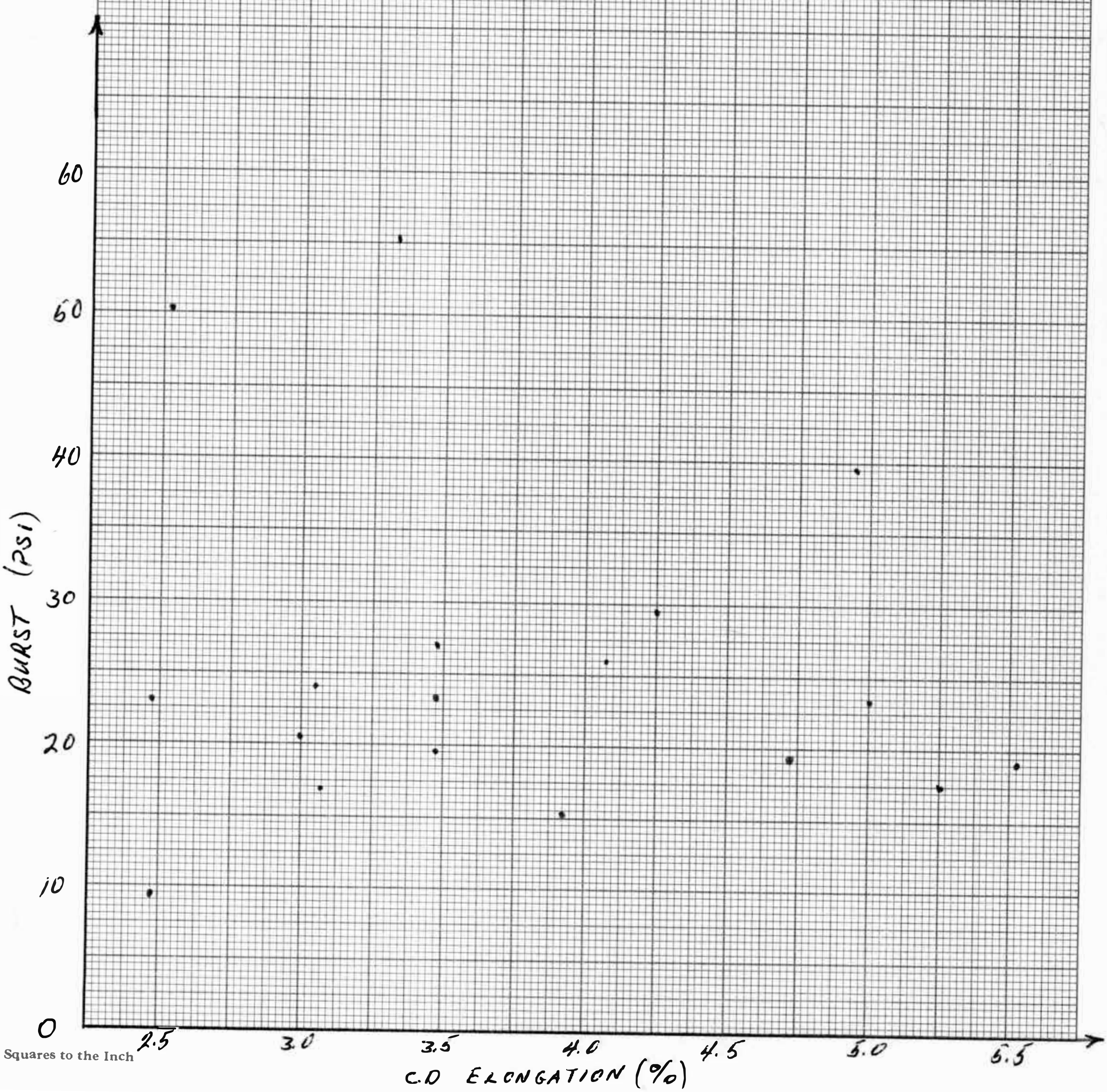


Figure 6

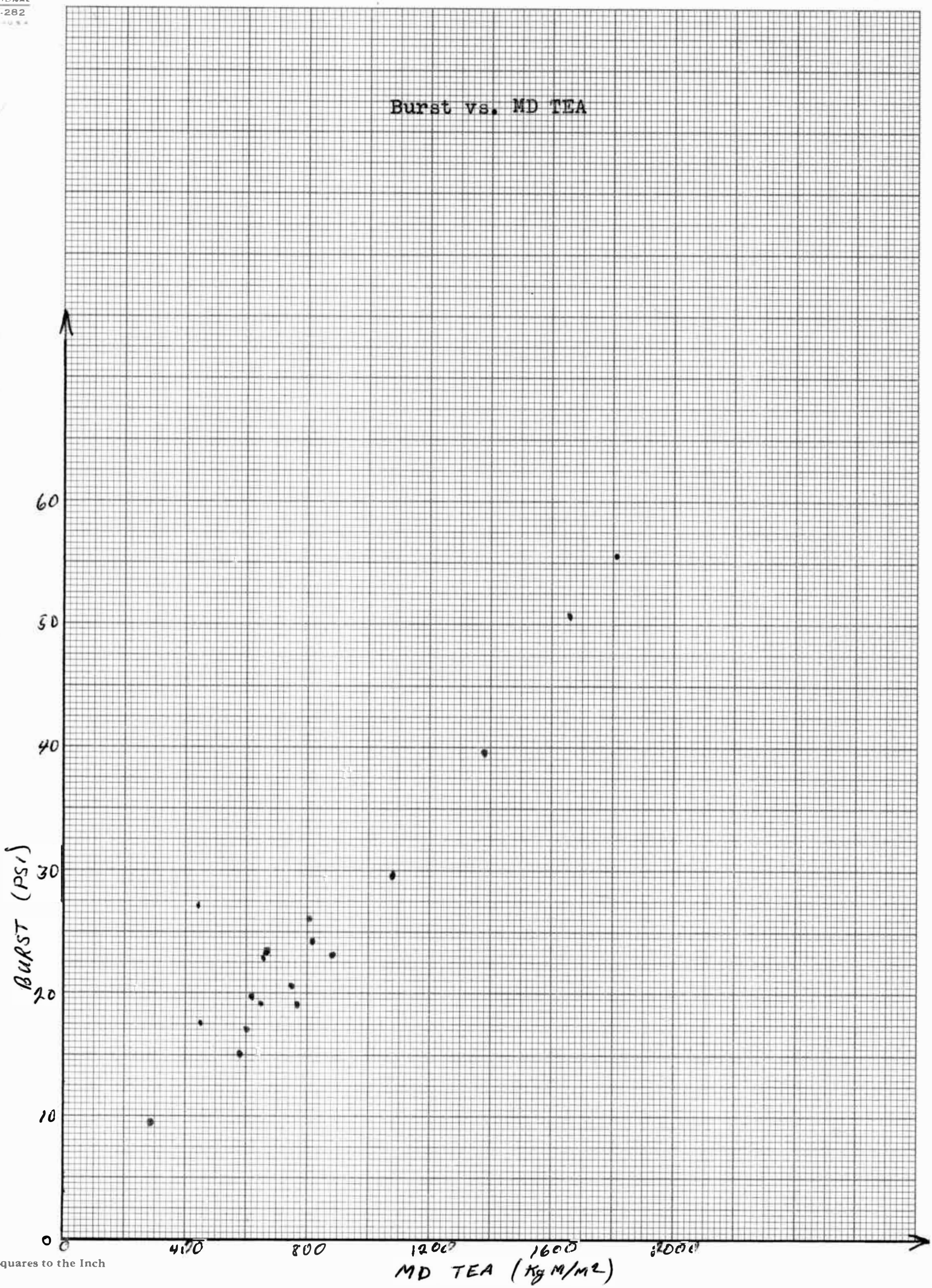
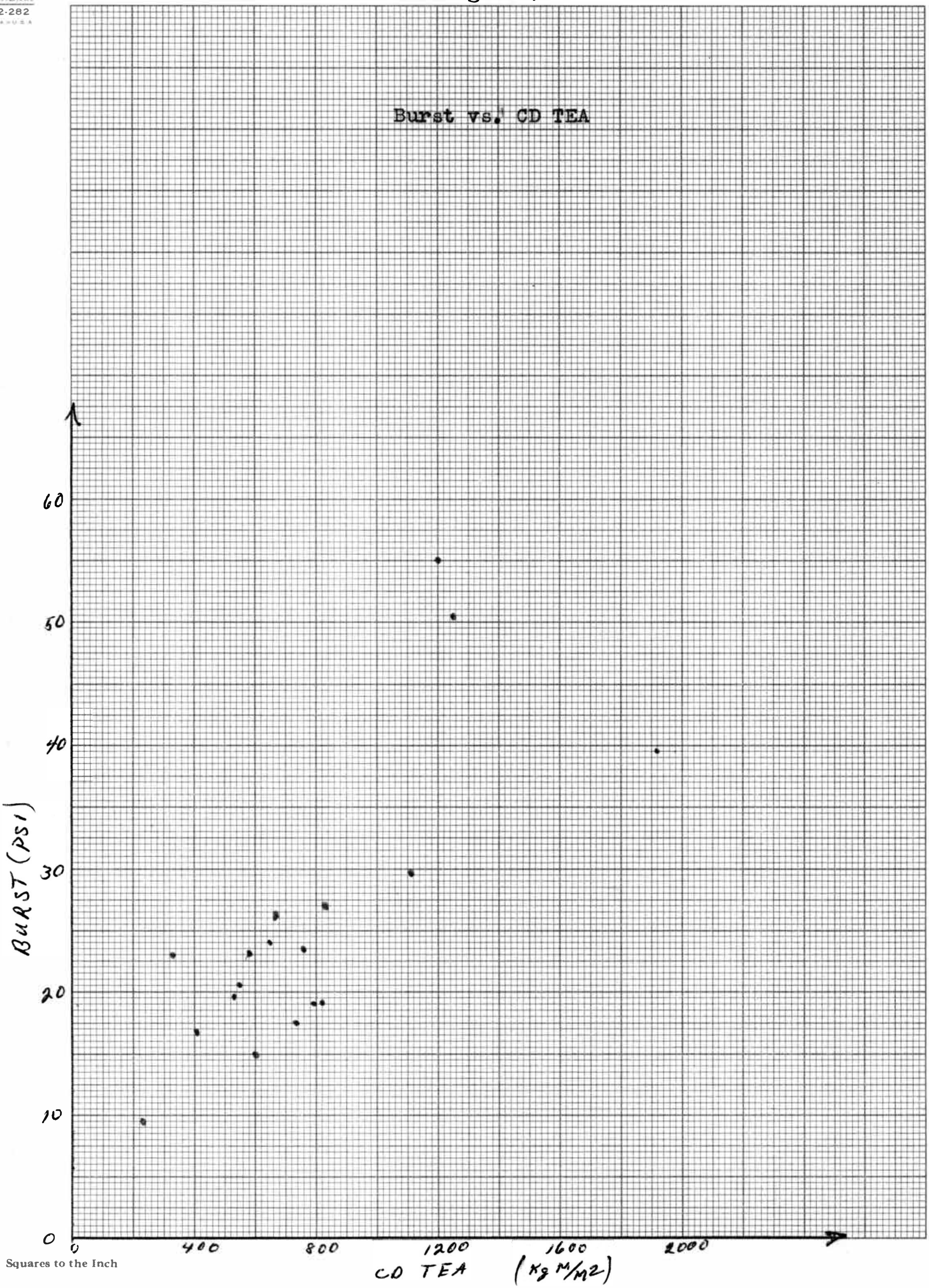
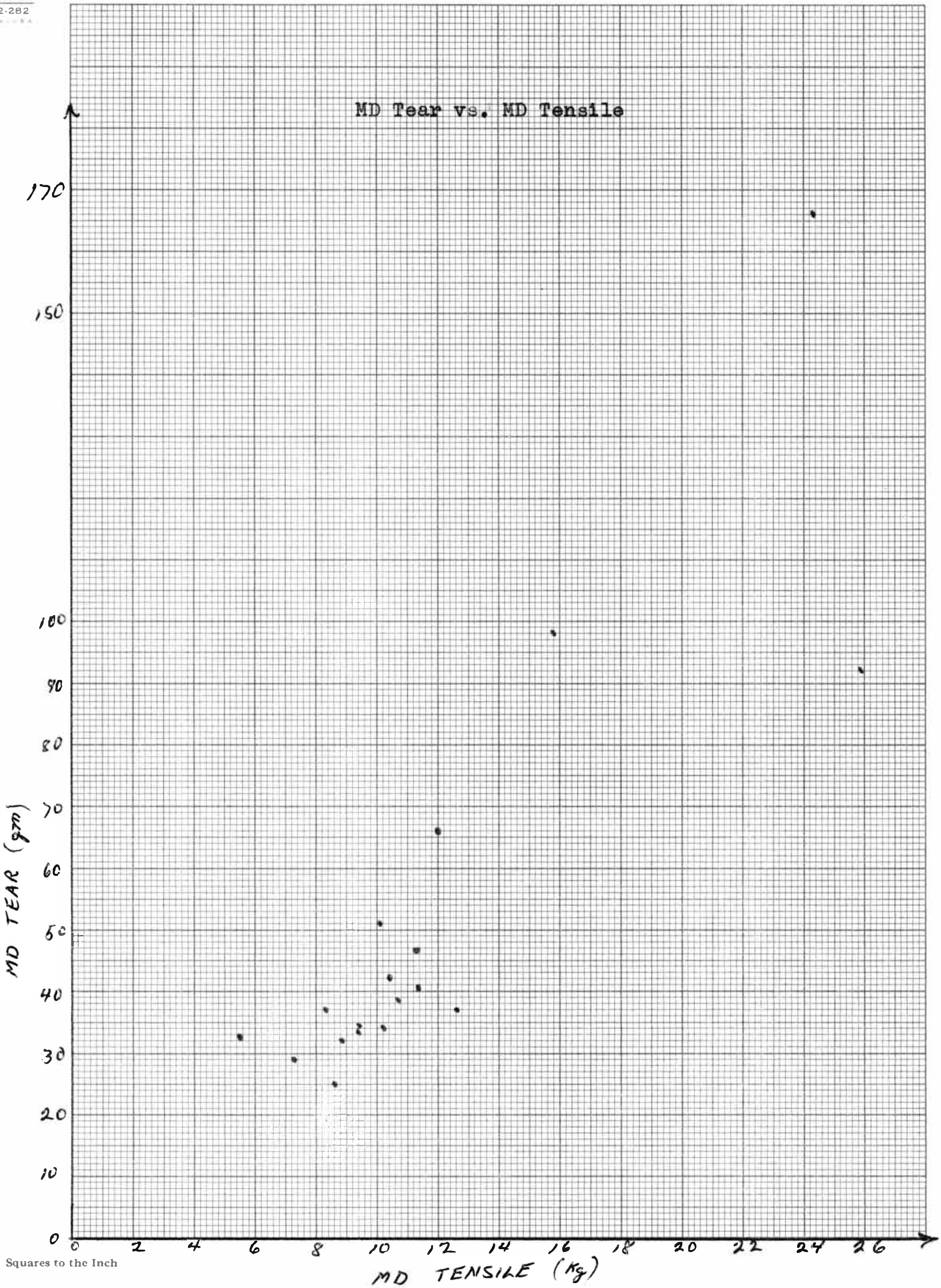

Burst vs. MD TEA
60
50
40
30
20
10
0
BURST (PSI)
0
400
800
1200
1600
2000
MD TEA (Kg M/m2)

Figure 7



20 Squares to the Inch

Figure 8



20 Squares to the Inch

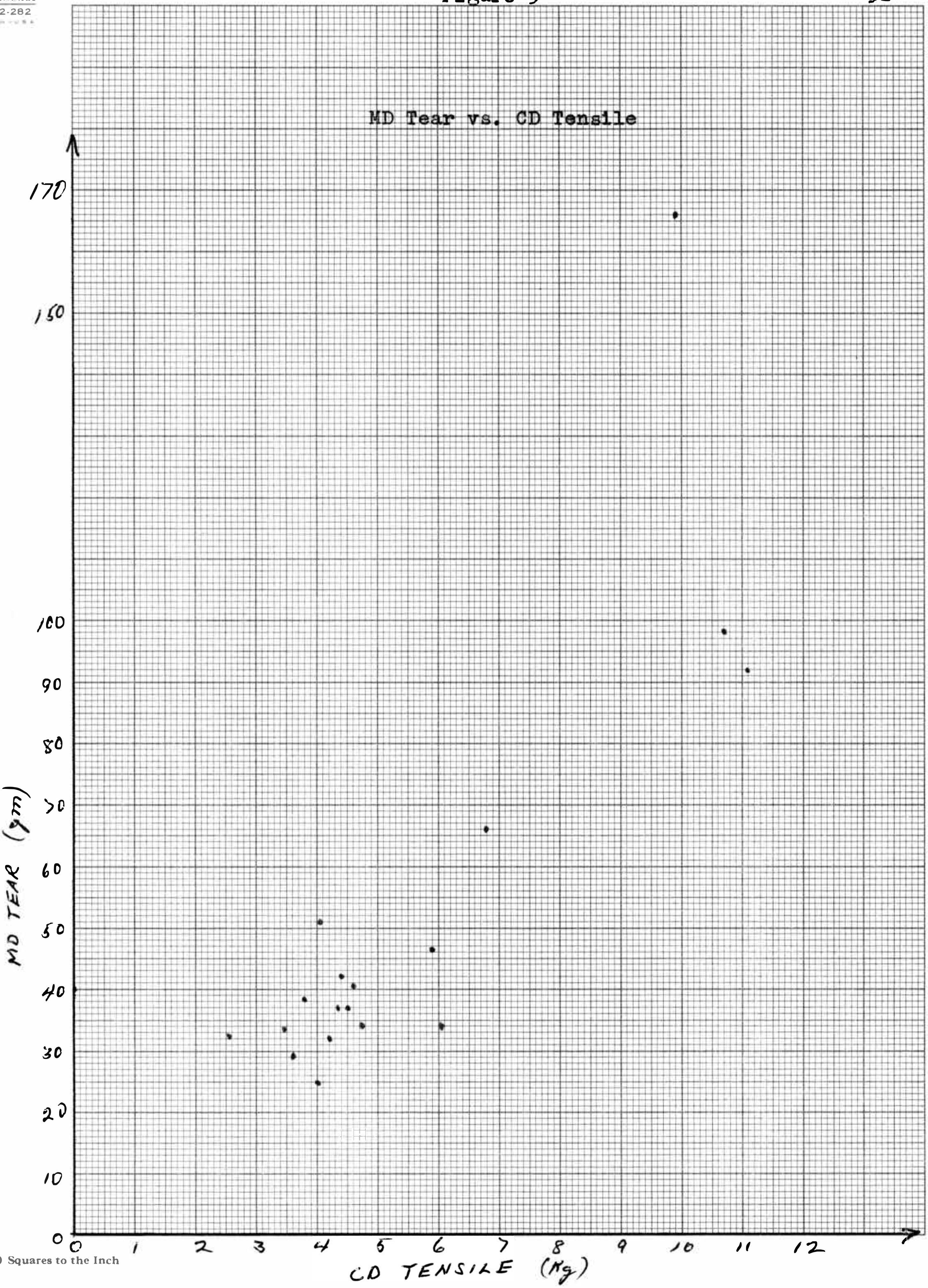

MD Tear vs. CD Tensile
MD TEAR (gm)
170
150
100
90
80
70
60
50
40
30
20
10
0
0
1
2
3
4
5
6
7
8
9
10
11
12
CD TENSILE (Kg)

Figure 10

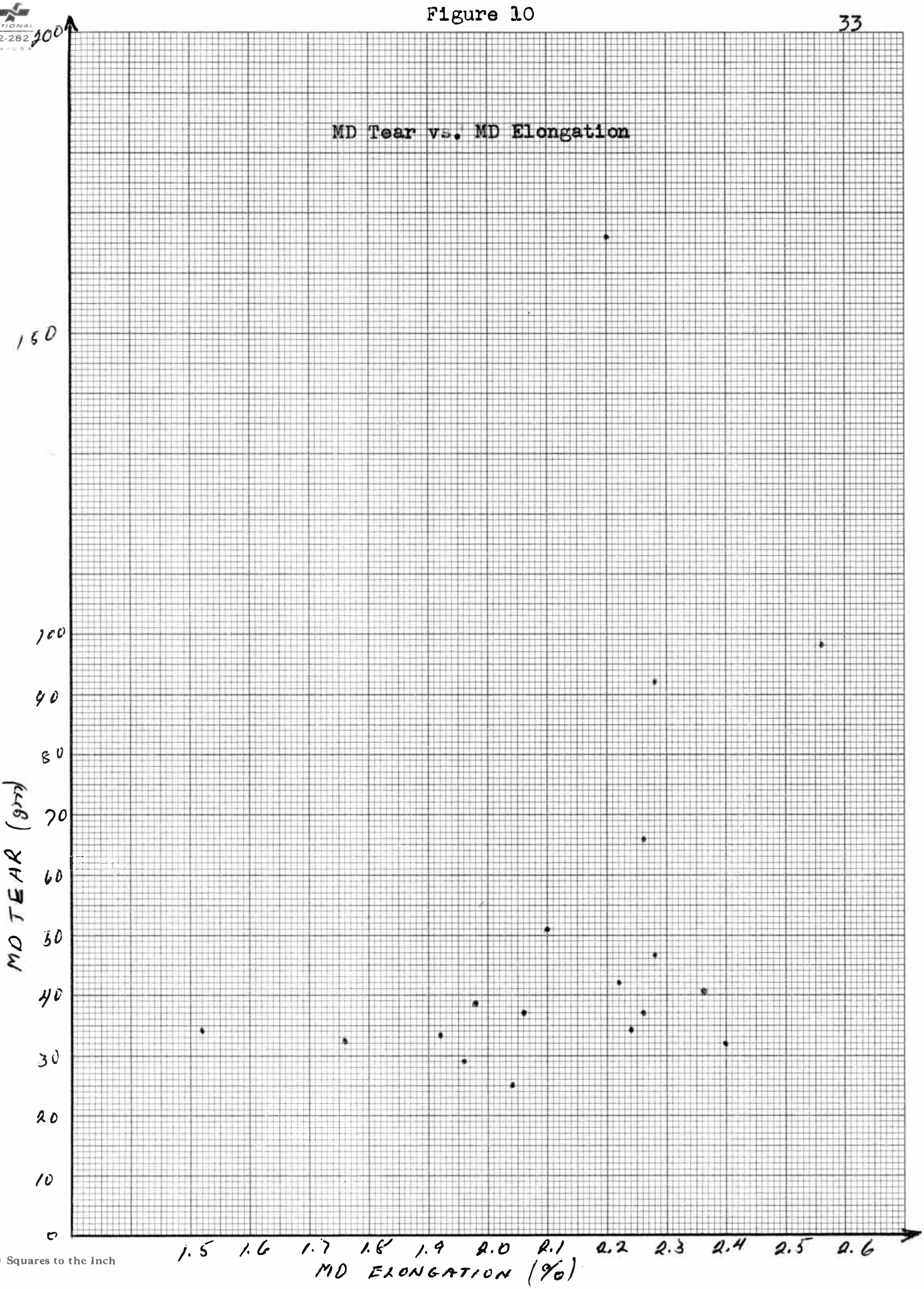

MD Tear vs. MD Elongation
200
150
100
90
80
70
60
50
40
30
20
10
0
MD TEAR (gm)
1.5
1.6
1.7
1.8
1.9
2.0
2.1
2.2
2.3
2.4
2.5
2.6
MD ELONGATION (%)

Figure 11

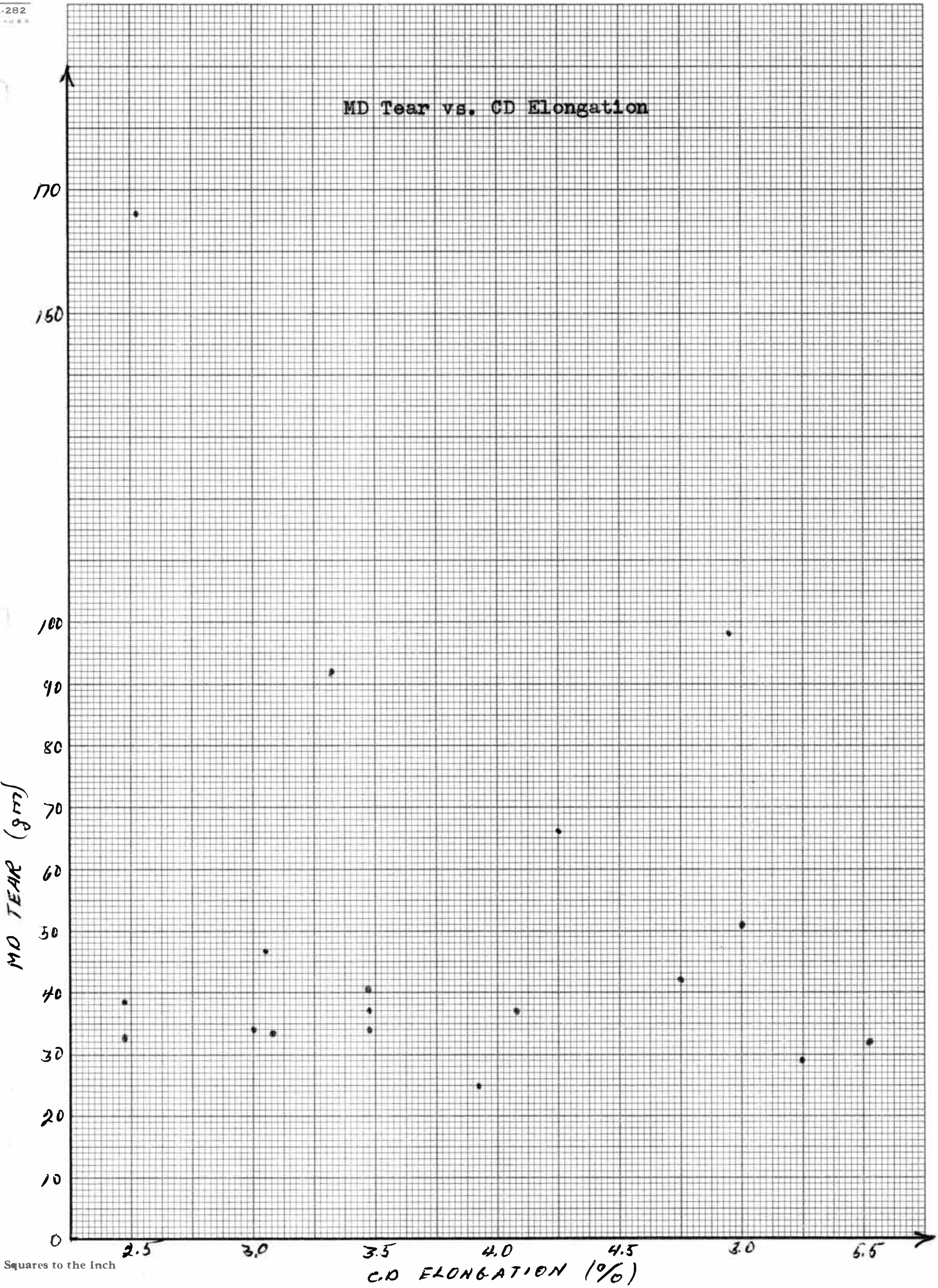
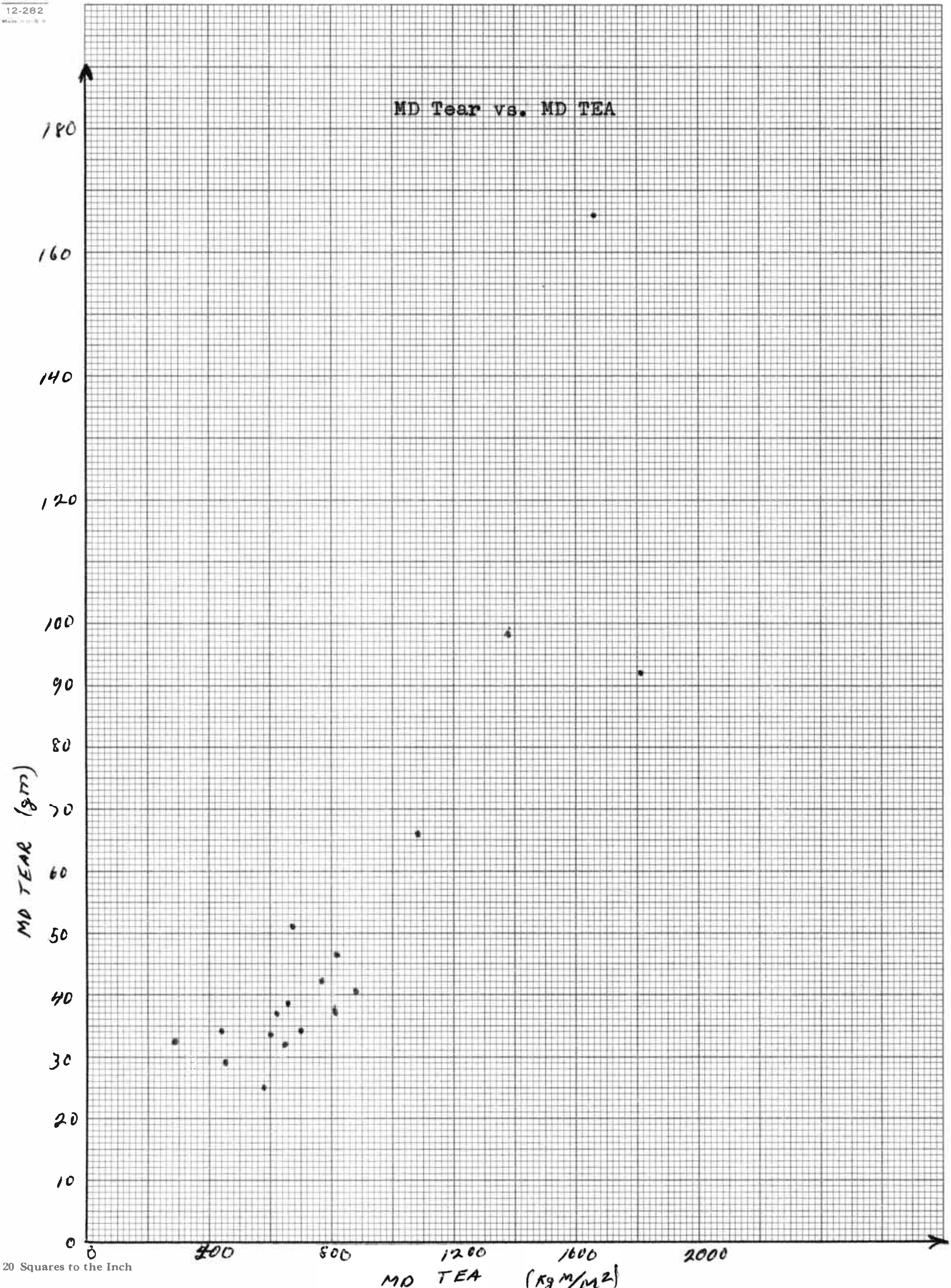

MD Tear vs. CD Elongation
MD TEAR (gm)
170
150
100
90
80
70
60
50
40
30
20
10
0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
C.D ELONGATION (%)

Figure 12



20 Squares to the Inch

Figure 13

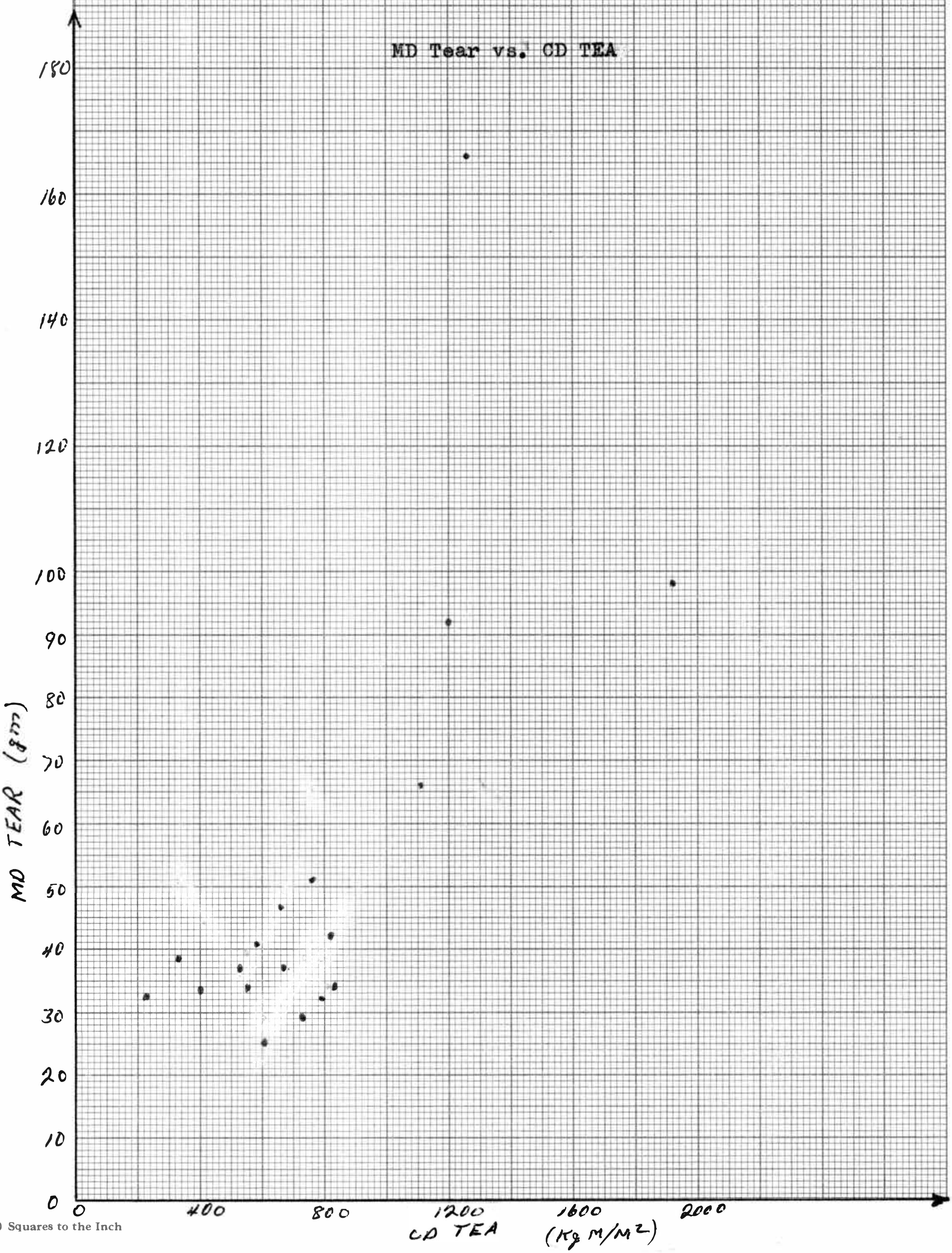
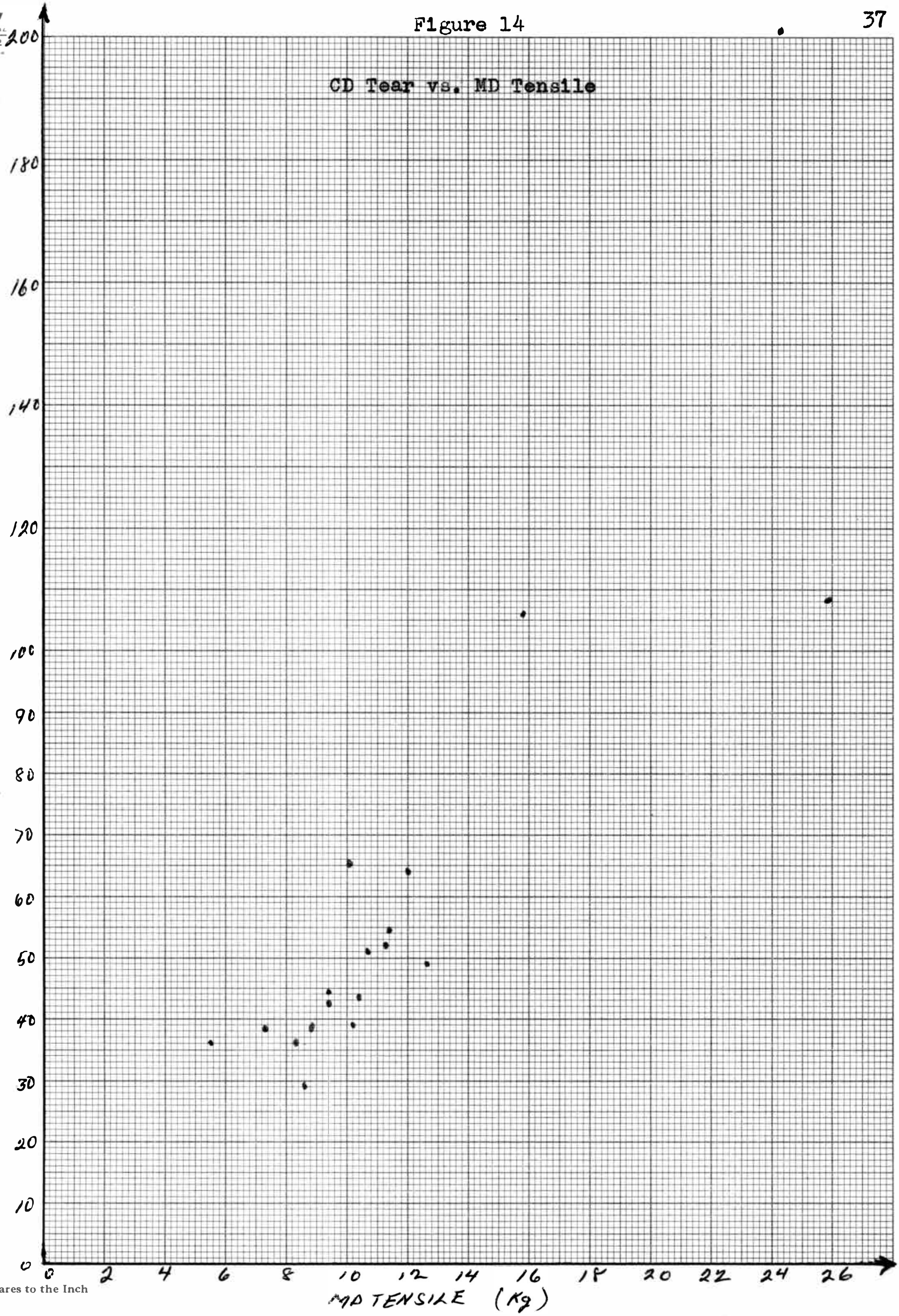

MD Tear vs. CD TEA
180
160
140
120
100
90
80
70
60
50
40
30
20
10
0
MD TEAR (gm)
0
400
800
1200
1600
2000
CD TEA (Kg M/M2)

Figure 14



20 Squares to the Inch

Figure 15

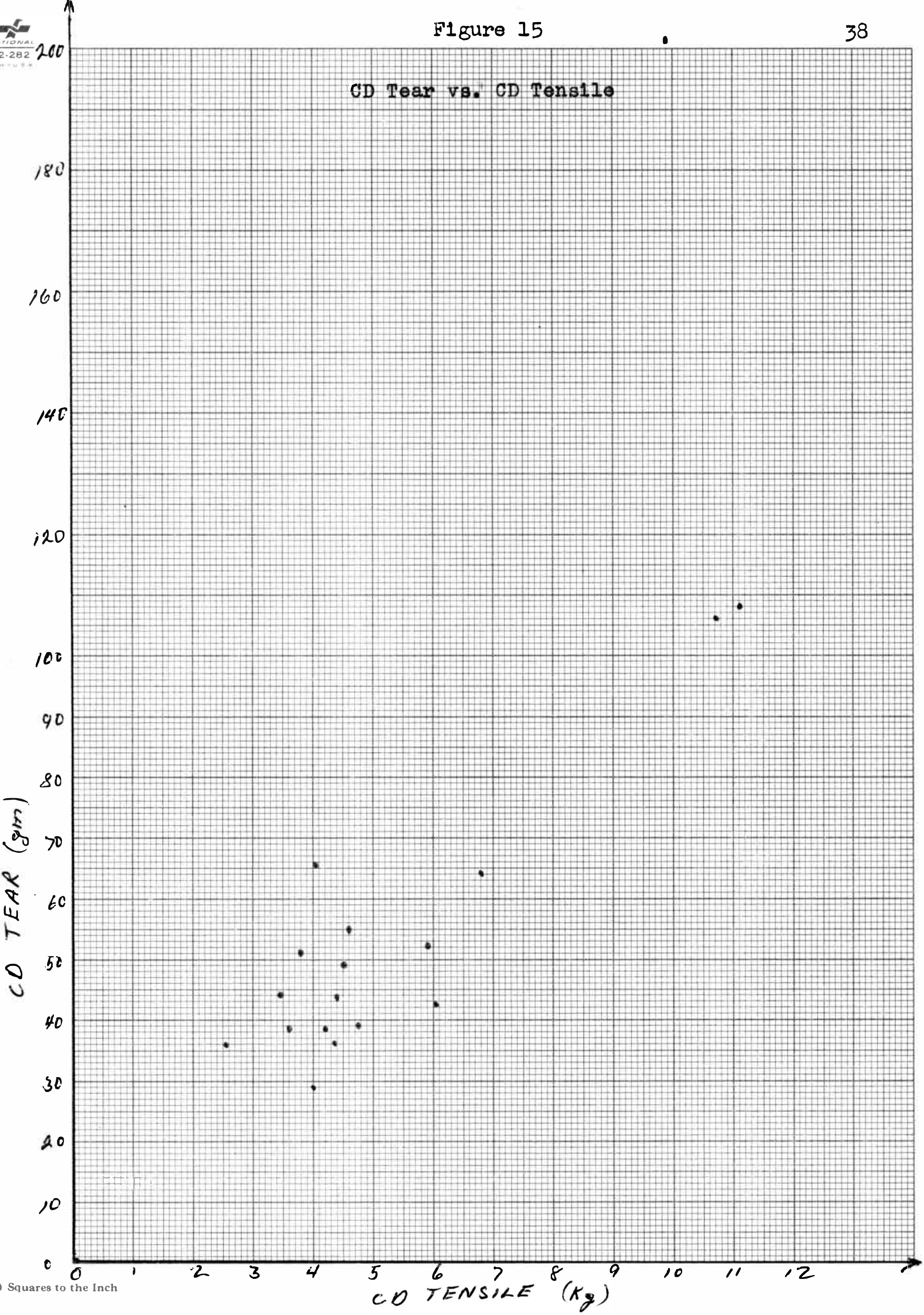

CD Tear vs. CD Tensile
CD TEAR (gm)
200
180
160
140
120
100
90
80
70
60
50
40
30
20
10
0
0
1
2
3
4
5
6
7
8
9
10
11
12
CD TENSILE (Kg)

Figure 16

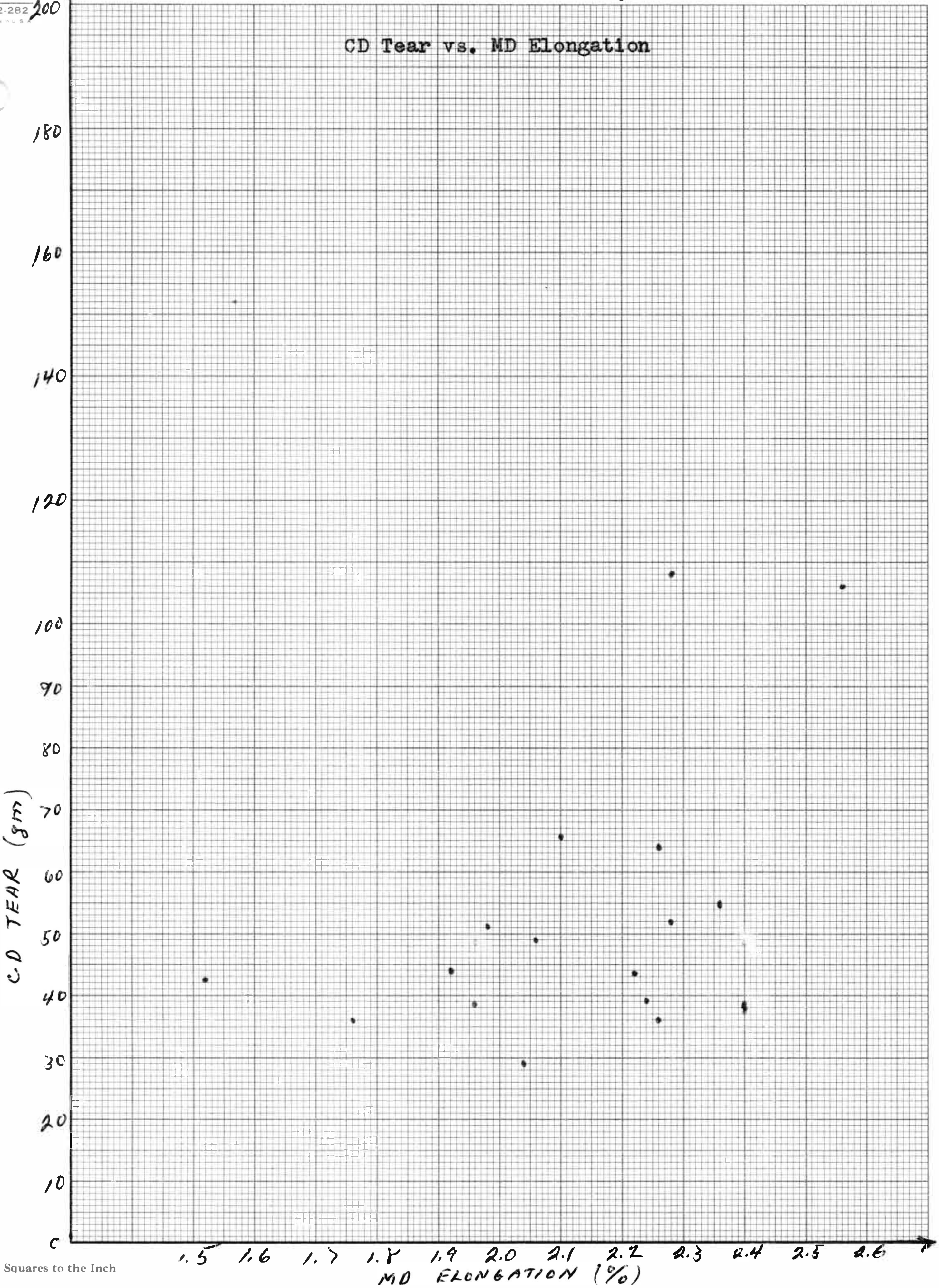

CD Tear vs. MD Elongation
CD TEAR (gm)
200
180
160
140
120
100
90
80
70
60
50
40
30
20
10
0
1.5
1.6
1.7
1.8
1.9
2.0
2.1
2.2
2.3
2.4
2.5
2.6
MD ELONGATION (%)

Figure 17

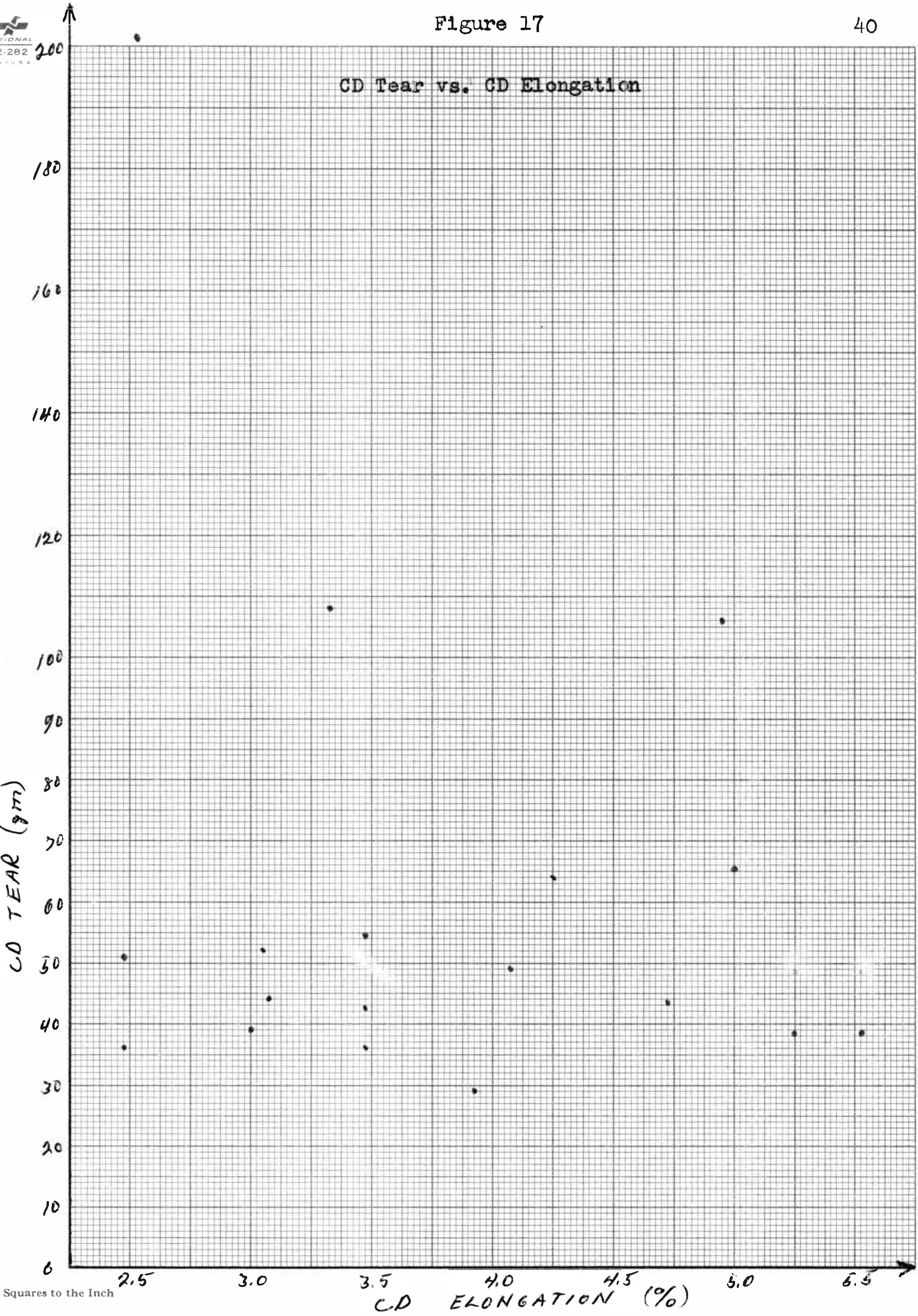

CD Tear vs. CD Elongation
CD TEAR (gm)
0
10
20
30
40
50
60
70
80
90
100
120
140
160
180
200
2.5
3.0
3.5
4.0
4.5
5.0
5.5
CD ELONGATION (%)

Figure 18 .

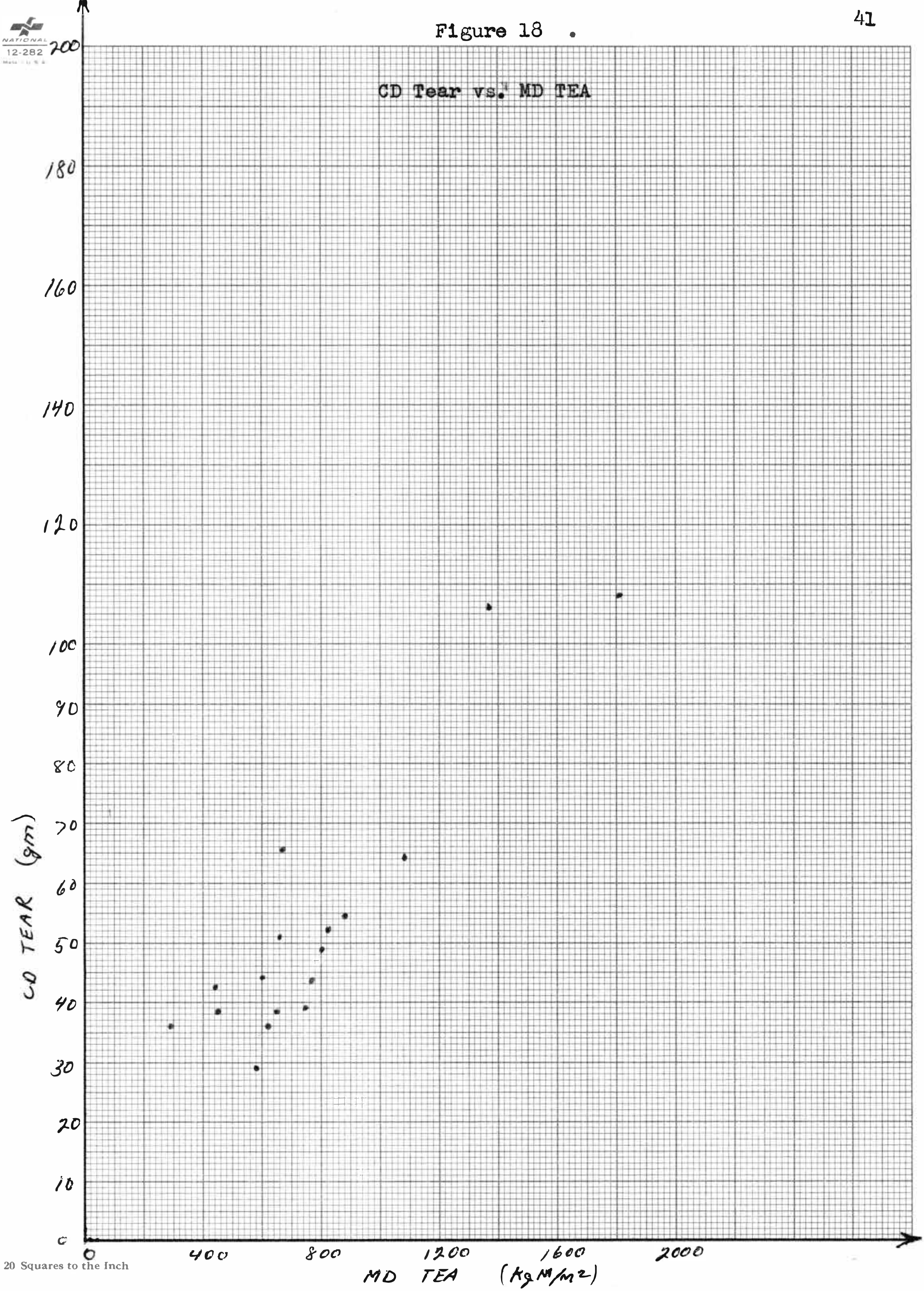

CD Tear vs. MD TEA
200
180
160
140
120
100
90
80
70
60
50
40
30
20
10
0
CD TEAR (gm)
0
400
800
1200
1600
2000
MD TEA (KgM/m2)
NATIONAL
12-282
20 Squares to the Inch

Figure 19

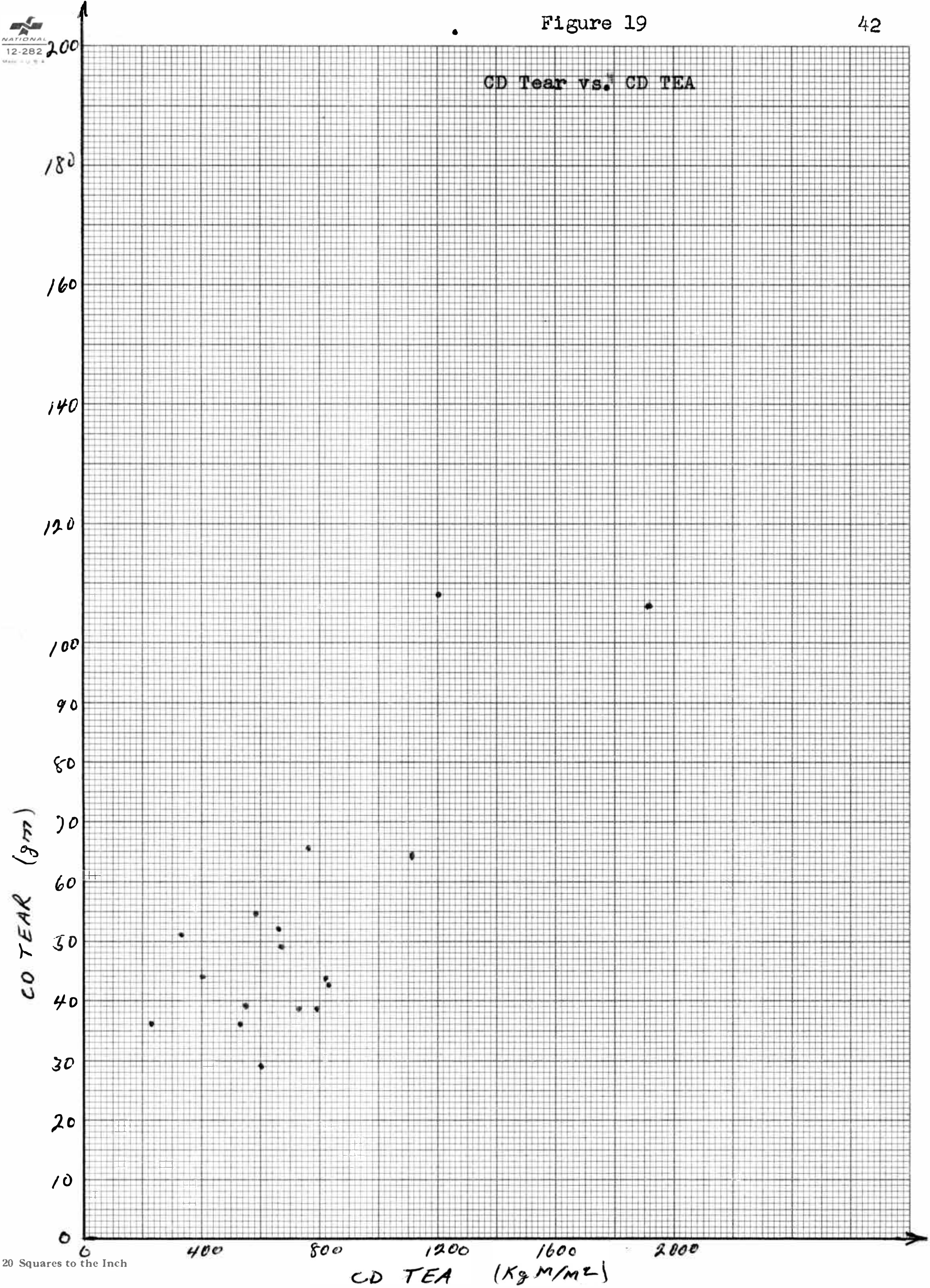
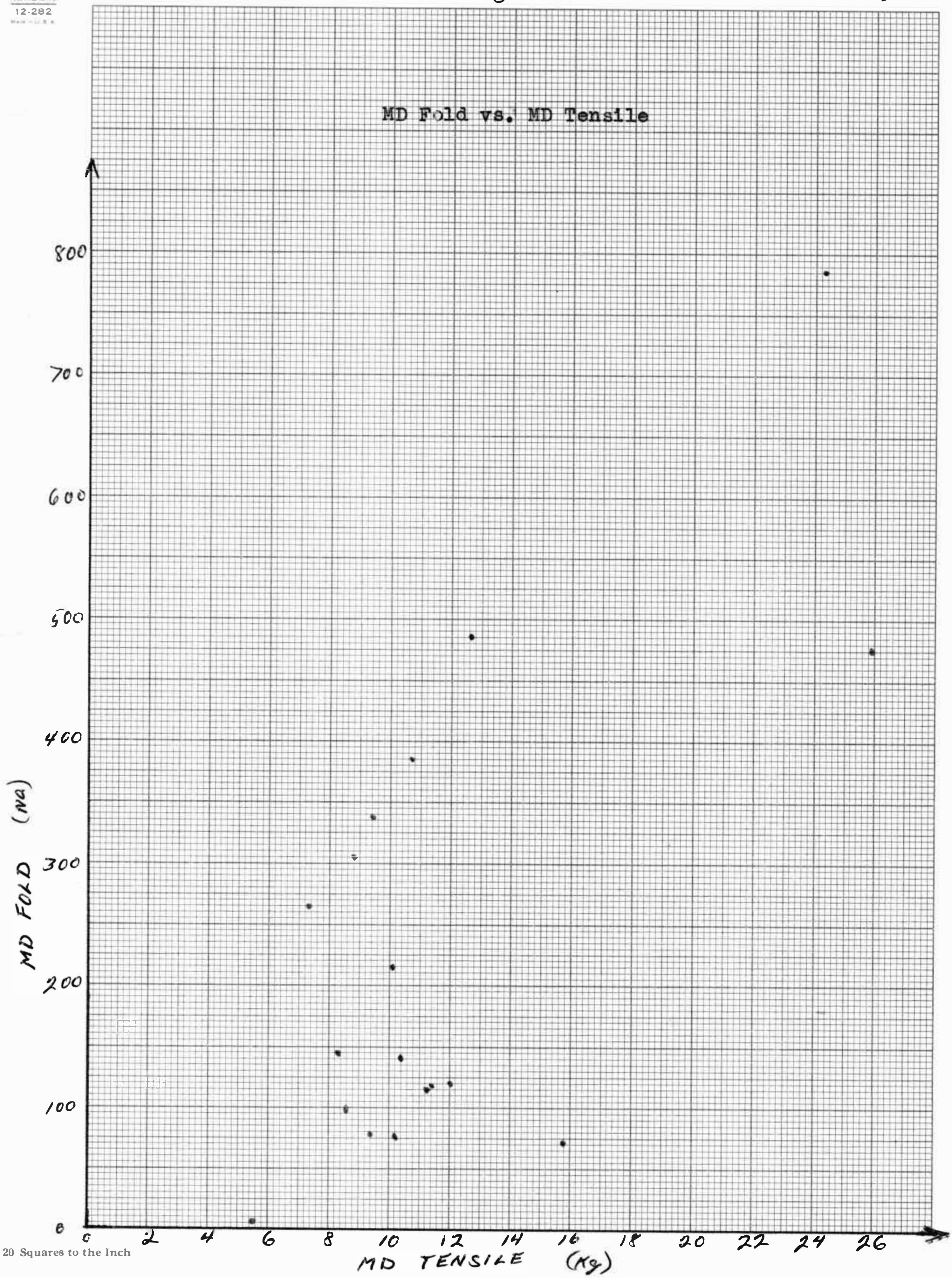

CD Tear vs. CD TEA
CD TEAR (gm)
CD TEA (Kg M/M2)
0
10
20
30
40
50
60
70
80
90
100
120
140
160
180
200
0
400
800
1200
1600
2000

Figure 20



MD Fold vs. MD Tensile
MD FOLD (No)
MD TENSILE (Kg)
0
100
200
300
400
500
600
700
800
0
2
4
6
8
10
12
14
16
18
20
22
24
26

Figure 21

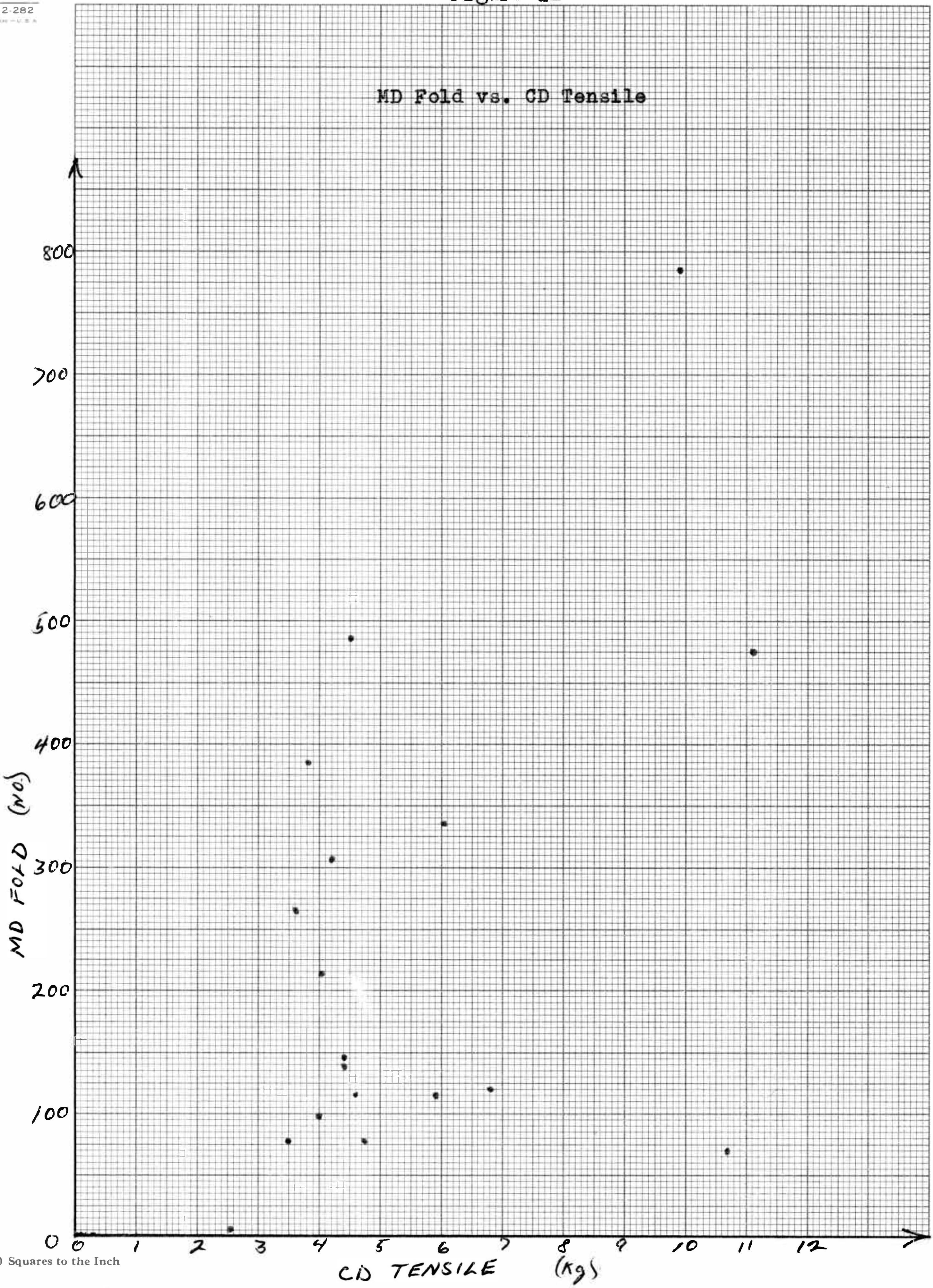

MD Fold vs. CD Tensile
MD FOLD (NO.)
CD TENSILE (Kg)
0
100
200
300
400
500
600
700
800
0 1 2 3 4 5 6 7 8 9 10 11 12

Figure 22

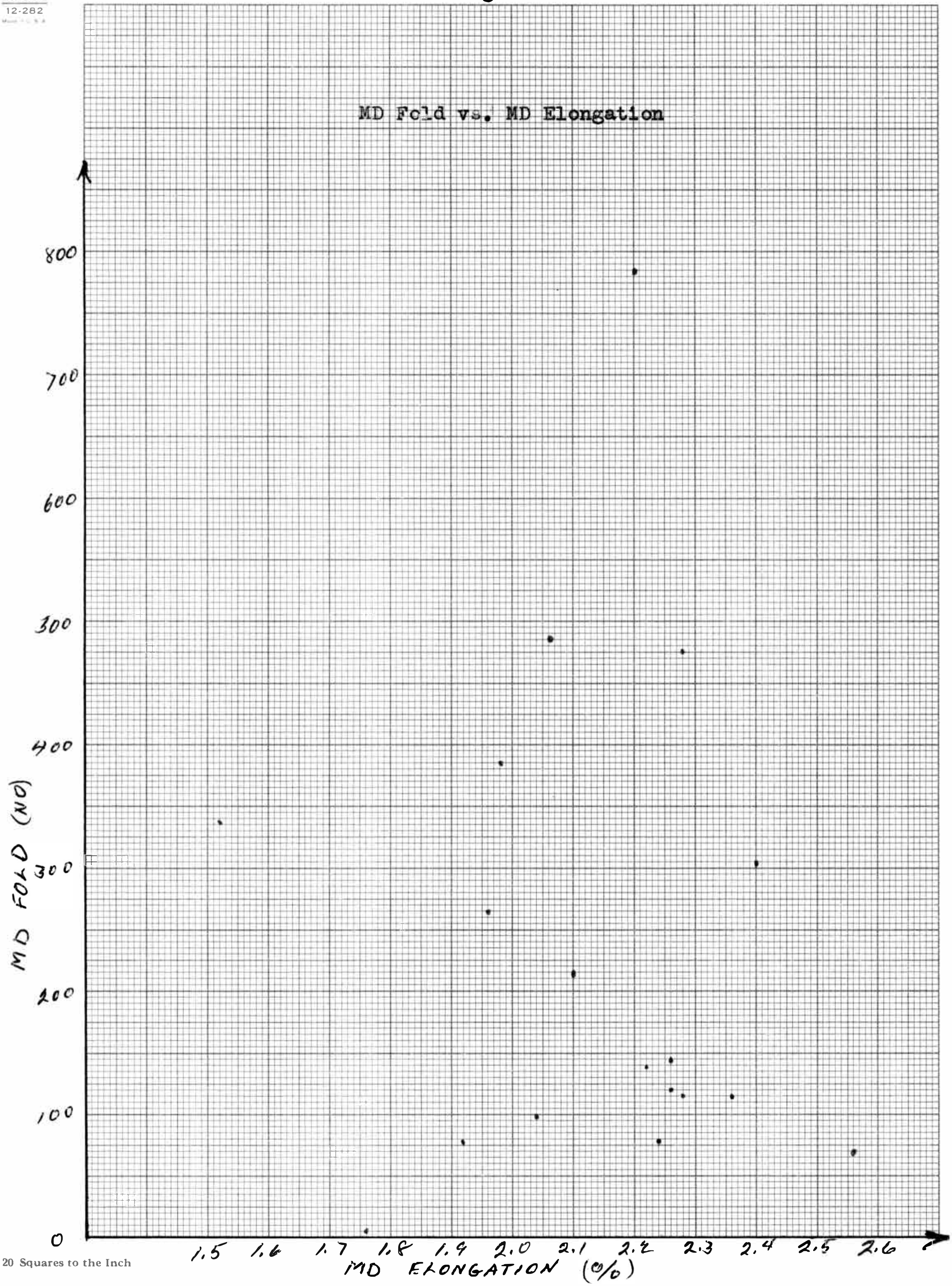

MD Fold vs. MD Elongation
800
700
600
300
400
300
200
100
0
MD FOLD (NO)
1.5
1.6
1.7
1.8
1.9
2.0
2.1
2.2
2.3
2.4
2.5
2.6
MD ELONGATION (%)

Figure 23

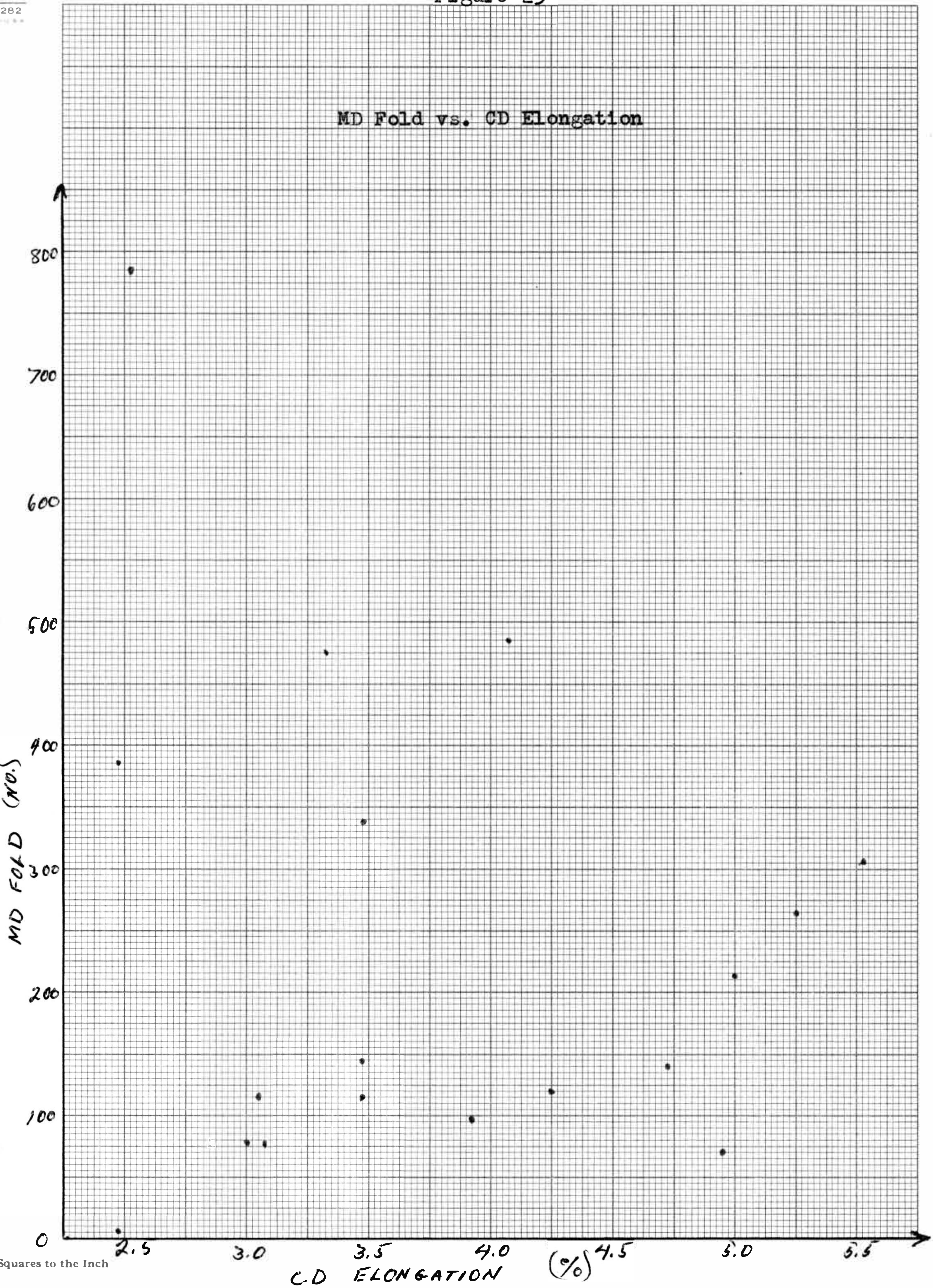

MD Fold vs. CD Elongation
MD FOLD (NO.)
800
700
600
500
400
300
200
100
0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
C.D ELONGATION (%)

Figure 24

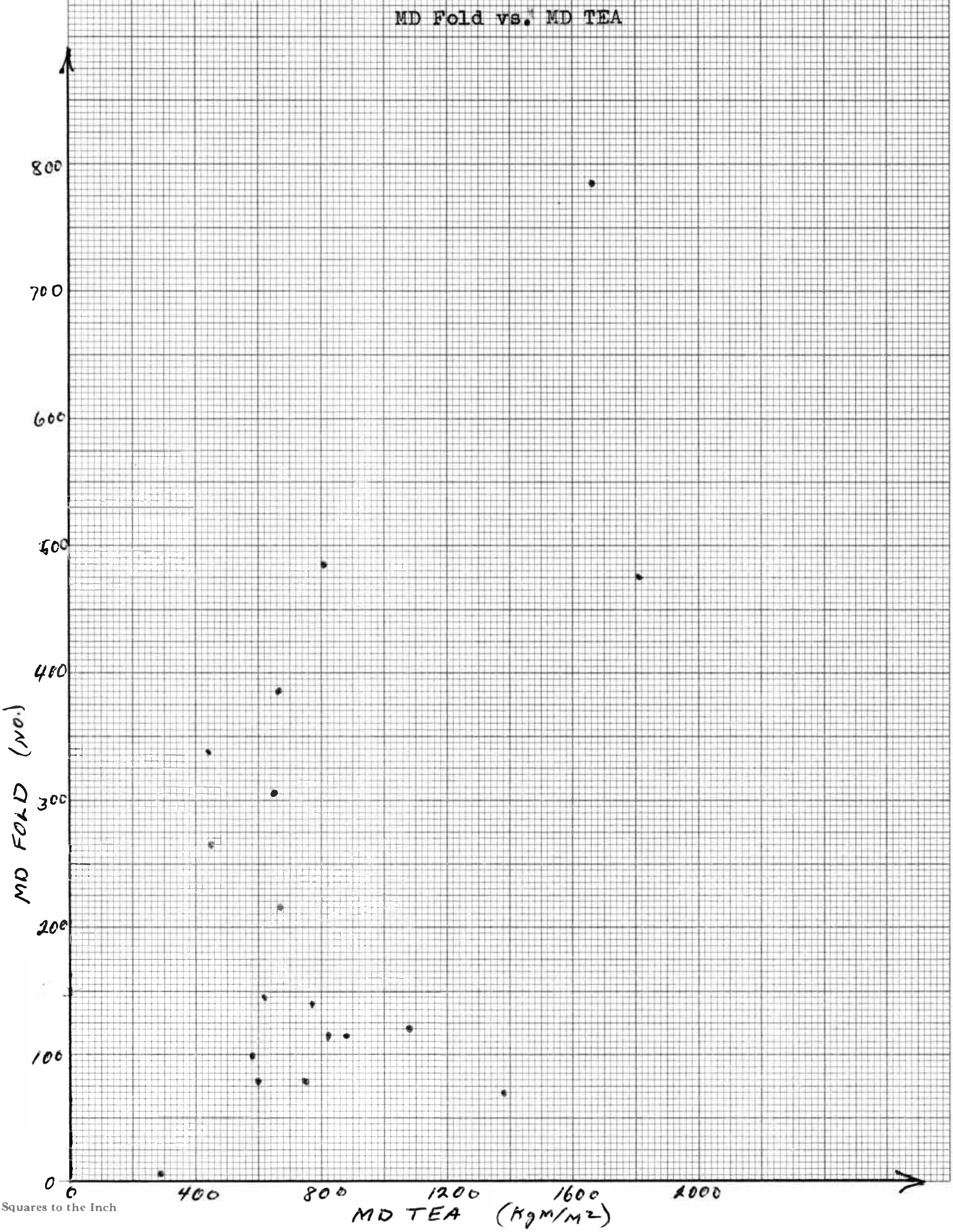
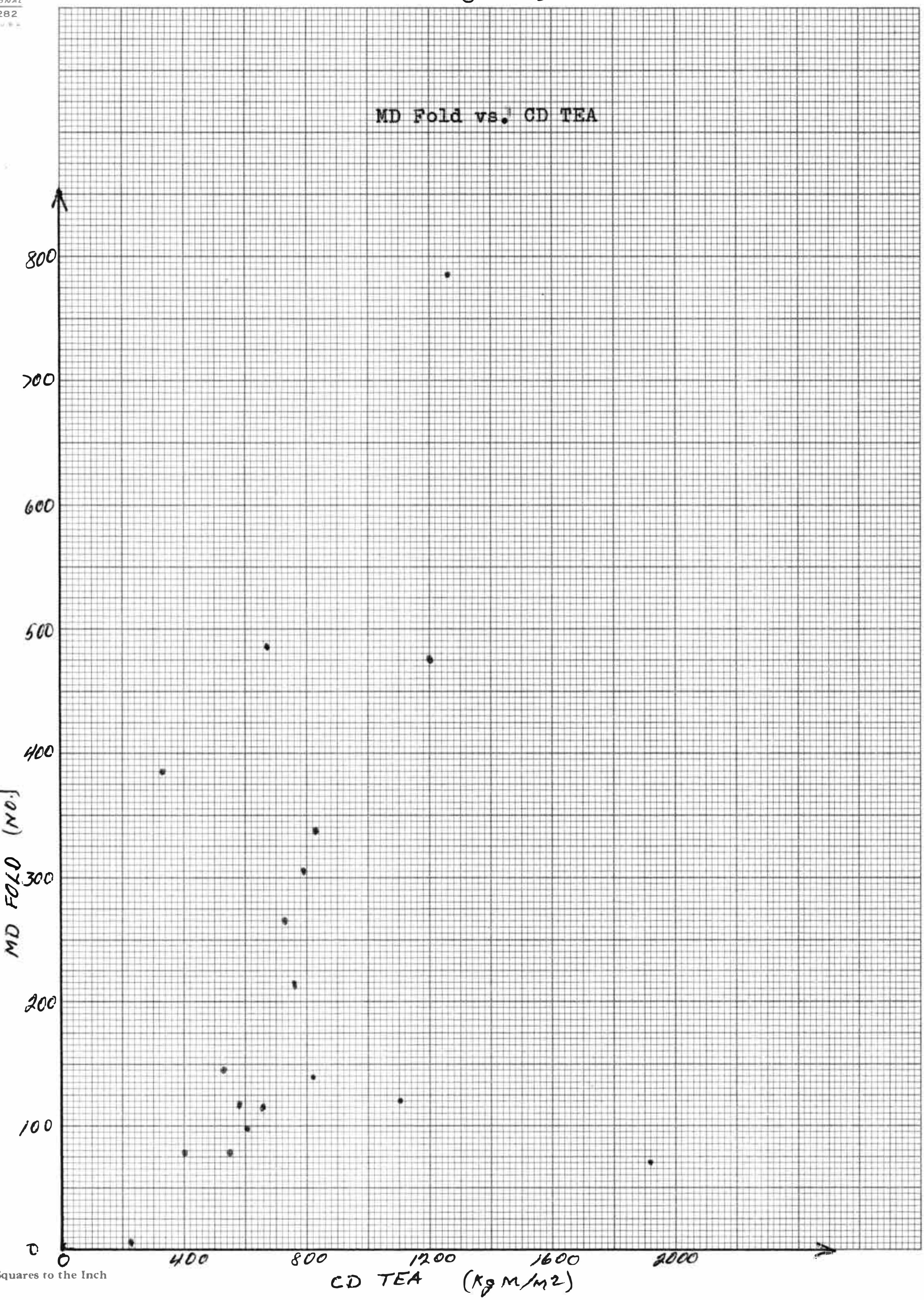

MD Fold vs. MD TEA
800
700
600
500
400
300
200
100
0
MD FOLD (NO.)
0
400
800
1200
1600
2000
MD TEA (Kgm/m2)

Figure 25



NATIONAL 12-282

20 Squares to the Inch

Figure 26

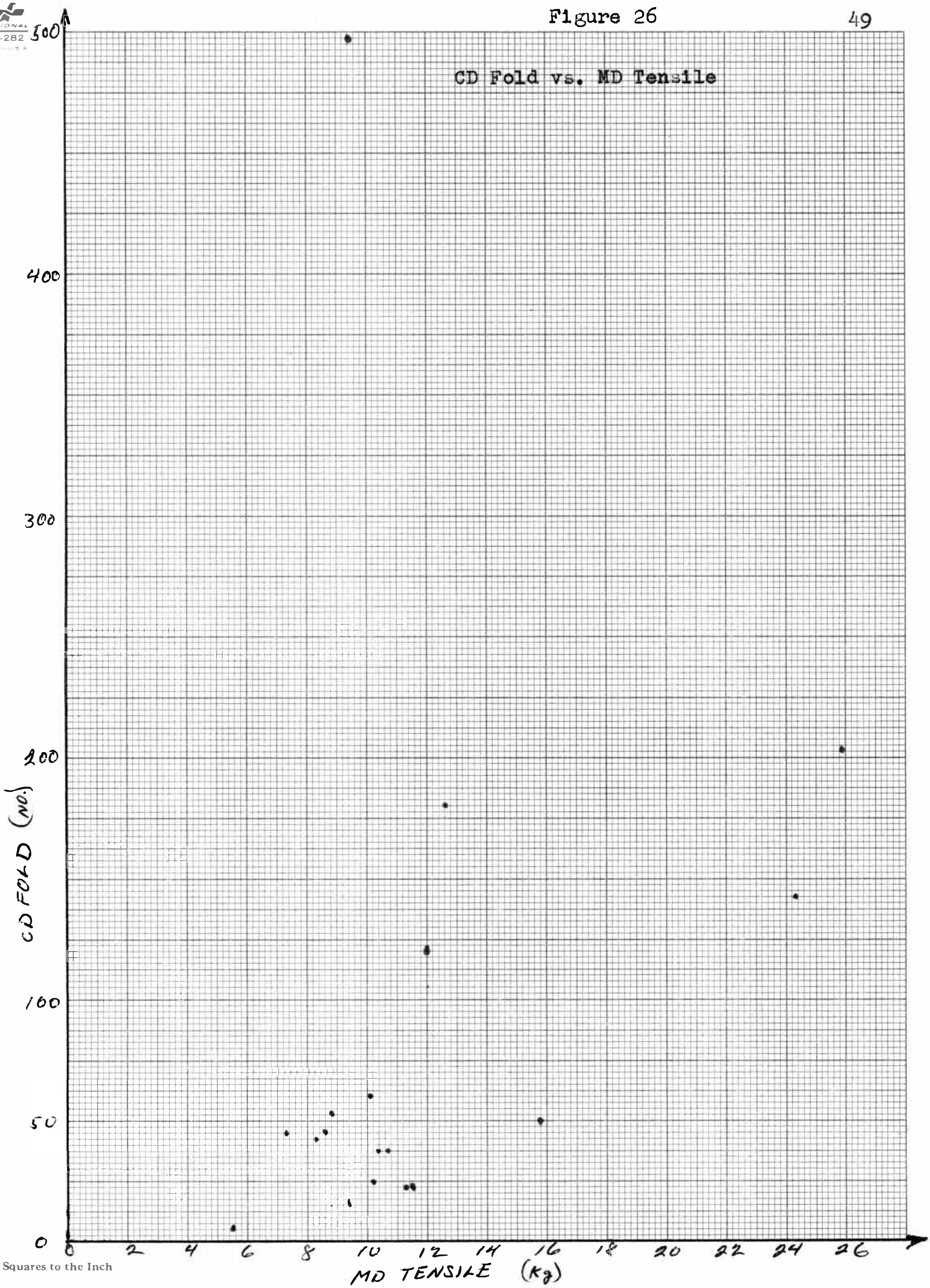
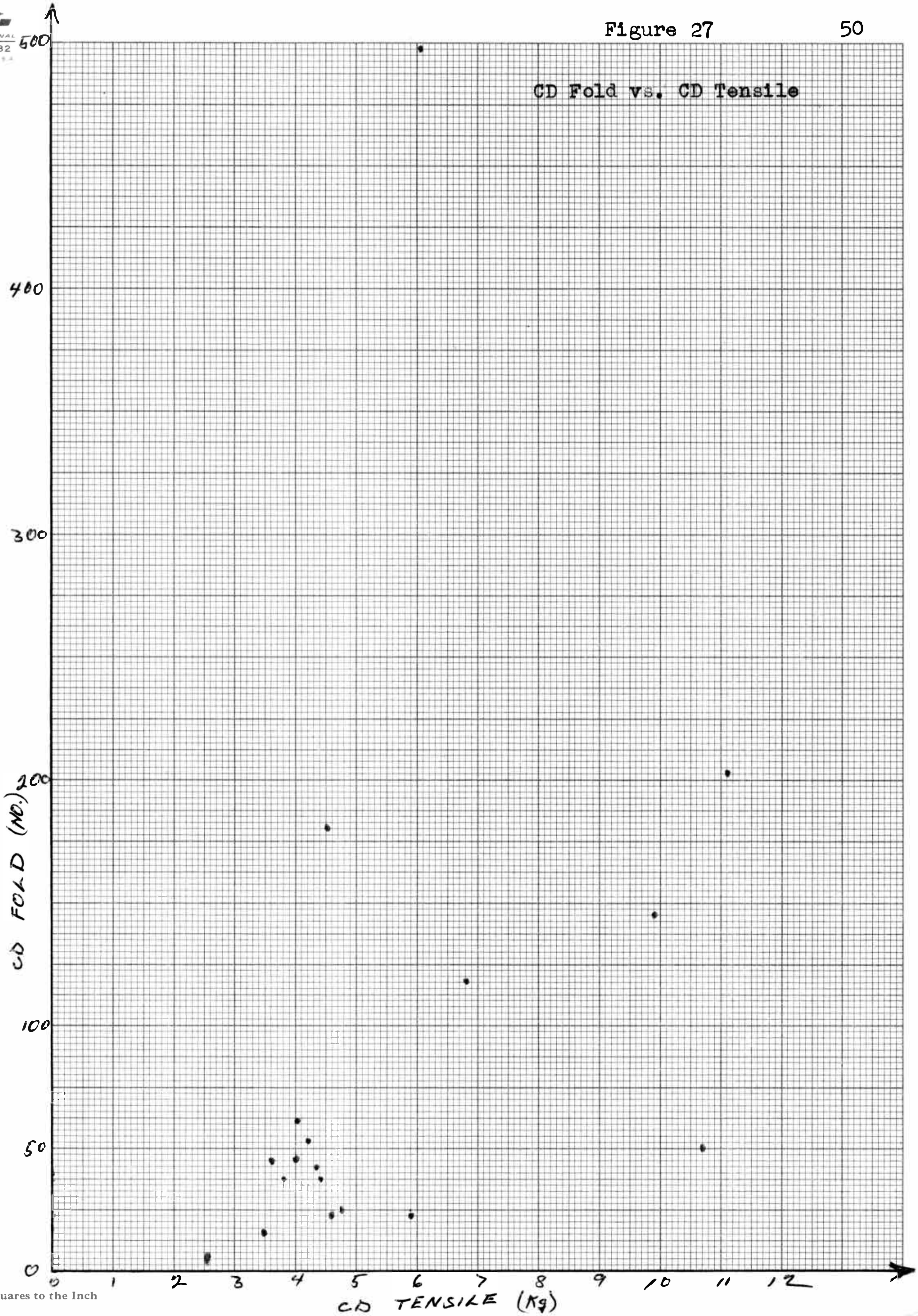

CD Fold vs. MD Tensile
CD FOLD (NO.)
MD TENSILE (Kg)
0
50
100
200
300
400
500
2
4
6
8
10
12
14
16
18
20
22
24
26

Figure 27



CD Fold vs. CD Tensile
CD FOLD (NO.)
CD TENSILE (Kg)
0
100
200
300
400
500
0
1
2
3
4
5
6
7
8
9
10
11
12

Figure 28

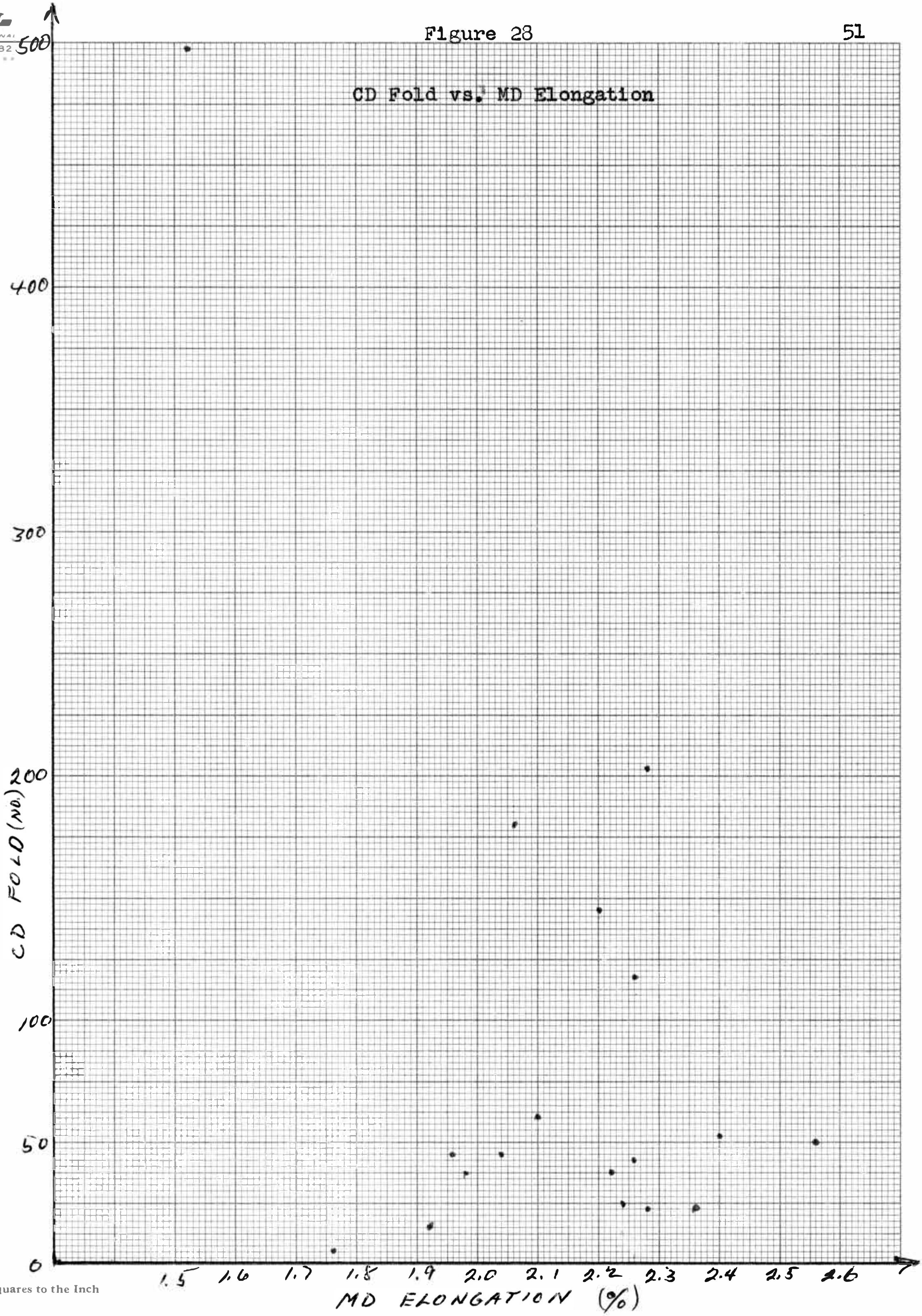

CD Fold vs. MD Elongation
CD FOLD (NO.)
500
400
300
200
100
50
0
1.5
1.6
1.7
1.8
1.9
2.0
2.1
2.2
2.3
2.4
2.5
2.6
MD ELONGATION (%)

Figure 29

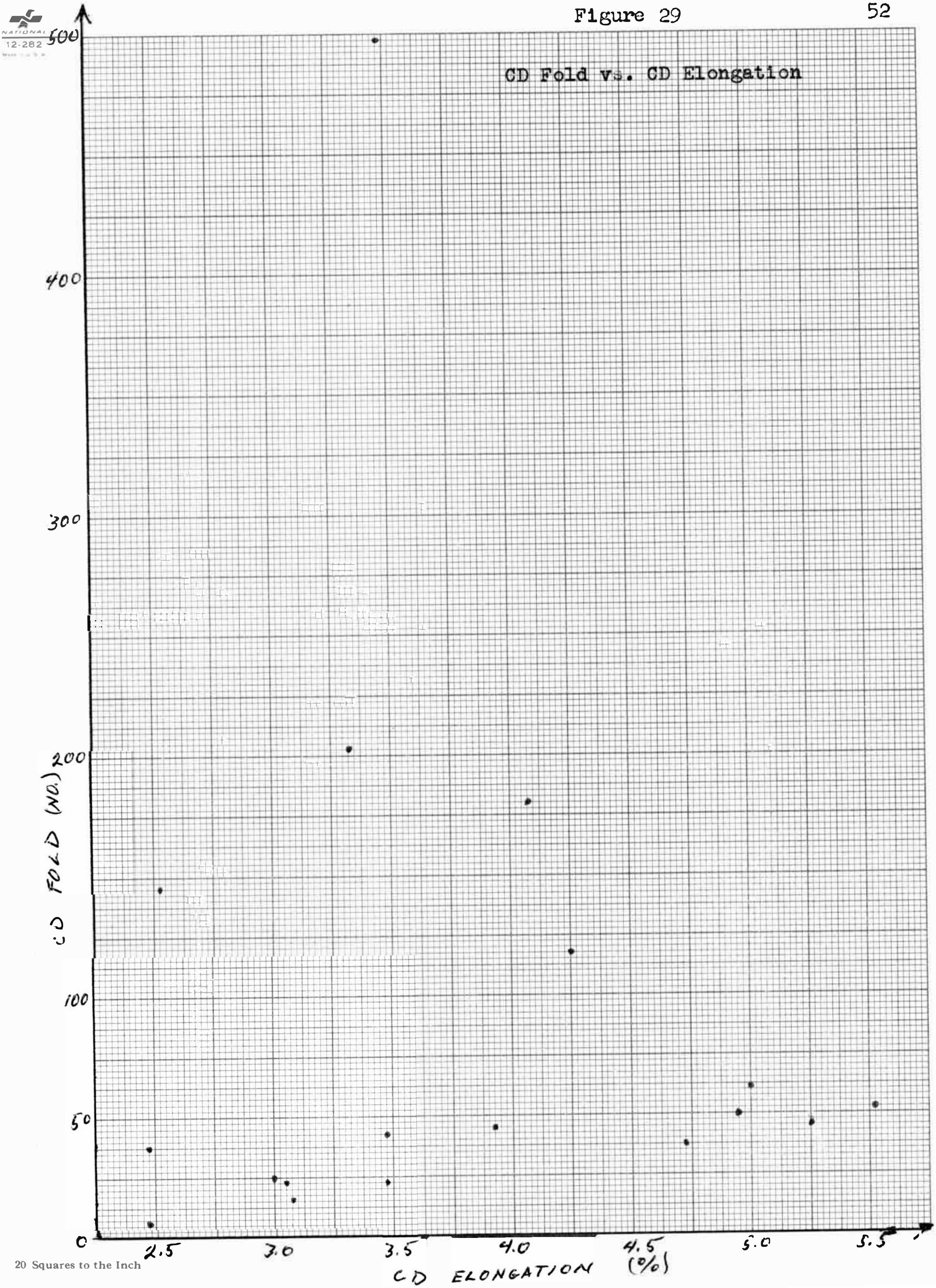

CD Fold vs. CD Elongation
500
400
300
200
100
50
0
CD FOLD (NO.)
2.5
3.0
3.5
4.0
4.5
5.0
5.5
CD ELONGATION (%)
20 Squares to the Inch
12-282

Figure 30

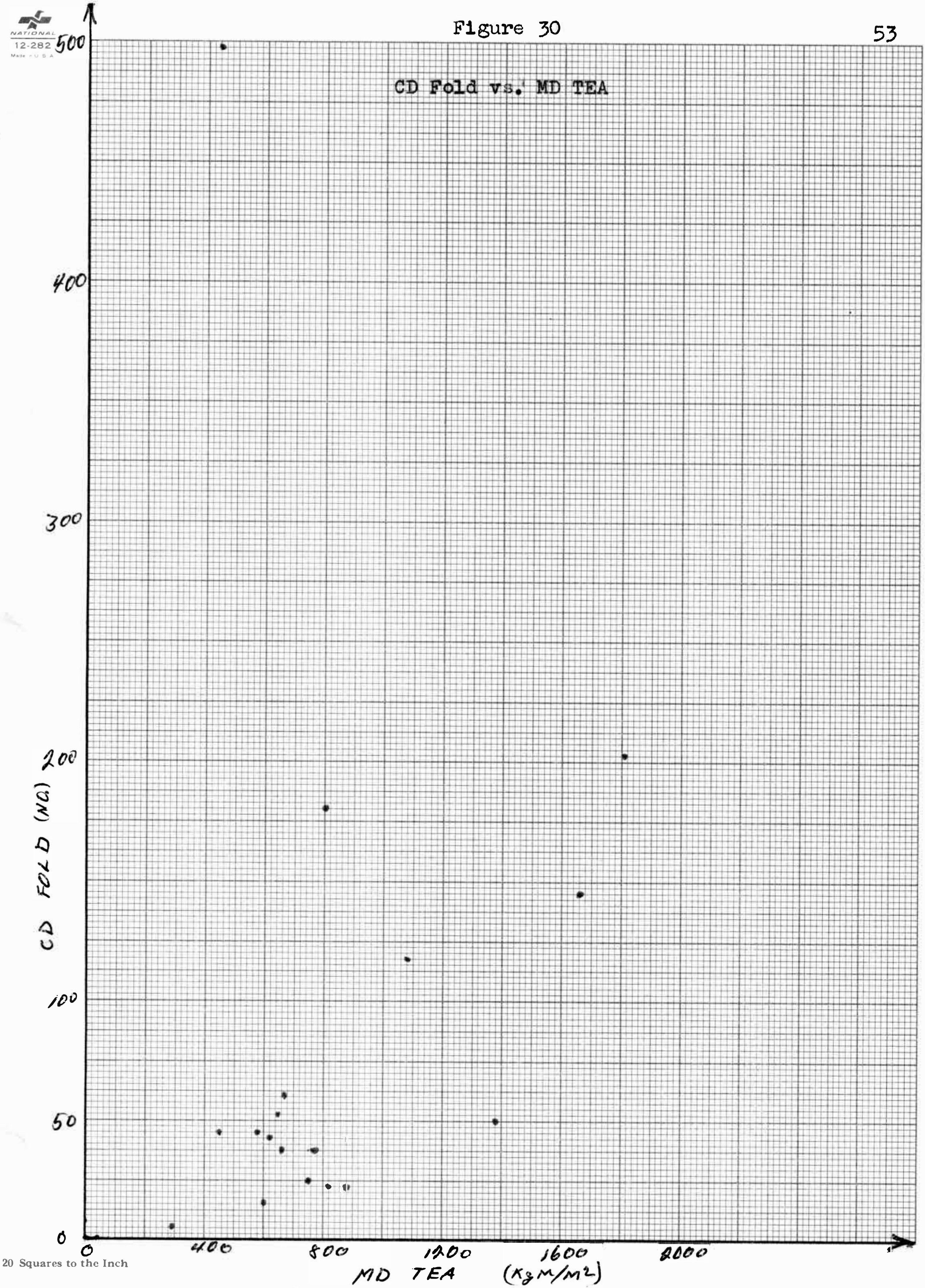
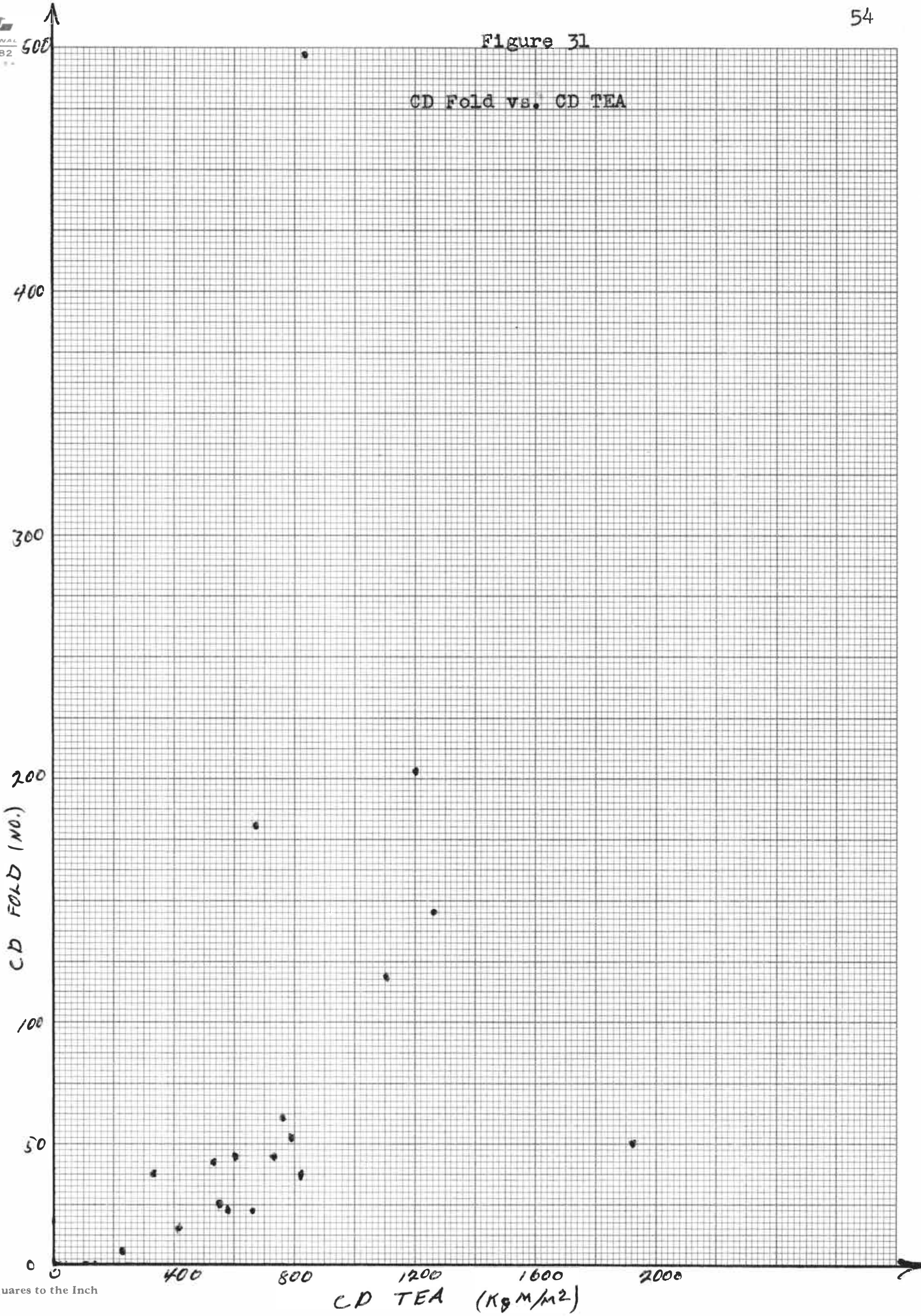

CD Fold vs. MD TEA
500
400
300
200
100
50
0
CD FOLD (NO.)
0
400
800
1200
1600
2000
MD TEA (KgM/M2)
20 Squares to the Inch

Figure 31


CD Fold vs. CD TEA
CD FOLD (NO.)
500
400
300
200
100
50
0
400
800
1200
1600
2000
CD TEA (KgM/m2)