4-1978

# The Use of Direct Measurement to Evaluate Wet Press Draws and Their Effect on Paper Properties

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# THE USE OF DIRECT MEASUREMENT TO EVALUATE WET PRESS DRAWS AND THEIR EFFECT ON PAPER PROPERTIES


By

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A Thesis Submitted to the

Faculty of the Department of

Paper Science & Engineering

in partial fulfillment

of the

Degree of Bachelor of Science


Western Michigan University
Kalamazoo, Michigan



April 1978

ABSTRACT

Previous laboratory investigations of the effects of paper machine draw tension on paper properties have been qualitative in nature. It is the object of this study to deal with quantitative values in examining the wet press area of the paper machine. Typically, by increasing draw tension machine direction tensile is improved, while elongation and cross direction tensile degrade. The establishment of known responses in paper properties to exact units in web tension would allow a control system to operate this draw area at optimum conditions. A cantilever beam force transducer was used to directly measure web tension at specific draw location in the press section.

Two fiber furnishes were used to study the effect of fiber length and fibrilar area with sheet directionality. The higher the percentage of softwood in the furnish, the more internal bonding could be oriented. The final paper properties as the draw tension between the couch and first press were inconclusive. Further studies may help substantiate the phenomenon of improved cross direction tensile and elongation. Machine direction tensile was the most improved in the draw between the first and second press at the center of the draw tension range. A water balance around the wet press together with porosity and Canadian standard freeness tests would aid in understanding the process of directionality. The water and fibril movement with respect to each other, determines the bonding site location, within the web. Straining the web after hydrogen bonding has occured, rapidly orients the bonds, relative to a similar draw tension while bonding is occuring. The critical tension is rapidly met after which degradation of strength is extreme.

Stabilization of the tension measuring device as recommended would provide exact figures of draw tension. The simplified web marking device

would provide an easy means of measuring web elongation. Substantial gains are possible in tensile and elongation properties, justifing further study in this subject.

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## INTRODUCTION

Upon examining earlier studies of the effects on sheet strength and elongation anisotropy (directionality) caused by paper machine wet end draws, the following three areas little is known. The exact measure of draw tension has not been correlated with changes seen in the final sheet anisotropy. The effect that fiber length has on the degree of anisotropy induced by draw tension has not yet been examined. The specific draw areas in the press section have not been independantly investigated as to the effects on the final strength and elongation anisotropy. The objective of this study is to establish a better understanding of these parameters to paper anisotropy.

Through a better understanding of the previously mentioned parameters optimum operation conditions can be determined for production press sections. The direct measurements of draw tension will give a quantitative value for further comparisons or industrial application. Stock makeup will determine the effective bonding area in the web, available to be alined by draw tension. Through examining the parts of the press section separately, a better understanding of the causes that sheet anisotropy is accomplished. Since each draw area has different characteristics, it is best to analyze them separately. Once an understanding of the parts are known, then their sum will be the total effect caused by the wet press section. This is true, assuming that the specific parts are independent variables.

LITERATURE REVIEW

The effects of stress on the paper web during manufacture has been questioned and studied for some time. Dry end variables were first thought to be the only cause of any anisotropy (directionality) caused by tension on the web. J. L. Gartshore agreed with this belief, in his study of burst strength with various machine draws.[1] He felt that the wet end (including presses) draw tension had no effect on the burst strength. Tensile strength and sheet extensibility (stretch) are the two parameters that determine burst strength. Therefore, it might be concluded that wet tension had no effect on these parameters.

Investigations by Carter contradicted this belief.[2] He found an increase in tensile strength after increasing tension in the draw through the press section. The increase due to the press section draw tension was sixteen percent of the total contribution of all the machine draws towards the total tensile strength increase. The mean strength of the web increase with increasing tension since the M.D. tensile increased more then the loss in C.D. tensile. Elongation of the web was noted to increase with tension, but not to the extent that tensile was effected.

This might explain why Gartshore saw no affect of wet tension on burst strength. Since burst is a measure of tensile and stretch, the increase in tensile gained by the web stress is balanced by the loss of stretch due to elongation of the web. Also, since the wet end draw tension contributes a small percentage (16% approximately) to the total strength anisotropy of the paper, it can be seen how it might be overlooked.

Cottrall agreed with Gartshore that the wet end tension has a negligable effect on burst and also tear, over a wide range of tensions.[3]

Various explanations have been postulated as to the cause of the general observed results of wet web tension. Namely, as wet web tension increases tensile increases to a point, and stretch drops off due to elongation in the web. The early workers in the area of anisotropy attributed this property to the orientation of the fibers along the direction of stress. M.D. Carter associated his finding of a disproportionate increase in strength due to fiber orientation.[2]

It appeared to Roberts and Bailey that the rolling action of the presses and/or the stretching of the paper between the draws had the effect of orienting the fibers.[4] This phenomenon is analogous to the increase in strength obtained by spinning artificial silk under tension.

This theory of fiber orientation went unchallenged for some time. H.F. Rance argues that even a ten percent stretch will not cause much change in gross fiber orientation.[5] Qualitatively, it seems reasonable that fiber orientation would cause strength anisotropy looking at the obvious effects it has on wet expansion anisotropy (curl is seen when a sheet is wet on one side). Rance also points out the limited quantitative knowledge in this area.

Experimental work of Maynard and Newman attempted to establish quantitative values to expansion anisotropy to fiber orientation.[6] No support was found that a gross fiber orientation could seriously increase any of the anisotropies of the finished paper.

It was then suggested that fibril orientation caused in the action from the couch to the first dryer resulted in the observed anisotropy of strength. Since the fibril area constitutes the bonding area in the sheet, it could be seen that a small shift in fibril orientation would result in bond directionality (anisotropy of strength).

Several mechanisms for this fibril orientation were suggested. The

most basic is the stretching of the web induces a small relative motion of the fibers in relation to one another which would cause a large orientation of their fibrils along the line of stress. Breitueit postulates that the flow of water from the pressed entrains and orients the micro-fibrils.[7] This is substantiated by the relative small anisotropy caused by experimental wet straining compared to that realized in the paper machine press section.

Danielson and Steenburg used fiber tagging to observe fiber orientation on the paper machine.[8] Samples were taken at different places along the machine. The combing action of the wire was found to be the chief cause of fiber orientation. However, the samples taken from the wire showed less anisotropy compared to the anisotropy developed in samples after the press section. This clearly contradicts the theory that fiber orientation is the sole cause of sheet anisotropy. For if this were true, then samples taken from the wire would have more directionality than the samples just after the presses. But just the opposite was found to be true, as shown in studies like that of Carter's values seen of Table I. Clearly proposing that the fiber orientation has little effect on anisotropy.

TABLE I

Alteration in Tensile Strength and Ratio

| | M.D. | C.D. | MEAN | RATIO |
|---|---|---|---|---|
| Just after slices | 8.88 | 8.36 | 8.62 | 1.063:1 |
| Just before boxes | 9.72 | 6.81 | 8.26 | 1.428:1 |
| After boxes | 9.62 | 6.58 | 8.10 | 1.462:1 |
| After suction couch | 12.10 | 7.75 | 9.92 | 1.56:1 |
| After presses | 14.00 | 8.29 | 11.14 | 1.69:1 |
| After cylinders | 27.47 | 14.93 | 21.20 | 1.84:1 |
| After air dryers | 32.38 | 16.60 | 24.59 | 1.962:1 |

Steenburg, Berkley and Barker, Landt and Rulon suggest that fibrils may become preferentially oriented when the sheet is stretched.[9,10,11] This would tend to orient the internal bonding site along the line of tension, increasing the sheet strength along this line at the expense of cross direction strength.

Corte and Schazchek went one step further in purposing that hydrogen bonds are oriented by stretching the sheet, giving anisotropy of strength along the line of tension.[12] The reasoning is that the bonding orientation is the primary factor in strength anisotropy since evidence in testing of the tensile theory has shown that tensile strength rarely exceeds one third the strength of an individual fiber. This would leave the limiting factor as bond strength in determining tensile strength. Bonding area and orientation would then tend to indicate the sheet strength anisotropy.

Van der Akker postulates that in the elongation of the wet web in which the bonds are in a relative plastic state, causes these fibrous elements between points of bonds to become straighter.[13] Further, when the paper dries, this condition becomes frozen in. This action of sliding fibers seems to increase the equalization of distribution of stress in the sheet when it's under tension. Imparting an increase in tensile strength and loss in stretching ability since the bends and kinks between bonds are straightened and froze in that position resulting in less extension. The straightened fiber-fibril systems in sheet, lead to a more evenly distributed stress when a load is applied, increasing the load is possible before failure.

This action passes through a point where improvement is halted and the effect is reversed. The fibers relative movement is then disrupting the sheet, resulting in decreasing the bonded area and the tendency for the stress distribution to be less uniform. This means the draw tension as it increases, improves tensile strength to a critical point, where it begins to drop off. The trend for stretch with increasing wet end draw tension is that it continues to decrease due to the froze in stiffness of the sheet. When the tension passes through the critical point, stretch would sharply drop off due to a decrease in bonding strength.

# EXPERIMENTAL PROCEDURE

## Apparatus Selection

To meet the demands of measuring draw tension at different points in the press section, the device must have the following characteristics: 1) accurately measure tensions, 2) be easily portable to the different test points, and 3) cheap to manufacture.

One apparatus that fits these requirements is the cantilever beam arrangement as diagramed in Figure 1. The beam measures the applied force by the change in resistance of strain gages attached near the fulcrum point. Resistance change of the strain gage is accurately measured by placing them in the active and compensating arms of the unbalanced wheatstone bridge circuit of the BAM-1. Actually, only one stain gage in the active arm and would be adequate, but the use of two gages doubles the sensitivity. The second compensating gage contributes in the same direction as the first, thus amplifying the change in resistance.

Calibration of the cantilever beam to measure the vertical force per linear foot of a draw is accomplished using calibrated weights as point sources. The comparison of shear and moment diagrams proves that this method wil duplicate the continuous loading of the beam as it actually will be used in the draw measurements. The final geometry of the beam with respect to the web during the machine run was different than when it was first calibrated. The correction factor for this is formulated on pg. 23. The use of calibrated weights to duplicate actual distributed loading is discussed on pg. 22.

Copper tubing was selected as the cantilever beam for the following reasons: 1) the rounded surface would be less likely to cause a web break, 2) it would be more flexible than a solid rod, and 3) the tubing could be selected from three readily accessable materials; iron, copper, and aluminum. An approximate value of 160 gr./in. was given as the wet web

breaking force. This calculates to 4.25 lb./ft. and was used as the upper calibration limit. Aluminum tubing under this loading would be permanately distorted. Copper tubing could hold this load and was more sensitive than iron tubing therefore, copper was used.

The sliding holder was the key to the versatility of the web tension measuring device. The horizontal length of the beams extention together with the vertical control along the base pole, could be adjusted to suit each particular areas geometric requirements. This dynamic ability allowed the web tension to be measured at the desired locations.

A web marking device was also constructed. It would be interesting to see how the sheet is stretched by each of the press draws singularly. It was hoped that this device would leave parallel rows of evenly spaced dots that could be used to measure both machine and cross direction web stretch.

The device consisted of an inverted flask filled with dye connected to five eye droppers through a maize of rubber and glass tubing, Figure 2. The flow of the droppers was controlled by adjusting the air flow to the top of the flask with a small valve. The eye dropper nozzles were evenly spaced along a bar across the front of the first press. The machine and cross machine distances between a constant set of evenly dots could be measured at the point of application then at different points through the press section. The difference in measured distance would constitute the stretch in the web.

Machine Run

The pilot paper machine at the Paper Science and Engineering Department of Western Michigan University, was used for this study. The variables that were kept constant were the following: Stock a) beating time b) PH 4.5-5.0 c) Rosin-3/4% d) Alum-2%; Machine a) speed-60 ft/min. b) dryer section draws

c) size press, not used, d) B.W.T. #40.5 (25 x 38 - 500). The only variables changed were the fiber furnishes, 60% bleached popular for the first run, and 60% bleached pine for the second run (the remaining percent was S.W. or H.W.). The draws that were individually changed while the remaining were at a normal load, were: 1) Couch to the first press (C-1p), 2) first press to the second press (1p-2p), and 3) second press to the first dryer section (2p-1d).

The sequence of draw measurements was the same for both furnishes. After the machine had stabilized to the Tappi standard basis weight of 60 gr./$m^2$ or #40.5 (25 x 38 - 500), the draw measurements began. Starting with the draw between the second press and the first dryer section, the cantilever beam apparatus was brought up into contact with the web. The draw was then adjusted to where it would almost break (and several times it did break). Even contact with the web along the beam was checked. The high tension reading was zeroed on the SCR, recording the strain gage chance from the BAM-1 output.

The draw tension was decreased stepwise, each change being marked on the web, then tagged at the reel. This was continued until the tension reading did not change or the web started to follow around a press roll. This process was followed individually back down the machine at the (1p-2p) and (C-1p) draw positions. Tension at the (C-1p) was started at slack draw then increased until a break occured during the first run. For the rest of the draws during the entire second run, draw changes went from high tension to slack draw.

Problems that occured as a result of apparatus design, were clearly revealed during the machine run. The web marking device provided a sporatic and uncontrolled discharge of dye. It was either a steady stream or non-uniform drops from only a few of the nozzles. The problem was that the

head of dye behind the nozzles could not be controlled simply by adjusting the air flow to the top of the flask. When enough air was allowed to flow into the flask, the headers to the nozzles were unevenly filled causing all the dye to go to a single nozzle and at a rate which would provide a steady flow. Basically, the system was not stable enough for such a small continuous flow. A more reliable system would be a reservoir and single pipe arrangement. The pipe would have carefully drilled holes along it, whose diameter for a corresponding liquid head would meter the dye to the web. Schematic shown in Figure 3.

The web tension device also had an inherent flaw. The drag of the web across the copper tube caused the beam to vibrate in the same plane as the web. This vibration caused the tension readings to fluctuate accordingly. The vibrations could be stabilized by holding the beam holder. A permanent solution to the problem would be to eliminate this movement about the axis of the base pole. The flexibility of the pipe alone would limit the amount of vibration that could be eliminated by strengthening the base half of the apparatus. This would be accomplished by attaching tripod looking supports extending from the base to the vertical pole.

Data Collection

The two paper rolls from the two runs were slabbed down and placed in the constant humidity room. The samples were cut into 25" by 38" booklets comprising four sheets from the center of the slabbed sheets (the 38" side in the machine direction). Time limited the number of booklets made to approximately eighty per run. Careful attention was made to sheet direction and the tags marking the draw changes and positions. Each booklet was weighed giving the four sheets an average basis weight.

Tensile samples were cut from each booklet in as close to the same position as possible. This was done so that the machine direction tensile

would be from the same position in the web. Hopefully, this would eliminate any variation in strength due to differential stretch of across the web, and the possible variation in basis weight across the web. Of course the position of the cross direction sample has no importance since it is completely random. Samples were then tested according to Tappi Stds. on the Instron tensile-elongation tester.

The tensile strength and T.E.A. (Tensile Elongation Absorbtion) were measured with the Instron. The T.E.A. ($Kgm/m^2$) was recorded using the integration capability of the Instron since this value is more meaningful then elongation, which does not take into account the loading, only the stretch/unit area ($m/m^2$).

Burst samples were taken from one sheet of each booklet and performed according to Tappi standards. The sheet selection from the booklet was based on which sample looked most uniform (unwrinkled, no shives, etc...).

The basis weight values for each booklet were used to linearly adjust the tensile, burst and elongation values to the standard 40.5 lb. ream. This was done by dividing 40.5 by the specific booklet basis weight and multiplying that factor by the average M.D. tensile values for that booklet. This would be repeated for the other data average values of burst and elongation. By adjusting for slight basis weight fluctuations, this variable might be eliminated.

These adjusted values were pooled together into groups of two or four booklet values whose average value was taken again. This was done to condense the data to smaller groups within the step changes in draw at each specific press area. This gave the average values of the samples between each step change in draw. The date was correlated with the draw tension ranges for the specific draw areas. This analysis was performed using standard statistical regression formulas to find the best fitting lines. Condensing in this way aided in the plotting of the graphs seen in Figures 4 thru 21.

Averaging the groups of booklet values in this way could tend to smooth out the important inflection points at critical draw values. The vibration problem with the tension measuring device removed the possibility of recording a specific value. General trends will instead be looked at with respect to the range in draw tension which was recordable.

## RESULTS PRESENTATION

### First Pilot Paper Machine Run

The presentation of data will begin with the first pilot paper machine run consisting of the sixty percent hardwood and forty percent softwood furnish, Table II. The draw tension for the couch to first press area ranged approximately eighteen grams/linear foot. Cross direction and machine direction T.E.A. decreased directly seventeen and thirty percent, respectively, as the draw tension was increased to the maximum eighteen grams/linear foot value. Cross direction T.E.A. remained greater than machine direction T.E.A. over the entire draw change. The trend for burst values increased fourteen percent then decreased to the original value symmetrically about the nine gr./lin. ft. draw tension.

The draw between the first and second press was changed by approximately twelve gr./lin. ft. Machine direction tensile increased five percent sharply up to four gr./lin. ft., then steadily increasing to the twelve gr./lin. ft. draw tension for a total of six percent increase in tensile. Cross direction tensile decreased directly by eleven percent of it's original value during the increasing draw range. T.E.A. increased thirty-one percent up to the four gr./lin. ft. value of draw tension, then remained unchanged over the remainder of the draw tension increase. Cross direction T.E.A. decreased twenty percent as a result of increased draw tension. Burst values decreased sharply by eight percent to an inflection point of approximately six gr./lin. ft., where the curve then increased ten percent at the maximum draw tension.

The last draw section to be examined of the first pilot machine run is the draw between the second press and the first dryer section. The draw range that could be accomplished was relatively small being approximately six gr./lin. ft. Machine direction and cross direction tensile decreased three percent and nine percent respectively, as draw tension increased.

The T.E.A. values in the machine direction were decreased by twenty percent of the original value over the draw range. The values for cross direction T.E.A. were correlated with draw tension with not enough significance to base any conclusions. Burst took a dramatic decrease of twenty-three percent as the draw tension was increased to the six gr./lin. ft. maximum.

Second Pilot Paper Machine Run

In this section the resulting data from the second machine run consisting of sixty percent softwood and forty percent hardwood furnish will be considered, Table III. Dealing first with the couch to first press draw area, whose draw tension range was twenty-six gr./lin. ft., the following trends were found. Machine direction tensile indicated no clear cut relationship with draw tension. Cross direction tensile increased ten percent up to the ten gr./lin. ft. draw tension then gradually decreased three percent over the remaining draw range. Machine direction T.E.A. values had a parabolic looking relationship, it increased twenty-eight percent to a peak about the seventeen gr./lin. ft. point, then decreased twenty-two percent. Cross direction T.E.A. was directly related to draw tension as it increased eleven percent as a result of the increased draw tension. Burst values increased by three percent to the ten gr./lin. ft. draw tension value then decreased linearly by ten percent with respect to the increased draw tension.

The second area to be examined is the draw between the first and second press. The largest draw range of the entire experiment was in this area, being approximately fifty gr./lin. ft. Machine direction tensile followed a parabolic function of draw tension, increasing fourteen percent by twenty-five gr./lin. ft,, then decreasing seven percent over the remainder of the draw tension increase. Cross direction tensile decreased sharply by seventeen percent at a ten gr./lin. ft. draw tension, then it gradually decreased four percent further at maximum draw tension. Machine direction

T.E.A. values steadily decreased directly by twenty percent with respect to the increased craw tension range. Cross direction T.E.A. values indicated a four percent increase as the draw tension is increased. This relationships correlation coefficient was 0.43, indicating that the data deviations about the best fitting line were wide. Burst values follow a parabolic function with respect to draw tension. Burst values increased seven percent for a twenty-five gr./lin. ft. draw tension then decreased nine percent as the draw tension is increased to the maximum fifty gr./lin. ft. point.

The final section's data presented is from the draw area between the second press and first dryer section. The draw tension range was six gr./lin. ft. in this area. Machine direction tensile had a parabolic looking function with draw tension increasing six percent for a maximum at three gr./lin. ft. draw tension, then decreasing over the remaining draw. Cross direction tensile values remained stable through out the draw tension increase. Burst values exhibited a similar parabolic trend as a function of draw tension. Burst increased six percent to an inflection point at the two gr./lin. ft. draw tension value then decreased ten percent at the maximum draw tension. Machine direction T.E.A. was directly a function of draw tension, decreasing twenty percent as the draw tension increased to the maximum point.

DISCUSSION OF RESULTS

The results of the first machine run consisting of the sixty percent hardwood and forty percent softwood furnish, will be discussed first. The data from the draw between the couch and first press agreed for the most part with previous studies. Typically machine direction tensile should increase at the expense of cross direction tensile. However, in this case, machine direction tensile decreased two percent as draw tension was increased. This inconsistancy is corrected by the burst trend which indicates an increase of machine direction tensile since elongation is clearly decreasing as seen in the thirty percent T.E.A. decline. The known correlation of machine direction tensile and burst together with the steepness of the burst curve, would tend to lower the significance of the slight trend of only a two percent change shown in machine direction tensile. The actual machine direction tensile trend was lost in the averaging of results or some unknown variable has entered in.

In the second draw area between the first and second press, the trends of tensile are seen as what would be expected as increased draw tension causes microfibril bond orientation in the machine direction. It is interesting to note the parallel trends of machine direction tensile and T.E.A.. Elongation in the machine direction has not been deminished enough to effect the T.E.A. function from following the tensile trend. The burst inflection point occurs near the draw tension stabilization point for tensile and T.E.A.

Considering the water movement in the web near the press nip, it would be possible to increase the machine direction elongation as well as tensile. Water near the center of the web flowing to the surface could move fibrils in the same direction. The increasing draw tension that brings the fibers

within the web together would reduce the spaces between the fibers. This would increase the hydraulic pressure or velocity of water flow in the cross plane direction. By causing bonds to be formed perpendicular to the line of force, the elongation of the paper is increased. Bonds are formed in the machine direction as well since the fibrils would not be swepted completely to ninety degrees with respect to the web plane.

The last section to be examined on the first machine run is the draw area between the second press and first dryer section. The beneficial bonding site orientation accomplished in the ealier sections is not allowed to happen because of the moisture content of the web. From earlier studies on the pilot paper machine at Western Michigan University, solids leaving the second press is approximately thirty-seven to forty-two percent for a standard 40.5 lb. basis weight. The critical bonding distance is thought to occur when the web is in the thirty to thirty-five percent solids region. In this area of moisture, the water molecules are drawn out from between the fibrils and they become close enough to form hydrogen bonding. This had already occured by the time the web reaches the second press to the first dryer section draw area. The draw tension, instead of orienting the microfibrils before bonding occurs, tears some of these existing bonds. The result is clearly seen, as a severe drop in tensile and burst over a slight change in draw tension.

Considering the results of the second machine run consisting of sixty percent softwood and forty percent hardwood, the discussion will begin in the couch to first press draw area. One abnormal response of these results to draw change was the ten percent increase in cross direction tensile as the draw tension was increased to ten gr./lin ft. The second unusual trend was with cross direction T.E.A. which increased as draw tension increased.

The long sofwood fibers are predominate in the web, and lay primarily in the machine direction. The fibrils are longer and are more prevalent in this furnish than the previous, allowing the following to happen more readily. In the plastic state of the web between the couch and first press, the draw tension causes the microfibrils to move relative to each other. The microfibrils are swepted from a radial position, that was caused by the water flow to the wire, to a more parallel one. The sweeping action of these fibrils provides more surface area for bonding between the parallel fibers. This process also causes them to come together closer for a more intimate contact. The result is an increase in cross machine tensile.

Cross direction elongation can also be seen to increase as a result of this sweeping action. As a cross direction load is applied, the parallel fibers are allowed to separate without breaking fibril bonds by pivoting microfibrils at their base which is attached to the fibril. The fibrils are in effect straightened until they are like the preswept condition.

Analyzing the results of the draw between the first and second press showed only one deviation from the normal response, in the cross direction T.E.A. This trend increased for a draw tension increase and had a low correlation coefficient. The correlation of the function with draw tension can not be heavily relied on for that reason. Tensile in the machine direction reaches a maximum at the corresponding draw tension that burst maximizes. This tends to indicate that burst is more dependent on machine direction tensile than elongation.

Despite the small range in draw tension in the second press to the first dryer section, the changes in strength and elongation properties were drastic. Maximum values were quickly reached then dropped off sharply with respect to the draw ranges in other sections. The trends were essentially

the same as commonly known results. The solidity of the C.D. tensile values indicates no effect by the small draw tension change. This effect could allow a total increase in tensile and burst strength at the optimum draw tension and the only expense being an elongation loss.

The sharpness of the previously mentioned responses is a result of existing bonds in the web before the web enters the draw between the second press and first dryer section. Relative movement between the fibrils is limited because of the bonds joining them together. The result is that bond orientation is quickly established with little tension and similarly broken down when the critical tension is exceeded.

CONCLUSIONS

The final sheet properties as a function of draw tension in between the couch to first press were inconclusive. Burst and machine direction tensile displayed opposite trends with respect to each other. T.E.A. values exhibited similar incongruent results. It has been postulated that the sweeping action of the microfibrils in the plastic state enhances the total amount of bond area. This would allow an increase in cross direction and elongation as well as orient bonds along the machine direction. The increased number of softwood fibers in the web improves the probability of this phenomenon, by providing more microfibrilar area than short hardwood fibers.

Machine direction tensile was improved the most at an optimum draw tension in the section between the first and second press. The optimum draw tension for both furnishes was near the center of the draw tension range. The moisture content and water removal is influential in this section of the press for two reasons. Stretching the web near the moisture that hydrogen bonding is occuring, more sites are accomplished. Water being removed from the web at the press nip directs microfibrils between the planes of fiber facilitates this hydraulic action.

Draw tension was the most critical between the second press and first dryer for both furnishes. No benefits were seen by increasing draw tension for the 60% hardwood furnish. The lack of fibrilar area allowed bond degradation, instead of orientation. The 60% softwood furnish, paper properties rapidly improved then degradation occured as in the previous furnish, when draw tension increased. When the bonds within the web are set, only a slight amount of draw tension is needed to orient then along the line of stress.

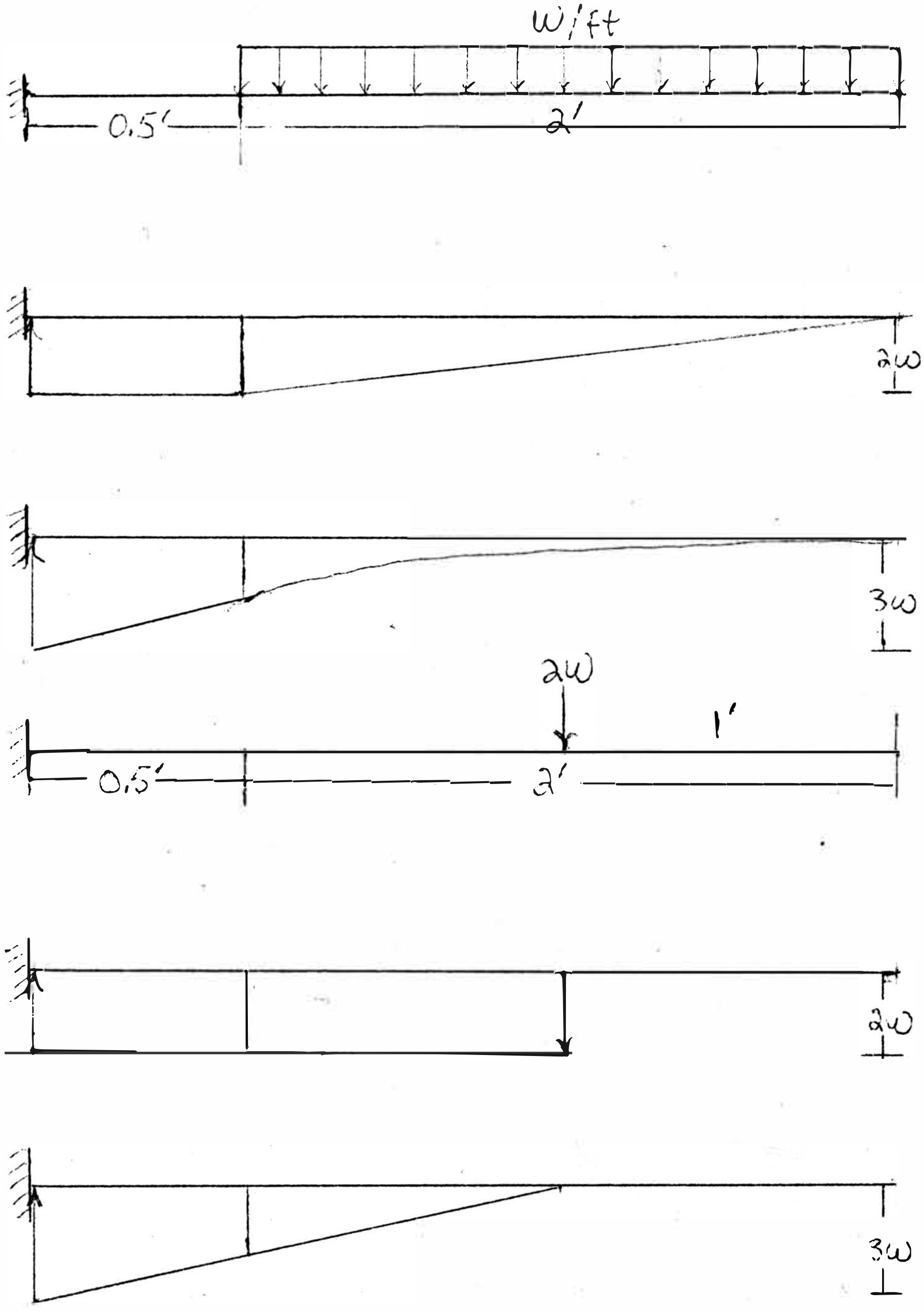
## RECOMMENDATIONS

The recommendations for industrial usage of this studies findings are limited because of the preliminary nature of this study. There were more variables encountered than previously known at the begining of research. Further study should include a water balance around the press section to get a handle on the water flows in the different areas in the press section. Porosity of samples taken from various areas along the press section would give some indication of the closing up of the web due to increased wet tension. Finally, Canadian standard freeness tests should be made of the stock used.

Improvements in the existing tension measuring device would be along the line of stabilization. Tripod like supports extending from the base plate to pole would help. A vertical slot guide for the extreme end of the contilever tube would eliminate most horizontal oscillation. The recommended web marking device would be as illustrated in Figure 3.

Cantilever Beam As a Force Transducer

Comparing Actual Continuous Load With Point Source Weights




Actual Loading

Shear

Moment

Calibration Geometry

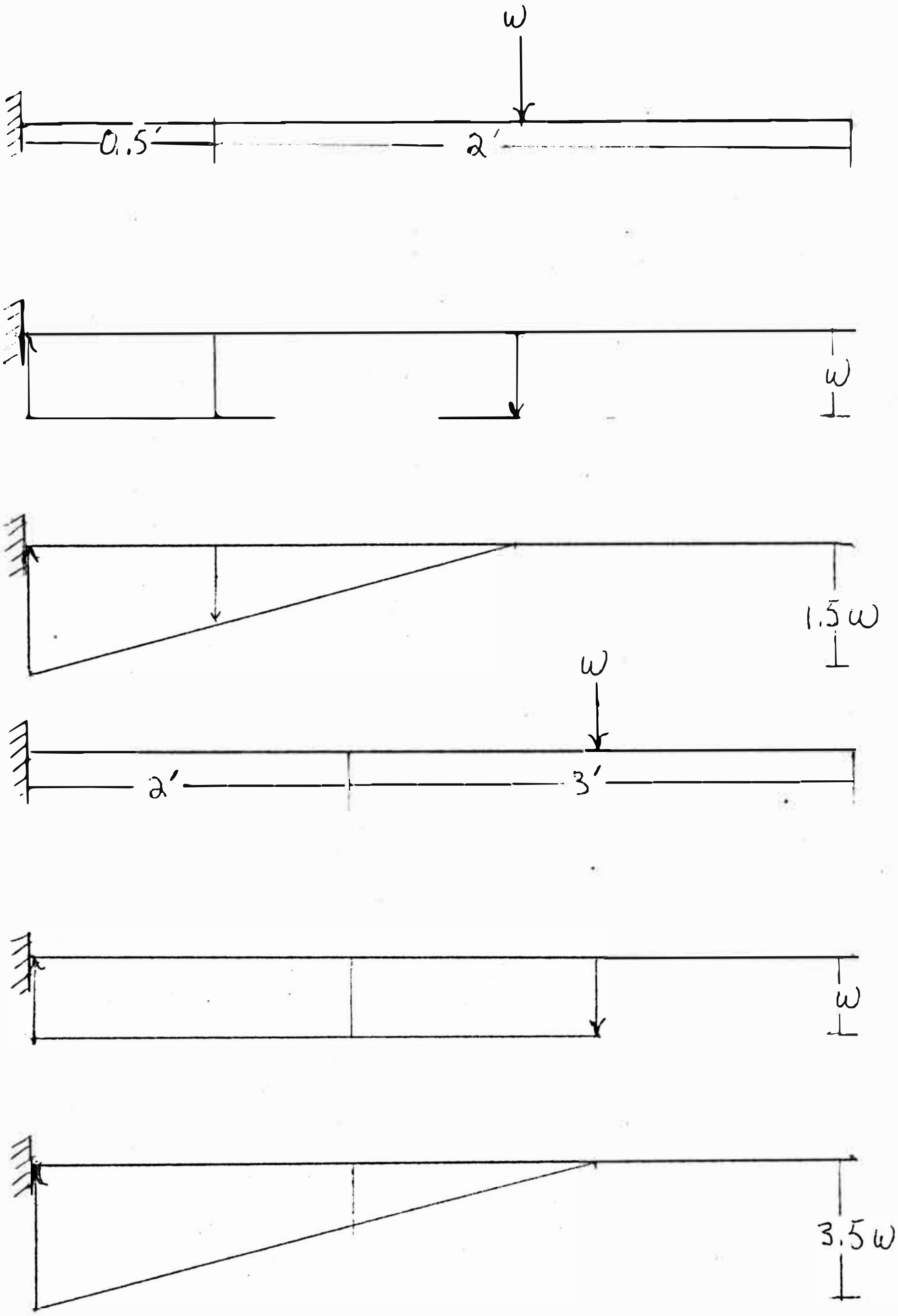
Shear

Moment

Shear and Moment are the same at fulcrum point, therefore point sources can be used to calibrate for actual loading conditions.

Calculations of Length Factor

Comparing Calibration to Actual Run Geometry




Calibrated Dimensions

Shear

Moment

Actual Run Dimensions

Shear

Moment

Shear is the same for both dimensions
Length factor = 1.5/3.5 = 0.43
Length factor x calibration reading = actual force

SCHEMATIC DIAGRAMS OF APPARATUS

Schematic of Web Tension Measuring Device

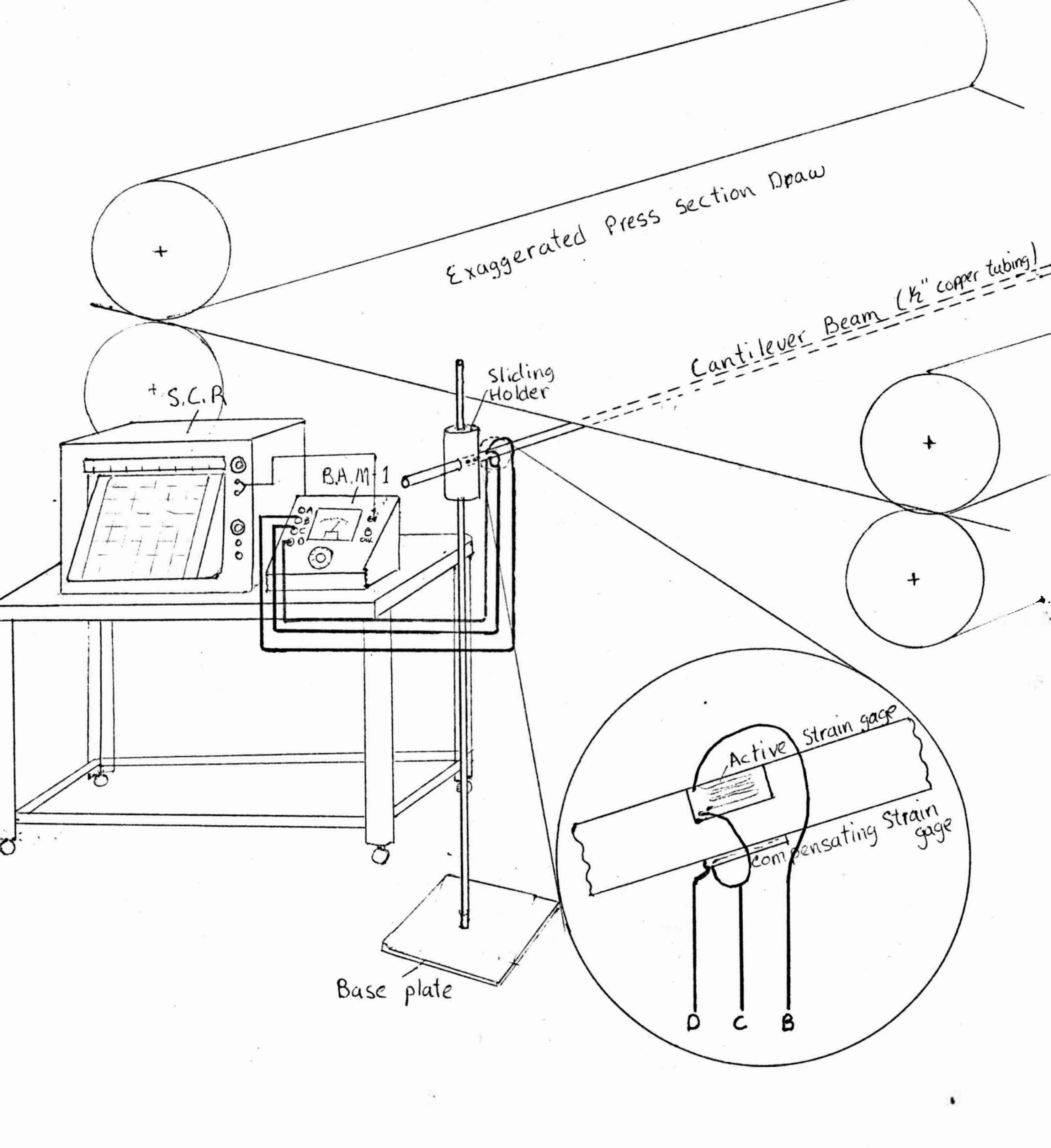



Figure 1

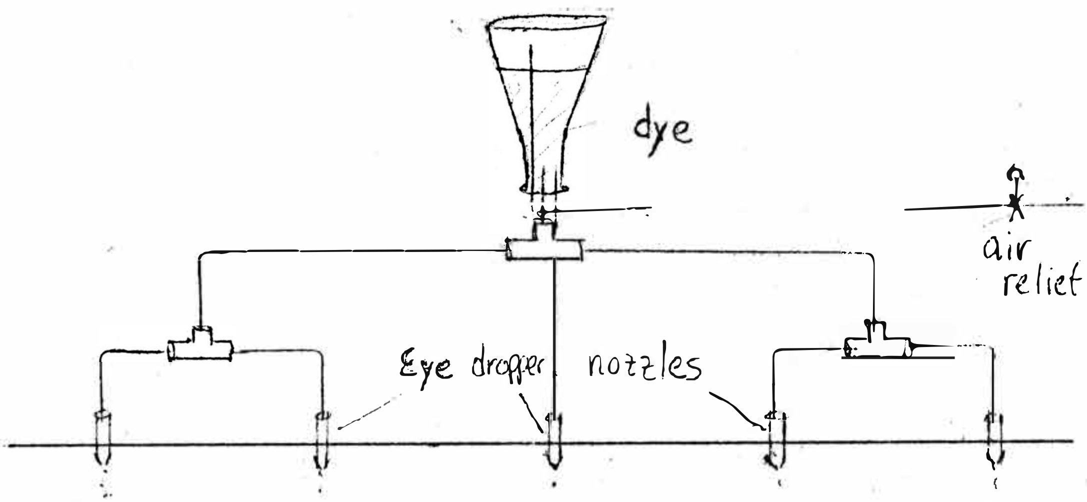



**Figure 2**

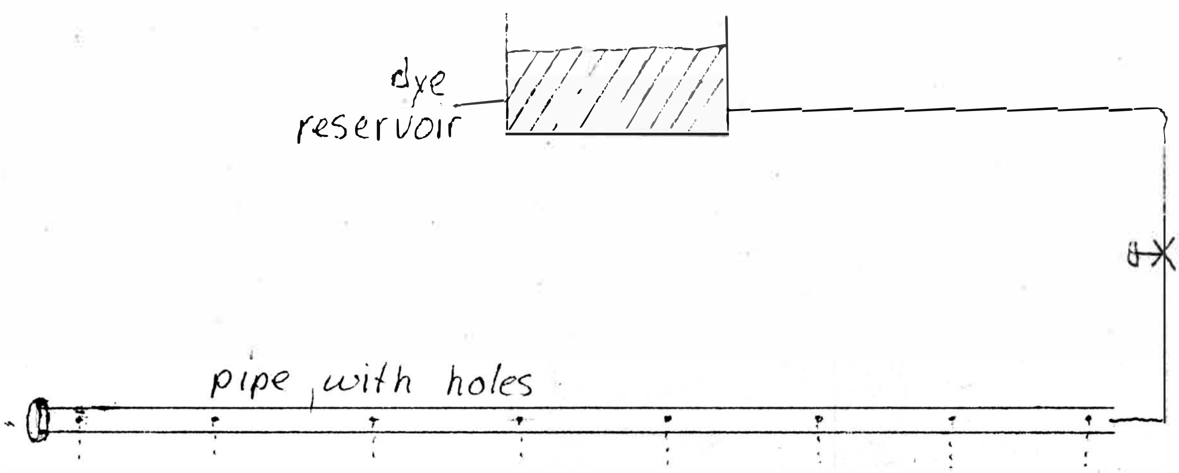



**Figure 3**

TABLE II

Condensed Data From First Pilot Machine Run (60% HW)

| Tensile (KG) | TEA ($Kgm/m^2$) | Burst (PSIG) | Draw Tension (gr./lin. ft.) |
|---|---|---|---|
| M.D. | C.D. | | |
| Couch to First Press Draw | | | |
| 5.90-4.57 | 2.23-4.47 | 17.76 | 18 |
| 5.89-4.72 | 2.28-4.88 | 17.49 | 14.4 |
| 5.94-4.38 | 2.25-4.91 | 18.16 | 10.8 |
| 5.76-3.87 | 2.36-4.79 | 18.40 | 7.2 |
| 5.99-4.72 | 2.32-5.17 | 18.18 | 3.6 |
| 5.96-4.98 | 2.28-5.36 | 18.01 | 0 |
| First Press to Second Press Draw | | | |
| 5.86-4.82 | 2.22-4.16 | 17.81 | 12 |
| 5.86-4.82 | 2.22-4.13 | 17.32 | 10.5 |
| 5.85-4.85 | 2.17-4.35 | 18.5 | 9.0 |
| 5.44-4.44 | 2.15-4.54 | 17.26 | 7.5 |
| 5.92-4.82 | 2.22-4.22 | 15.98 | 6.0 |
| 5.62-4.69 | 2.33-4.79 | 16.46 | 4.5 |
| 5.93-4.88 | 2.30-4.35 | 16.98 | 3.0 |
| 5.72-4.6 | 2.48-5.10 | 17.82 | 1.5 |
| 5.61-4.22 | 2.34-4.63 | 16.97 | 0 |
| Second Press to First Dryer Section Draw | | | |
| 5.58-4.98 | 2.31-5.0 | 17.36 | 6 |
| 5.41-4.16 | 2.36-4.79 | 17.26 | 5.25 |
| 5.62-4.54 | 2.38-5.1 | 17.92 | 4.5 |
| 5.63-4.63 | 2.38-4.76 | 18.48 | 3.75 |
| 5.57-4.76 | 2.45-5.1 | 19.28 | 3.0 |
| 5.77-5.29 | 2.53-5.36 | 19.26 | 2.25 |
| 5.61-5.29 | 2.43-4.54 | 19.16 | 1.5 |
| 5.48-5.17 | 2.52-5.42 | 19.69 | 0.75 |
| 5.73-6.11 | 2.45-4.79 | 20.64 | 0 |

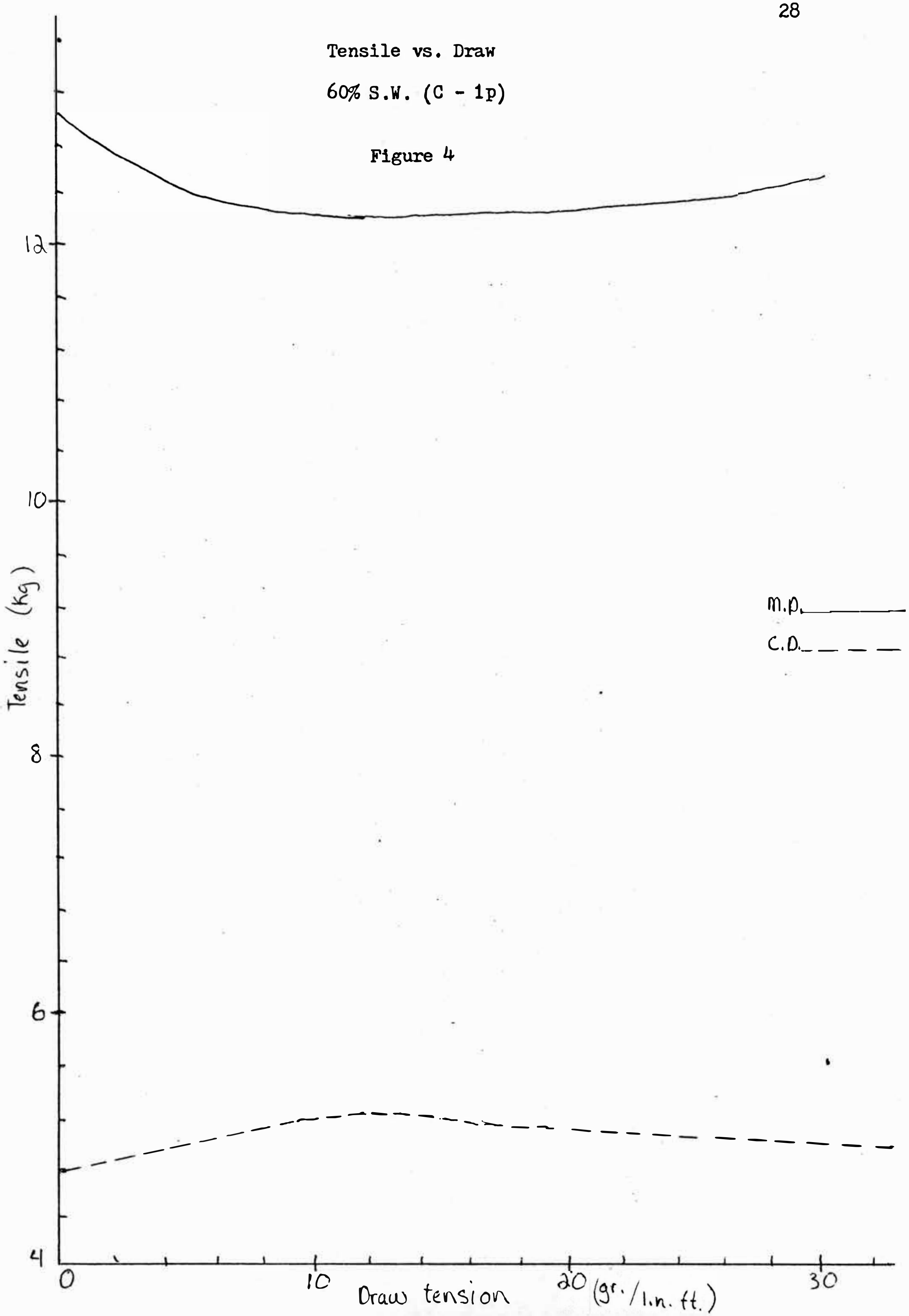
TABLE III

Condensed Data From Second Pilot Paper Machine Run (60% SW)

| Tensile (KG) M.D. | TEA ($Kgm/m^2$) C.D. | Burst (PSIG) | Draw Tension (gr. /lin. ft.) |
|---|---|---|---|
| Couch to First Press Draw | | | |
| 5.84-4.66 | 2.57-6.11 | 18.6 | 26 |
| 6.20-5.04 | 2.48-5.76 | 19.4 | 21.7 |
| 6.18-5.48 | 2.49-5.85 | 19.4 | 17.3 |
| 6.29-5.10 | 2.51-5.79 | 19.7 | 13.0 |
| 6.36-5.38 | 2.60-6.26 | 20.6 | 8.7 |
| 5.92-4.63 | 2.54-5.60 | 20.0 | 4.3 |
| 6.24-4.88 | 2.47-5.54 | 20.7 | 0 |
| First Press to Second Press Draw | | | |
| 6.31-4.72 | 2.43-5.35 | 20.1 | 50.0 |
| 6.32-4.97 | 2.42-5.48 | 20.5 | 43.8 |
| 6.6 -5.41 | 2.47-5.41 | 21.0 | 37.5 |
| 6.56-5.07 | 2.47-5.22 | 21.6 | 31.3 |
| 6.28-5.13 | 2.46-5.35 | 21.3 | 25.0 |
| 6.52-5.54 | 2.49-5.51 | 21.8 | 18.8 |
| 6.41-5.63 | 2.46-5.16 | 20.9 | 12.5 |
| 6.40-5.85 | 2.50-5.26 | 21.0 | 6.3 |
| 5.86-5.13 | 2.66-5.6 | 20.3 | 0 |
| Second Press to First Dryer Section Draw | | | |
| 5.74-4.72 | 2.52-5.73 | 19.2 | 6 |
| 5.65-4.66 | 2.48-5.19 | 19.2 | 5.1 |
| 5.82-4.82 | 2.42-5.41 | 19.3 | 4.3 |
| 5.78-5.35 | 2.56-5.73 | 20.2 | 3.4 |
| 5.76-5.04 | 2.57-5.76 | 20.7 | 2.6 |
| 5.77-5.07 | 2.47-5.16 | 21.4 | 1.7 |
| 5.67-5.6 | 2.49-5.98 | 20.7 | 0.8 |
| 5.55-5.51 | 2.49-5.19 | 20.8 | 0 |

# APPENDIX II

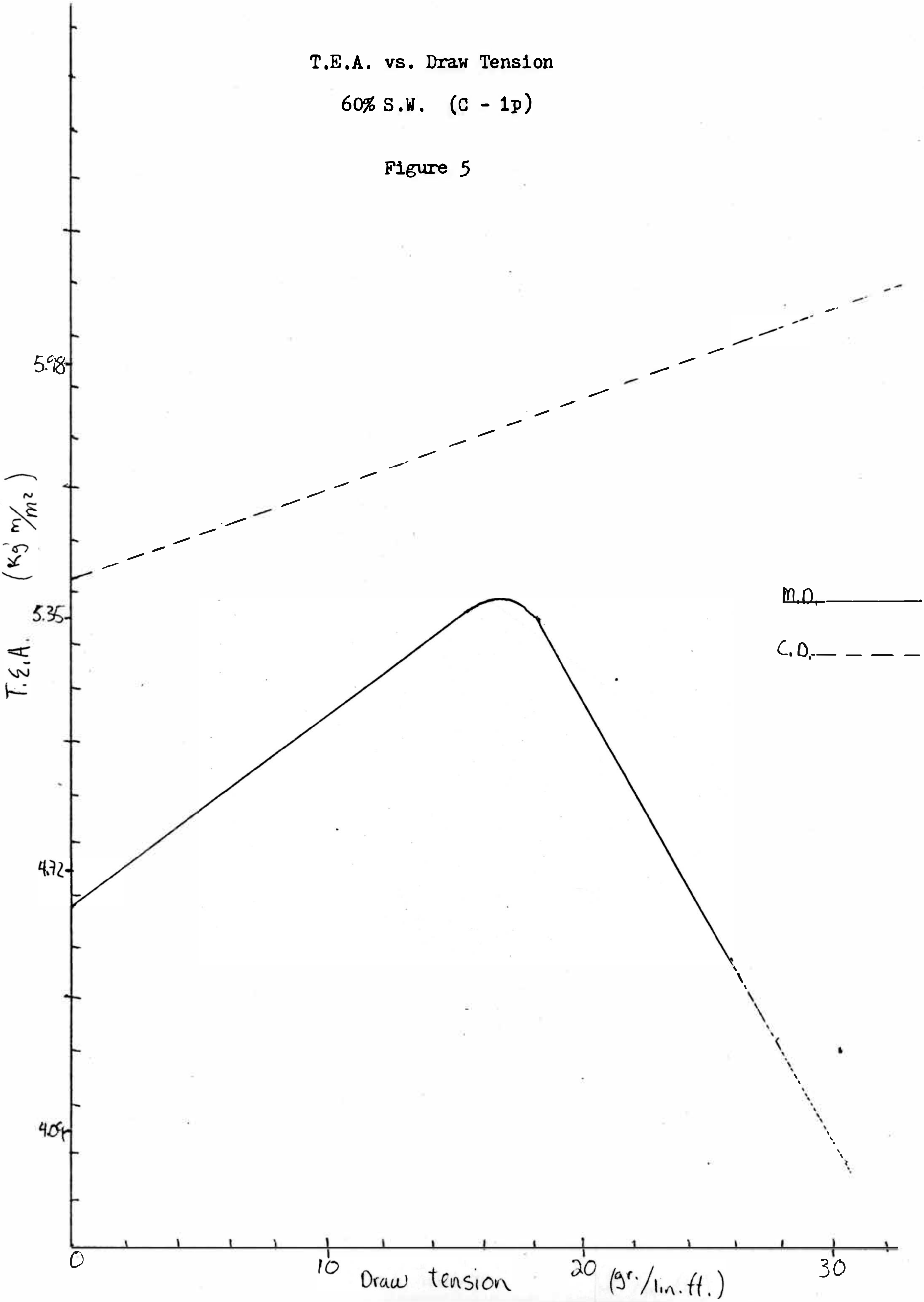
## Graphical Display of Data


Tensile vs. Draw
60% S.W. (C - 1p)
Figure 4
m.p.
C.D.
Tensile (kg)
12
10
8
6
4
0
10
20
30
Draw tension (gr./l.n. ft.)

T.E.A. vs. Draw Tension

60% S.W. (C - 1p)

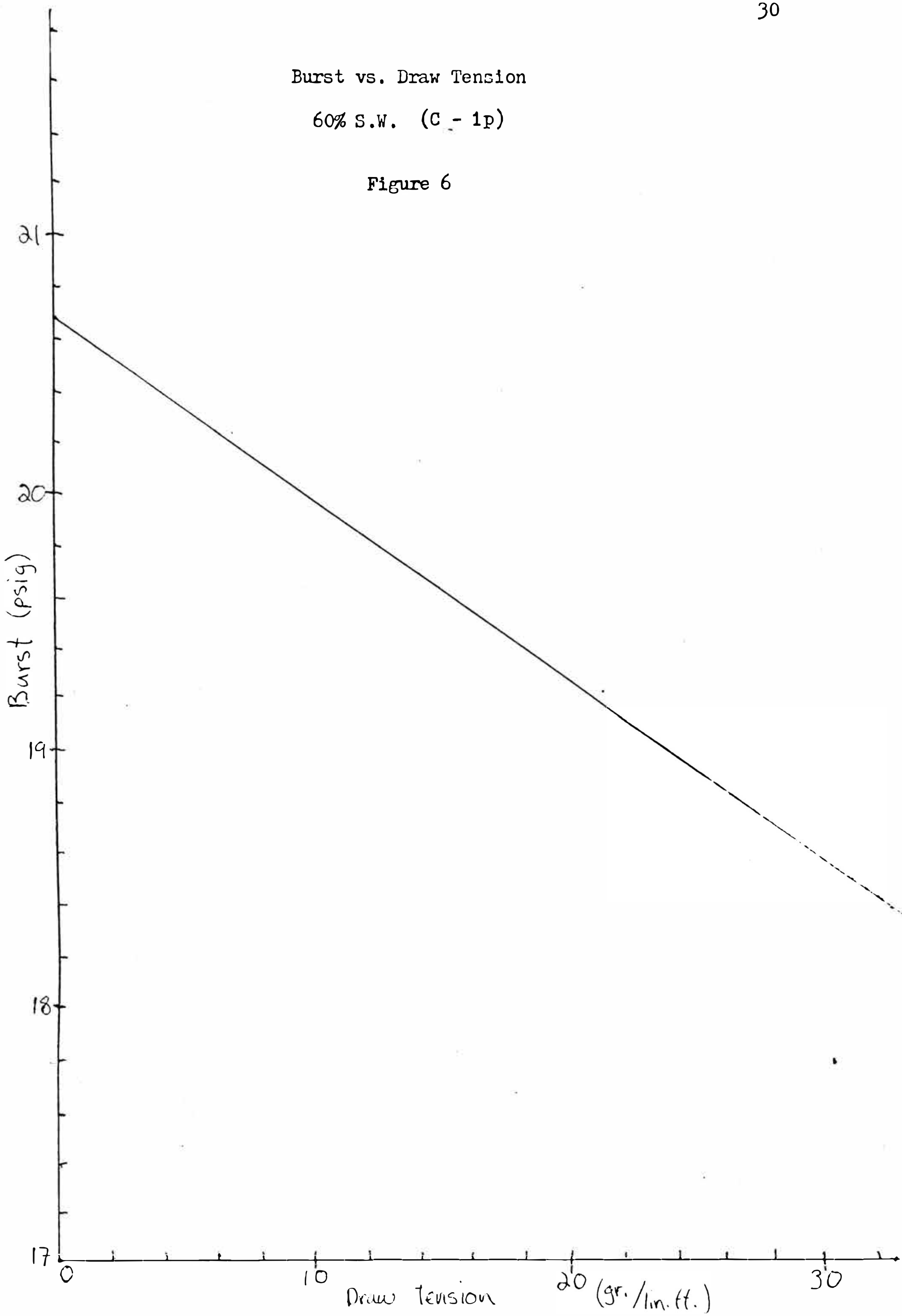
Figure 5

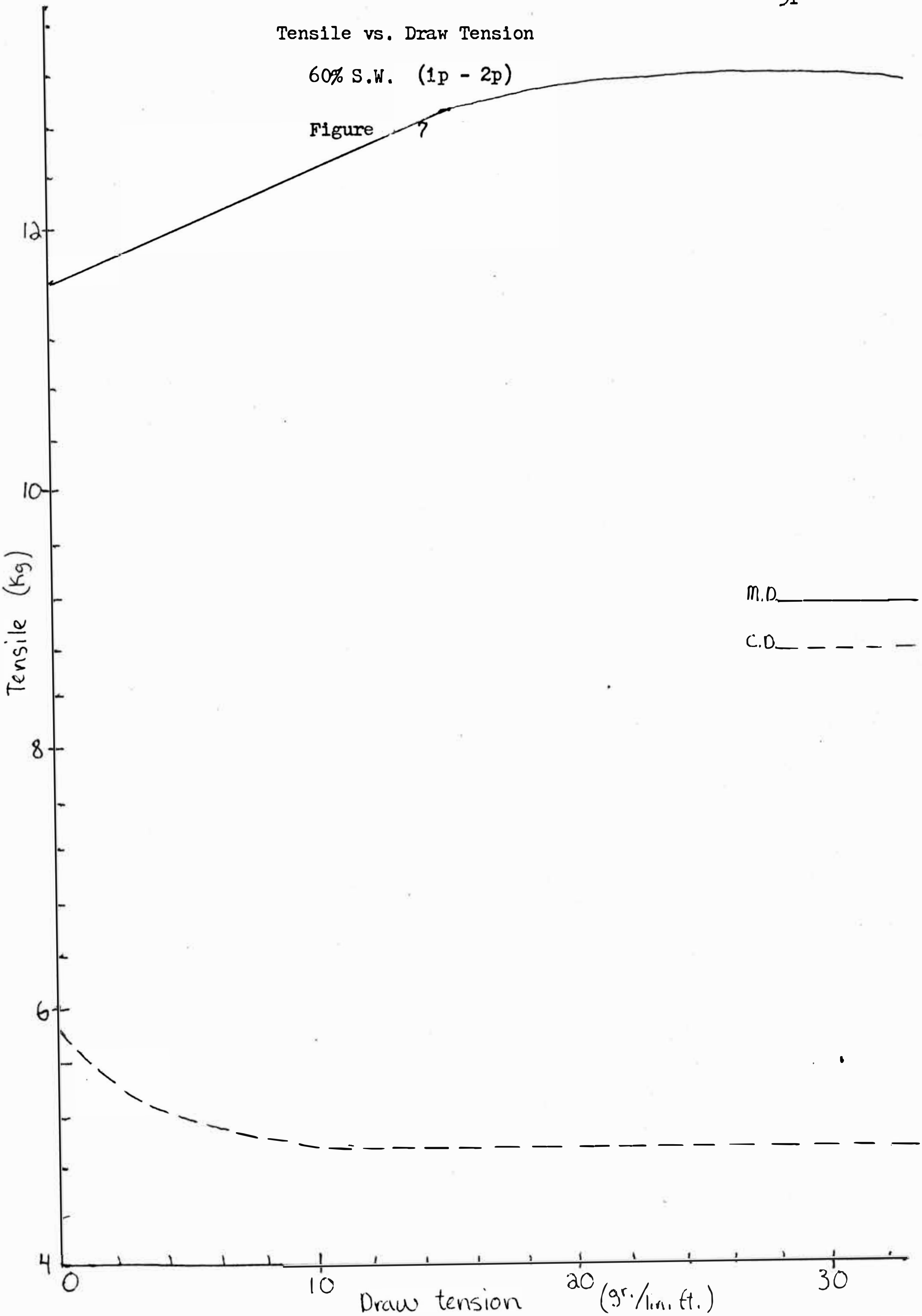


Burst vs. Draw Tension

60% S.W. (C - 1p)

Figure 6

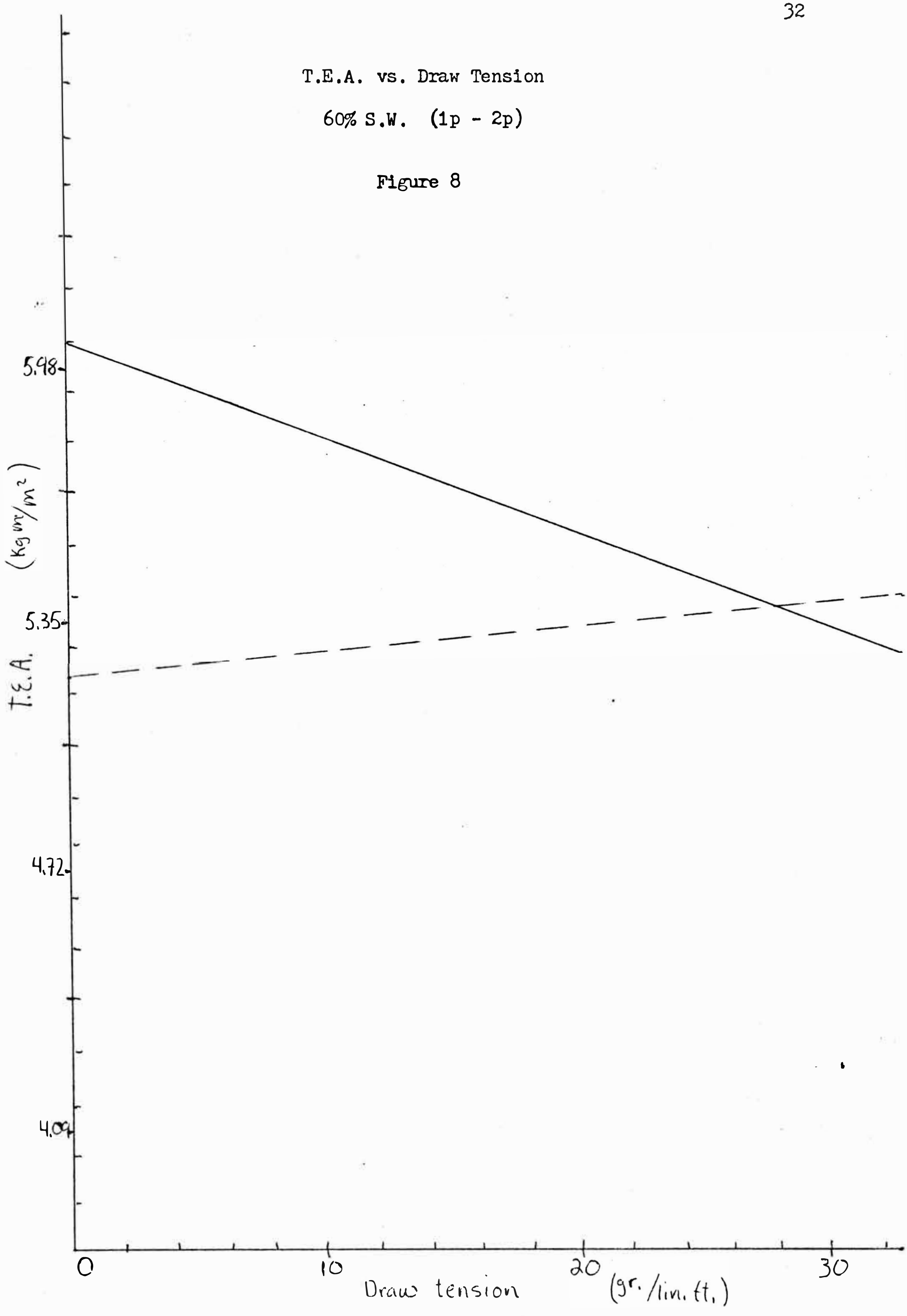



Tensile vs. Draw Tension
60% S.W. (1p - 2p)
Figure 7
12
10
8
6
4
Tensile (Kg)
M.D.
C.D.
0
10
20
30
Draw tension (gr./lin. ft.)

T.E.A. vs. Draw Tension

60% S.W. (1p - 2p)

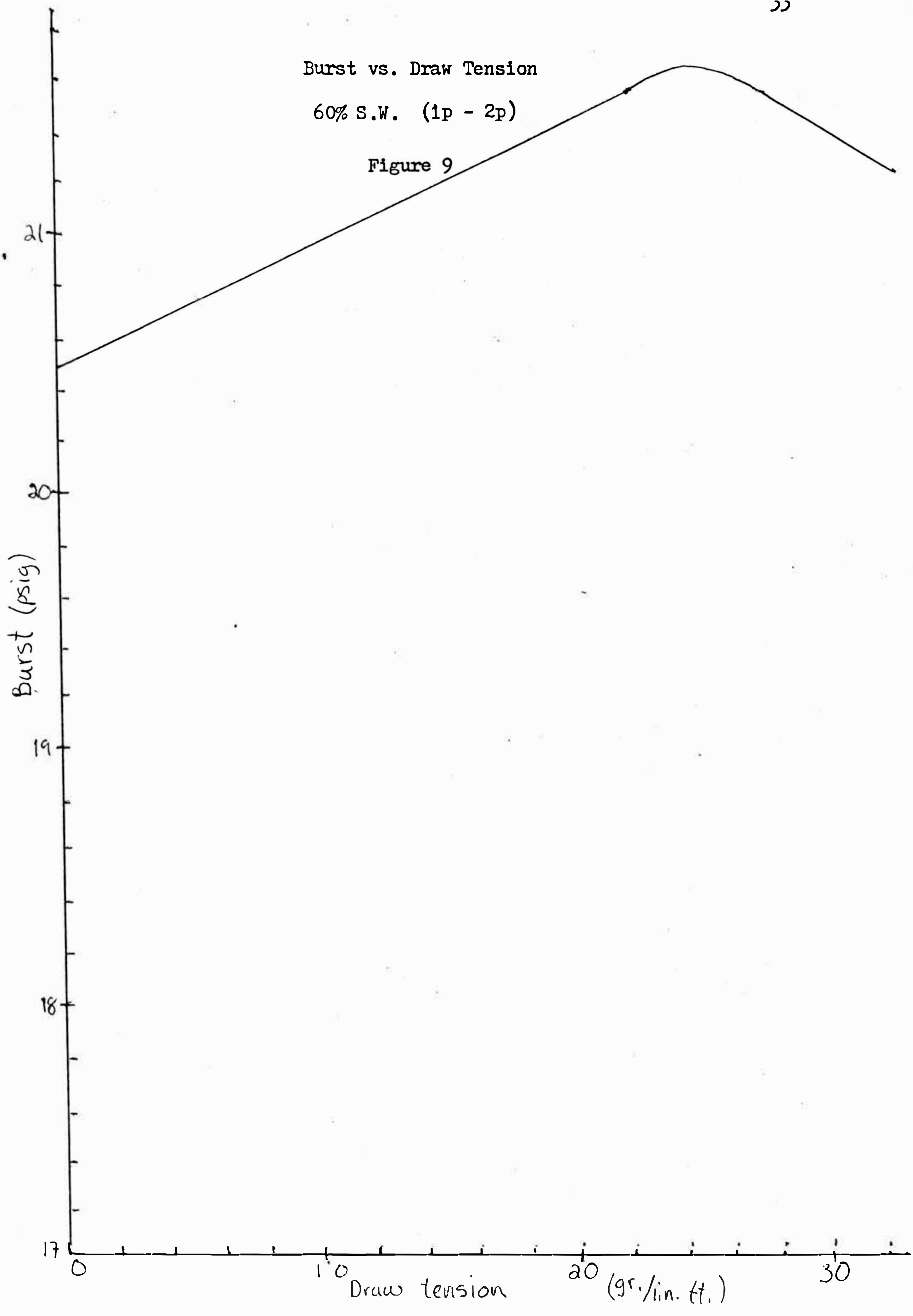
Figure 8



Burst vs. Draw Tension

60% S.W. (1p - 2p)

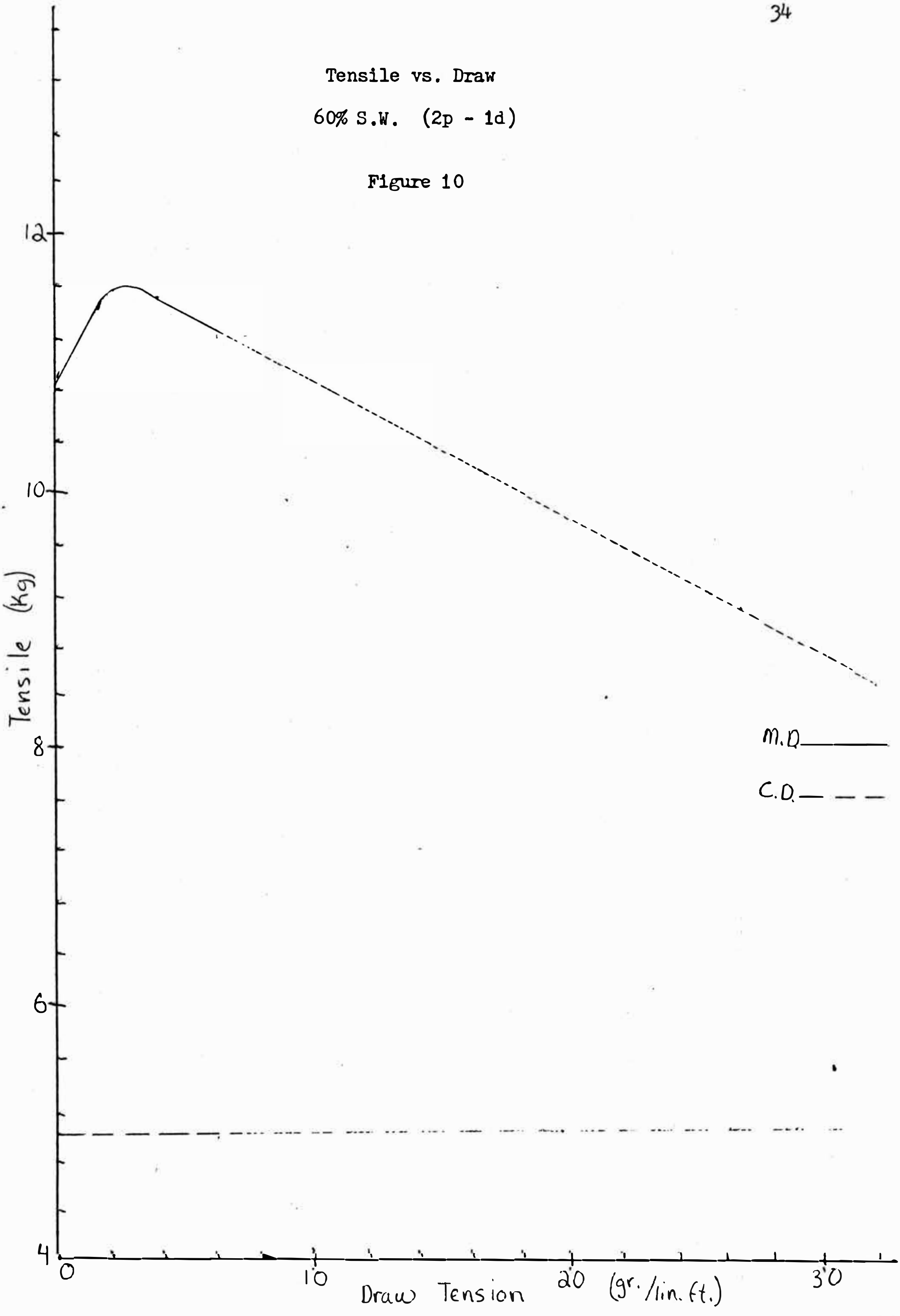
Figure 9



Tensile vs. Draw

60% S.W. (2p - 1d)

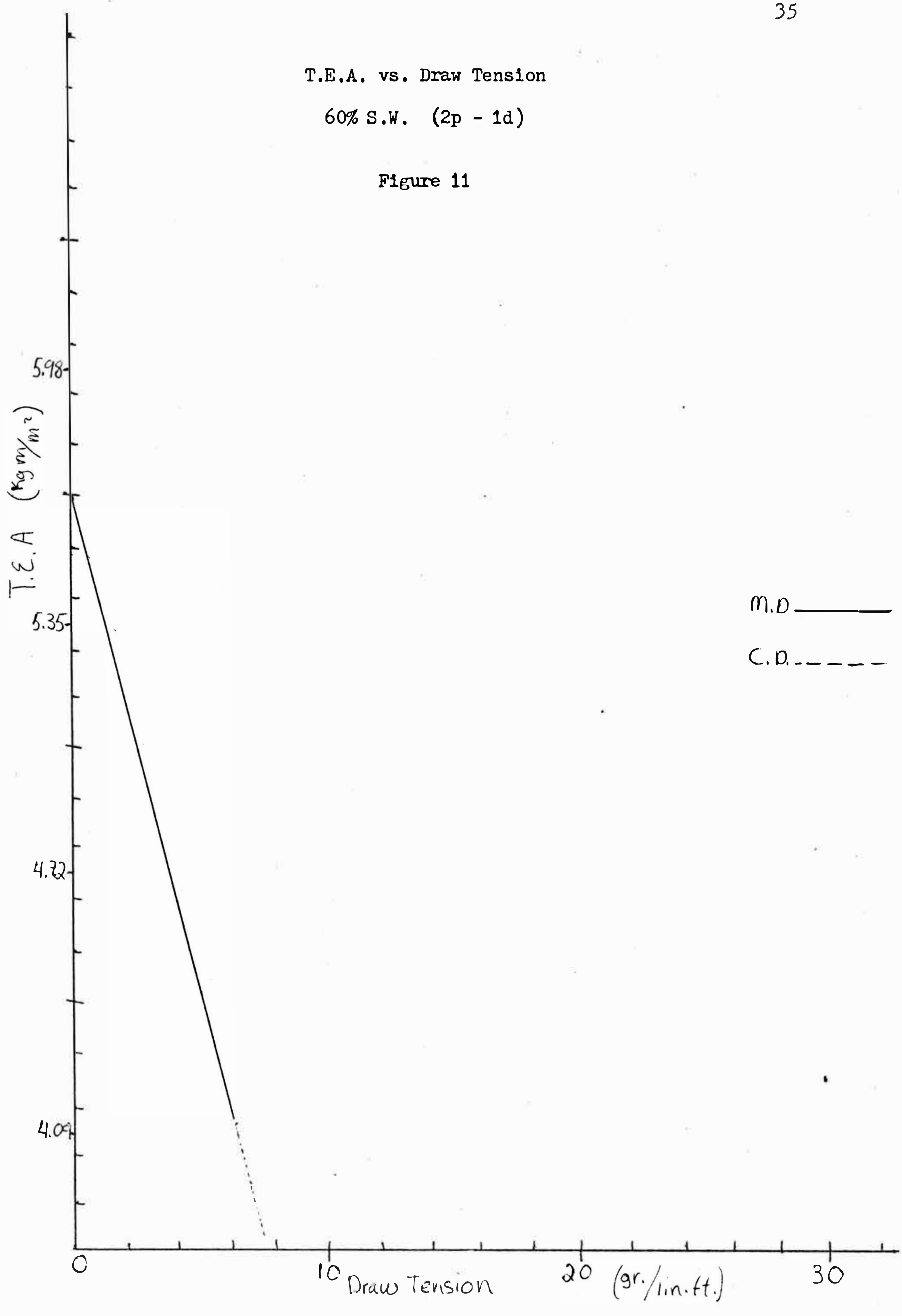
Figure 10



T.E.A. vs. Draw Tension

60% S.W. (2p - 1d)

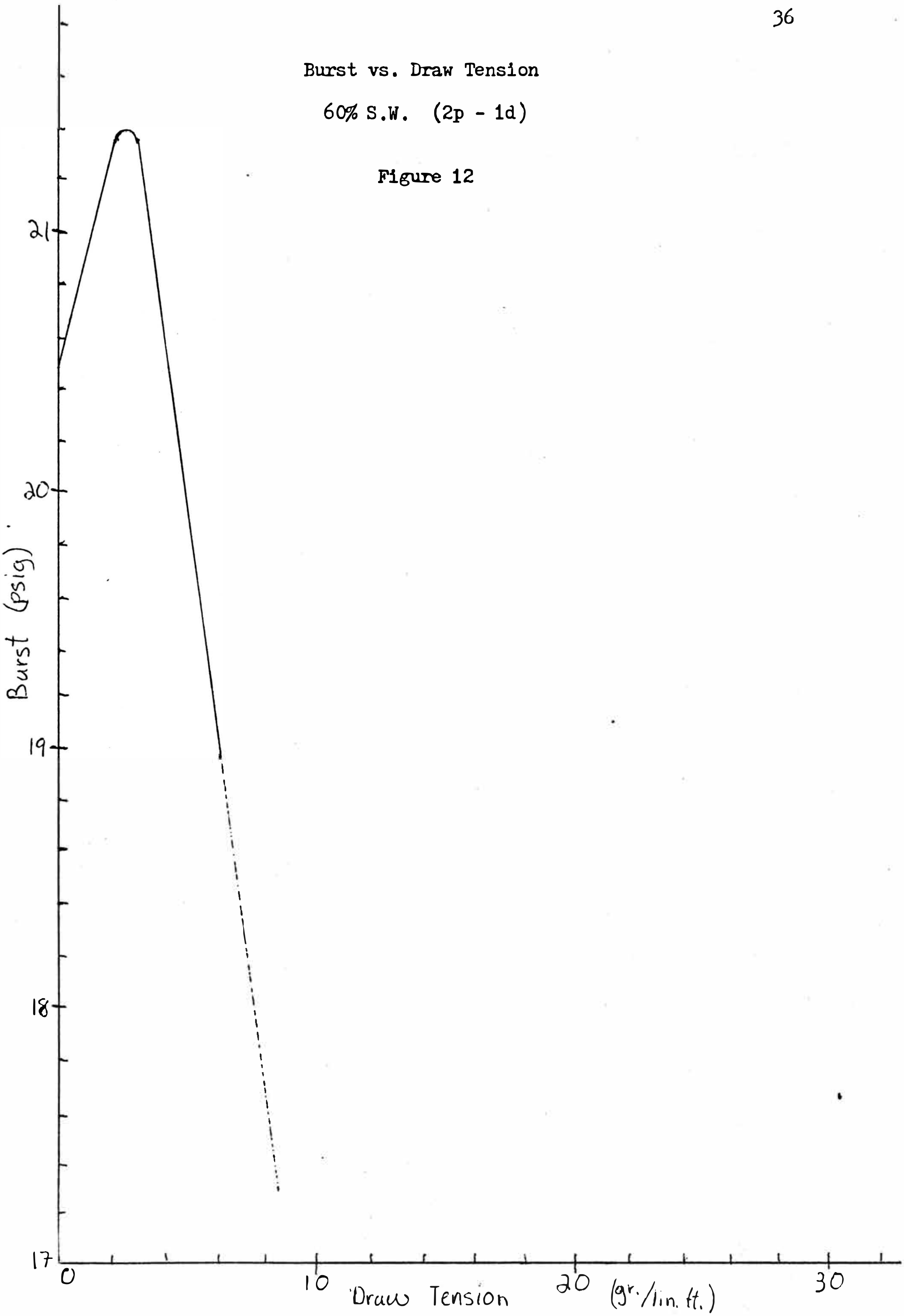
Figure 11



Burst vs. Draw Tension

60% S.W. (2p - 1d)

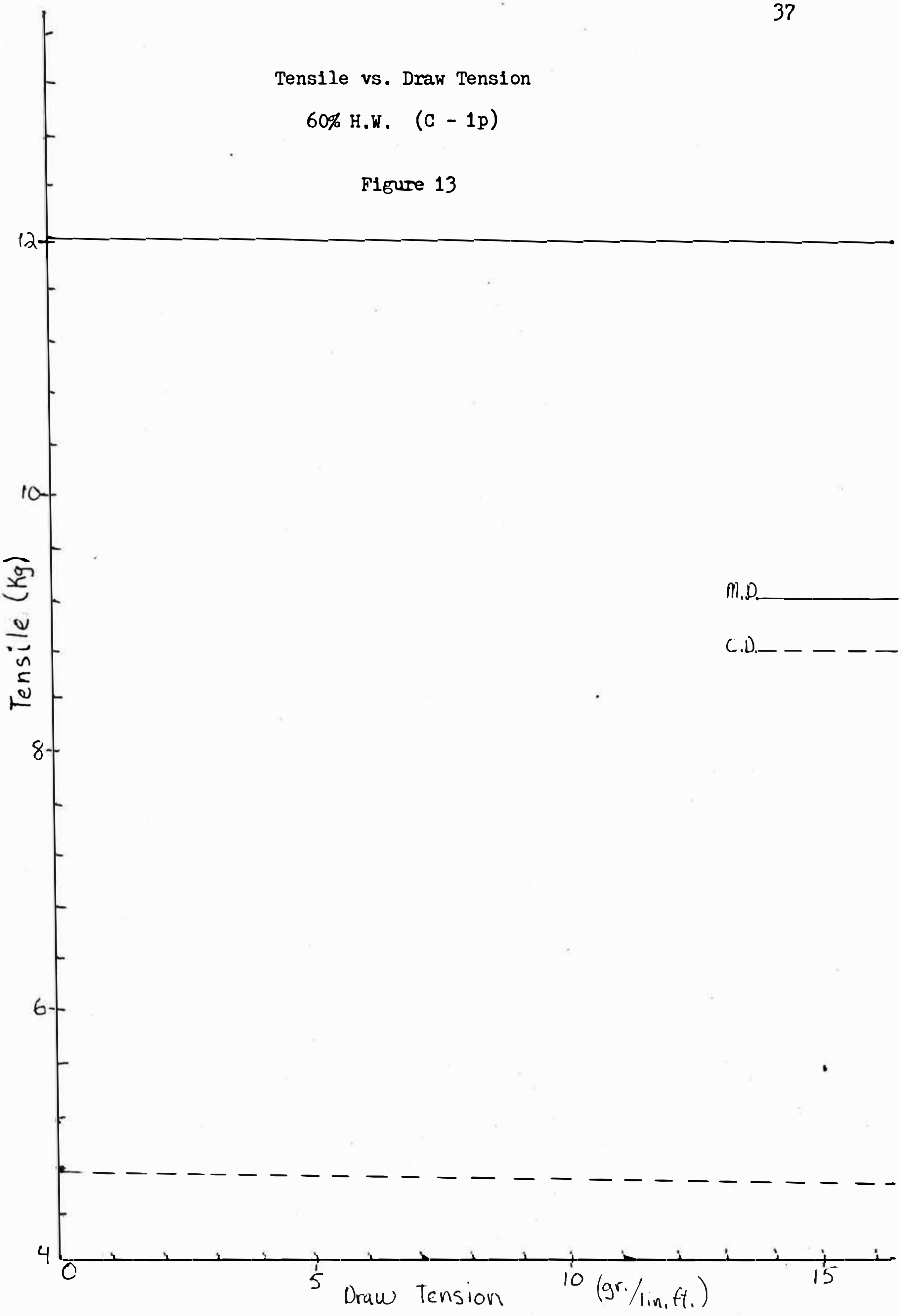
Figure 12



Tensile vs. Draw Tension

60% H.W. (C - 1p)

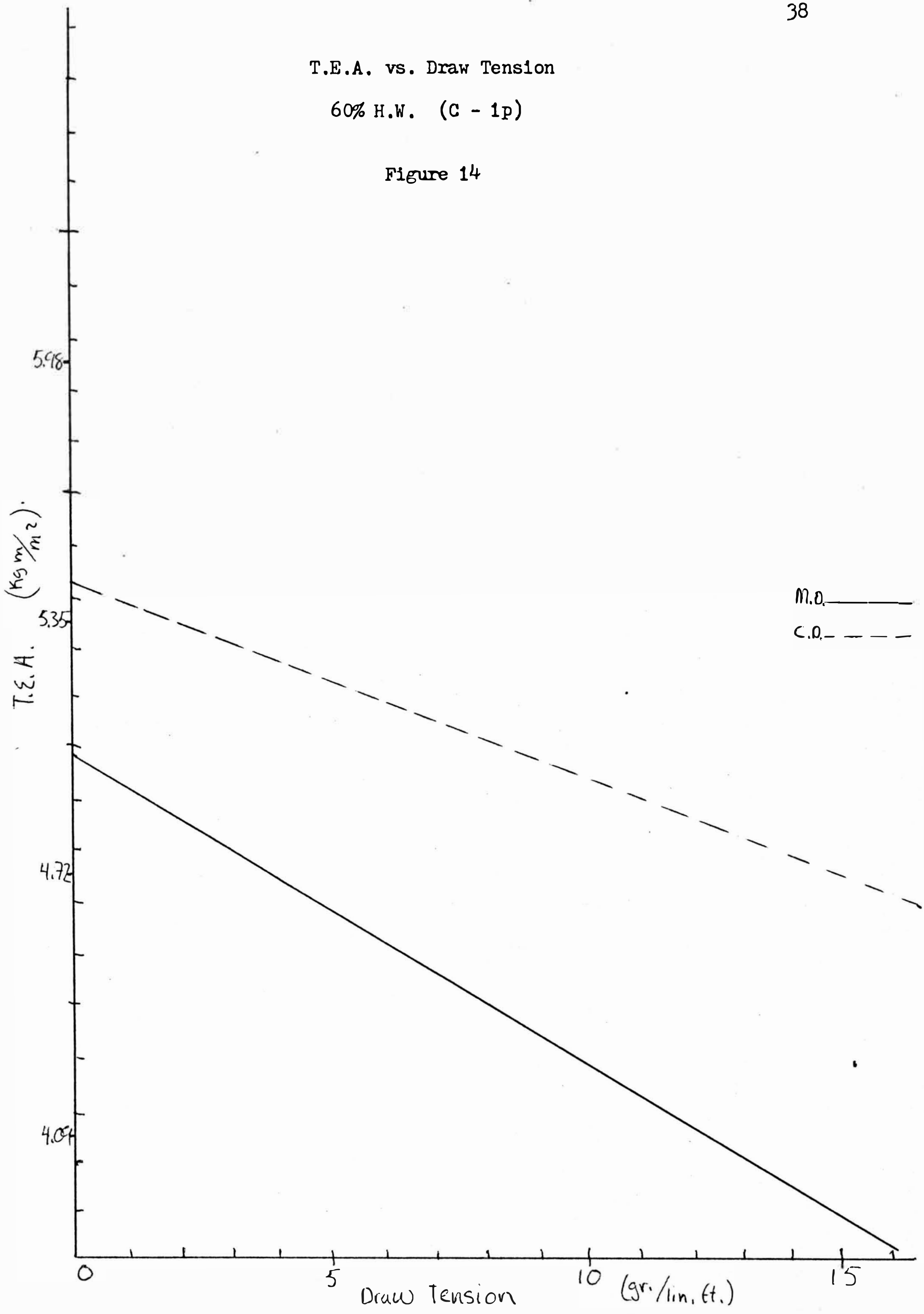
Figure 13



T.E.A. vs. Draw Tension

60% H.W. (C - 1p)

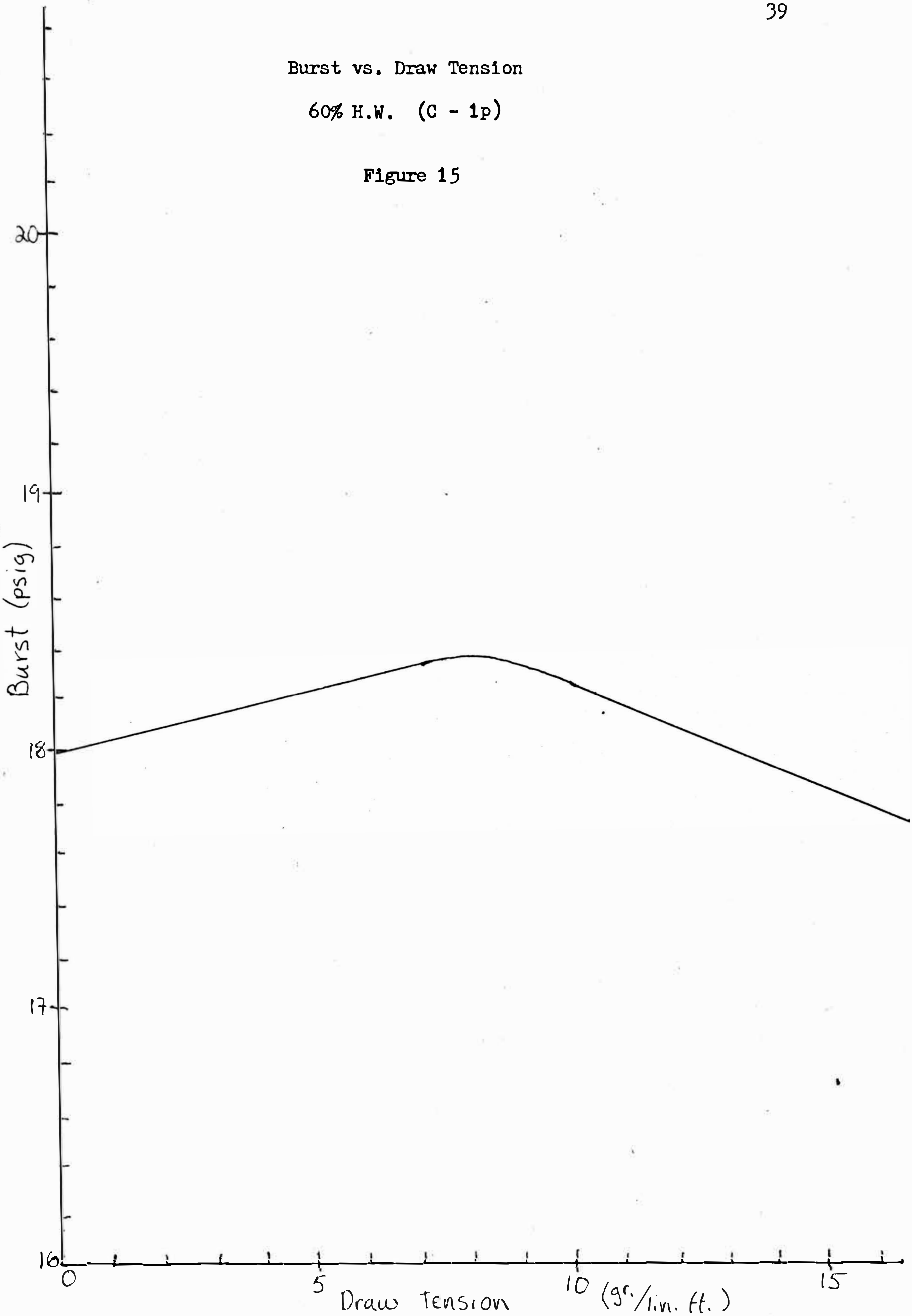
Figure 14



Burst vs. Draw Tension

60% H.W. (C - 1p)

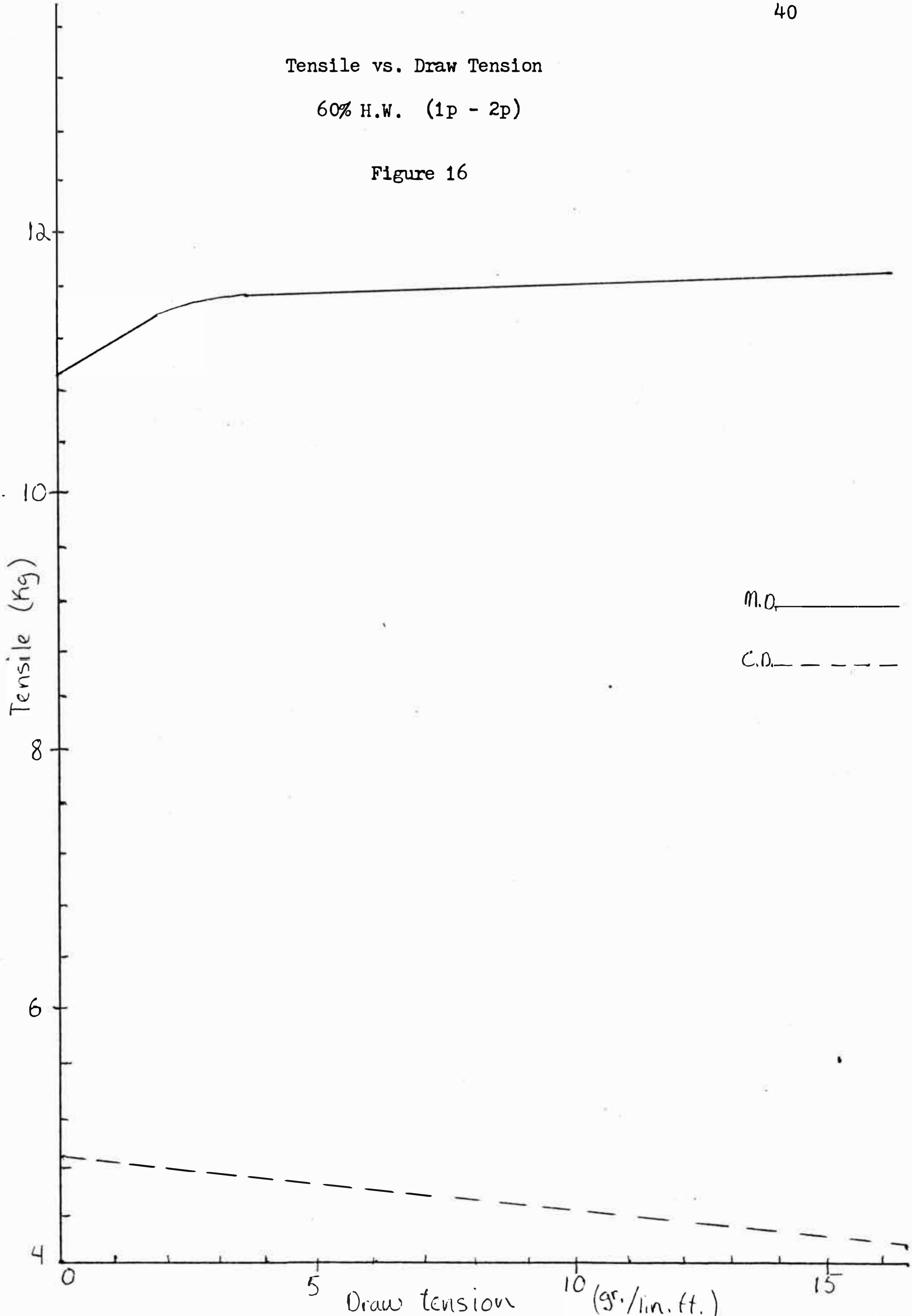
Figure 15



Tensile vs. Draw Tension

60% H.W. (1p - 2p)

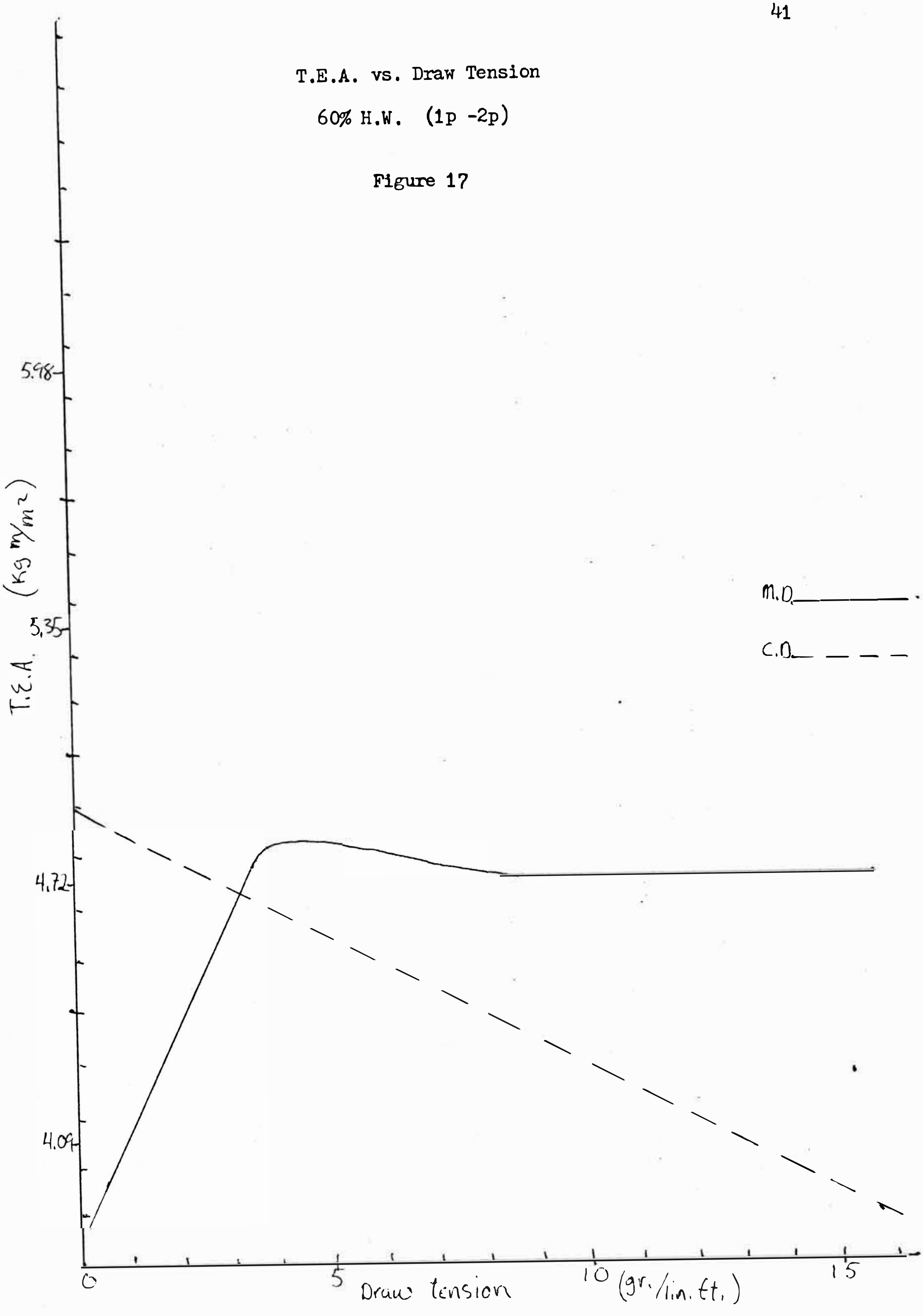
Figure 16



T.E.A. vs. Draw Tension

60% H.W. (1p -2p)

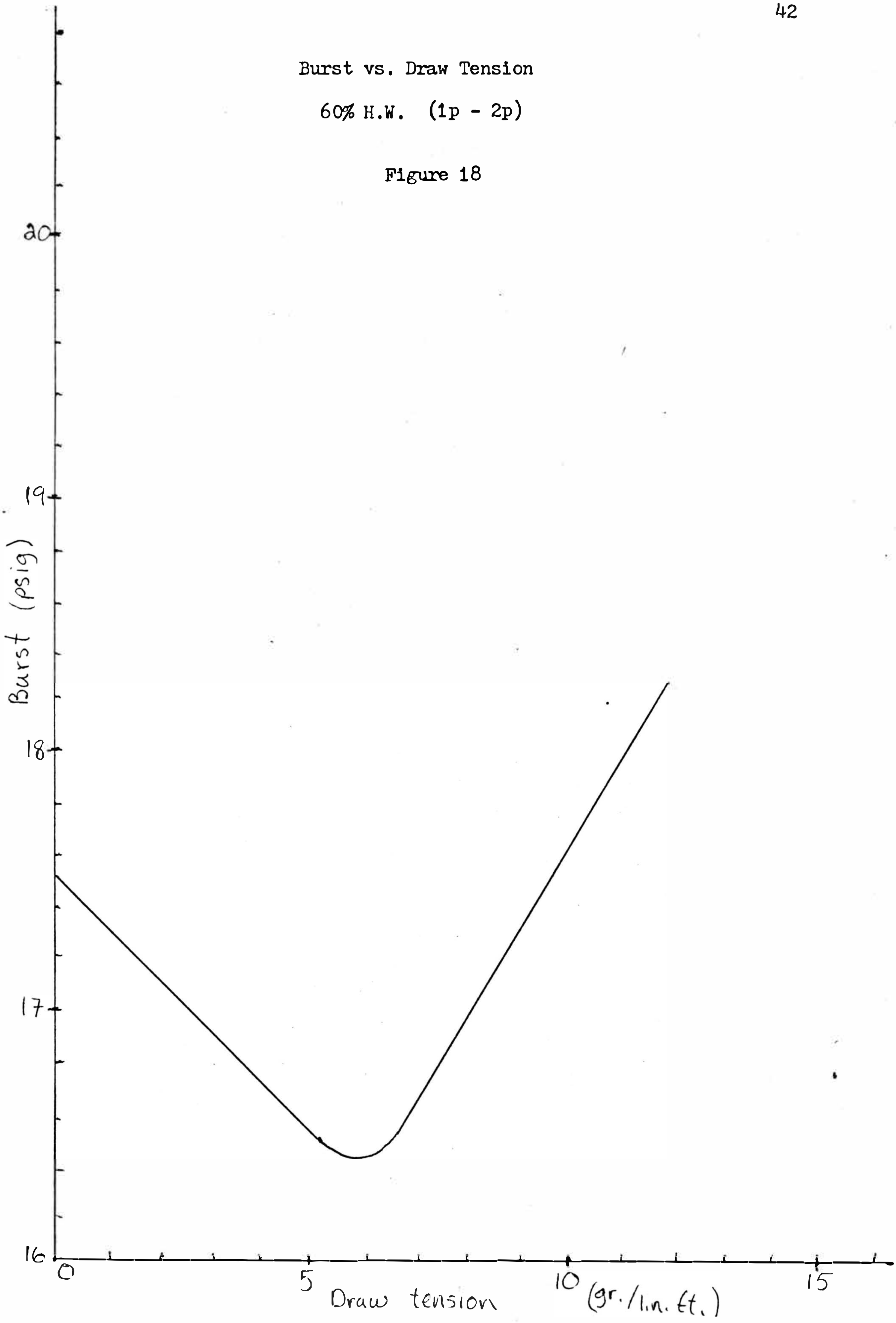
Figure 17



Burst vs. Draw Tension

60% H.W. (1p - 2p)

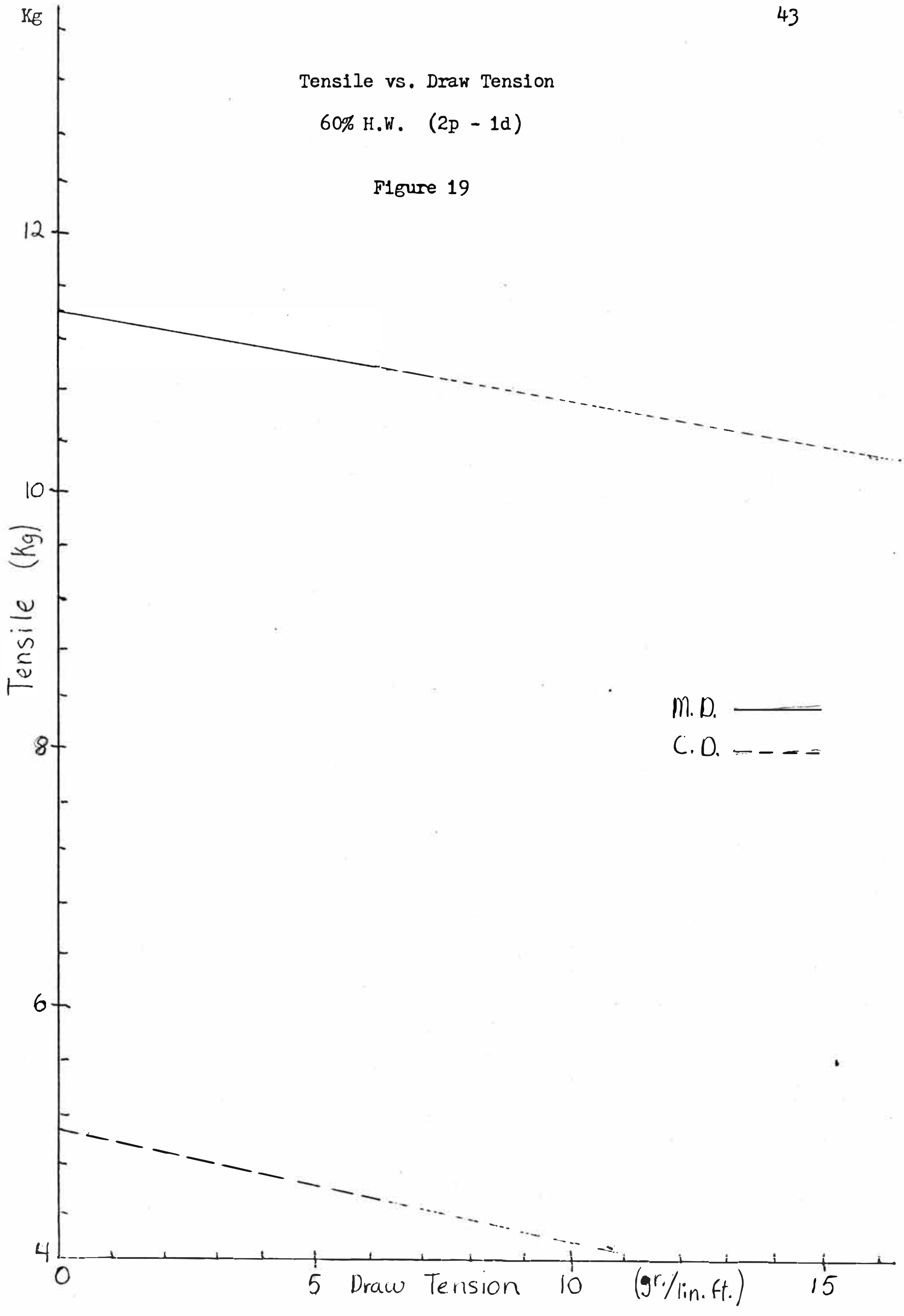
Figure 18



Tensile vs. Draw Tension

60% H.W. (2p - 1d)

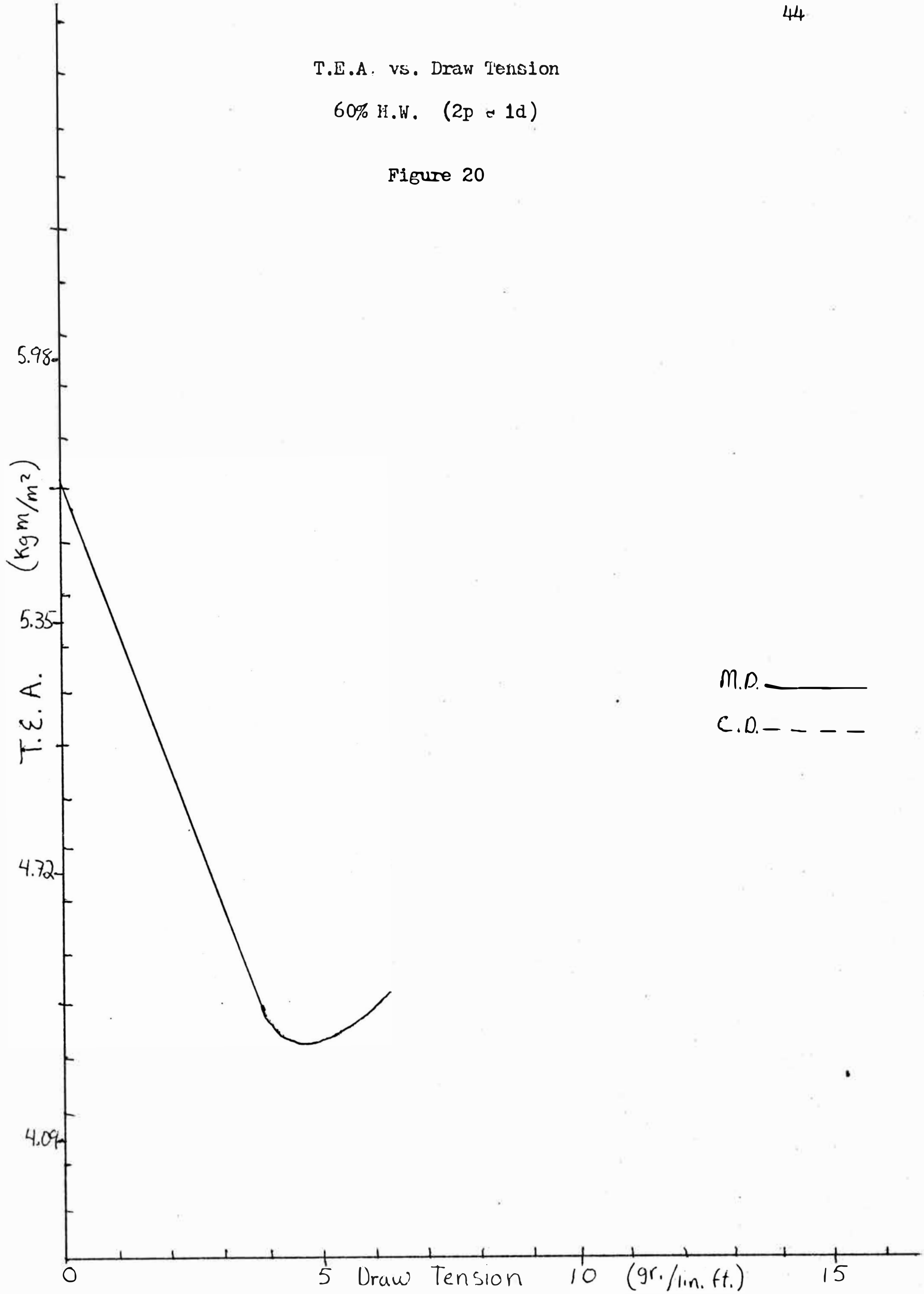
Figure 19



T.E.A. vs. Draw Tension

60% H.W. (2p ~ 1d)

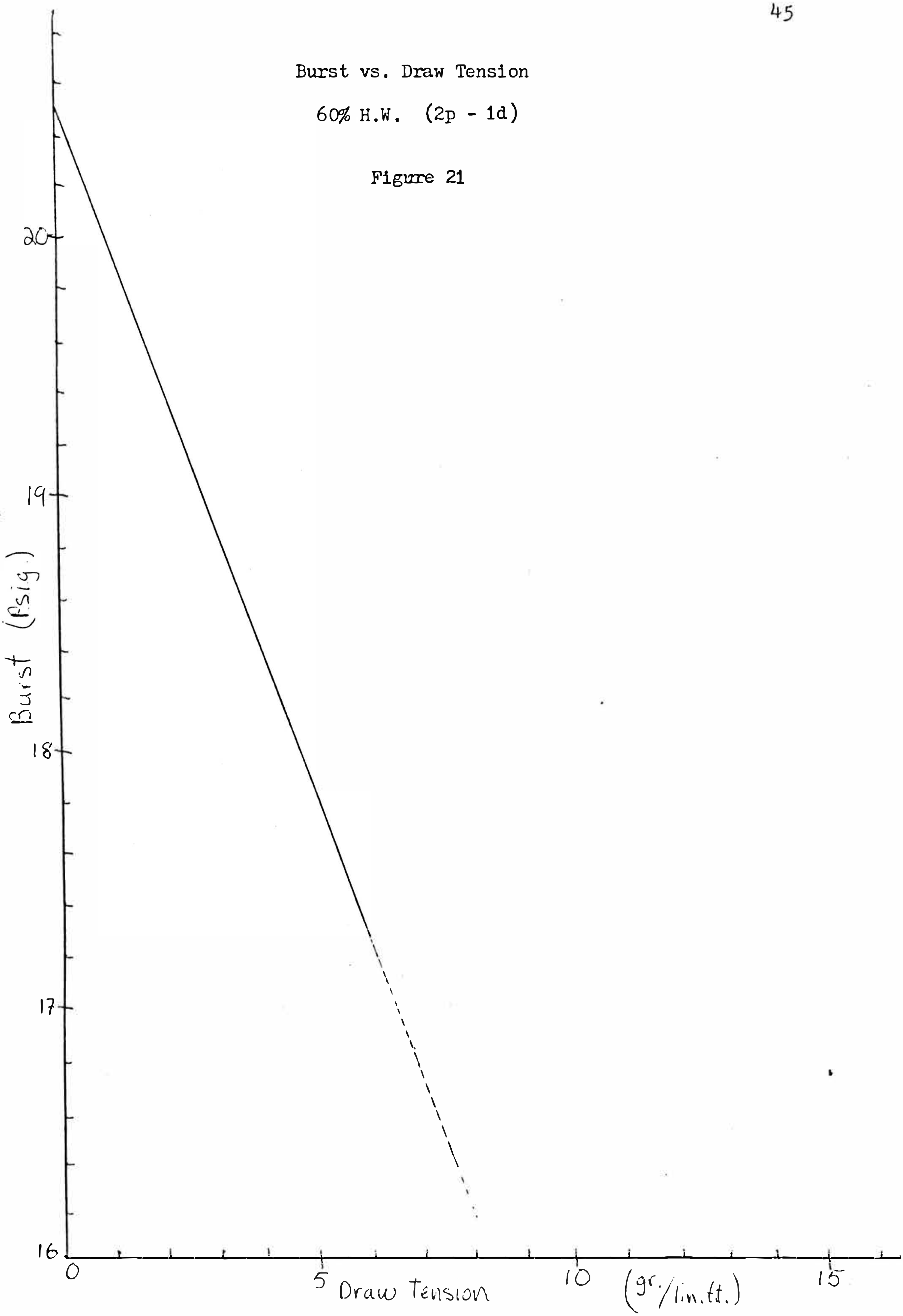
Figure 20



Burst vs. Draw Tension

60% H.W. (2p - 1d)

Figure 21



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