THE SPRING RESEARCH ASSOCIATION

AN INVESTIGATION INTO THE EFFECT OF BEND RADII, BEND ALLOWANCE AND SPRINGBACK IN STRIP FORMING

Progress Report No. 1

by

G. C. Bird, B.Sc.

Report No. 204

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SUMMARY

The object of the present investigation into strip forming is to produce data for die design relating to CS 70 carbon steel strip when formed by a cylindrical punch.

The investigation covers a range of six material thicknesses from 0.008 in to 0.048 in and, so far, work on three material thicknesses (0.008 in, 0.028 in and 0.048 in) has been completed. Work is continuing at the moment in obtaining data for strip of 0.012 in thickness.

The results of the forming operation have been successful in that bend angles have been obtained consistent to $\pm 1^{\circ}$ or better. The data are plotted on graphs relating the springback of the strip to the formed radius and the formed angle. By using dimensionless ratios as axes, a single graph can be used for the design of a wide range of dies.

From the mechanical properties of the materials determined from a tensile test, a theoretical relationship has been derived whereby the formed angle can be predicted to an accuracy of better than 5%.

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(July 1972)

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1. INTRODUCTION

In the design of forming tools for thin strip it is necessary to know the effect of springback of the strip so that an allowance can be made for this in the tool design. The present method involves a certain amount of trial and error, and any improvement in predicting the effect of springback would be very worthwhile.

The purpose of this research programme is to produce data which relate the formed angle and diameter of strip when bent round a cylindrical punch to the final angle and diameter after springback.

The data produced will be presented in the form of graphs or nomograms so that they can be used easily by press tool designers.

2. MATERIAL

The material to be investigated is carbon steel strip CS 70 to BS 1449. Data are being produced for strip ranging in thickness from 0.008 in to 0.048 in with a nominal width of 1 inch. It is intended to produce data on this material over a hardness range of 150 to 200 HV, and this first investigation is of strip with a nominal hardness of 150 HV.

As far as possible strip is being used cut to length straight from the coil, but in some cases it is necessary to straighten the strip either by roller straighteners or, for the thinnest strip, by low temperature heat treatment under stress.

Other materials will be investigated subsequently but as the same press tools will be used, the strip will be of the same thickness range.

3. EXPERIMENTAL DESIGN

For the investigation six material thicknesses are to be used, with five different bend indices before forming and four bend angles for each thickness. Thus 120 (6x5x4) dies are needed to complete the programme.

Material thickness: 0.008 in, 0.012 in, 0.018 in, 0.028 in, 0.036 in, and 0.048 in.

Bend Indices (Mean bend diameter/strip thickness) - Db/t: 13, 19, 29, 37, 49

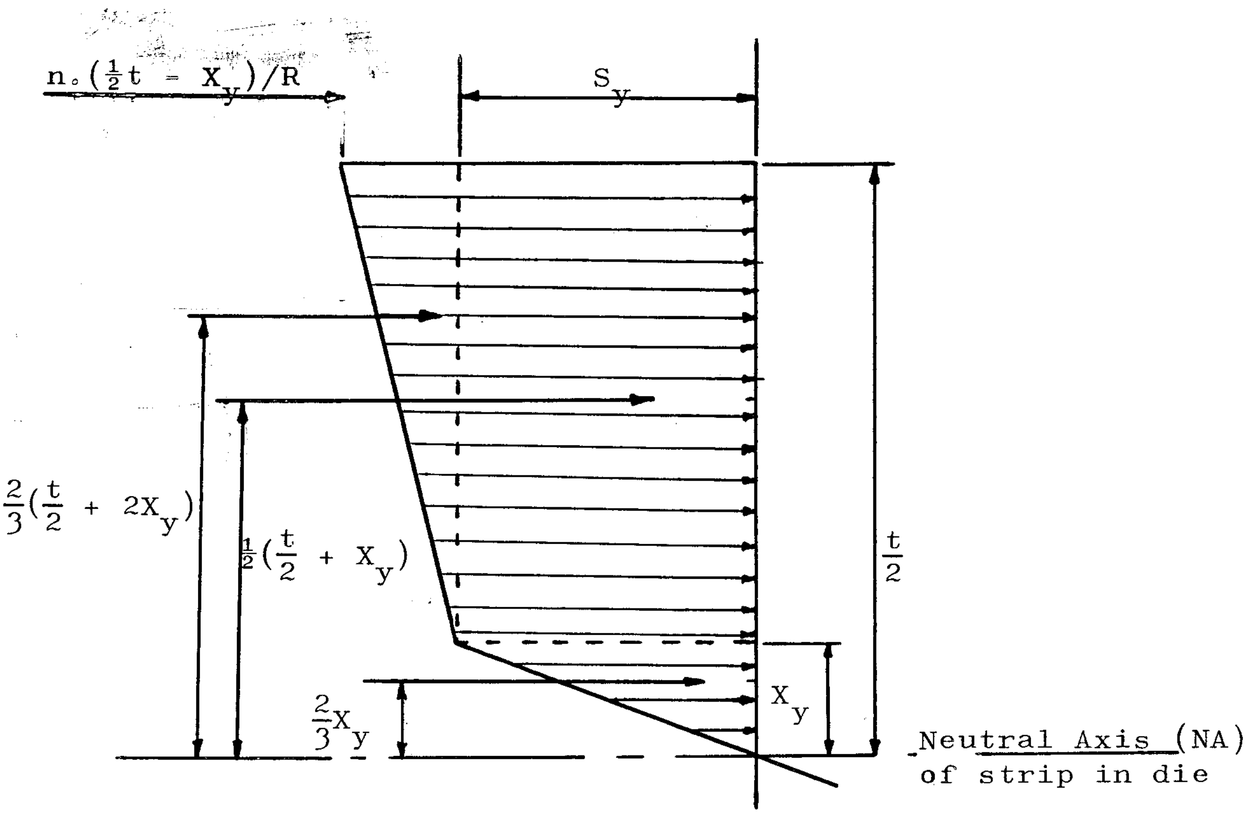
Bend angles: 180°, 130°, 90°, 60°

The speed of tool action is to be selected according to the material thickness in the following relationship:-

Thickness (in)	0.008	0.012	0.018	0.028	0.036	0.048
Strokes/min	140	130	115	90	70	50

4. THEORETICAL CONSIDERATIONS

The stress distribution over a cross section of the material in the die is shown in the diagram on the following page:-



Nomenclature:-

E	Youngs modulus	
R	Radius of curvature of strip in the die	(to NA)
r	Radius of curvature of strip in the die after release from die	(to NA)
S_y	Elastic Limit	
t	Thickness of strip	
X_y	Location of yield point from neutral axis	
n	rate of increase in stress with strain beyong elastic limit*	

Resultant forces and moment arms for the stress distributions are indicated. The bending moment M for the cross section then is given below

* Since $E = \frac{X}{R}$ at any point on the strip, increase in stress due to strain hardening $= n.\ \frac{\Delta X}{R}$ beyond the elastic limit.

$$M = 2\left[\frac{1}{2}.b.S_y.X_y.\frac{2}{3}.X_y + b.S_y.\left(\frac{t}{2} - X_y\right).\frac{1}{2}.\left(\frac{t}{2} + X_y\right)\right.$$

$$\left. + \frac{b}{2}.\frac{n}{R}.\left(\frac{t}{2} - X_y\right).\left(\frac{t}{2} - X_y\right).\frac{2}{3}.\left(\frac{t}{2} + 2X_y\right)\right]$$

$$= \frac{b.Sy}{12}.\left(3t^2 - 4X_y^{\,2}\right) + \frac{2nb}{3R}.\left(\frac{t}{2} - X_y\right)^2.\left(\frac{t}{2} + 2X_y\right)$$

$$M = \frac{b.Sy}{12}.\left(3t^2 - 4X_y^{\,2}\right) + \frac{nb}{12R}.\left(t^3 - 12tX_y^{\,2} + 16X_y^{\,3}\right) \quad (1)$$

The elementary beam equation S = EX/R is valid for the elastic range. From this

$$S_y = \frac{EXy}{R} \quad (2)$$

Substituting (2) into Equation (1) gives

$$M = \frac{EI}{R}.\left[3\left(\frac{Xy}{t}\right) - 4\left(\frac{Xy}{t}\right)^3\right] + \frac{nI}{R}.\left[1 - 12\left(\frac{Xy}{t}\right)^2 + 16\left(\frac{Xy}{t}\right)^3\right]$$

and $$\frac{M}{EI} = \frac{1}{R}.\left[3\left(\frac{Xy}{t}\right) - 4\left(\frac{Xy}{t}\right)^3\right] + \frac{n}{ER}.\left[1 - 12\left(\frac{Xy}{t}\right)^2 + 16\left(\frac{Xy}{t}\right)^3\right] \quad (3)$$

Where $I = \frac{bt^3}{12}$

When the strip is removed from the die, moments M are released. This is equivalent to superimposing the elastic stress distribution for which:-

$$\frac{1}{r_o} = \frac{M}{EI}$$

where $1/r_o$ is the change in curvature resulting from the release of moments M

The final curvature

$$\frac{1}{r} = \frac{1}{R} - \frac{1}{r_o} = \frac{1}{R} - \frac{1}{EI}$$

$$\frac{1}{r} = \frac{1}{R} - \frac{1}{R}\cdot\left[3\left(\frac{Xy}{t}\right) - 4\left(\frac{Xy}{t}\right)^3\right] - \frac{n}{ER}\cdot\left[1 - 12\left(\frac{Xy}{t}\right)^2 + 16\left(\frac{Xy}{t}\right)^3\right] \quad (4)$$

Substitution for X_y from equation (2) gives

$$\frac{R}{r} = 4\left(\frac{RSy}{Et}\right)^3 - \left(\frac{RSy}{Et}\right) + 1 - \frac{n}{E}\left[16\left(\frac{RSy}{Et}\right)^3 - 12\left(\frac{RSy}{Et}\right)^2 + 1\right] \quad (5)$$

However $\frac{D_b}{D_f} = \frac{R}{r}$

and for a particular design of die

$$\frac{RSy}{Et} = \text{constant, } K$$

Thus equation (5) reduces to

$$\frac{D_b}{D_f} = 4K^3 - K + 1 - \frac{n}{E}\left(16K^3 - 12K^2 + 1\right)$$

or if the increase in stress beyong the elastic limit is very small

$$\frac{D_b}{D_f} = 4K^3 - K + 1$$

5. MODIFICATIONS TO DIES

A preliminary set of dies was manufactured and the investigation carried out for the CS 70 strip as described. Because of the poor results obtained, even when rubber pads were placed under the dies to even out the load on punching, it was decided to modify the design of the dies slightly, so that they would be manufactured to a greater degree of accuracy, and to repeat the experiment.

The modifications carried out on the dies are shown in Fig. 1. Instead of the die being made from a single piece of metal, the circular segment of the forming radius is made from one piece, bored to a depth to give the correct angle at the ends of the arc. On to the top of this part, two top plates are aligned and secured with dowels and screws. These plates are machined to give the correct bend angle with a suitable entry radius, and to give a flat section on the formed strip between 1/8 in and 1/4 in long on which the formed angle can be measured after punching.

6. PROCEDURE

The punch and die are set up as an open pair on a Worcester 6-ton bench power press (Fig. 2). The clearance between the tool and the die is adjusted until it is equal to the thickness of the strip being used. For the 0.028 in strip this was done by measuring the height of the bottom position of the punch in relation to the bottom of the die and by adjusting the stroke of the cam-operated plunger until the difference was the strip thickness. This method could lead to inaccuracies arising from the subtraction and addition of several readings, and does not take account of any dynamic effects. The method adopted on the 0.048 in and subsequent strips was to use solder wire and to adjust the stroke of the plunger until the thickness of the wire after punching is the thickness of the strip. This method has the advantage of a direct reading of the gap from a micrometer and that the wire could be positioned in the place where the strip is to be measured.

For each set of conditions, 50 specimens are being produced and the included angles measured on a Nikon profile projector. To ensure that the strip about to be formed is at right angles to the punch, two lugs are provided on the top plates of the die against which the strip is located. The angles are always measured on this edge of the strip. The change in bend diameter is in the same ratio as the change in bend angle.

7. WORK COMPLETED

To date, all the work has been completed on the 0.008 in, 0.028 in and 0.048 in strip, i.e. the dies have been manufactured and the strip formed and measured. Work has commenced on the forming of the 0.012 in strip.

Because of their small diameter some of the dies for the three smallest material thicknesses cannot be bored with a boring tool, as the larger ones have been, and they are therefore being manufactured with a ball-end cutter. Since these cutters are available in a restricted number of sizes, some of the shape ratios are slightly different from those desired. By suitable selection of the punch sizes one die can be used for strips of two strip thicknesses. A saving of nine sets of dies is possible by this expedient and this should reduce the time necessary for completion of the project. The sizes of the dies and the bend indices used are given in Table I.

8. RESULTS

8.1 Material Dimensions

When the coils of the 0.048 in strip were measured they were found to be between 0.049 in and 0.050 in thick and in places to have a variation in thickness of 0.001 in across the width of the strip. (The tolerance on thickness specified in B.S. 1449 for this material is ± 0.0015 in.) Because of this variation the punches were turned 0.004 in under size on diameter and the dies set to give a clearance of 0.050 in. The average thickness of the 0.028 in strip was 0.028 in with a variation of ± 0.0005 in along the length of coil used. The dies were set to give the desired gap of 0.028 in. On the 0.008 in strip no measurable variation was found in the strip thickness and the dies were set to the nominal thickness.

8.2 Strip Forming

The results obtained from forming the first three thicknesses are shown in Tables II, III and IV. The tables show the mean formed angle for each die and the range, measured by 95% Confidence Limits (± 2 standard deviations), obtained by statistical analysis of the results.

From these data for each die the ratio of Mean Formed Angle/Bend Angle (Springback Ratio) is calculated and plotted against the Bend Index (D_b/t). As is shown in the Appendix, the ratio Mean Formed Angle/Bend Angle is equal to the ratio Bend Diameter/Formed Diameter (D_b/D_f), and always has a value less than unity. Figs. 3-5 show the graphs of the dimensionless ratios D_b/D_f vs D_b/t and each point represents an average of the 50 results from one die. Thus on each graph there are four points for one value of D_b/t and five values of D_b/t for each strip thickness.

From Figs. 3-5 are derived Figs. 6-8 on which the values of D_b/D_f are plotted against the Formed Index (D_f/t). These graphs, which are non-linear, are readily obtained from the original graphs since:-

$$\frac{Df}{t} = \frac{Db}{t} \times \frac{1}{D_b/D_f}$$

On each graph is shown the line obtained from the theoretical considerations described in Section 4, with the allowance for the rise in stress beyond the elastic limit of the material.

8.3 Material Properties

For each of the three strip thicknesses used to date, a tensile test was performed on a sample length. The stress-strain curves obtained are shown in Fig. 9 and the relevant properties for each thickness are shown in Table V. This table also shows the carbon content determined from a sample of each strip. The specification for CS 70 in B.S. 1449 calls for a carbon content between 0.65% and 0.75% and either a maximum tensile strength of 38 tonf/in^2 or a maximum hardness of 175 HV in the dead soft condition.

After the specimens had been formed the hardness of the strip was measured for each strip thickness. From each set of 90° and 60° dies five samples were taken and the hardness measured at four points on the flat portion of the strip. The results obtained are shown in Table VI, the values for the mean and range being based on the twenty hardness readings. The average values for each thickness and the equivalent value of U.T.S. are included in Table V.

9. DISCUSSION OF RESULTS

For a constant strip thickness and bend index the formed angle (the angle measured after the strip has been removed from the die) is directly proportional to the bend angle. Thus for a set of dies with four bend angles, the ratio D_b/D_f (equal to Formed Angle/Bend Angle) should be constant. From a comparison of Tables II-IV it will be seen that the results from the forming operation on the 0.050 in dies are the most consistent, the range being about 0.6° compared with 1.2° and 1.5° for the 0.028 in and 0.008 in dies.

In the case of the 0.028 in dies which were investigated first, the poorer results may be caused either by the difference in strip thickness or by the improved means of setting up, used on the second thickness. The results from the 0.008 in dies show the most variation of the three sets; the reasons for this could be the difficulty in obtaining flat specimens, the effect of the low temperature heat treatment the strip received or the very small size of the dies in relation to the strip width.

From the results for the 0.028 in strip shown in Table III, it will be noted that in general the variation in formed angle is greater for the 180° bend angle than for the other three. This is probably because for this die configuration the strip is to some extent 'drawn' between the punch and the die sides (see Fig. 1), whereas for the other three dies, the strip is pressed on the circular section of the die. For bend angles other than 180^{o} the variation in formed angle would seem to be independant of bend angle or bend index. For these dies, the range of the formed angle is constant at about 1^{o} and this would seem the best figure that could be achieved consistently. For the other two strip thicknesses, where the scatter in formed angle is greater, this trend is not so noticeable.

From the graphs of Springback Ratio versus Bend Index (Figs. 3-5) it will be seen that, for the 0.028 in and 0.050 in strip thicknesses, a straight line can be drawn through the set of points. For the data for the 0.008 in strip however the scatter is too great for the line to be drawn with great accuracy.

As is shown elsewhere(1), it is the Elastic Limit of the material which influences the formed angle of the strip, so the greater the variation in the Elastic Limit of the material the greater the scatter in the formed angle. The elastic limit is dependent upon the ultimate tensile strength (U.T.S.) of the material and a measure of the U.T.S. is given by the hardness of the specimen which is easily determinable. In Table VI it will be seen that for the 0.008 in strip the variation in the hardness readings is 25-30 HV which is equivalent to a variation in the U.T.S. of 100 N/mm^2. For this material the ratio Elastic Limit/U.T.S. (determined from the tensile test) is 0.8, so the variation in the Elastic Limit of the specimens is about 80 N/mm^2. For the other strip thicknesses the variation in the hardness of the specimens is of the order of 10 HV equal to a variation of 30 N/mm^2 in the U.T.S. The ratio Elastic Limit/U.T.S. is only about 0.5 so the variation in the Elastic Limit for these thicknesses is about 15 N/mm^2, about a fifth of that of the 0.008 in strip.

On the first graphs (Figs. 3-5) the values of D_b/D_f determined from the results are plotted against the values of D_b/t to which the dies were manufactured. Figs. 6-8 show the values of D_b/D_f plotted against the derived values of D_f/t, and these can be used for the design of dies. Since the values of t, the strip thickness and D_f, the desired bend diameter, are both known, the value of D_b, the actual forming diameter, can be found from the value of D_b/D_f read off on the y-axis of the graph.

The line which can be drawn through the points on the graph is below the line predicted from the stress-strain curves of the strip as shown in Section 4. This is to say that the formed angle is less than is predicted and the error in the springback ratio is between 2-5%. This discrepancy is most noticeable on the small dies which have $D_b/t < 20$ and for which on all three thicknesses the formed angle is less than would be expected. This would seem to lead to the observation that with the small bend radii the stress strain relationship beyond the yield point has more influence than is indicated from the theoretical considerations.

10. CONCLUSIONS

(1) Over the range of bend indices tested and for a single hardness the Springback Ratio (D_b/D_f) is inversely proportional to the Bend Index (D_b/t).

(2) Since the strip thickness and punch diameter can be displayed in the form of dimensionless ratios, the most important variable in strip forming is the Elastic Limit of the material, which is most easily estimated in terms of the hardness.

(3) With the straight strip of uniform hardness the smallest variation in formed angle that can consistently be achieved is $1^o - 2^o$.

(4) Scatter in the springback of steel strip is caused by the variation in Elastic Limit of the strip.

(5) Theoretical considerations from the mechanical properties of the strip can lead to the estimation of the springback ratio within 2-5%.

(6) Scatter in the springback ratio increases with smaller Bend Indices and with thinner strip.

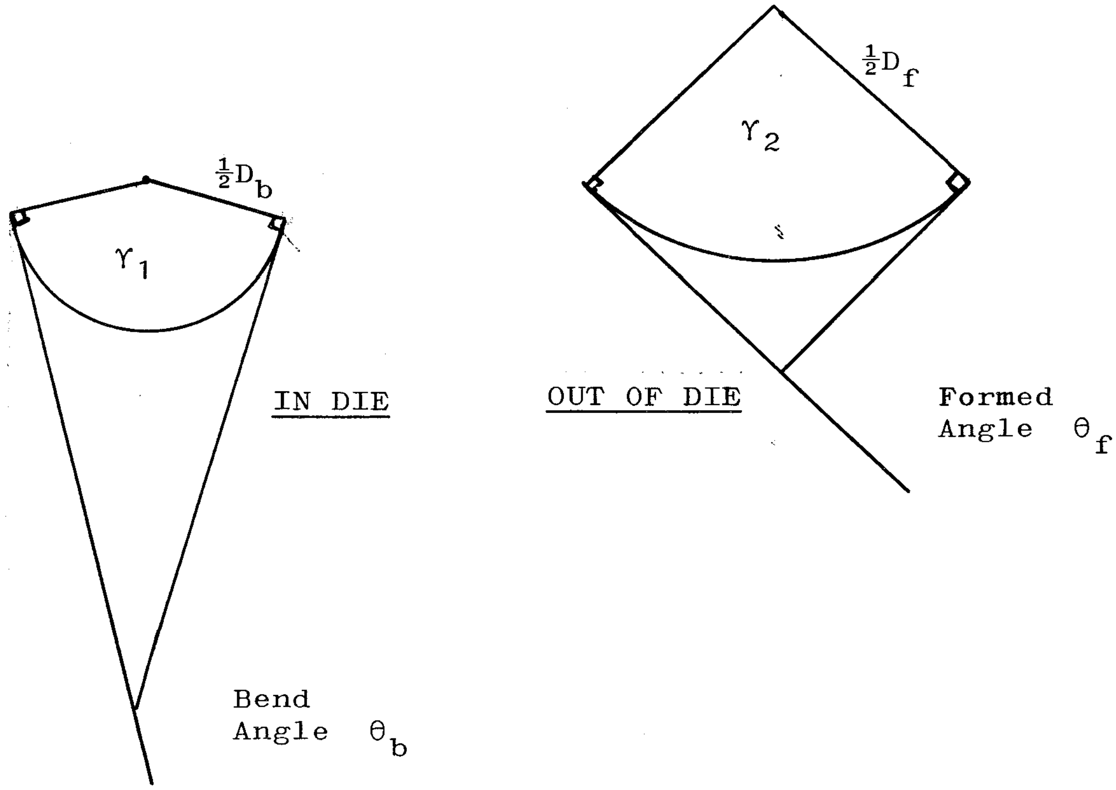
(7) In view of the difficulty in obtaining flat specimens for forming, it would be better if the diameter of the coils of strip were larger, 3 ft in diameter or greater.

11. REFERENCES

(1) F. J. Gardiner. "The Spring Back of Metals" ASME Paper No. 55-A-66.

APPENDIX I

Relationship Between Formed Angle and Bend Diameter



D_b = Mean bend diameter

D_f = Mean formed diameter

From the diagram it can be seen that for the length of strip in the die, since $1 \propto r\gamma$ and in this case 1 is constant,

$$\tfrac{1}{2}D_b \cdot \gamma_1 = \tfrac{1}{2}D_f \cdot \gamma_2$$

$$\frac{D_b}{D_f} = \frac{\gamma_2}{\gamma_1}$$

Now $\gamma_1 = \theta_b$

and $\gamma_2 = \theta_f$

$$\therefore \frac{Db}{Df} = \frac{\theta f}{\theta b}$$

TABLE I DIMENSIONS OF DIES

Die Number	Strip Thickness (t)	Die Diameter (in)	Bend Diameter (D_b)	Nominal Bend Index	Actual Bend Index (D_b/t)
1	0.048 in*	2.400	2.350	49	47.0
2	0.048 in*	1.824	1.774	37	35.4
3	0.048 in*	1.440	1.390	29	27.8
4	0.048 in*	0.960	0.910	19	18.2
5	0.048 in*	0.672	0.622	13	12.4
6	0.036 in	1.824	1.788	49	49.6
7	0.036 in	1.400	1.364	37	37.8
8	0.036 in	1.064	1.028	29	29.0
9	0.036 in	0.720	0.684	19	19.0
10	0.036 in	0.504	0.468	13	13.0
11	0.028 in	1.400	1.372	49	49.0
12	0.028 in	1.064	1.036	37	37.0
13	0.028 in	0.840	0.812	29	29.0
14	0.028 in	0.562	0.534	19	19.0
15	0.028 in	0.393	0.365	13	13.0
16	0.018 in	0.900	0.882	49	49.0
17	0.018 in	0.672	0.654	37	36.4
18	0.018 in	0.562	0.544	29	30.2
19	0.018 in	0.354	0.336	19	18.6
20	0.018 in	0.250	0.232	13	12.8
21	0.012 in	0.600	0.588	49	49.0
22	0.012 in	0.456	0.444	37	37.0
23	0.012 in	0.354	0.342	29	28.4
24	0.012 in	0.236	0.224	19	18.6
25	0.012 in	0.157	0.145	13	12.0
26	0.008 in	0.393	0.385	49	48.0
27	0.008 in	0.312	0.304	37	38.0
28	0.008 in	0.236	0.228	29	28.5
29	0.008 in	0.157	0.149	19	18.6
30	0.008 in	0.118	0.110	13	13.8

* Actual strip thickness was 0.050 in

TABLE II   RESULTS FROM 0.008 IN STRIP

Die Number	Bend Angle (°)	Mean Formed Angle (°)	Range (°) (95% Limits)
26A	180	156.2	4.2
26B	130	112.0	2.9
26C	90	76.3	2.7
26D	60	51.6	1.4
27A	180	166.6	2.3
27B	130	119.1	3.1
27C	90	82.3	2.5
27D	60	55.0	1.3
28A	180	170.0	2.2
28B	130	122.0	2.2
28C	90	82.4	1.9
28D	60	55.1	1.6
29A	180	171.3	3.4
29B	130	123.0	5.7
29C	90	86.9	1.1
29D	60	54.3	1.2
30A	180	168.0	3.9
30B	130	117.4	6.4
30C	90	80.3	1.8
30D	60	51.5	2.3

TABLE III RESULTS FROM 0.028 IN STRIP

Die Number	Bend Angle (°)	Mean Formed Angle (°)	Range (°) (95% Limits)
11A	180	158.6	3.9
11B	130	113.5	6.7
11C	90	78.7	3.4
11D	60	52.7	3.1
12A	180	162.3	2.3
12B	130	117.5	2.4
12C	90	81.4	2.0
12D	60	55.6	1.4
13A	180	165.4	2.3
13B	130	119.5	3.6
13C	90	83.0	2.1
13D	60	56.3	2.1
14A	180	169.3	1.8
14B	130	120.8	2.1
14C	90	82.6	1.5
14D	60	53.8	1.8
15A	180	170.0	1.1
15B	130	120.6	1.4
15C	90	82.5	1.5
15D	60	55.2	2.4

TABLE IV RESULTS FROM 0.050 IN STRIP

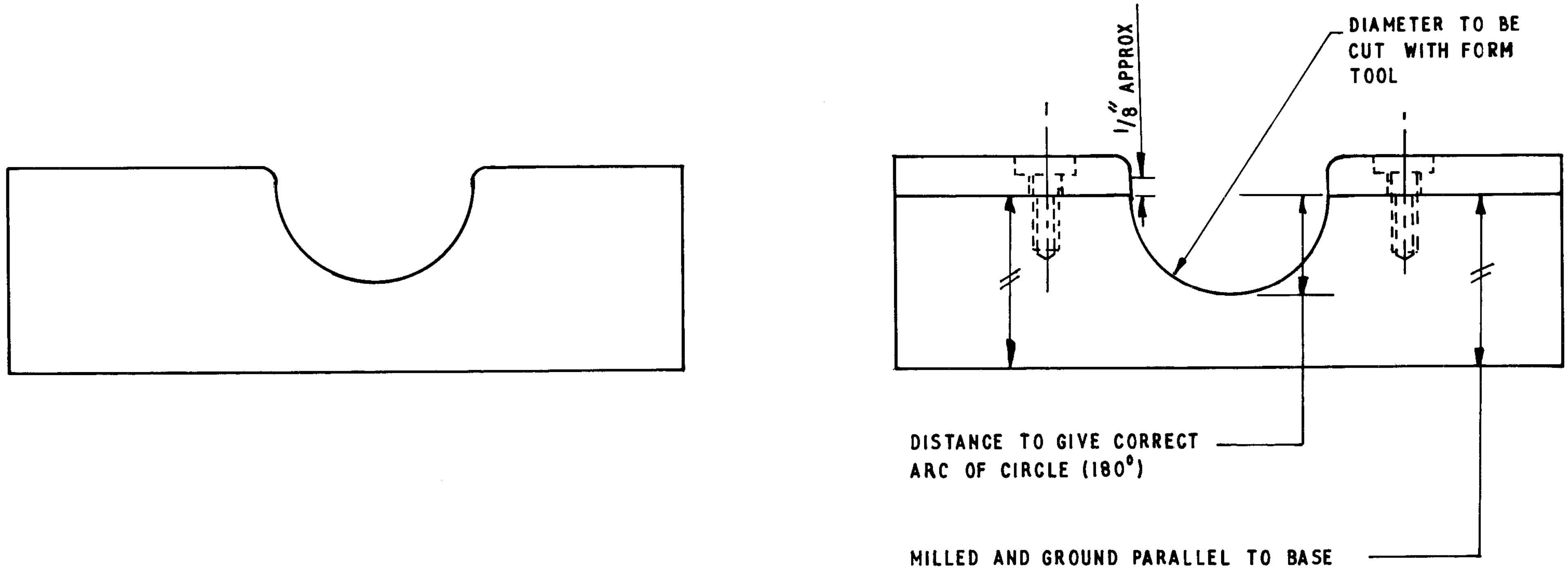
Die Number	Bend Angle (°)	Mean Formed Angle (°)	Range (°) (95% Limits)
1A	180	155.7	2.5
1B	130	111.5	1.4
1C	90	77.8	0.9
1D	60	50.5	1.0
2A	180	159.3	2.0
2B	130	116.7	0.8
2C	90	79.8	0.9
2D	60	52.3	1.1
3A	180	163.6	1.6
3B	130	116.8	1.2
3C	90	81.0	0.8
3D	60	53.9	0.7
4A	180	164.6	1.1
4B	130	119.8	1.5
4C	90	82.8	0.8
4D	60	55.5	1.0
5A	180	169.3	1.6
5B	130	122.1	0.7
5C	90	84.8	0.7
5D	60	57.9	0.5

TABLE V PROPERTIES OF CS 70 STRIP

Strip Thickness (in)	0.008	0.028	0.050
U.T.S. (N/mm^2)	540	520	560
Elastic Limit (N/mm^2)	420	250	300
0.1% Proof Stress (N/mm^2)	440	270	340
0.2% Proof Stress (N/mm^2)	440	280	350
% Elongation	54	-	-
Ratio Elastic Limit/U.T.S.	0.80	0.48	0.54
% Carbon Content	0.71	0.66	0.63
Average Hardness (HV)	136	149	175
Equivalent U.T.S. (N/mm^2)	450	490	590
Ratio Sy/E	2.06×10^{-3}	1.33×10^{-3}	1.73×10^{-3}
Ratio n/E	0.3×10^{-3}	6.3×10^{-3}	4.0×10^{-3}

TABLE VI HARDNESS VALUES OF FORMED STRIP

Die Number	Thickness	Mean Hardness	Range
1C	0.050 in	172 HV 30	8 HV
1D	0.050 in	173 HV 30	7 HV
2C	0.050 in	174 HV 30	14 HV
2D	0.050 in	171 HV 30	8 HV
3C	0.050 in	175 HV 30	15 HV
3D	0.050 in	175 HV 30	8 HV
4C	0.050 in	178 HV 30	13 HV
4D	0.050 in	177 HV 30	12 HV
5C	0.050 in	176 HV 30	9 HV
5D	0.050 in	178 HV 30	9 HV
11D	0.028 in	148 HV 20	9 HV
12D	0.028 in	150 HV 20	10 HV
13D	0.028 in	149 HV 20	9 HV
14D	0.028 in	149 HV 20	7 HV
15D	0.028 in	149 HV 20	10 HV
26C	0.008 in	138 HV 5	24 HV
26D	0.008 in	131 HV 5	23 HV
27C	0.008 in	132 HV 5	22 HV
27D	0.008 in	136 HV 5	14 HV
28C	0.008 in	140 HV 5	33 HV
28D	0.008 in	133 HV 5	20 HV
29C	0.008 in	138 HV 5	28 HV
29D	0.008 in	133 HV 5	23 HV
30C	0.008 in	142 HV 5	24 HV
30D	0.008 in	134 HV 5	29 HV



OLD DIE

NEW DIE

FIG. 1 MODIFICATION TO DIES

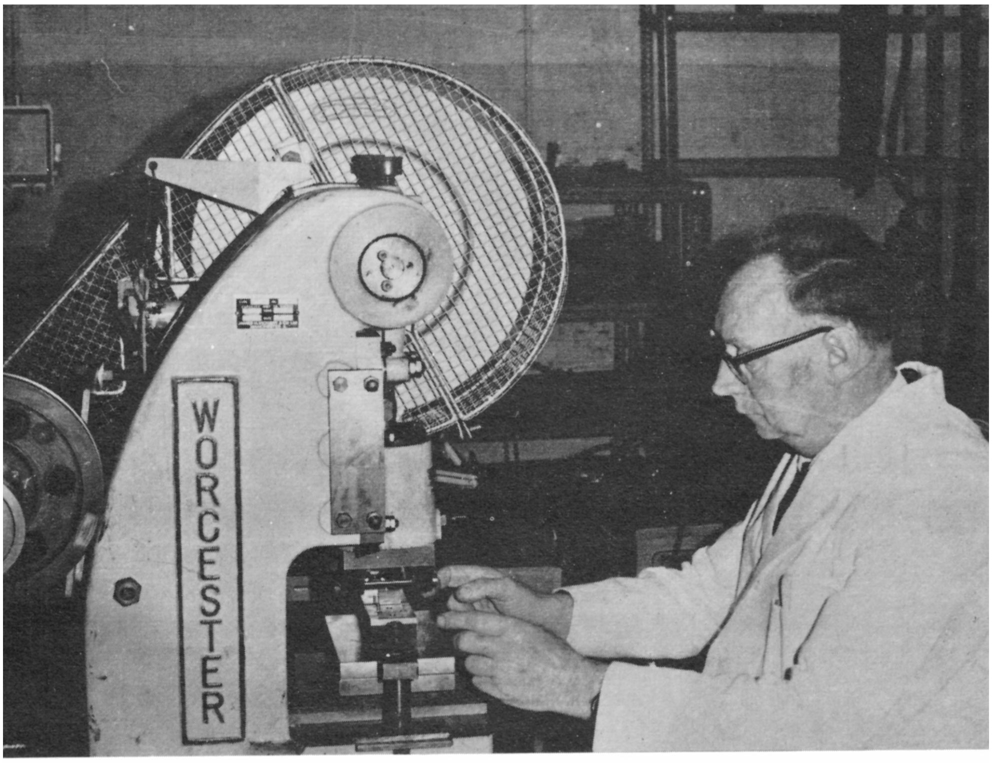


FIG. 2 ARRANGEMENT OF DIE AND PRESS TOOL

(SAFETY GUARDS NOT SHOWN)

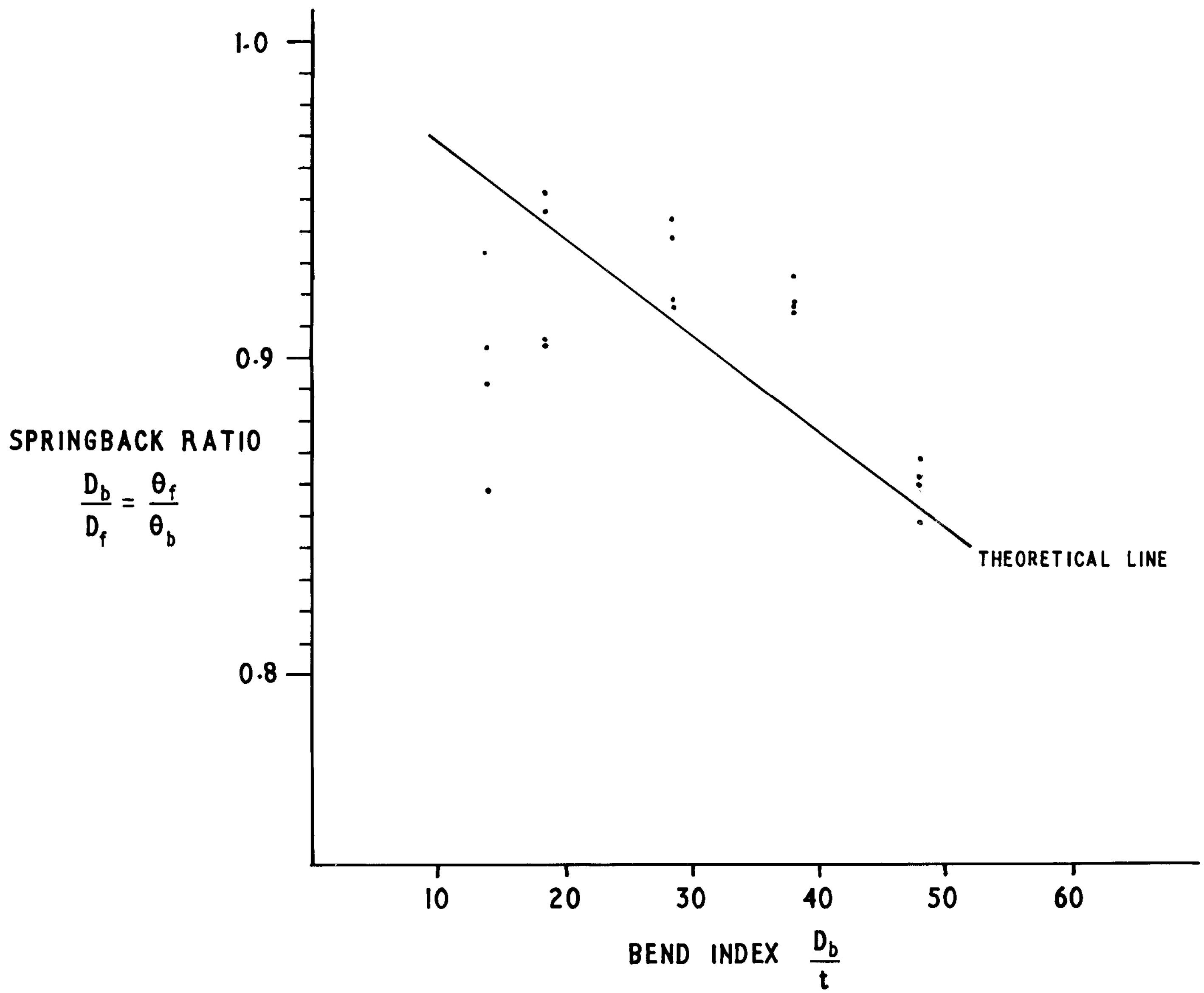


FIG. 3 GRAPH OF SPRINGBACK RATIO vs BEND INDEX FOR 0·008 in STRIP

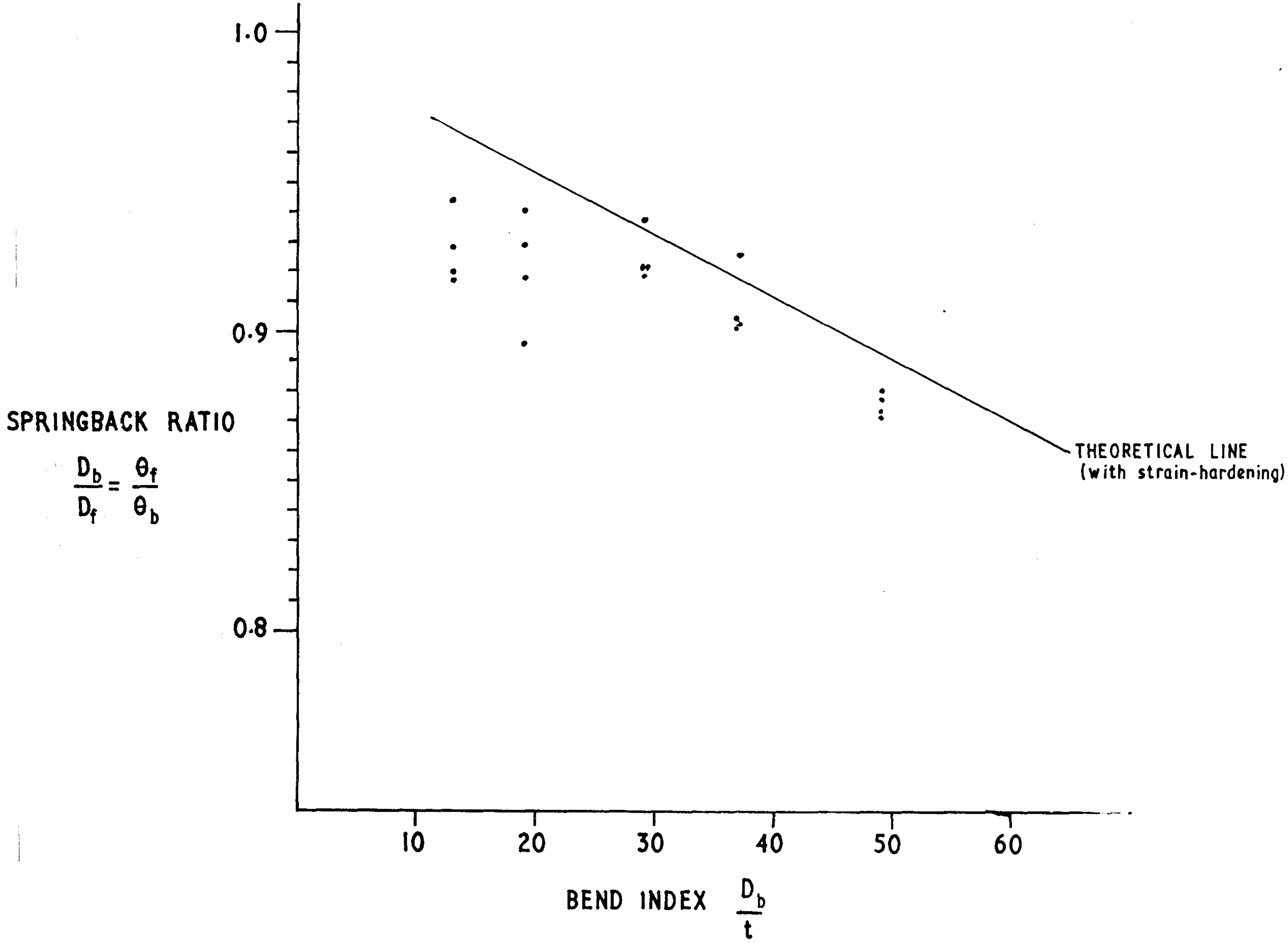


FIG. 4 GRAPH OF SPRINGBACK RATIO vs BEND INDEX FOR 0.028in STRIP

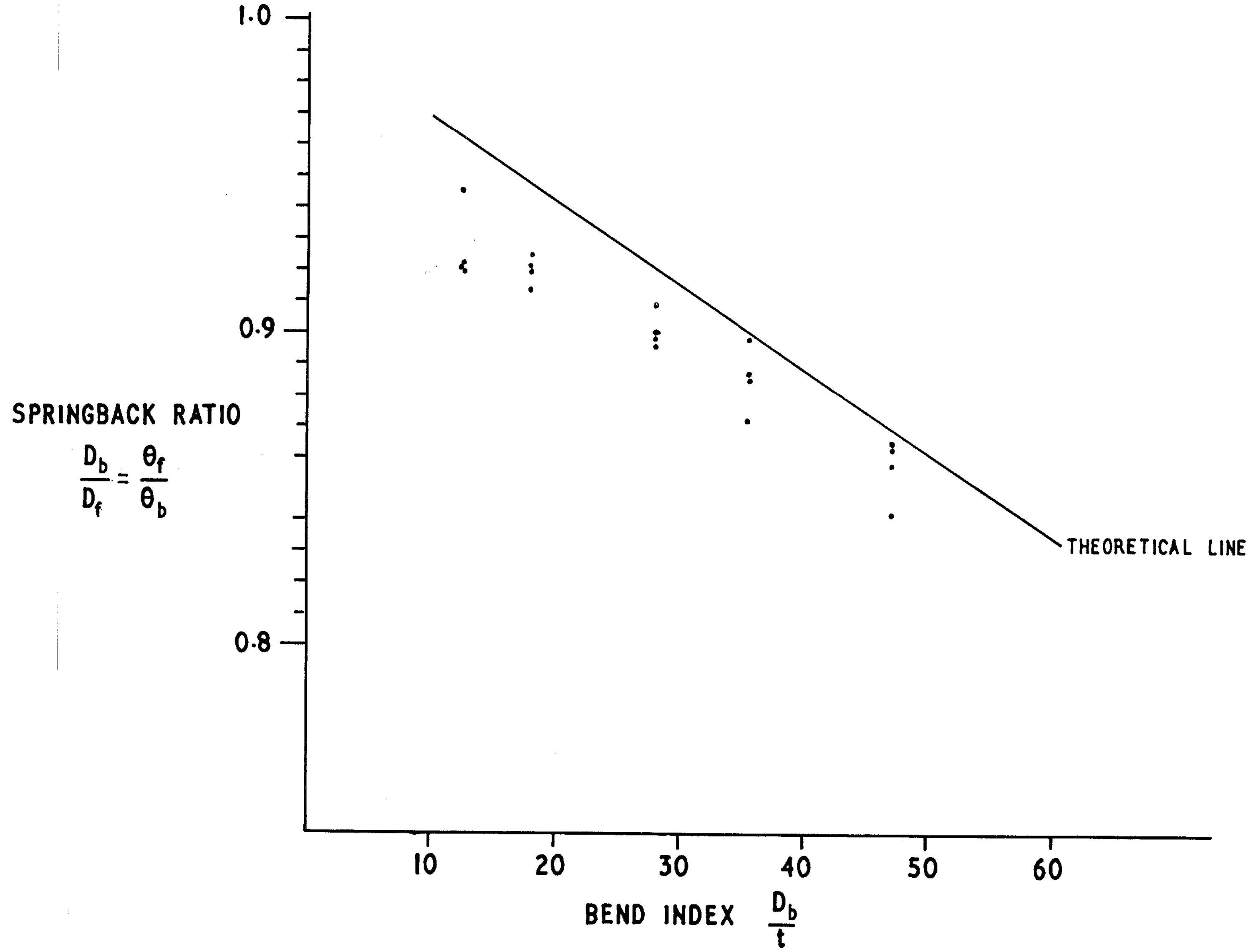


FIG. 5 GRAPH OF SPRINGBACK RATIO vs BEND INDEX FOR 0.050in STRIP

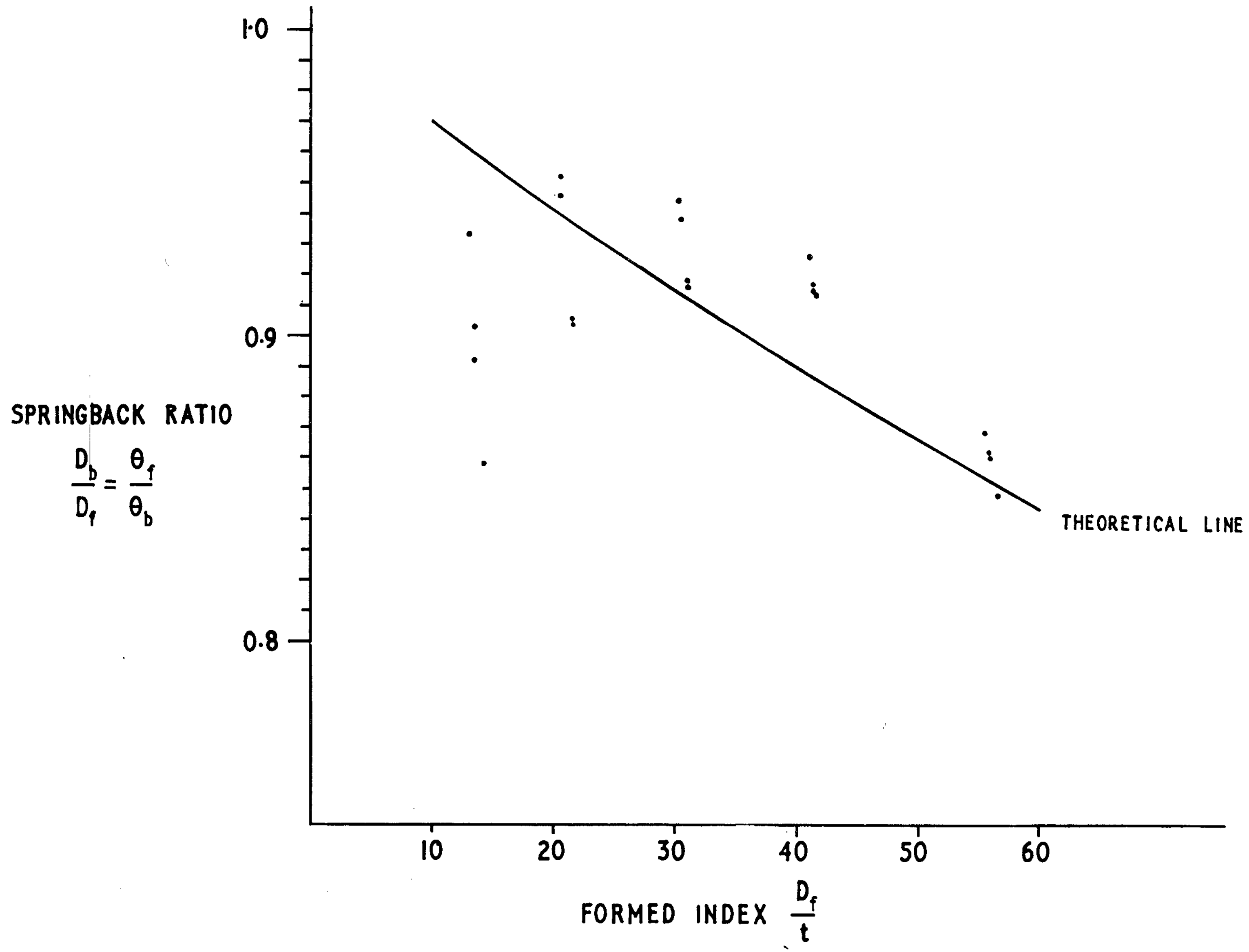


FIG. 6 GRAPH OF SPRINGBACK RATIO vs FORMED INDEX FOR 0·008in STRIP

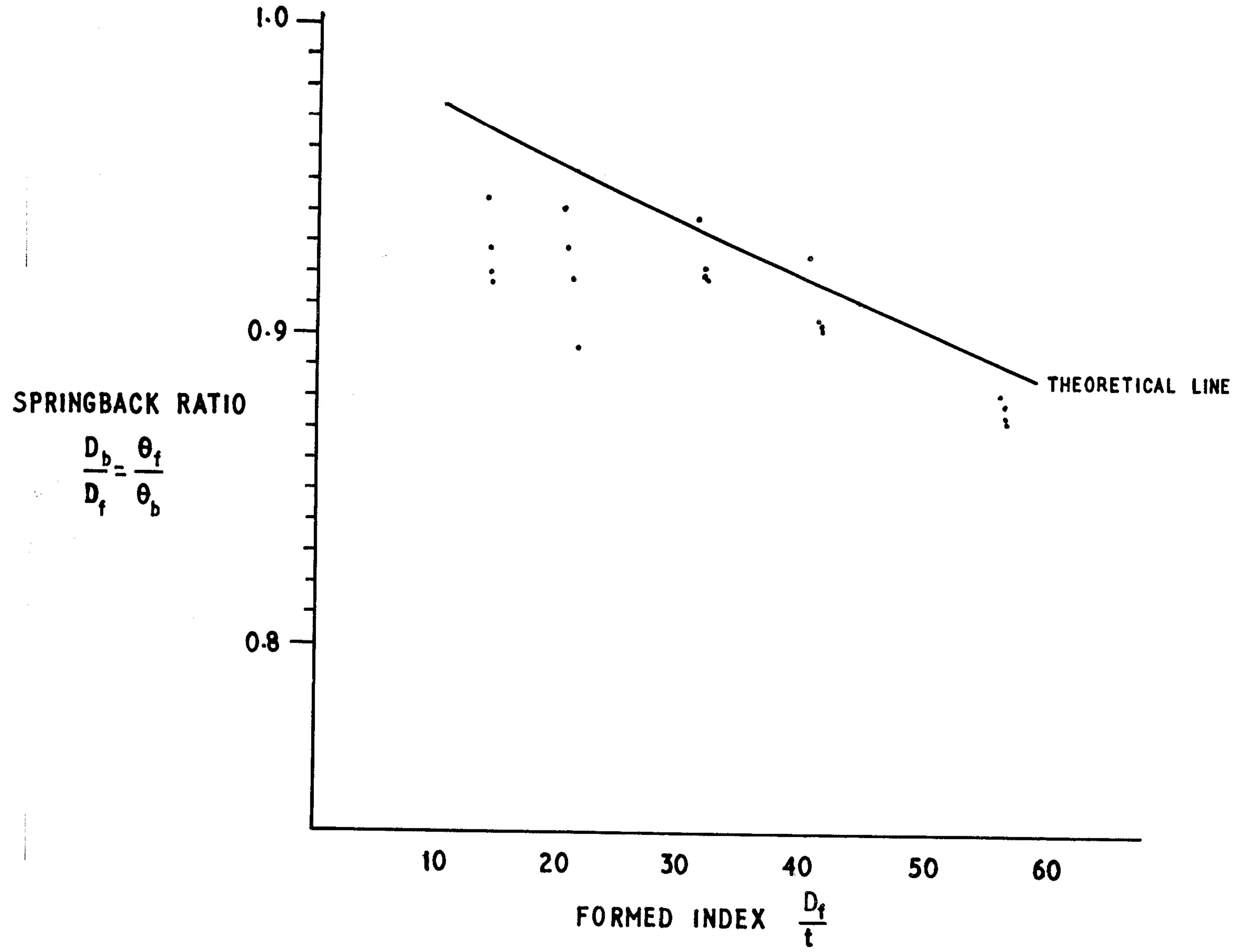


FIG. 7 GRAPH OF SPRINGBACK RATIO vs FORMED INDEX FOR 0.028in STRIP

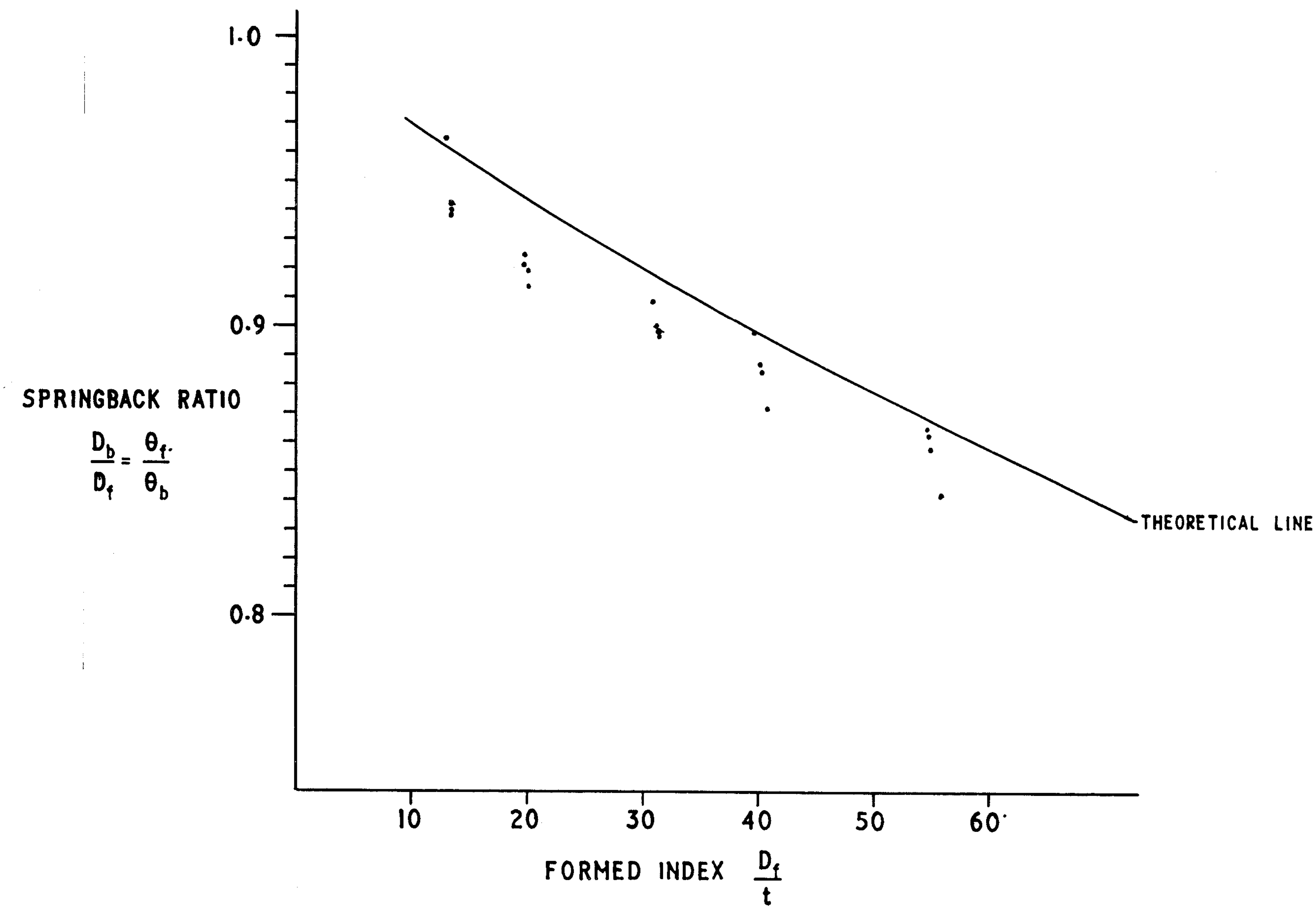


FIG. 8 GRAPH OF SPRINGBACK RATIO vs FORMED INDEX FOR 0.050in STRIP

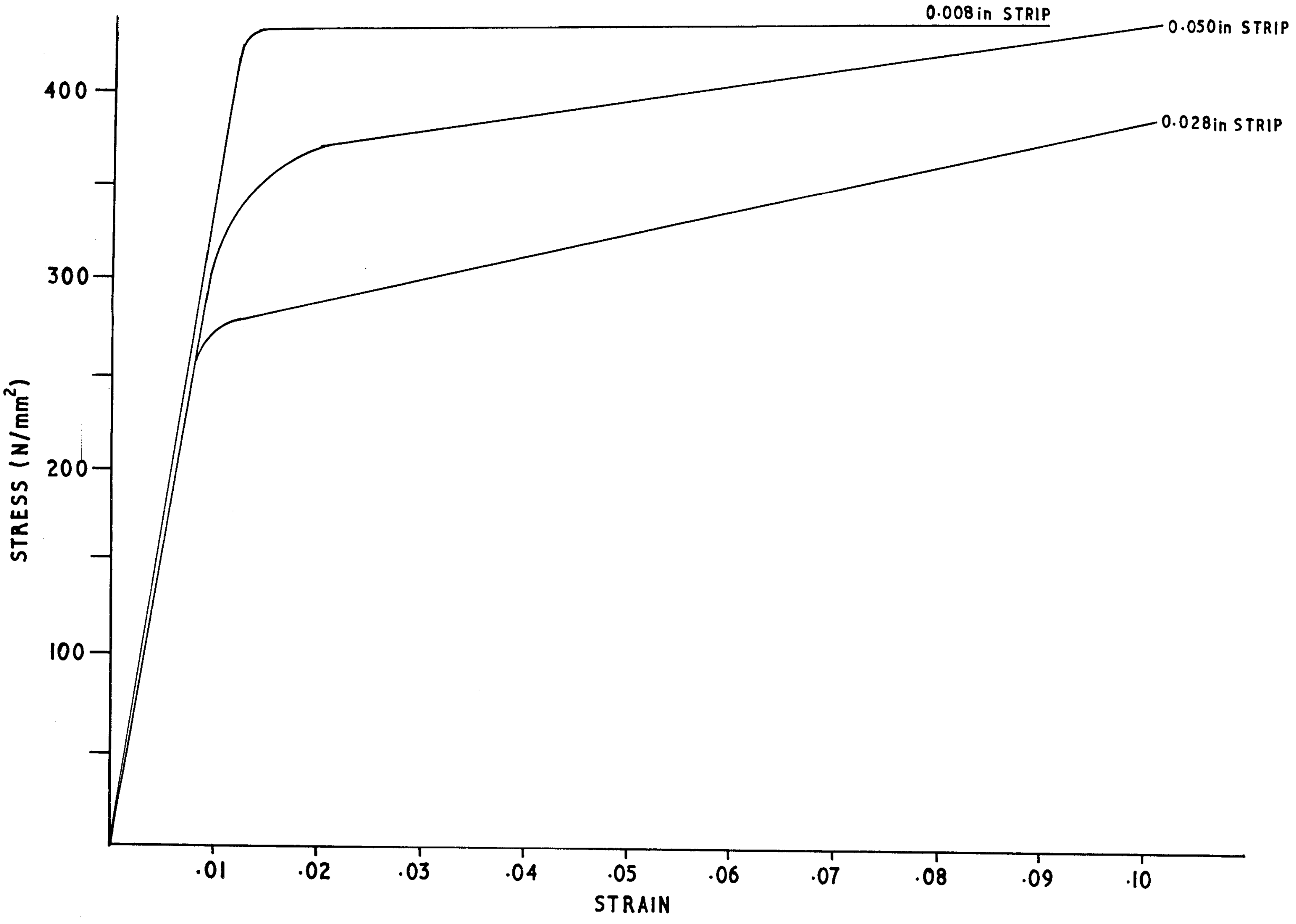


FIG. 9 STRESS—STRAIN CURVES FOR CS70 STRIP