THE SPRING RESEARCH ASSOCIATION

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

Progress Report No. 2

by

G.C. Bird, B.Sc.

Report No. 230

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SUMMARY

The object of this investigation into strip forming has been to produce data for die design relating to annealed CS70 carbon steel strip, when formed by a cylindrical punch.

The results have been presented in the same manner as in the first progress report (Research Report 204). The same consistency of forming has been achieved. The first progress report covered the material thicknesses, 0.028 in. and 0.050 in. while this report deals with the remaining thicknesses 0.012 in., 0.018 in. and 0.036 in.

For the range of strip forming where the bend diameter is between 10 and 60 times the strip thickness, graphs have been drawn for all six thicknesses enabling the designer to predict the shape of the die required to an accuracy of between 2 and 5%.

Future work is to be undertaken on annealed Copper beryllium, Hard phosphor bronze and hardened and tempered CS70.

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1. INTRODUCTION

The object of this research programme has been to produce data which relate the formed angle and thickness of strip to the bend angle and diameter, using a cylindrical punch.

The previous report (Research Report 204) described the procedure used in the work and the method of presentation of results. This report covers the work on the remainder of the first material to be investigated, annealed CS70 to BS 1449 Part 1: 1972.

The data presented in both reports have been combined to produce graphs relating the various parameters, for use by press tool designers.

2. MATERIAL

The material used was annealed carbon steel strip, CS70 to BS 1449 Part 1: 1972 in thicknesses of 0.012 in., 0.018 in. and 0.036 in. and with a nominal hardness of 150 HV. As in the case of 0.008 in. strip tested previously, the 0.012 in. and 0.018in. material had to be straightened by low temperature heat treatment under stress. This consisted of coiling a length of strip the opposite way to its natural direction, inserting in a tube and soaking at 450°C in a furnace for half an hour.

3. RESULTS

3.1 Material Dimensions

The thickness of the strip was measured at various points on the coil and in all cases was found to be within the specified tolerance for thickness for carbon steels as shown below.

Nominal thickness	Measured thickness	Permissible thickness
0.012	0.0120 - 0.0125	0.0112 - 0.0128
0.018	0.0175 - 0.0180	0.0170 - 0.0190
0.036	0.0365 - 0.0370	0.0345 - 0.0375

3.2 Strip Forming

The results obtained from forming the three thicknesses of strip are shown in Tables I - III. The tables show the average formed angle for each die and the range of angles, based on the 95% confidence limits (± 2 standard deviations) obtained by statistical analysis of the 50 measured specimens.

For each group of four dies of one bend index, the average Springback Ratio was calculated. This was also done for the results obtained with the other three strip thicknesses and the values of Springback Ratio and Bend Index for all the dies are given in Table IV.

For each strip thickness, a graph has been drawn of Springback Ratio against Bend Index. These are shown for all six strip thicknesses in Figs. 1 - 6. On each graph, the line through the five points is the "best - fit" line determined by calculation by the "least squares" method. Fig. 7 has been drawn from the data presented in Figs. 1 - 6. The method used to obtain the formed diameter is shown overleaf:-

For a given Springback Ratio ($D_b/D_f = K$)

$$D_f = \frac{\frac{Db}{t} \cdot t}{D_b/D_f}$$

where D_b = Bend diameter

D_f = Formed diameter

t = Material thickness

3.3 Material properties

For each of the three strip thicknesses used, tensile tests were carried out in duplicate, after heat treatment where applicable. The data obtained are shown in Table V which also gives the carbon content determined from a sample of each strip. The material specification calls for a carbon content between 0.65% and 0.75%; only the 0.036 in. thick material was outside the specification.

The maximum permitted tensile strength is 580 N/mm^2 and all three materials had a lower tensile strength than this.

The hardness of the strip used in forming was measured on samples from two dies in each set. Table VI shows the average value and range of the twenty measurements for each die.

4. DISCUSSION OF RESULTS

From a comparison of Tables I - III, it will be seen that the most consistent forming results were achieved with the thickest strip, 0.036in., and that, in general, the more consistent results were obtained with the smaller bend angles. These two observations concur with the results obtained previously where the 0.050 in. strip gave the most consistent formed angles.

From Table V it can be seen that the tensile strength decreases with increasing strip thickness and that, for the 0.012 in. and 0.018 in. strip, the limit of proportionality is only slightly less than the 0.1%, 0.2% and 0.5% Proof Stresses. This indicates that there is a very distinct yield point in the material and very little increase in stress beyond the yield point. For the 0.036 in. material the yield is less distinct although the Proof Stresses show that the stress-strain curve is very flat.

Comparing these tensile test results with those obtained previously, it is interesting to note that, with the thinner strip, the yield point is more pronounced and the plastic portion of the stress-strain curve virtually flat.

Table VI shows the hardness values of the three thicknesses and again it will be noticed that the scatter in the readings is greatest for the thinnest strip.

From the graphs of Springback Ratio versus Bend Index, Figs. 1 -6, it will be seen that there is less scatter on the graphs for the thicker strip.

The scatter is measured by the correlation coefficient which for the results of the 0.008 in. strip is 0.573 and for the results of the 0.050 in. strip is 0.991. The points on the graphs represent Springback Ratio of each set of dies for one bend index. Each point is the average of 200 measurements. A variation of 2° in the formed angle for a 90° bend, or of 4° for a 180° bend, would alter the Springback Ratio by 0.025. It can be seen that for all the strip thicknesses, with the exception of 0.008 in. strip, the lines drawn through the points are accurate to $\pm$ 2%.

There are two main reasons for the scatter in the results. One is the variation in the elastic properties of the material, the other is some slight curvature in the strip before forming. Here, the use of the material in the annealed condition meant that the strip was not perfectly flat when it came off the coil. Even with the use of roller straighteners or the heat treatment method described earlier, the specimens used were slightly curved, making it difficult to measure the formed angle accurately.

The theoretical considerations presented in the previous report in all three cases quite seriously underestimated the measured springback, the material having a higher apparent yield stress than that measured.

The range of Formed Indices used in the experiment was between 10 and 60 and Fig. 7 has been drawn using this range of Formed Indices to provide a graph which can be easily used by tool designers. It is interesting to note that, on this chart, the lines drawn for each strip thickness are approximately parallel and thus data for intermediate thicknesses can easily be interpolated. The line which differs most from the pattern of the other five is that for the 0.008 in. strip, where the scatter in the results is greatest.

It should be noted that the lines on this chart are affected by the hardness of the material used. For the 0.012 in., 0.018 in., 0.028 in. and 0.036 in. material, the hardness was in the range 150 - 160 HV but for the 0.008 in. and 0.050 in. strip the average hardness was 135 HV and 175 HV respectively.

5. APPLICATIONS OF RESULTS

The data presented in Fig. 7 can be used to estimate the shape of a die needed to make a given part.

From Fig. 7 the springback correction factor can be calculated, given the thickness and diameter of the part to be made. To obtain the diameter of the die required, the desired diameter has to be multiplied by the value of the correction factor. To obtain the bend angle of the die, the desired angle has merely to be divided by the value of the correction factor.

For example, a part is required to be formed from 0.028 in. material with an outside diameter of 1.30 in. and a bend angle of 76^{o}. From Fig. 7, the correction factor is 0.896. Therefore the diameter of the die is 1.30 x 0.896 = 1.165 in., and the bend angle of the die is 76/0.896 = 85^{o}.

6. FUTURE WORK

The investigation to date has covered annealed CS70 to BS 1449 Part 1: 1972 with a nominal hardness of 150 HV. The next three materials which will be investigated simultaneously are:

1. Phosphor bronze - PB 102 to BS 2870 in the Hard condition. (180 - 200 HV)
2. Beryllium Copper - CB 101 to BS 2870 in the annealed condition (85 - 120 HV)
3. Carbon Steel - CS70 to BS 1449 Part 1: 1972 in the hardened and tempered condition (450 - 480 HV)

In view of the difficulties encountered in the previous work, the material is to be obtained in flat lengths wherever possible.

7. CONCLUSIONS

(1) The variation in the results of the forming operation is caused by variation in the material properties.

(2) The accuracy of measurement of the springback angle is reduced by not having flat specimens.

(3) The springback properties of annealed CS70 strip have been assessed for six material thicknesses and die design data, accurate to within ± 2%, have been produced.

TABLE I RESULTS FROM 0.012 in. STRIP

DIE NUMBER	BEND ANGLE (°)	MEAN FORMED ANGLE (°)	RANGE (°) (95% LIMITS)
21A	180	163.6	5.6
21B	130	119.6	1.7
21C	90	80.4	1.1
21D	60	53.0	0.7
22A	180	161.1	3.2
22B	130	118.2	3.0
22C	90	81.7	2.5
22D	60	53.8	2.3
23A	180	167.0	3.9
23B	130	119.6	2.6
23C	90	81.7	3.0
23D	60	51.7	1.6
24A	180	168.7	1.7
24B	130	117.2	2.1
24C	90	79.7	1.4
24D	60	54.8	3.7
25A	180	170.1	1.7
25B	130	120.5	2.9
25C	90	85.6	2.8
25D	60	57.0	3.9

TABLE II   RESULTS FROM 0.018 in. STRIP

DIE NUMBER	BEND ANGLE (°)	MEAN FORMED ANGLE (°)	RANGE (°) (95% LIMITS)
16A	180	157.7	5.1
16B	130	115.6	2.6
16C	90	82.3	3.4
16D	60	53.8	0.5
17A	180	166.6	2.3
17B	130	118.1	3.0
17C	90	83.0	1.5
17D	60	54.5	1.8
18A	180	166.0	2.6
18B	130	119.3	1.0
18C	90	84.2	2.3
18D	60	54.3	2.8
19A	180	170.7	1.6
19B	130	122.0	1.2
19C	90	81.3	1.2
19D	60	53.5	0.4
20A	180	169.5	3.0
20B	130	121.3	2.0
20C	90	82.2	1.8
20D	60	57.0	3.0

TABLE III RESULTS FROM 0.036 in. STRIP

DIE NUMBER	BEND ANGLE (°)	MEAN FORMED ANGLE (°)	RANGE (°) (95% LIMITS)
6A	180	159.9	6.9
6B	130	117.1	3.9
6C	90	79.2	3.6
6D	60	52.4	0.9
7A	180	161.6	2.4
7B	130	116.1	3.0
7C	90	78.6	2.0
7D	60	52.4	1.8
8A	180	163.6	1.8
8B	130	118.8	2.6
8C	90	82.1	1.5
8D	60	54.2	0.6
9A	180	165.0	1.8
9B	130	119.9	0.7
9C	90	83.6	0.9
9D	60	56.5	1.2
10A	180	167.8	1.7
10B	130	121.6	1.3
10C	90	86.8	1.4
10D	60	59.4	1.5

TABLE IV VALUES OF SPRINGBACK RATIO

DIE NUMBER	STRIP THICKNESS	BEND INDEX	SPRINGBACK RATIO
1	0.050 in.	47.0	0.857
2	"	35.4	0.885
3	"	27.8	0.901
4	"	18.2	0.920
5	"	12.4	0.947
6	0.036 in.	49.6	0.886
7	"	37.8	0.885
8	"	29.0	0.910
9	"	19.0	0.928
10	"	13.0	0.955
11	0.028 in.	49.0	0.876
12	"	37.0	0.909
13	"	29.0	0.924
14	"	19.0	0.921
15	"	13.0	0.927
16	0.018 in.	49.0	0.894
17	"	36.4	0.916
18	"	30.2	0.920
19	"	18.6	0.920
20	"	12.8	0.934
21	0.012 in.	49.0	0.901
22	"	37.0	0.902
23	"	28.4	0.904
24	"	18.6	0.909
25	"	12.0	0.943
26	0.008 in	48.0	0.859
27	"	38.0	0.918
28	"	28.5	0.929
29	"	18.6	0.942
30	"	13.8	0.897

TABLE V   PROPERTIES OF CS70 STRIP

STRIP THICKNESS (in) (mm)	0.012 0.30	0.018 0.46	0.036 0.91
TENSILE STRENGTH (N/mm^2)	555	530	520
LIMIT OF PROPORTIONALITY (N/mm^2)	418	385	222
0.1% PROOF STRESS (N/mm^2)	418	398	292
0.2% PROOF STRESS (N/mm^2)	420	400	302
0.5% PROOF STRESS (N/mm^2)	420	400	305
ELONGATION (%)	35	36	32
RATIO $\frac{\text{L of P}}{\text{TENSILE STRENGTH}}$	0.75	0.73	0.43
CARBON CONTENT %	0.66	0.69	0.64
AVERAGE HARDNESS (HV)	154	158	158
RATIO $\frac{\text{L of P}}{\text{ELASTICITY MODULUS}}$	2.0×10^{-3}	1.86×10^{-3}	1.07×10^{-3}

TABLE VI HARDNESS VALUES

DIE NUMBER	STRIP THICKNESS	AVERAGE HARDNESS	HARDNESS RANGE
6C	0.036 in.	158 HV 20	10
6D	"	158 HV 20	9
7C	"	159 HV 20	11
7D	"	159 HV 20	7
8C	"	157 HV 20	9
8D	"	159 HV 20	5
9C	"	156 HV 20	10
9D	"	160 HV 20	8
10C	"	161 HV 20	13
10D	"	158 HV 20	6
16C	0.018 in.	158 HV 10	16
16D	"	160 HV 10	15
17C	"	158 HV 10	12
17D	"	161 HV 10	14
18C	"	157 HV 10	10
18D	"	154 HV 10	12
19C	"	155 HV 10	13
19D	"	156 HV 10	12
20C	"	160 HV 10	15
20D	"	158 HV 10	13
21C	0.012 in.	150 HV 5	9
21D	"	154 HV 5	18
22C	"	154 HV 5	13
22D	"	155 HV 5	17
23C	"	152 HV 5	20
23D	"	156 HV 5	13
24C	"	157 HV 5	15
24D	"	155 HV 5	15
25C	"	155 HV 5	15
25D	"	156 HV 5	20

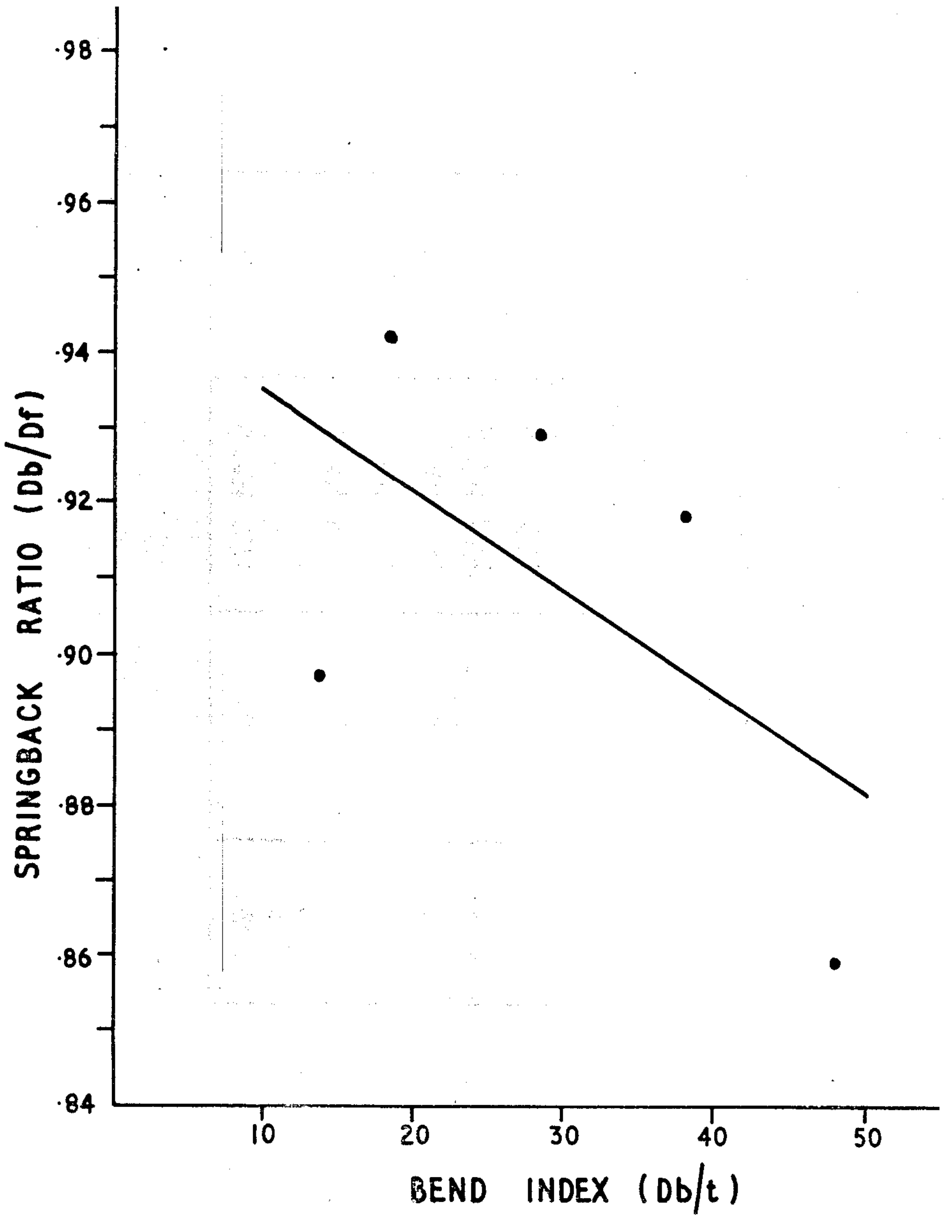

FIG. 1. GRAPH FOR 0·008 in. STRIP

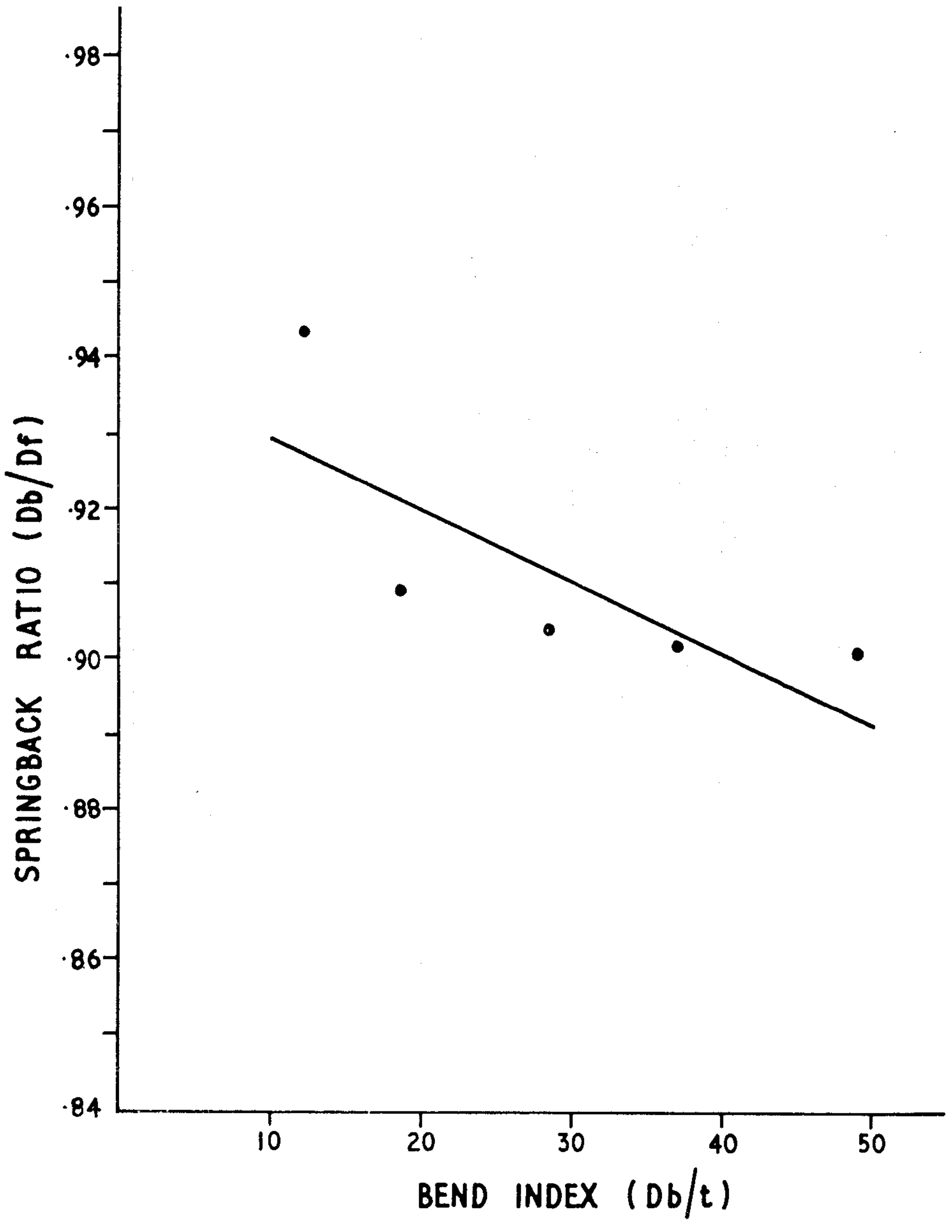

FIG. 2. GRAPH FOR 0·012 in. STRIP

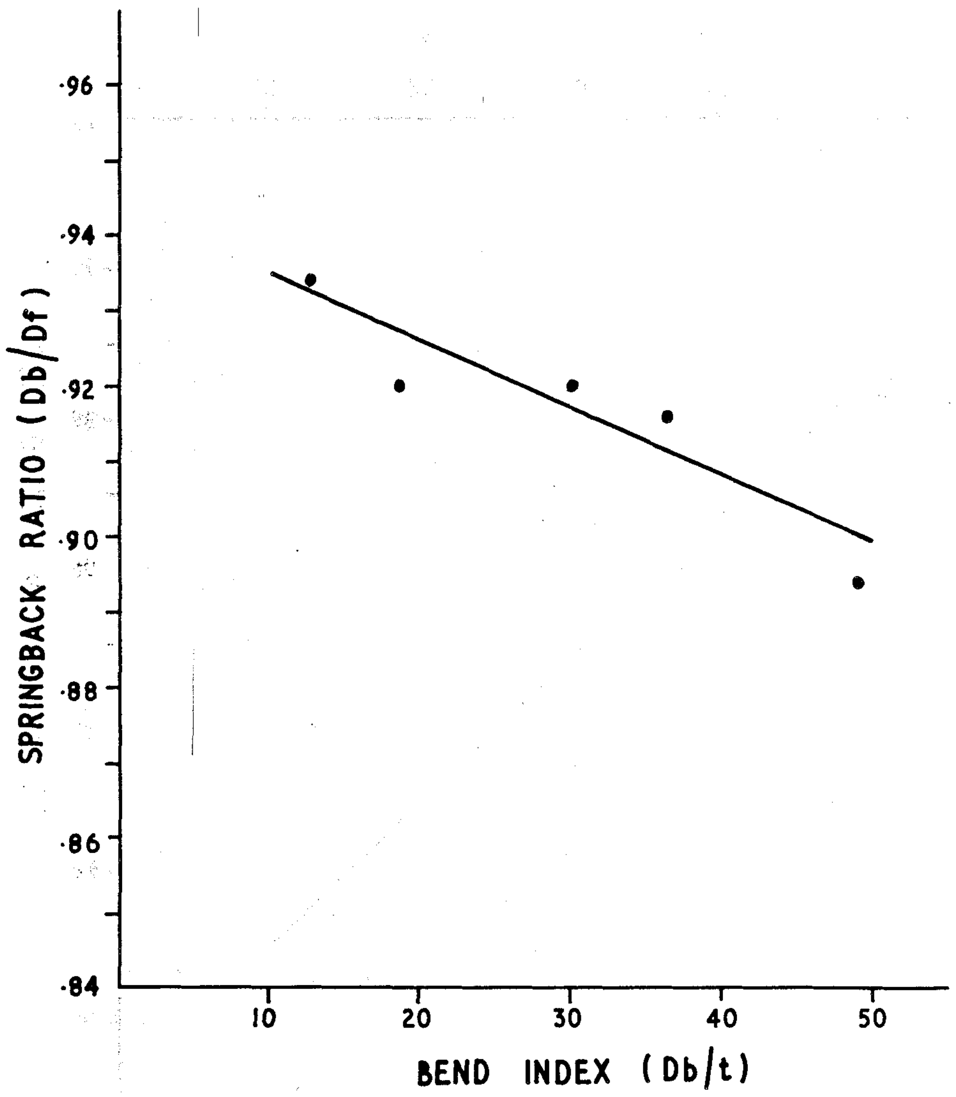

FIG. 3. GRAPH FOR 0·018in. STRIP

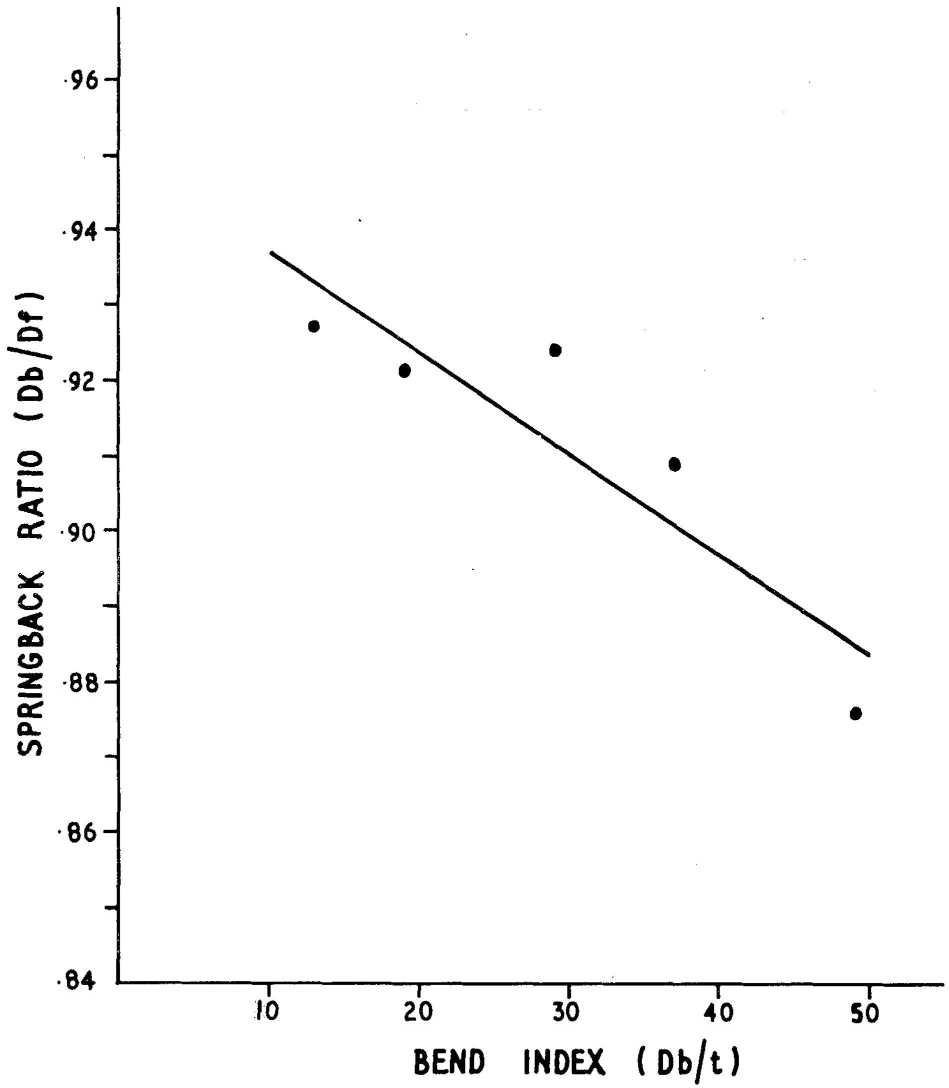

FIG. 4. GRAPH FOR 0·028in. STRIP

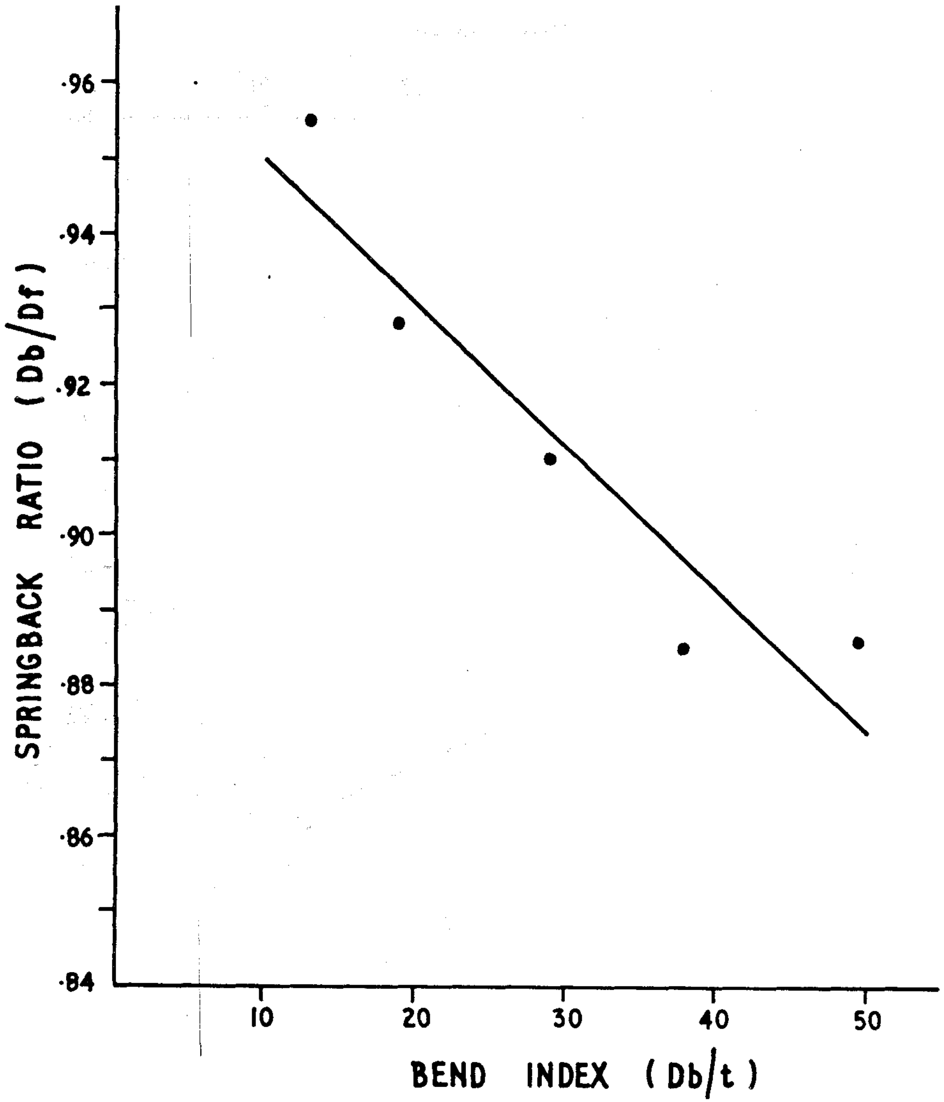

FIG. 5. GRAPH FOR 0·036in. STRIP

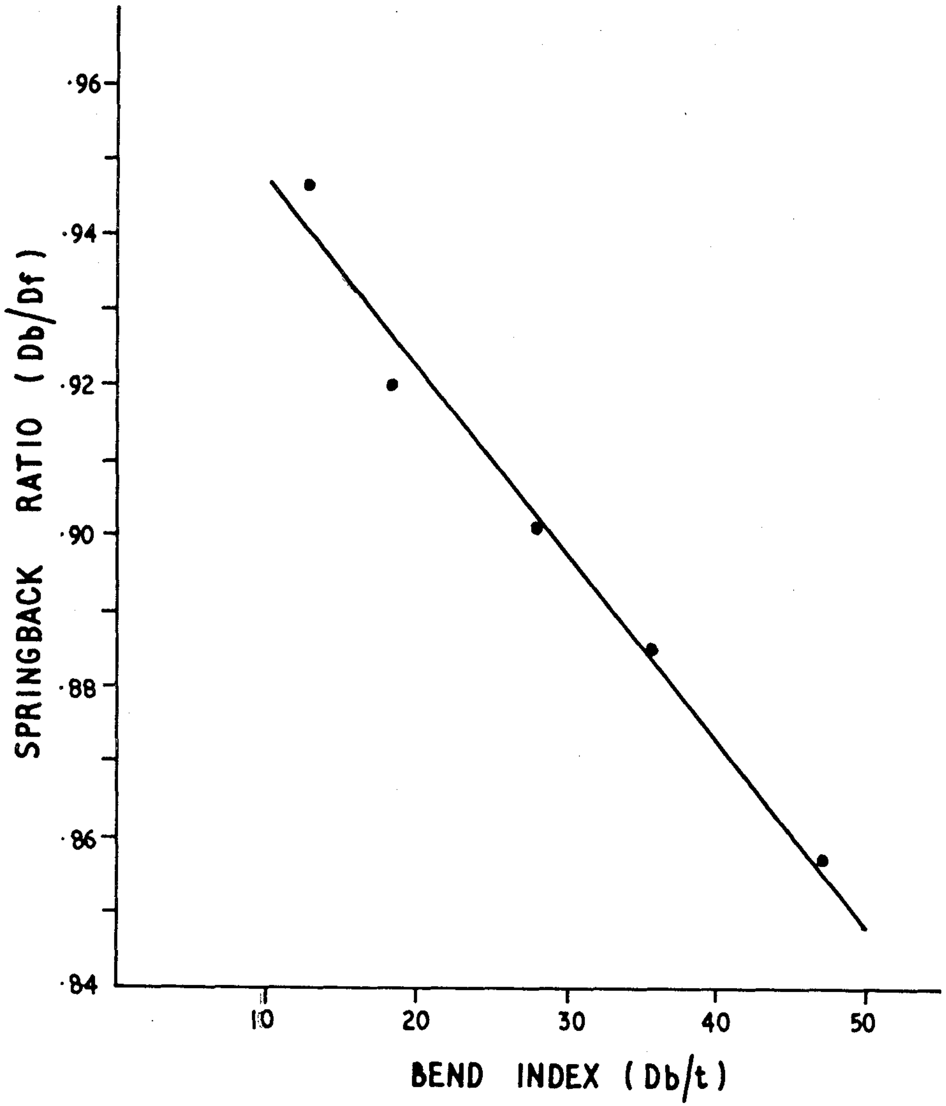

FIG. 6. GRAPH FOR 0·050in. STRIP

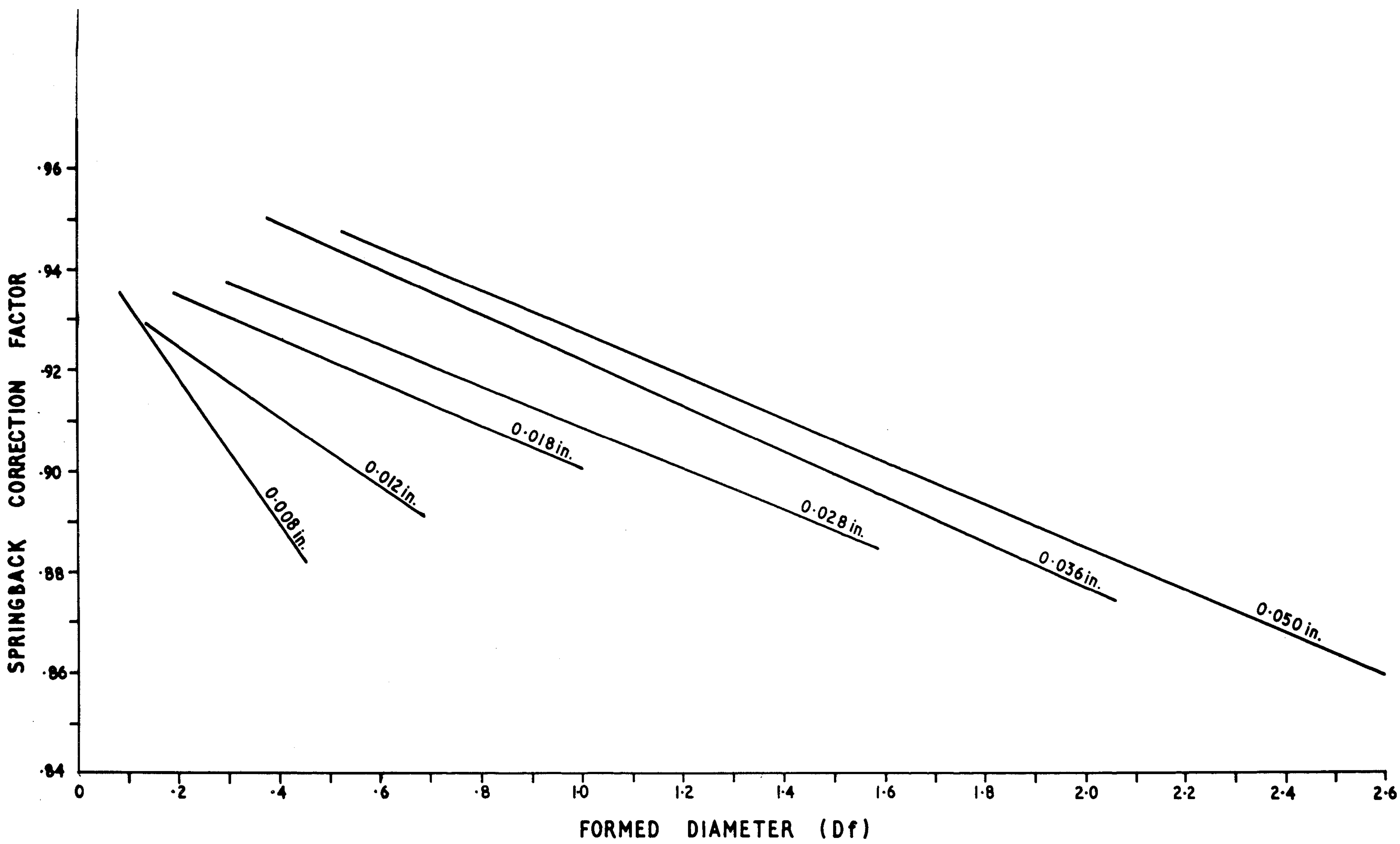

FIG. 7. DESIGN CHART FOR ANNEALED CS 70 STRIP TO B.S. 1449