THE SPRING RESEARCH AND MANUFACTURERS' ASSOCIATION

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

Progress Report No. 3

by

Ing. P.A.M. Korzilius

Report No. 261

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SUMMARY

The object of this part of the investigation into strip forming has been to produce data for die design relating to pre-hardened and tempered CS80 carbon steel, hard phosphor bronze (PB102) and annealed copper beryllium (CB101) strip, when formed by a cylindrical punch.

The results have been presented in a similar manner to that used in the two previous progress reports for annealed CS70 carbon steel strip. A consistency in strip forming of $\pm$ 2% has also been achieved for the materials described here. Graphs have been drawn for all six strip thicknesses, for the range of strip forming in which the bend diameter is between 10 and 60 times the strip thickness. The graphs enable the press tool designer to estimate the correct dimensions of the required die.

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1. INTRODUCTION

The object of this research project was to produce data for die design, relating the formed angle, formed diameter and strip thickness to the bend angle and bend diameter of spring strip when formed by a cylindrical punch.

The two previous progress reports (Research Reports 204 and 230) described the underlying theory of the work and the procedure used, as well as the results obtained with annealed CS70 strip to BS 1449 Part 1: 1972. This report describes similar work carried out with hard phosphor bronze, annealed copper beryllium and hardened and tempered CS80.

The data obtained will be presented in this report in a similar manner as before, and also in the form of charts which are to be published separately as an aid to die designers, to enable them to determine quickly the shape of a die necessary to produce parts to a given angle and diameter.

2. MATERIAL

The materials used in this part of the investigation were:

a) hard phosphor bronze to BS 2870: PB102 (175-220 Hv);
b) annealed copper beryllium to BS 2870: CB101 (85-120 Hv);
c) hardened and tempered carbon steel to BS 1449: CS80 (460-520 Hv).

The material, which was obtained in flat lengths in order to reduce the straightening difficulties encountered in the previous work, was of the following nominal thicknesses: 0.20; 0.30; 0.46; 0.71; 0.91 and 1.22 mm. The width of the strip was 25 mm in the case of the hardened and tempered CS80 and 12 mm for both the non ferrous materials.

3. RESULTS

3.1 Material Dimensions

The thickness was measured at random on the length of strip and, in all cases, was found to be within the specified tolerances, as shown in Table I.

3.2 Strip Forming

For purposes of clarity, the nomenclature used in this report with regard to strip forming is illustrated in Fig. 10.

The investigation covers five different bend indices before forming and four bend angles for each material thickness (details are given in Table II). For each set of conditions, 50 specimens were produced and the formed angles measured on a Nikon profile projector. The results obtained from forming the six thicknesses of the three materials are shown in Tables III to VIII. The tables show the average formed angle for each die and the range measured by the 95% confidence limits ($\pm$ 2 standard deviations), obtained by statistical analysis of the results.

For each strip thickness, the average springback ratio was determined for each group of four dies of one bend index. The springback ratio and bend index values for all dies in the three materials are given in Table IX. 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 to 6. On each graph, the line through the five points is the "best fit" line determined by calculation using

the "least squares" method. On the basis of these graphs, it was possible to draw Figs. 7 to 9, representing the formed diameter as a function of the springback correction factor, within the range of strip thickness and bend ratios investigated. The formed diameter was calculated using the following relationship:

$$D_f = \frac{D_b/t \quad . \quad t}{D_b/D_f}$$

where D_b = Bend diameter

D_f = Formed diameter

t = Material thickness

Alternatively, since the ratio of formed diameter and bend diameter is inversely proportional to the ratio of formed angle and bend angle, the formed angle can be determined as follows:

$$\frac{D_b}{D_f} = K = \frac{\Theta_f}{\Theta_b}$$

3.3 Material Properties

For each strip thickness of the three materials used, tensile tests were carried out. The data obtained are shown in Tables X to XII, as are the main details of the chemical composition and average hardness values, as determined from samples of each strip.

Carbon Steel CS80

The specified carbon content for this material is between 0.75% and 0.85%. Only the 0.20 mm thick material, at 0.94%C, was outside the specification but its average hardness was still within the range of the other materials.

Copper Beryllium CB101

The material specification for CB101, in the annealed condition, calls for a hardness between 85 and 120 Hv and a tensile strength between 410 and 540 N/mm^2. Only the 1.22 mm thick material, at 122 Hv, was slightly outside the hardness specification.

Phosphor Bronze PB102

For phosphor bronze in the hard condition a minimum tensile strength of 580 N/mm^2 and a hardness within the range of 175 to 220 Hv are specified. The material generally met this specification, except that the hardness values for the 0.2 mm and 0.3 mm strip were below the minimum specified.

4. DISCUSSION OF RESULTS

It will be noticed from Tables III to VIII that, in general, the variation in formed angle is greater for the 180° bend angle than for the other three. This may be attributable to the shape of the die; in this case, to some extent, the strip is drawn into the die, while to produce the other three bend angles the strip is only pressed in the circular section of the die. For bend angles other than 180°, the variation in formed angle drops slightly with a decreasing bend angle; the best results that could be achieved consistently were $\pm 2\%$ of the bend angle. The formed angle of the strip depends upon the elastic limit of the material - the lower the elastic limit in relation to the total stress during punching, the smaller the amount of springback that can be expected. Moreover, the greater the variation in the elastic limit of the material, the greater the scatter that can be expected in formed angle measurements. Tables X to XII give the range of hardness values for the different materials and thicknesses, which also indicates the variation in the tensile strength. The hardness range and the ratio elastic limit/tensile strength together form a measure of the possible scatter in the elastic

limit, which was found to be smallest for CS80 material and largest for phosphor bronze. The difference in the scatter of the punch results was, in fact, found to be in the same order.

In general, it can be said that the degree of precision possible in predicting springback depends on the level of consistency to which the material can be produced.

Figs. 7 to 9 enable the designer to estimate the shape of a die needed to make a given part. The springback correction factor can be calculated, when the thickness and the diameter of the part to be made are known. To calculate the diameter of the die required, the diameter desired should be multiplied by the value of the correction factor, and the bend angle of the die can be calculated by dividing the angle desired by the correction factor.

Fig. 10 shows the nomenclature used in this report. The Association is also producing charts for the materials investigated that will enable toolmakers to determine directly the allowances for diameter and angle. These charts will cover the same bend index range and show bend and angle allowances.

5. FUTURE WORK

The work to date has covered four materials; the three described in this report and also annealed carbon steel CS70 to BS 1449 Part 1: 1972 as described in Reports 204 and 230.

The next material to be investigated in a similar manner is stainless steel En 58A with a hardness of 400-450 Hv. In addition, the investigation will be extended to incorporate other characteristics that may have an influence on the springback data obtained, particular attention being given to:

(1) a comparison of results from powerpress and flypress springback data; and

(2) distortion caused by heat treatment after forming of copper beryllium strip.

6. CONCLUSIONS

1. The springback properties of pre-hardened and tempered carbon steel CS80, hard phosphor bronze and annealed copper beryllium in six material thicknesses have been investigated, and design data have been produced, accurate to $\pm$2% of the bend angle.

2. The variation in the results of the forming operation is attributable to variation in material properties.

TABLE I RESULTS OF THICKNESS TOLERANCE MEASUREMENTS

Material	Nominal Thickness in	Nominal Thickness mm	Measured Thickness mm	Permissible Thickness mm
CS80	0.008	0.20	0.208 - 0.210	0.194 - 0.212
	0.012	0.30	0.305 - 0.311	0.292 - 0.318
	0.018	0.46	0.462 - 0.478	0.432 - 0.483
	0.028	0.71	0.739 - 0.741	0.673 - 0.749
	0.036	0.91	0.932 - 0.949	0.876 - 0.952
	0.048	1.22	1.240 - 1.251	1.181 - 1.257
CB101	0.008	0.20	0.201 - 0.212	0.193 - 0.213
	0.012	0.30	0.304 - 0.314	0.292 - 0.317
	0.018	0.46	0.453 - 0.460	0.439 - 0.475
	0.028	0.71	0.698 - 0.713	0.686 - 0.737
	0.036	0.91	0.905 - 0.918	0.889 - 0.940
	0.048	1.22	1.196 - 1.236	1.186 - 1.252
PB102	0.008	0.20	0.189 - 0.204	0.188 - 0.218
	0.012	0.30	0.318 - 0.324	0.284 - 0.325
	0.018	0.46	0.465 - 0.480	0.432 - 0.483
	0.028	0.71	0.722 - 0.735	0.681 - 0.742
	0.036	0.91	0.911 - 0.926	0.876 - 0.952
	0.048	1.22	1.240 - 1.248	1.168 - 1.270

TABLE II DIE DIMENSIONS

Die Number	Strip thickness t (mm)	Die diameter (mm)	Bend diameter D_b (mm)	Nominal Bend Index	Actual Bend Index D_b/t
1	1.22	60.96	59.74	49	49.0
2	1.22	46.33	45.11	37	37.0
3	1.22	36.58	35.36	29	29.0
4	1.22	24.38	23.16	19	19.0
5	1.22	17.07	15.85	13	13.0
6	0.91	46.33	45.42	49	49.7
7	0.91	35.56	34.65	37	37.8
8	0.91	27.02	26.11	29	28.5
9	0.91	18.29	17.37	19	19.0
10	0.91	12.80	11.89	13	13.0
11	0.71	35.56	34.85	49	49.0
12	0.71	27.03	26.32	37	37.0
13	0.71	21.34	20.63	29	29.0
14	0.71	14.27	13.56	19	19.0
15	0.71	9.98	9.27	13	13.0
16	0.46	22.86	22.86	49	49.0
17	0.46	17.07	16.61	37	36.4
18	0.46	14.27	13.82	29	30.2
19	0.46	8.99	8.53	19	18.7
20	0.46	6.35	5.89	13	12.9
21	0.30	15.24	14.93	49	49.0
22	0.30	11.58	11.28	37	37.0
23	0.30	8.99	8.69	29	28.5
24	0.30	5.99	5.69	19	18.6
25	0.30	3.99	3.68	13	12.1
26	0.20	9.98	9.78	49	48.2
27	0.20	7.92	7.72	37	38.0
28	0.20	5.99	5.79	29	28.5
29	0.20	3.99	3.78	19	18.6
30	0.20	3.00	2.79	13	13.8

TABLE III RESULTS FROM 1.22 mm STRIP

		CS80		COPPER-BERYLLIUM		PHOSPHOR BRONZE	
DIE NUMBER	BEND ANGLE (°)	MEAN FORMED ANGLE (°)	RANGE (°) (95% LIMITS)	MEAN FORMED ANGLE (°)	RANGE (°) (95% LIMITS)	MEAN FORMED ANGLE (°)	RANGE (°) (95% LIMITS)
1 A	180	90.1	4.7	153.0	5.8	121.5	3.9
1 B	130	69.6	3.6	112.1	3.7	86.5	5.3
1 C	90	42.2	1.1	79.2	3.2	60.4	2.2
1 D	60	25.7	1.8	49.1	2.1	37.5	2.5
2 A	180	84.8	7.3	156.0	3.2	135.8	4.7
2 B	130	75.7	1.2	117.0	1.7	100.5	0.9
2 C	90	49.1	0.7	80.1	1.0	67.4	2.1
2 D	60	32.0	0.7	53.2	0.9	44.3	0.7
3 A	180	106.1	4.9	165.1	3.0	144.4	3.3
3 B	130	82.8	1.0	117.5	3.4	104.6	2.5
3 C	90	55.2	1.2	81.3	1.1	71.4	1.9
3 D	60	35.1	0.7	54.3	1.2	47.5	1.2
4 A	180	125.3	4.8	165.5	2.6	156.4	0.8
4 B	130	94.6	1.0	121.1	2.9	113.9	1.5
4 C	90	62.2	0.9	82.2	1.9	76.5	1.0
4 D	60	41.0	0.3	56.6	1.9	52.0	0.4
5 A	180	140.3	3.8	168.4	2.0	162.9	4.3
5 B	130	101.3	0.9	121.1	2.1	115.8	1.9
5 C	90	66.4	1.9	82.4	2.2	78.8	1.0
5 D	60	42.4	0.7	54.5	1.4	51.1	0.9

TABLE IV RESULTS FROM 0.91 mm STRIP

		C.S. 80		COPPER-BERYLLIUM		PHOSPHOR BRONZE	
DIE NUMBER	BEND ANGLE (°)	MEAN FORMED ANGLE (°)	RANGE (°) (95% LIMITS)	MEAN FORMED ANGLE (°)	RANGE (°) (95% LIMITS)	MEAN FORMED ANGLE (°)	RANGE (°) (95% LIMITS
6 A	180	86.3	5.3	154.5	5.2	125.9	5.6
6 B	130	58.0	3.2	115.8	4.3	89.8	4.2
6 C	90	37.3	1.7	79.6	1.6	61.1	3.9
6 D	60	23.7	1.7	52.5	2.1	39.0	3.9
7 A	180	79.2	5.0	159.5	4.2	135.6	5.1
7 B	130	67.9	2.0	114.6	4.5	95.7	2.7
7 C	90	45.1	1.9	79.2	1.6	64.8	3.1
7 D	60	28.8	1.2	53.4	1.3	44.4	2.2
8 A	180	99.2	9.9	165.3	3.6	144.4	3.8
8 B	130	80.6	1.8	120.8	2.9	105.4	3.4
8 C	90	54.3	1.8	83.4	2.0	72.4	2.4
8 D	60	33.3	1.2	54.7	2.0	46.4	1.9
9 A	180	122.9	3.5	164.7	3.0	152.5	3.9
9 B	130	91.1	1.9	120.7	1.8	109.9	3.0
9 C	90	61.1	1.5	84.5	1.8	76.2	2.6
9 D	60	38.3	1.0	55.4	3.8	49.2	1.4
10 A	180	140.2	3.8	166.5	2.4	158.6	2.1
10 B	130	99.9	1.2	121.9	1.3	113.9	1.7
10 C	90	69.3	1.3	88.3	1.6	82.3	2.2
10 D	60	41.9	1.3	55.7	1.7	49.5	1.2

TABLE V RESULTS FROM 0.71 mm STRIP

		C.S. 80		COPPER-BERYLLIUM		PHOSPHOR BRONZE	
DIE NUMBER	BEND ANGLE (°)	MEAN FORMED ANGLE (°)	RANGE (°) (95% LIMITS)	MEAN FORMED ANGLE (°)	RANGE (°) (95% LIMITS)	MEAN FORMED ANGLE (°)	RANGE (°) (95% LIMITS)
11 A	180	84.8	2.0	149.8	3.8	117.9	4.9
11 B	130	56.1	1.5	108.5	2.1	82.0	3.0
11 C	90	36.6	1.0	74.9	2.2	55.6	1.7
11 D	60	22.8	1.2	49.4	1.5	36.1	2.6
12 A	180	82.1	5.4	154.1	2.5	127.2	4.2
12 B	130	70.2	1.5	115.2	2.6	93.2	2.6
12 C	90	47.0	1.4	80.1	1.9	64.2	2.2
12 D	60	30.6	0.9	53.6	1.1	42.2	2.5
13 A	180	101.3	7.9	161.0	2.1	139.1	4.6
13 B	130	78.6	0.9	115.8	1.6	98.1	2.5
13 C	90	53.8	0.8	82.1	1.4	68.5	1.4
13 D	60	33.3	1.0	54.0	1.2	43.7	2.2
14 A	180	126.0	5.7	164.4	1.6	151.4	2.9
14 B	130	92.1	1.1	118.6	1.9	106.7	1.7
14 C	90	61.7	0.7	84.0	1.3	74.6	1.2
14 D	60	39.5	0.6	56.2	1.4	49.2	2.0
15 A	180	142.0	3.0	168.2	2.0	160.4	2.9
15 B	130	101.4	0.9	122.3	1.2	113.9	1.2
15 C	90	65.3	0.8	82.9	1.6	76.7	1.5
15 D	60	41.6	0.8	56.7	0.5	50.0	1.4

TABLE VI RESULTS FROM 0.46 mm STRIP

		C.S. 80		COPPER-BERYLLIUM		PHOSPHOR BRONZE	
DIE NUMBER	BEND ANGLE (°)	MEAN FORMED ANGLE (°)	RANGE (°) (95% LIMITS)	MEAN FORMED ANGLE (°)	RANGE (°) (95% LIMITS)	MEAN FORMED ANGLE (°)	RANGE (°) (95% LIMITS)
16 A	180	52.1	5.5	151.9	4.9	121.3	2.9
16 B	130	50.9	3.9	111.8	2.5	85.4	3.9
16 C	90	37.2	2.5	84.4	2.5	65.5	3.4
16 D	60	21.3	1.9	51.4	1.4	38.7	2.4
17 A	180	75.2	5.4	157.6	3.6	132.7	5.0
17 B	130	65.0	2.1	114.7	1.8	94.1	4.6
17 C	90	43.5	1.5	79.8	1.8	65.4	2.0
17 D	60	28.6	1.0	53.9	1.3	44.2	2.0
18 A	180	87.5	3.7	158.0	1.7	137.3	4.3
18 B	130	71.5	1.5	115.0	2.4	97.7	4.6
18 C	90	46.5	2.0	80.8	1.4	68.8	2.5
18 D	60	31.8	1.8	55.8	1.5	48.3	1.6
19 A	180	124.8	6.5	167.1	2.8	154.7	2.1
19 B	130	92.2	2.2	121.8	1.7	110.2	3.8
19 C	90	58.2	1.9	81.2	1.4	73.7	2.2
19 D	60	37.3	1.7	51.2	1.0	50.2	1.8
20 A	180	140.5	5.0	170.8	6.6	164.3	6.9
20 B	130	102.0	2.0	123.8	1.5	118.2	3.9
20 C	90	66.9	2.2	86.4	1.2	82.2	1.9
20 D	60	45.6	1.3	64.7	2.3	59.5	2.3

TABLE VII RESULTS FROM 0.30 mm STRIP

		C.S. 80		COPPER-BERYLLIUM		PHOSPHOR BRONZE	
DIE NUMBER	BEND ANGLE (°)	MEAN FORMED ANGLE (°)	RANGE (°) (95% LIMITS)	MEAN FORMED ANGLE (°)	RANGE (°) (95% LIMITS)	MEAN FORMED ANGLE (°)	RANGE (°) (95% LIMITS)
21 A	180	84.1	2.4	150.5	3.4	123.4	4.9
21 B	130	59.6	2.6	116.4	4.0	96.2	4.2
21 C	90	37.9	1.8	78.2	3.7	61.7	3.0
21 D	60	23.9	1.2	51.6	4.6	40.7	2.2
22 A	180	100.6	2.4	154.4	2.8	133.6	3.8
22 B	130	70.0	1.8	115.3	4.3	98.4	3.6
22 C	90	46.7	1.1	79.4	1.4	67.1	2.1
22 D	60	31.2	1.1	55.6	5.0	47.3	2.3
23 A	180	108.9	3.9	162.3	3.8	146.9	3.7
23 B	130	81.7	1.2	118.1	2.6	105.1	3.2
23 C	90	53.0	0.9	81.7	2.1	71.7	2.2
23 D	60	32.7	0.6	55.4	2.4	48.2	1.7
24 A	180	136.5	3.8	164.5	3.1	157.2	3.5
24 B	130	95.2	1.8	122.0	3.7	114.3	2.7
24 C	90	64.2	0.9	85.8	2.3	79.7	2.3
24 D	60	43.3	0.9	64.3	4.2	57.1	1.5
25 A	180	148.6	2.6	168.6	2.6	164.0	4.9
25 B	130	103.6	3.2	125.0	4.6	119.8	3.0
25 C	90	63.3	2.3	85.6	2.7	76.5	3.2
25 D	60	43.1	1.8	60.1	4.4	54.4	3.5

TABLE VIII RESULTS FROM 0.20 mm STRIP

		C.S. 80		COPPER-BERYLLIUM		PHOSPHOR BRONZE	
DIE NUMBER	BEND ANGLE (°)	MEAN FORMED ANGLE (°)	RANGE (°) (95% LIMITS)	MEAN FORMED ANGLE (°)	RANGE (°) (95% LIMITS)	MEAN FORMED ANGLE (°)	RANGE (°) (95% LIMITS)
26 A	180	71.5	1.4	148.4	3.4	110.4	4.8
26 B	130	46.5	1.2	109.4	2.9	78.2	5.2
26 C	90	29.1	1.1	75.6	4.0	52.0	2.7
26 D	60	20.6	1.1	52.7	4.9	35.8	2.9
27 A	180	92.7	2.2	166.0	4.2	129.2	5.7
27 B	130	61.3	2.3	120.0	3.8	92.2	4.0
27 C	90	37.6	1.6	79.4	3.9	60.8	2.9
27 D	60	25.7	1.0	57.4	3.3	44.5	2.4
28 A	180	107.1	5.2	165.7	4.9	137.1	4.2
28 B	130	73.7	1.9	123.9	2.3	101.7	3.7
28 C	90	48.4	1.3	83.5	1.4	66.5	3.0
28 D	60	31.0	0.5	62.0	1.3	49.1	2.2
29 A	180	130.3	3.0	167.0	2.1	146.6	4.6
29 B	130	91.5	2.9	125.2	2.2	110.5	4.0
29 C	90	60.4	1.0	90.7	1.6	79.6	2.9
29 D	60	36.4	1.2	66.7	1.7	56.3	2.3
30 A	180	139.7	2.3	172.3	2.5	157.9	3.7
30 B	130	90.6	1.6	121.3	1.6	106.1	1.7
30 C	90	62.6	1.1	90.9	1.5	73.5	1.5
30 D	60	41.7	0.9	68.0	1.7	53.6	1.3

TABLE IX VALUES OF SPRINGBACK RATIO

Die Number	Strip Thickness (mm)	Bend Index	Springback Ratio		
			Copper Beryllium	CS 80	Phosphor Bronze
1	1.22	49.0	0.853	0.483	0.659
2	"	37.0	0.886	0.533	0.754
3	"	29.0	0.907	0.606	0.798
4	"	19.0	0.927	0.699	0.865
5	"	13.0	0.923	0.751	0.881
6	0.91	49.7	0.877	0.434	0.680
7	"	37.8	0.884	0.486	0.737
8	"	28.5	0.921	0.582	0.798
9	"	19.0	0.926	0.675	0.840
10	"	13.0	0.943	0.754	0.874
11	0.71	49.0	0.830	0.422	0.626
12	"	37.0	0.881	0.507	0.710
13	"	29.0	0.899	0.580	0.754
14	"	19.0	0.924	0.688	0.828
15	"	13.0	0.935	0.747	0.863
16	0.46	49.0	0.853	0.362	0.676
17	"	36.4	0.886	0.469	0.731
18	"	30.2	0.897	0.521	0.771
19	"	18.7	0.905	0.668	0.841
20	"	12.9	0.954	0.767	0.932
21	0.30	49.0	0.865	0.436	0.697
22	"	37.0	0.888	0.534	0.758
23	"	28.5	0.910	0.592	0.806
24	"	18.6	0.935	0.731	0.897
25	"	12.1	0.950	0.761	0.897
26	0.20	48.2	0.846	0.355	0.597
27	"	38.0	0.921	0.458	0.711
28	"	28.5	0.959	0.554	0.775
29	"	18.6	0.967	0.676	0.872
30	"	13.8	-	0.716	0.851

TABLE X PROPERTIES OF CS80 STRIP

	STRIP THICKNESS (mm)						AS SPECIFIED
	0.20	0.30	0.46	0.71	0.91	1.22	
Tensile Strength (R_m) N/mm^2	1700	1505	1620	1580	1510	1465	
Limit of Proportionality N/mm^2	915	785	715	735	645	790	
0.1% Proof Stress N/mm^2	1495	1350	1410	1385	1275	1260	
0.2% Proof Stress N/mm^2	1535	1370	1445	1410	1315	1305	
Elongation %	2.4	6.3	4.7	3.1	2.3	3.1	
Carbon Content %	0.94	0.79	0.71	0.76	0.82	0.81	0.75 - 0.85
L of P / R_m	0.54	0.52	0.44	0.46	0.43	0.53	
Average Hardness Hv	487	473	512	497	478	476	460 - 520
Hardness Range Hv	3	2	4	2	2	2	

TABLE XI PROPERTIES OF CB101 STRIP

	STRIP THICKNESS (mm)						AS SPECIFIED
	0.20	0.30	0.46	0.71	0.91	1.22	
Tensile Strength (R_m) N/mm^2	410	500	475	475	450	465	410 - 540
Limit of Proportionality N/mm^2	-	135	125	135	105	140	
0.1% Proof Stress N/mm^2	165	200	200	215	200	220	
0.2% Proof Stress N/mm^2	175	210	215	230	215	240	
Elongation %	35.0	38.3	41.4	36.7	35.9	43.8	40 - 60
Be Content %	1.91	1.85	1.75	1.80	1.78	1.81	1.7 - 1.9
Ni Content %	0.02	0.05	0.02	0.01	0.03	0.03	)
Co Content %	0.19	0.34	0.41	0.33	0.22	0.26	)0.05 - 0.40)
L of P / R_m	-	0.27	0.26	0.29	0.24	0.30	
Average Hardness Hv	86	100	106	118	117	122	85 - 120
Hardness Range Hv	3	5	8	11	7	2	

TABLE XII PROPERTIES OF PB102 STRIP

	STRIP THICKNESS (mm)						AS SPECIFIED
	0.20	0.30	0.46	0.71	0.91	1.22	
Tensile Strength (R_m) N/mm^2	595	590	590	635	580	615	Min. 580
Limit of Proportionality N/mm^2	400	320	365	330	270	360	
0.1% Proof Stress N/mm^2	570	505	555	555	485	545	
0.2% Proof Stress N/mm^2	590	530	570	595	515	575	
Elongation %	7.0	8.6	5.5	9.4	15.0	8.6	Min. 4.0
P Content %	0.45	0.25	0.27	0.23	0.48	0.27	0.02 - 0.04
Sn Content %	4.75	4.95	4.91	5.90	4.60	5.04	4.5 - 6.0
L of P/R_m -	0.67	0.54	0.62	0.52	0.47	0.59	
Average Hardness Hv	170	167	207	217	194	204	175 - 220
Hardness Range Hv	6	2	3	10	4	8	

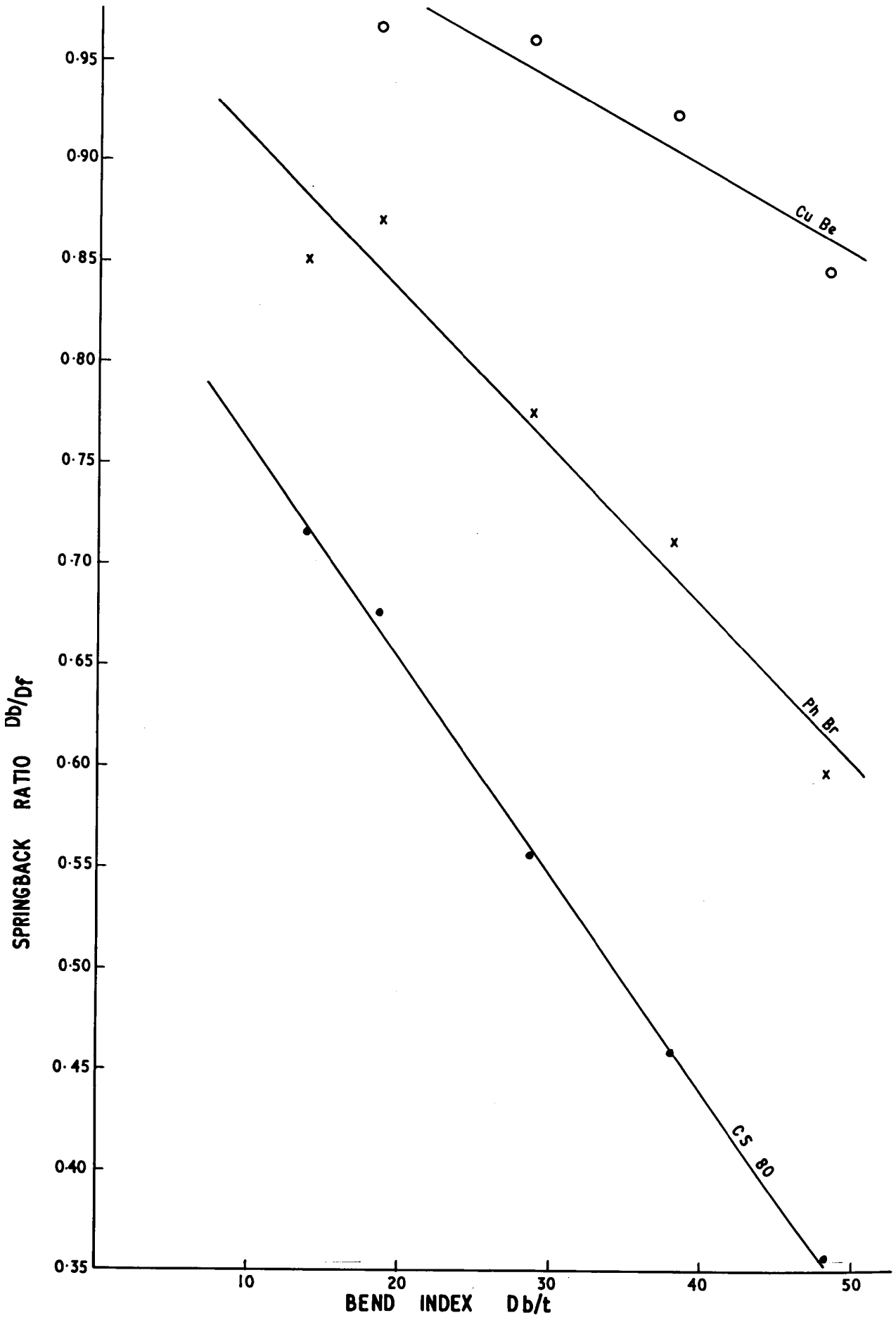


FIG. 1 GRAPH OF SPRINGBACK VS BEND INDEX FOR 0·20mm STRIP

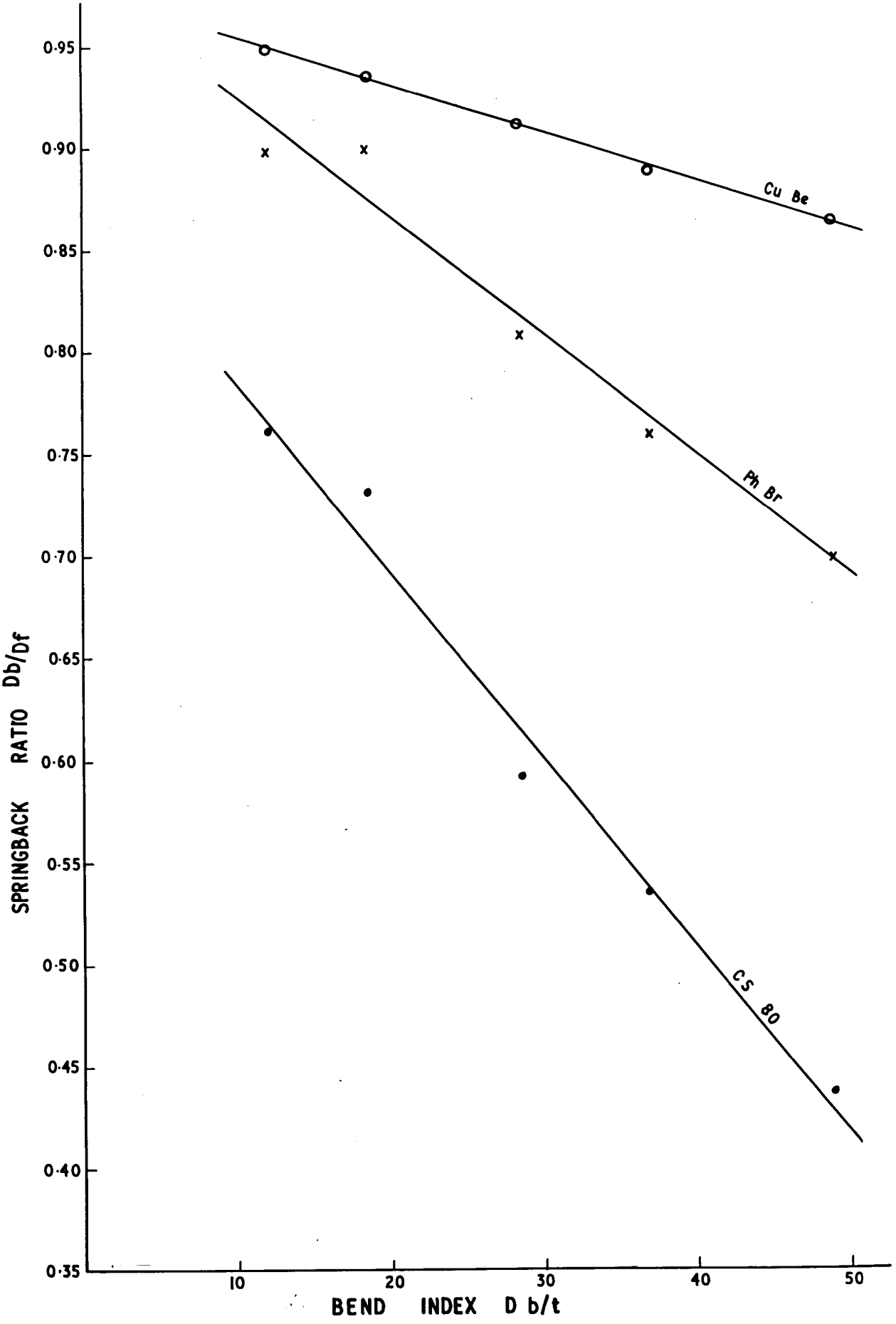


FIG. 2 GRAPH OF SPRINGBACK VS BEND INDEX FOR 0·30 mm STRIP.

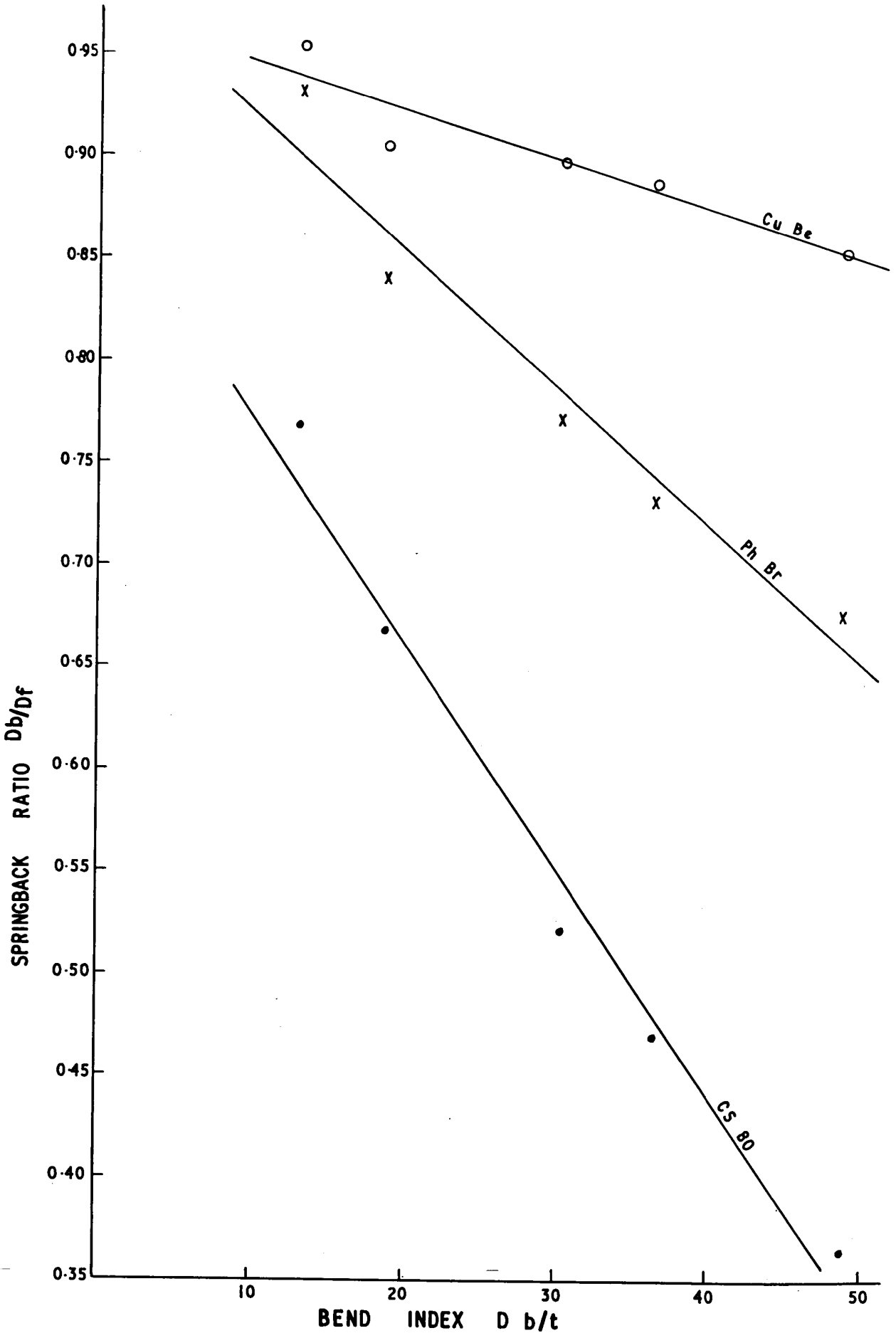


FIG. 3 GRAPH OF SPRINGBACK VS BEND INDEX FOR 0·46mm STRIP.

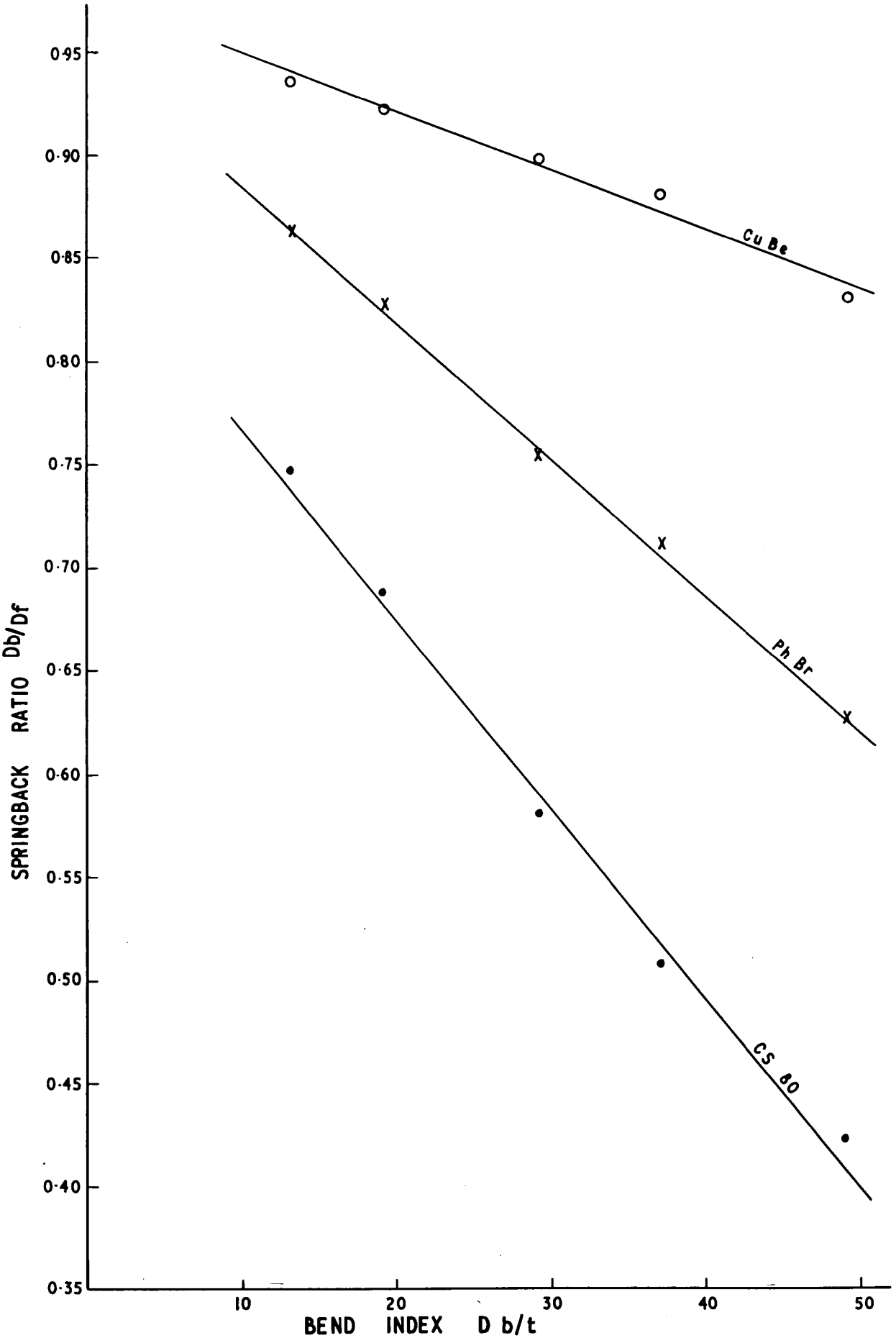


FIG. 4 GRAPH OF SPRINGBACK VS BEND INDEX FOR 0·71 mm STRIP.

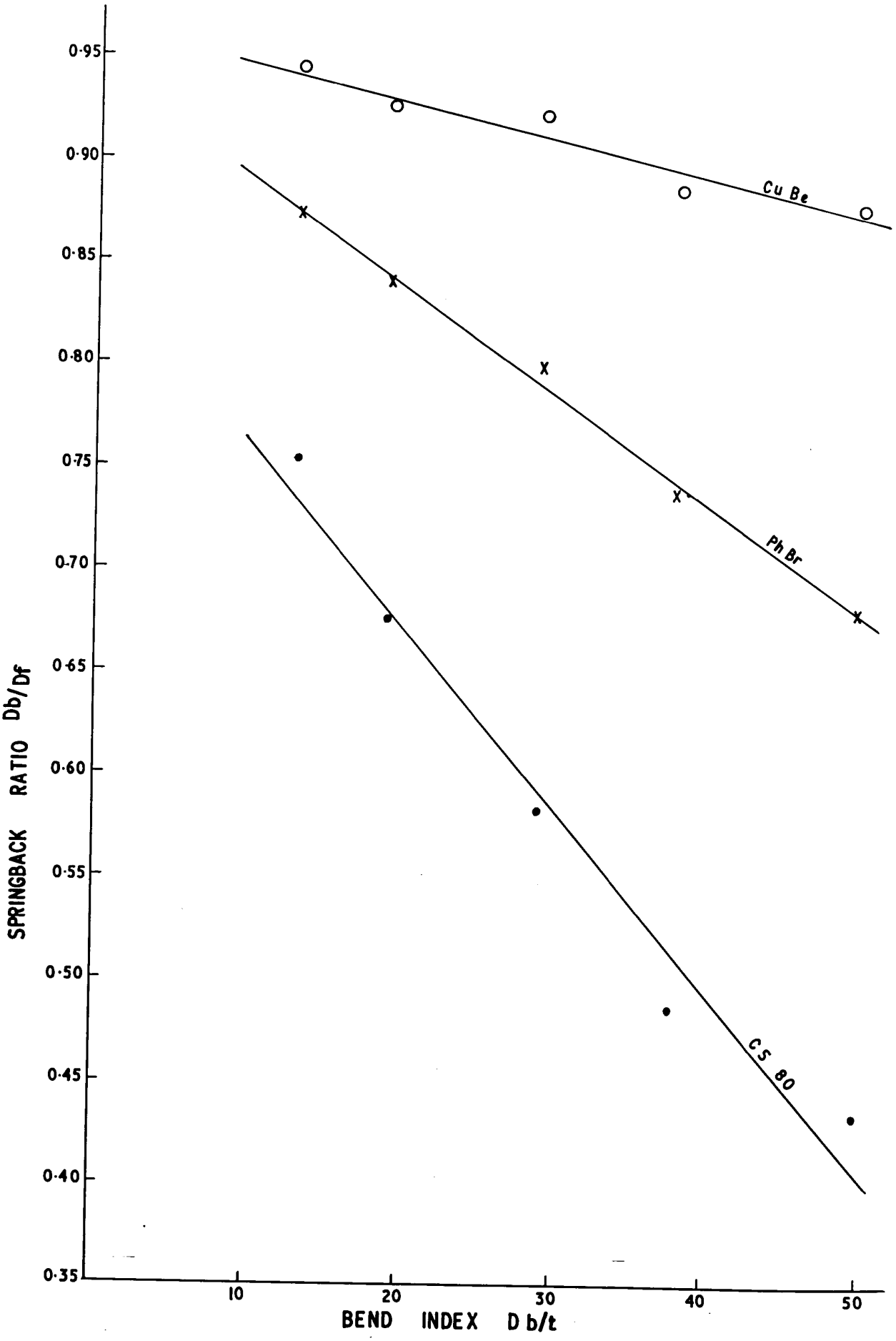


FIG 5 GRAPH OF SPRINGBACK VS BEND INDEX FOR 0·91 mm STRIP.

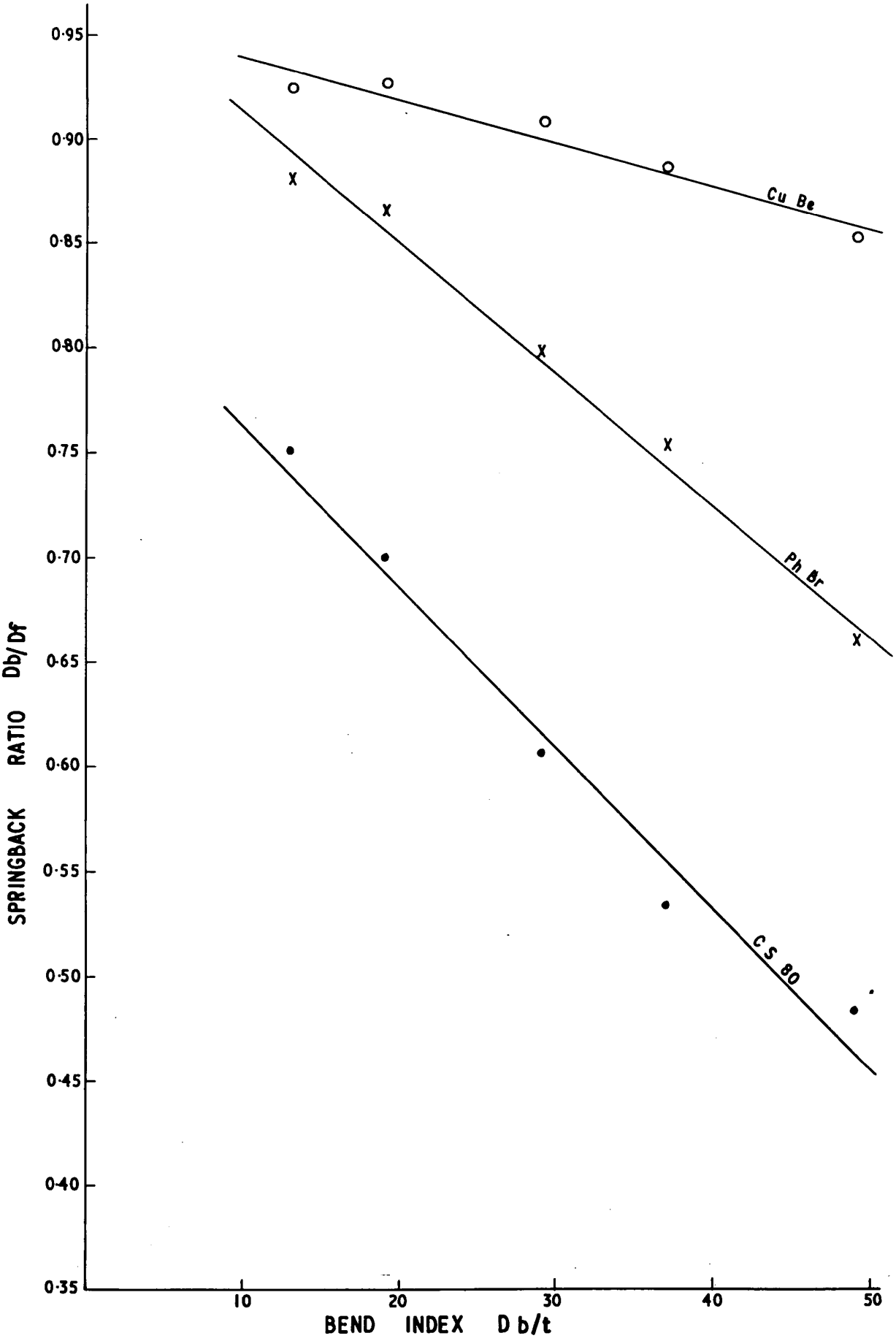


FIG. 6 GRAPH OF SPRINGBACK VS BEND INDEX FOR 1·22 mm STRIP

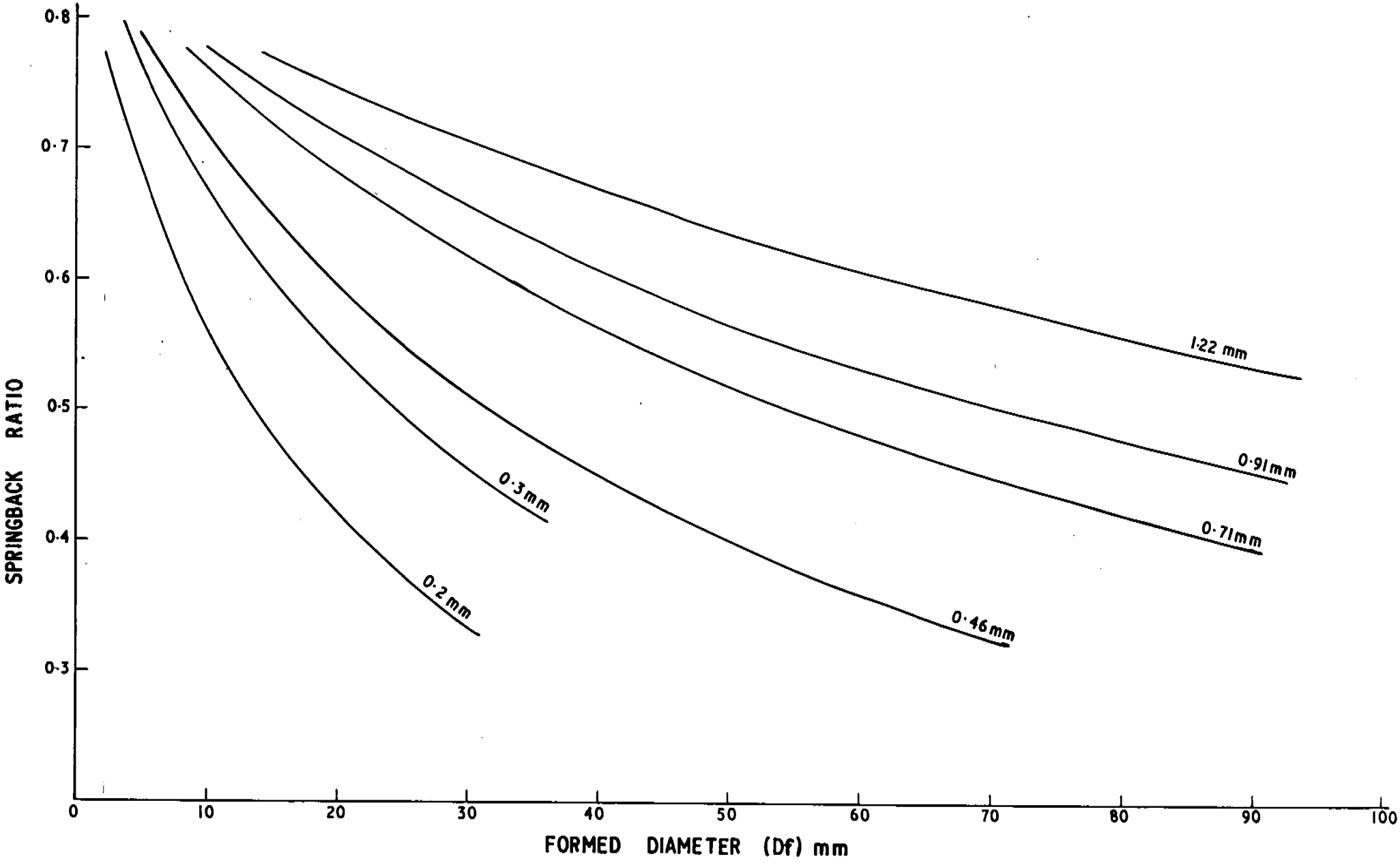


FIG. 7 DESIGN CHART FOR HARDENED & TEMPERED CS 80 STRIP TO BS 1449.

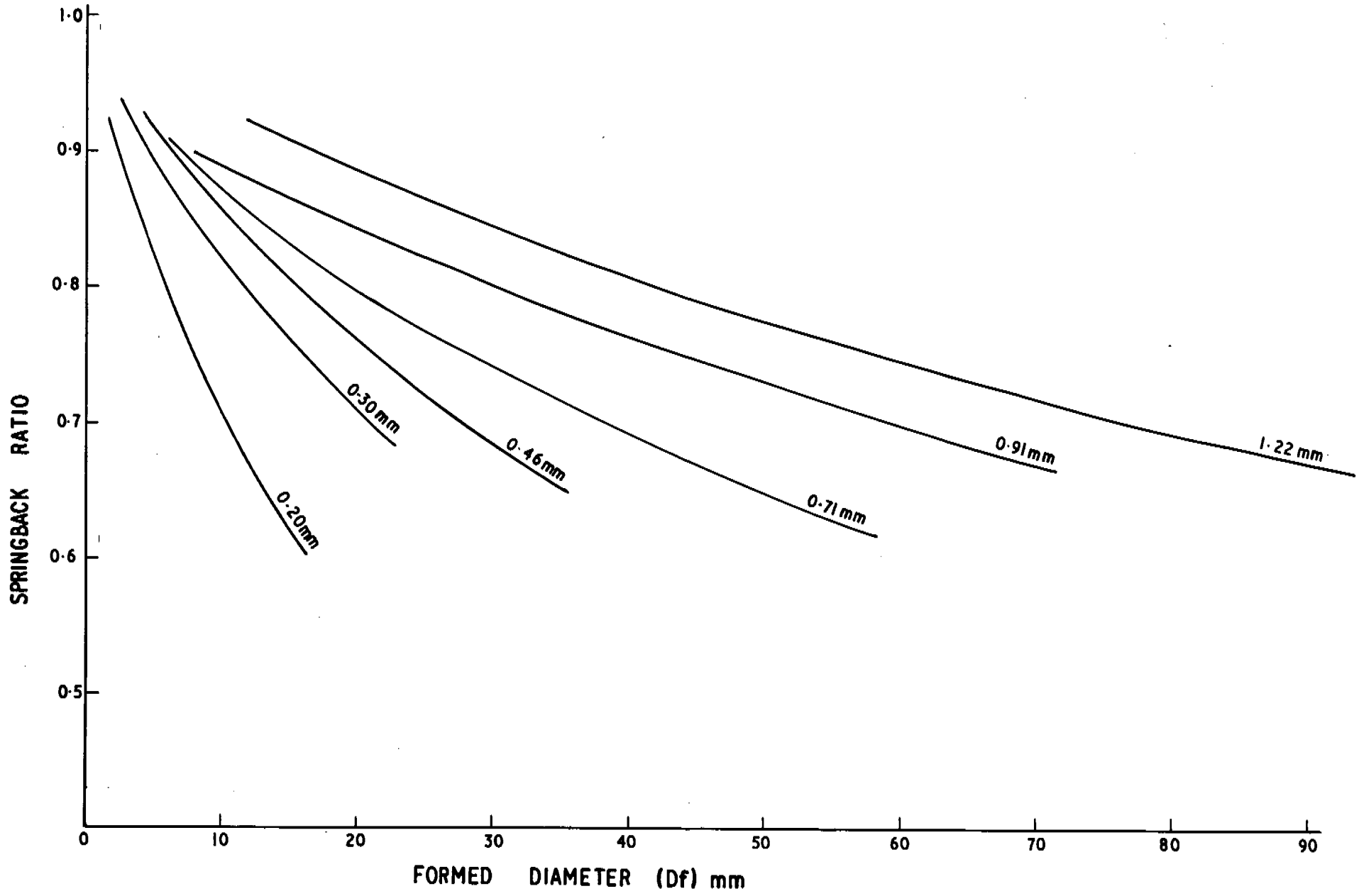


FIG. 8 DESIGN CHART FOR HARD PHOSPHOR BRONZE STRIP TO BS 2870: PB 102

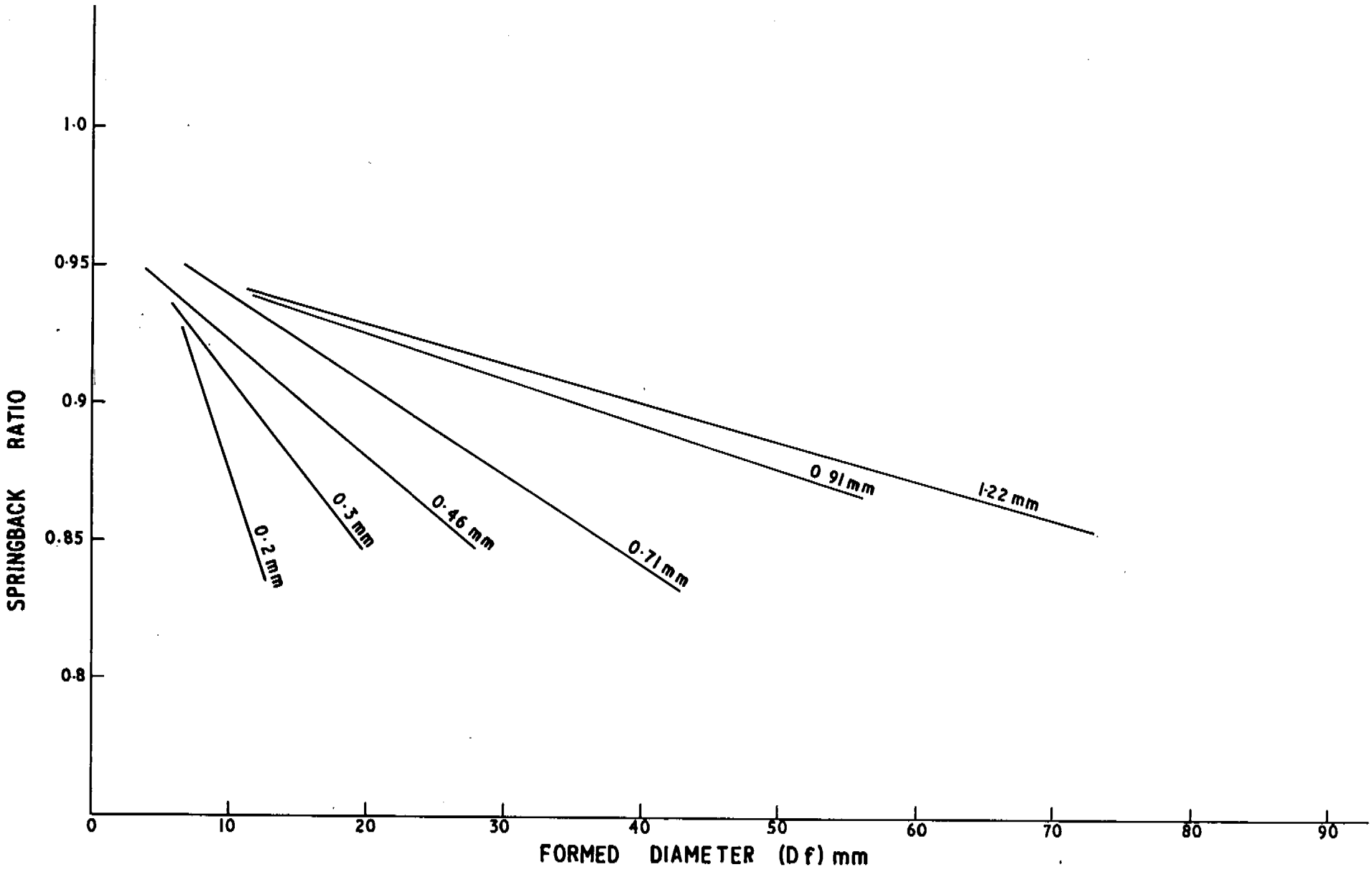
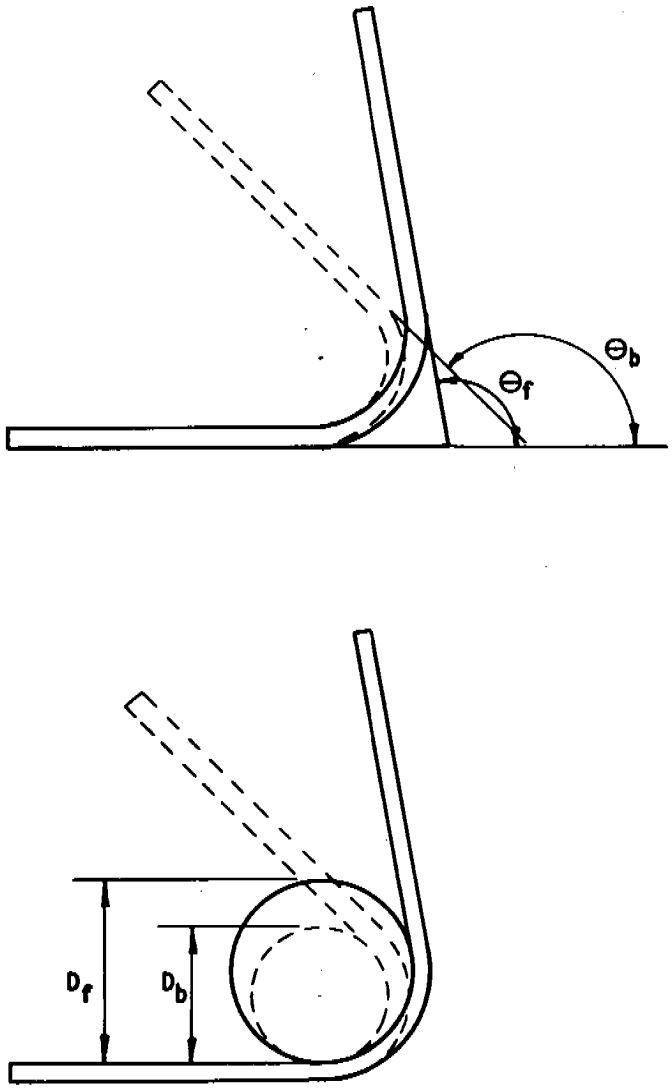


FIG. 9 DESIGN CHART FOR ANNEALED COPPER BERYLLIUM TO BS 2870: CB 101



Θ_b : BEND ANGLE

Θ_f : FORMED ANGLE

D_b : BEND DIAMETER

D_f : FORMED DIAMETER

$\Theta_b - \Theta_f$: ANGLE ALLOWANCE

$D_f - D_b$: BEND ALLOWANCE

$\frac{D_b}{D_f}$: SPRINGBACK RATIO

$\frac{D_b}{t}$: BEND INDEX

FIG. 10 NOMENCLATURE