THE SPRING RESEARCH & MANUFACTURERS' ASSOCIATION

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

by

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Report No. 286

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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 stainless steel strip (BS 302S25), formed by a cylindrical punch.

The results are presented in a similar manner to that employed in the three previous reports. A consistency in strip forming of ± 2.5% has been achieved in the tests for stainless steel, as compared with ± 2% for the materials tested previously. Graphs have been drawn for the range of strip forming to enable the press tool designer to estimate the correct dimensions of the die required.

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1. INTRODUCTION

The object of this investigation into strip forming has been to produce data for die design relating the formed angle and thickness of strip, when formed by a cylindrical punch, to the bend angle and diameter.

Three previous reports (Research Reports 204, 230 and 261) described the test procedure and the theoretical aspects of the work. Results have been given for annealed CS70, hardened and tempered CS80, hard phosphor-bronze and annealed copper-beryllium strip. This report deals with similar work carried out with stainless steel strip (302S25 to BS 1449 Pt4 having a hardness range of 400 - 450 HV). The results obtained are presented in the form of graphs, as were those for the materials investigated previously. Design charts are given to enable the design of a die to be established quickly.

2. MATERIAL

The material (302S25 to BS 1449Pt4 having a hardness of 400 - 450 HV) was obtained in flat lengths of 2m in order to avoid possible influences from any initial curvature of the strip. The width of the strip was 12.5mm and material of the following nominal thicknesses was investigated 0.20; 0.30; 0.46; 0.71; 0.91; and 1.22mm

3. RESULTS

3.1 Material Dimensions

The material thickness was measured at random on the lengths of strip and was found to be within the specified tolerance range, as is shown in Table 1.

3.2 Strip Forming

Five different bend indices before forming and four bend angles for each strip thickness were investigated and 50 specimens were formed for each of these conditions (See Table III for die details). The angles thus formed were measured employing a Nikon profile projector. The results obtained from forming the six thicknesses are given in Tables IV to VI, which show the average formed angle for each die and also the 95% confidence limits obtained by statistical analysis of the results.

The average springback ratio was determined for each group of four dies with the same bend index and for each strip thickness. The springback ratios calculated for all dies are shown in Table VII, together with the corresponding bend indices. On the basis of these results, graphs have been drawn relating the springback ratio to the bend index for strip of each thickness (Figs. 1 to 3). The linear relationship was determined by applying the "least squares" method to the five points and thus obtaining the 'best-fit' line. Using these graphs and the relationship

$$D_f = \frac{D_b/t \cdot t}{D_b/D_f} \qquad \text{(See Fig.5)}$$

Fig. 4 was drawn, representing the formed diameter as a function of the springback correction factor, for the strip thicknesses investigated. Since the ratio of formed diameter to the bend diameter is inversely proportional to the ratio of formed angle to the bend angle, the formed angle can also be determined, thus:

$$D_b/D_f = k = \frac{\theta_f}{\theta_b}$$

3.3 Material Properties

Tensile tests were carried out for strip of each thickness and the results are given in Table II. This table also shows average hardness values, as determined from samples of each strip, and details of the nickel and chromium contents.

The specified nickel content for 302S25 material is between 8.00 and 11.00%. Only the 0.20 mm strip with a nickel content of 7.50% did not conform to the specification (strip of this thickness was probably supplied as hard rolled 301 S21). However, both the hardness value and the elastic limit of the 0.20 mm strip were comparable to those of other thicknesses; on these grounds the strip was accepted for the investigation.

4. DISCUSSION

The results obtained were similar to those for the materials tested previously. Again, the actual variation in formed angle is greater for the 180° bend angle than for the other three, as a result of the slight drawing action that occurs in a 180° circular die section. The actual variation decreases with decreasing bend angle and, in general, a consistency of $\pm$ 2.5% of the bend angle could be achieved with this material. As was explained in previous reports, the consistency of the formed angle of the strip is related to the variation in the elastic limit of the material. The hardness range and the ratio of elastic limit to tensile strength are an indication of the possible scatter in the elastic limit that can be expected.

The variation in the hardness values of the stainless steel tested, is wider than in the materials tested previously.

It may be, therefore, that the accuracy of punching is less in the case of stainless steel (± 2.5%) than for the other materials (± 2%).

Fig. 4 allows the shape of a die required to produce a required part to be estimated. The springback correction factor can be established for a given diameter and thickness of the product and the die dimensions can then be calculated as follows:

- Diameter: Multiply the desired diameter by the springback correction factor established;
- Bend Angle: Divide the desired bend angle by the springback correction factor.

Fig. 5 shows the nomenclature used.

5. CONCLUSION

The springback properties of 302S25, stainless steel having a hardness range of 400 - 450 HV have been investigated and design data produced. The variation in the results can be attributed to the variation in material properties.

TABLE I RESULTS OF STRIP THICKNESS MEASUREMENTS

NOMINAL THICKNESS in	NOMINAL THICKNESS mm	MEASURED THICKNESS mm	B.S. TOLERANCE mm
0.008	0.20	0.204 - 0.208	0.194 - 0.212
0.012	0.30	0.307 - 0.316	0.292 - 0.318
0.018	0.46	0.450 - 0.461	0.432 - 0.483
0.028	0.71	0.708 - 0.720	0.673 - 0.749
0.036	0.91	0.902 - 0.950	0.876 - 0.952
0.048	1.22	1.210 - 1.130	1.181 - 1.257

TABLE II MATERIAL PROPERTIES

	STRIP THICKNESS (mm)					
	0.20	0.30	0.46	0.71	0.91	1.22
Tensile Strength (R_m), N/mm^2	1310	1360	1385	1350	1460	1370
Limit of Proportionality, N/mm^2	650	660	675	580	650	545
0.1% Proof Stress, N/mm^2	1100	1140	1150	1060	1160	1055
0.2% Proof Stress, N/mm^2	1190	1255	1295	1220	1330	1196
Limit of Proportionality	0.50	0.48	0.49	0.43	0.44	0.40
Average Hardness, HV	444	439	445	423	447	433
Hardness Range, HV	6	12	10	6	9	9
Nickel Content, %	7.50	9.10	8.74	8.76	8.61	8.29
Chromium Content, %	17.5	18.6	17.9	17.7	17.3	17.1

TABLE III DIMENSIONS OF DIES

DIE NUMBER	STRIP THICKNESS t (mm)	DIE DIAMETER D_d (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	18.92	17.37	19	19.0
10	0.91	12.80	11.39	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	22.40	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 IV RESULTS OBTAINED WITH 1.22 mm STRIP

BEND ANGLE (°)	1.2 mm STRIP			0.91 mm STRIP		
	DIE NO.	MEAN FORMED ANGLE (°)	RANGE (95% LIMITS) (°)	DIE NO.	MEAN FORMED ANGLE (°)	RANGE (95% LIMITS) (°)
180	1A	78.31	3.7	6A	75.14	3.1
130	1B	52.81	1.2	6B	53.17	2.7
90	1C	36.43	1.2	6C	35.92	2.7
60	1D	22.91	1.5	6D	23.11	2.3
180	2A	95.07	4.0	7A	94.11	2.5
130	2B	67.74	1.2	7B	65.70	2.1
90	2C	45.86	1.1	7C	44.70	2.5
60	2D	28.87	0.8	7D	27.41	1.9
180	3A	106.13	3.3	8A	103.35	2.4
130	3B	79.45	1.1	8B	80.18	2.0
90	3C	49.98	1.0	8C	54.59	2.1
60	4D	33.53	0.7	8D	33.86	2.2
180	4A	126.54	2.6	9A	128.63	3.3
130	4B	93.21	1.1	9B	91.20	2.5
90	4C	61.08	0.8	9C	63.07	1.9
60	4D	40.51	0.9	9D	40.92	1.7
180	5A	144.48	2.2	10A	140.25	2.4
130	5B	104.84	1.0	10B	101.01	2.3
90	5C	68.54	0.8	10C	71.56	2.3
60	5D	44.57	0.8	10D	40.79	2.0

TABLE V RESULTS OBTAINED WITH 0.71 and 0.46 mm STRIP

BEND ANGLE (°)	0.71 mm STRIP			0.46 mm STRIP		
	DIE NO.	MEAN FORMED ANGLE (°)	RANGE (95% Limits) (°)	DIE No.	MEAN FORMED ANGLE (°)	RANGE (95% Limits) (°)
180	11A	71.71	3.3	16A	82.48	1.7
130	11A	57.61	1.1	16B	53.95	1.4
90	11C	40.04	1.1	16C	39.53	1.6
60	11D	24.99	0.8	16D	22.82	1.0
180	12A	93.12	2.9	13A	99.43	1.9
130	12B	72.43	1.2	17B	65.43	1.6
90	12C	50.10	1.0	17C	44.21	2.0
60	12D	32.35	1.0	17D	29.32	1.4
180	13A	115.22	3.3	18A	108.36	1.6
130	13B	81.34	1.9	18B	72.30	1.5
90	13C	57.37	1.4	18C	51.19	2.6
60	13D	35.67	1.4	18D	32.59	1.4
180	14A	132.98	3.4	19A	133.41	1.6
130	14B	94.12	1.3	19B	93.85	1.5
90	14C	66.39	1.3	19C	60.26	1.4
60	14D	39.99	1.4	19D	36.81	1.2
180	15A	144.62	1.5	20A	145.03	1.9
130	15B	103.18	1.2	20B	104.88	1.5
90	15C	69.29	1.3	20C	67.33	1.4
60	15D	44.70	1.0	20D	47.42	1.4

TABLE VI RESULTS OBTAINED WITH 0.30 and 0.20 mm STRIP

BEND ANGLE (°)	0.30 mm STRIP			0.20 mm STRIP		
	DIE NO.	MEAN FORMED ANGLE (°)	RANGE (95% LIMITS) (°)	DIE NO.	MEAN FORMED ANGLE (°)	RANGE (95% LIMITS) (°)
180	21A	86.04	1.8	26A	82.87	1.9
130	21B	62.01	2.1	26B	56.57	1.5
90	21C	38.89	1.1	26C	39.45	1.1
60	21D	26.75	1.1	26D	27.46	1.4
180	22A	101.87	1.6	27A	101.60	2.3
130	22B	71.56	1.1	27B	68.21	1.5
90	22C	47.98	0.9	27C	48.10	1.6
60	22D	32.42	0.8	27D	33.22	1.1
180	23A	117.74	2.3	28A	115.85	1.9
130	23B	82.21	2.3	28B	83.04	1.1
90	23C	55.46	2.3	28C	56.54	1.3
60	23D	37.65	2.1	28D	38.49	0.9
180	24A	134.04	2.3	29A	132.15	2.3
130	24B	99.68	1.3	29B	100.45	1.6
90	24C	66.04	1.2	29C	71.14	1.4
60	24D	46.98	1.3	29D	47.95	1.3
180	25A	147.99	1.4	30A	143.85	1.7
130	25B	106.54	1.3	30B	103.77	1.3
90	25C	73.46	1.6	30C	68.62	1.2
60	25D	48.58	1.5	30D	45.13	1.7

TABLE VII VALUES OF SPRINGBACK RATIO

DIE NUMBER	STRIP THICKNESS (mm)	BEND INDEX	SPRINGBACK RATIO
1	1.22	49.0	0.4069
2	"	37.0	0.5099
3	"	49.0	0.4069
4	"	19.0	0.6934
5	"	13.0	0.7783
6	0.91	49.7	0.4027
7	"	37.8	0.4956
8	"	28.5	0.5904
9	"	19.0	0.6997
10	"	13.0	0.7578
11	0.71	49.0	0.4256
12	"	37.0	0.5425
13	"	29.0	0.6244
14	"	19.0	0.7167
15	"	13.0	0.7780
16	0.46	49.0	0.4232
17	"	36.4	0.5089
18	"	30.2	0.5675
19	"	18.7	0.6865
20	"	12.9	0.7877
21	0.30	49.0	0.4582
22	"	37.0	0.5474
23	"	28.5	0.6325
24	"	18.6	0.7570
25	"	12.1	0.8169
26	0.20	48.2	0.4478
27	"	38.0	0.5443
28	"	28.5	0.6380
29	"	18.6	0.7741
30	"	13.8	0.7780

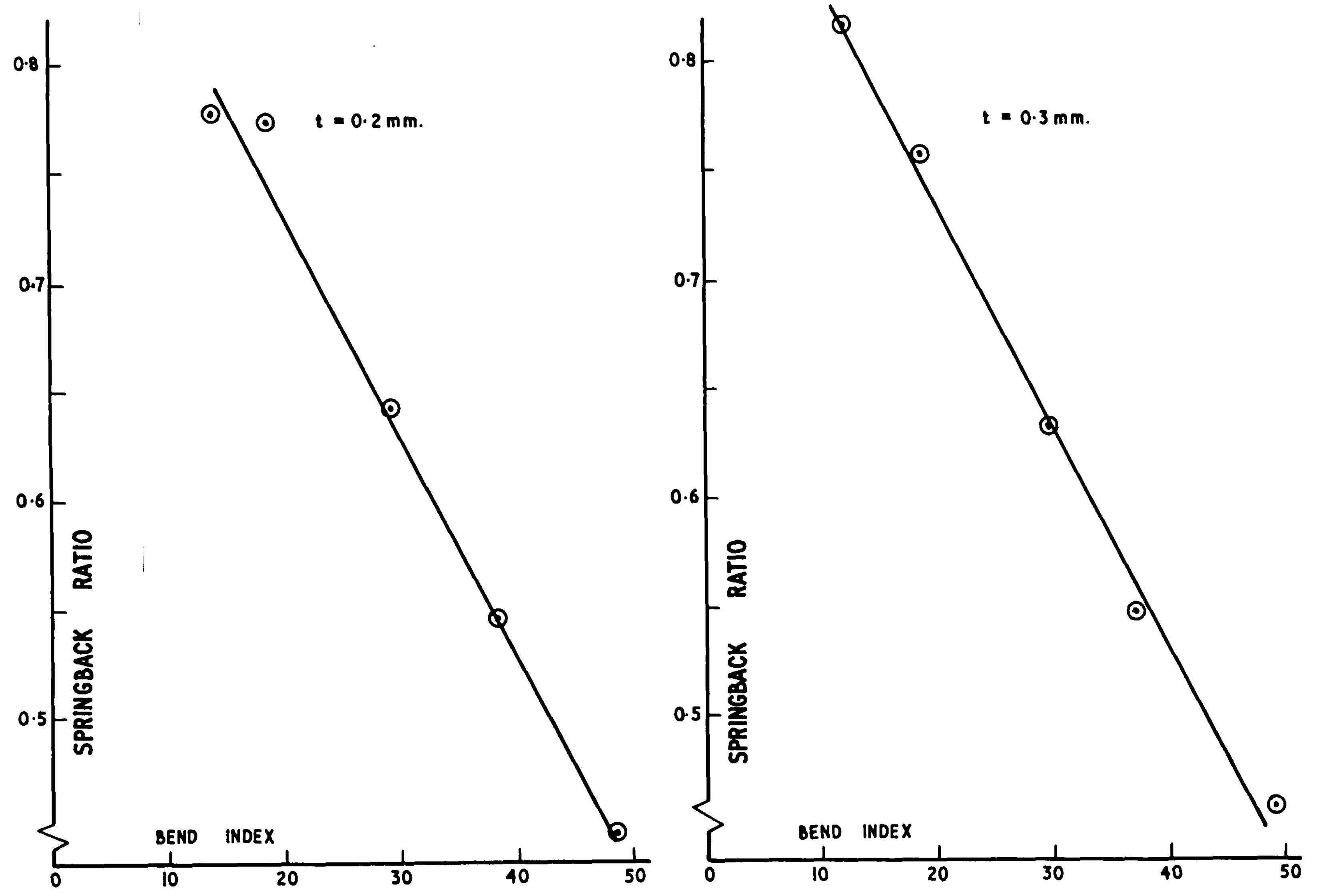


FIG. I. SPRINGBACK Vs BEND INDEX FOR 0·20 AND 0·30 mm STRIP.

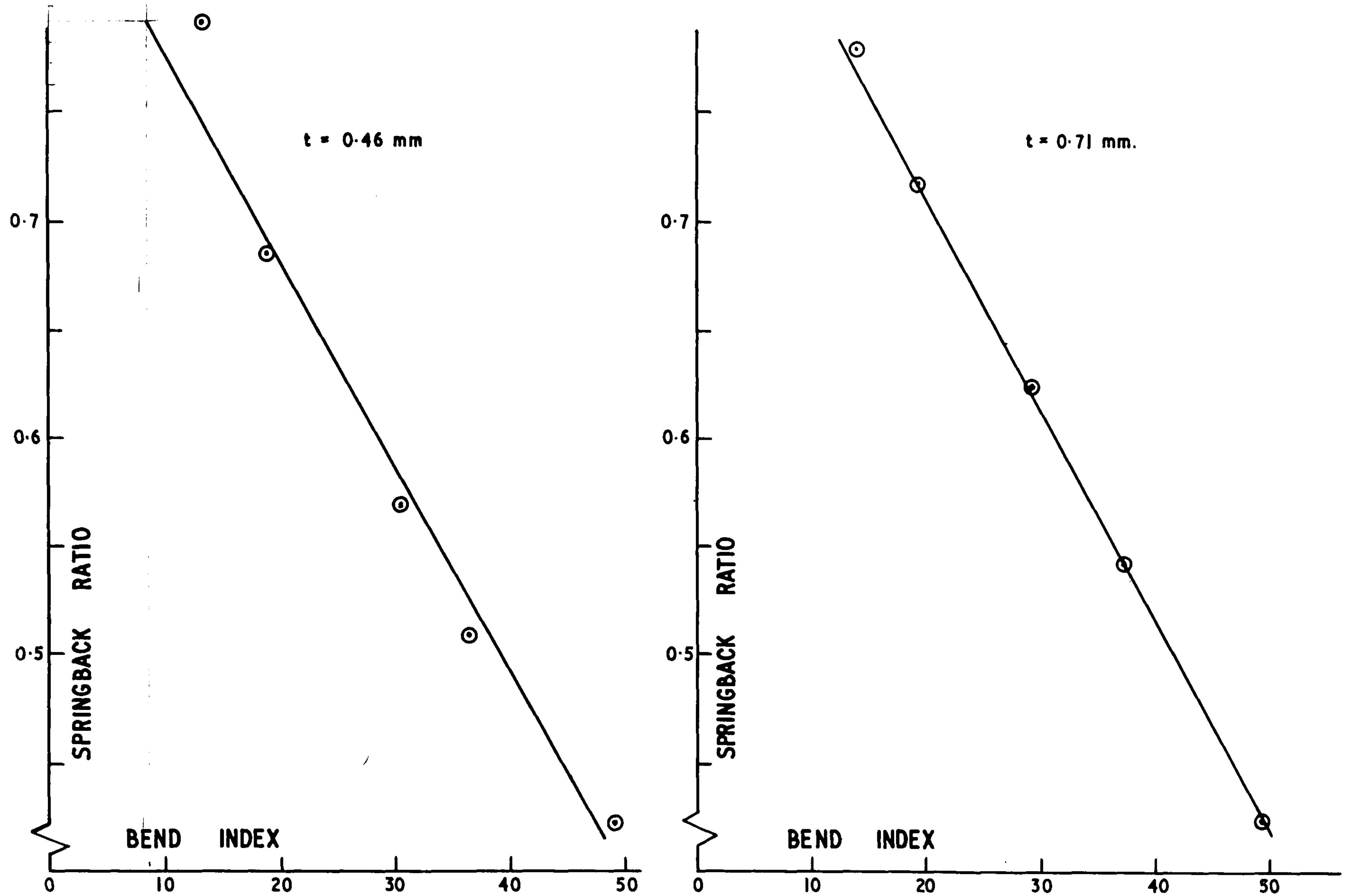


FIG. 2 SPRINGBACK Vs BEND INDEX FOR 0·46 AND 0·71 mm STRIP.

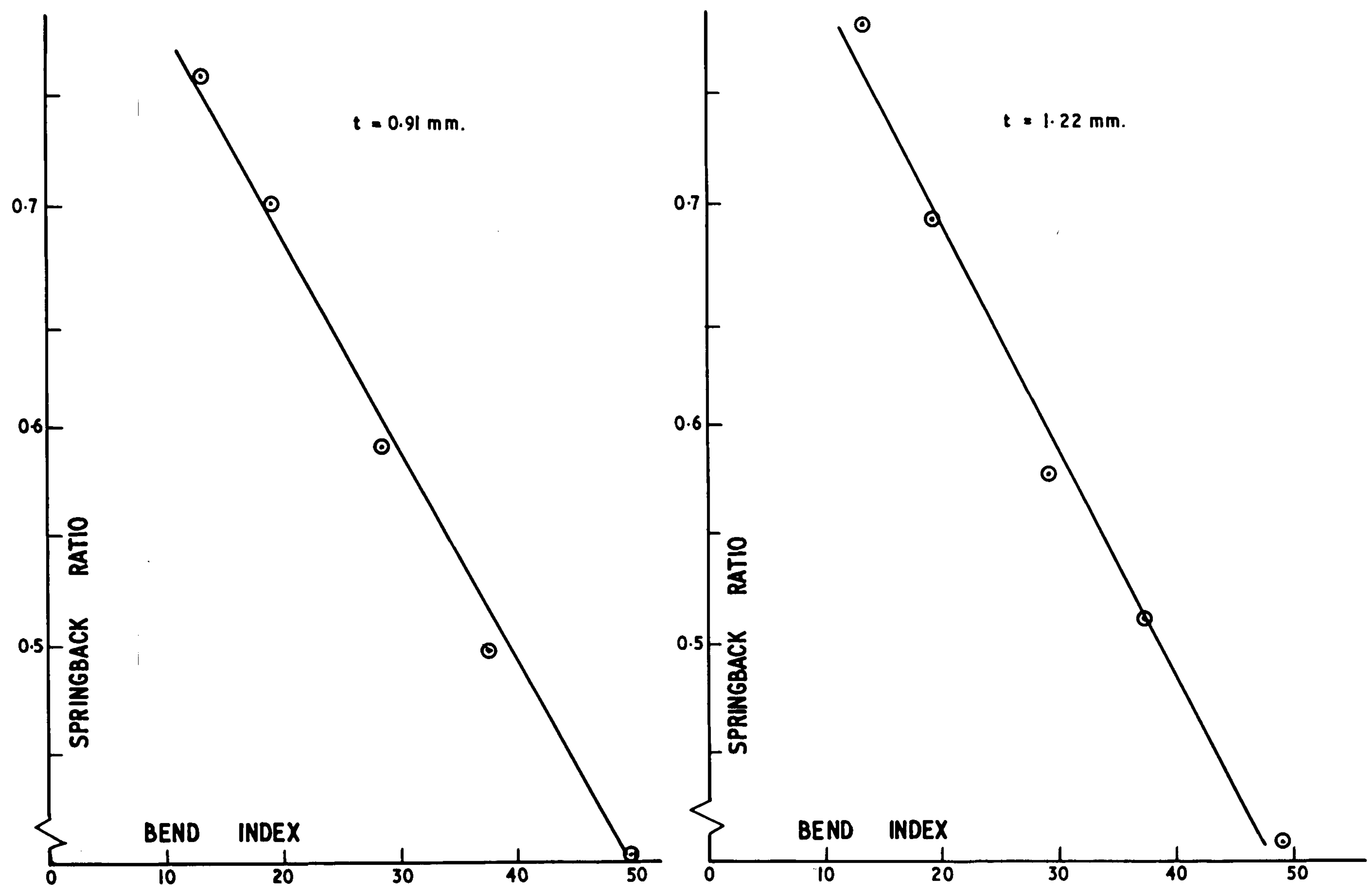
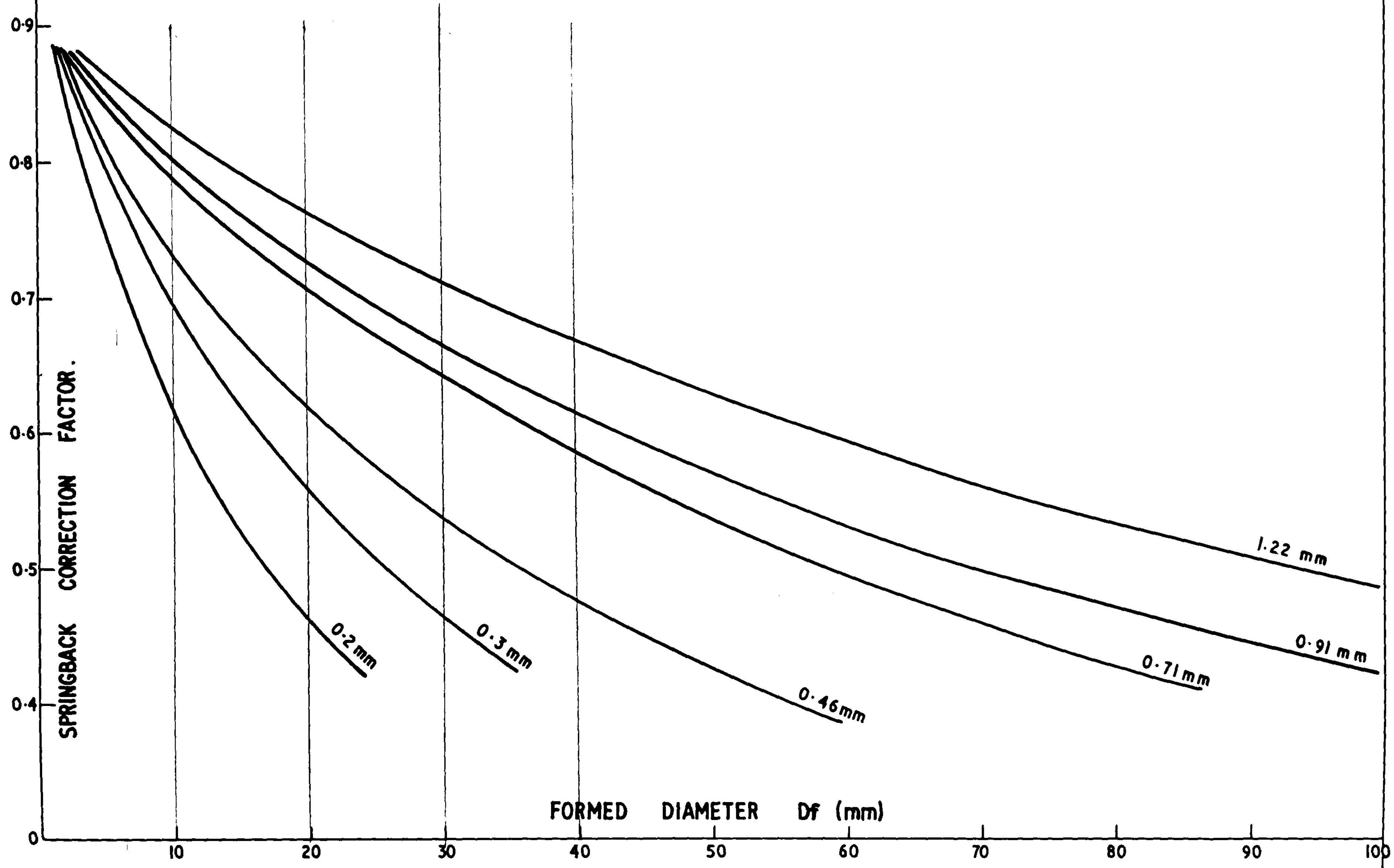


FIG. 3 SPRINGBACK Vs BEND INDEX FOR 0·91 AND 1·22 mm STRIP.

FIG. 4 DESIGN CHART FOR STAINLESS STEEL STRIP. (400 - 450 HV)



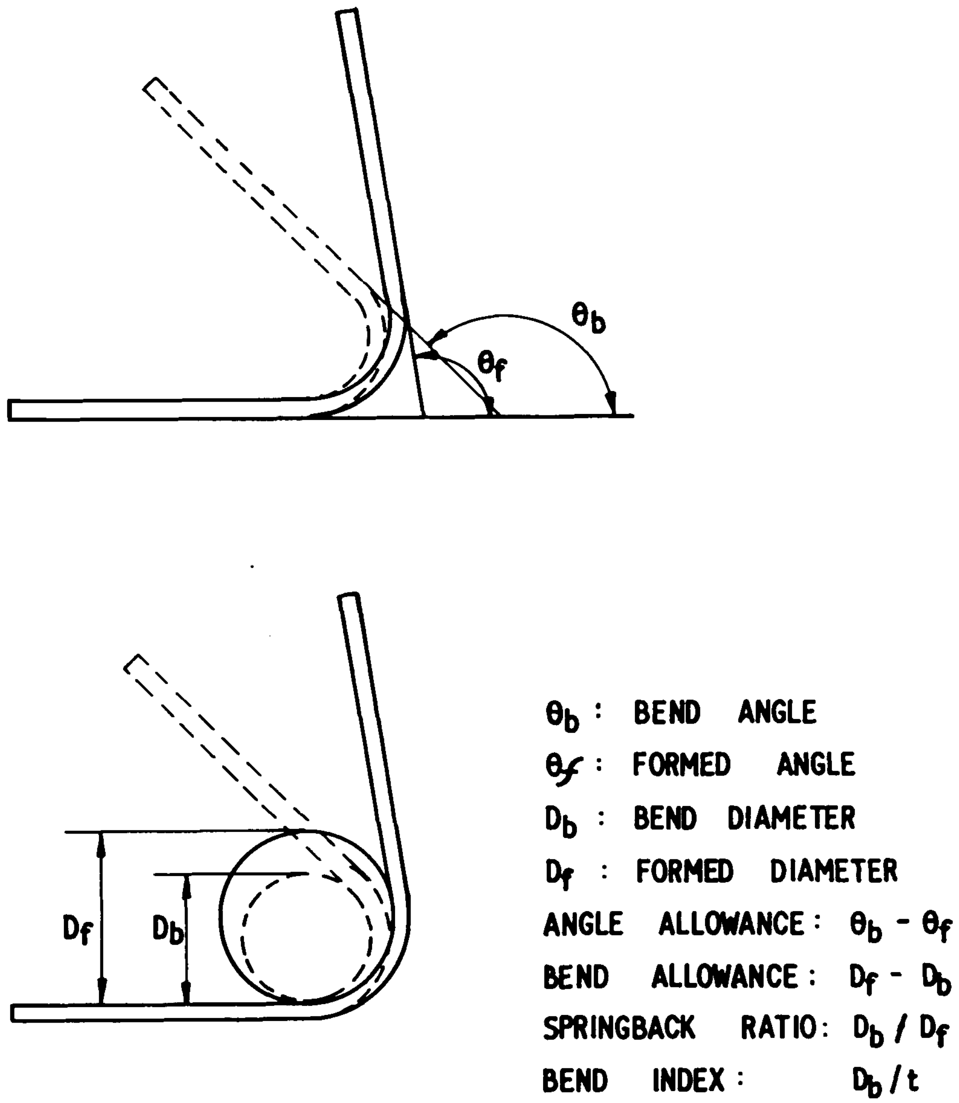


FIG. 5 NOMENCLATURE.