THE SPRING RESEARCH AND MANUFACTURERS' ASSOCIATION

MINIMUM BEND RATIOS FOR SPRING STRIP MATERIALS - A LITERATURE SURVEY

by

C.J. Webb, B. Tech.

Report No. 278

July 1977

THE SPRING RESEARCH AND MANUFACTURERS' ASSOCIATION

Report No. 278

MINIMUM BEND RATIOS FOR SPRING STRIP MATERIALS - A LITERATURE SURVEY

SUMMARY

A literature survey on the smallest bend radii that can be used with the commonest spring strip materials has been undertaken. The information obtained is presented, where available, in the form of the minimum bend ratio, for 90° and 180° bends, both parallel and perpendicular to the direction of rolling, at appropriate levels of hardness or tensile strength.

July 1977

CONTENTS

CONTENTS (Cont.)

MINIMUM BEND RATIOS FOR SPRING STRIP MATERIALS - A LITERATURE SURVEY

by

C.J. Webb, B. Tech.

1. INTRODUCTION

A literature survey has been carried out to extract information available on minimum forming bend ratios giving recommendations as to their use when forming spring strip components. The information obtained is presented and discussed in this report and recommendations are made to indicate where further experimental work should be undertaken.

The data presented in the form of tables and graphs have mostly been extracted from the publications of material manufacturers and stockists although a few have been obtained from journal articles. Information has also been obtained from the appropriate British Standards where these give bend test data.

2. MATERIALS

The materials in the survey have been classified into five groups. They are:

a) Annealed cold rolled carbon spring steel (CS)
b) Cold rolled hardened and tempered carbon spring steel (CSHT)
c) Cold rolled stainless spring steel
d) Beryllium copper alloys
e) Other copper alloys

The bends are defined as being either parallel (longitudinal) or perpendicular (transverse) to the direction of rolling and the angle of bend is given as either 90° or 180°. The most common-type of bend is 90° but the more ductile materials are tested at 180°, as this is a more complete and severer test of the ducility of the material.

3. RESULTS

With the exception of the data for annealed carbon steel strip, which are given in Table I, the information obtained is shown in the form of graphs. The graphs demonstrate that the minimum bend radius R (internal radius of bend), expressed as a function of t (material thickness), varies with the materials strength. In some cases, for one particular material, information is available on different angles of bend and for bending in different directions; in such cases the exact conditions for the curve are stated.

4. DISCUSSION

4.1 Annealed Cold Rolled Carbon Spring Steel

From Table I it can be seen that for all the literature examined the largest minimum bend ratio stated is 3t which is for the highest carbon content. As the range of minimum bend ratios is very small, changing the orientation and angle of the bend has only a limited effect on the minimum bend ratio.

4.2 Hardened and Tempered Carbon Steel Strip

Fig. 1 shows the minimum bend radius data obtained from two sources. Four other sources (10), (11), (13), (14), were not sufficiently explicit for the data to be included on the graph. In three of these sources, so-called 'minimum' ratios were given, but the bending angle or the alignment of the bend to the direction of rolling were not stated. It could be argued that the term "minimum bend radius" implies a 180° bend angle parallel to the direction of rolling but, as this was not stated, the information has not been included. From Fig. 1 it can be seen that the bend radii put forward by Skelskey[(2)] are more severe than the data contained in the Draft British Specification[(9)] which does not take into account any difference in formability between materials of differing carbon content. Skelskey's data indicates that a reduction in carbon content for strip of the same thickness and hardness results in a smaller minimum bending radius. It could be concluded therefore that the Draft British

Standard graph consists of bend data mainly for high carbon steel and that some of the values might be considered to be conservative for steels of lower carbon content, although experimental evidence would be needed to verify this.
The information derived from Skelskey is given for 2 ranges of ductility, the points within each range representing strips of varying thickness and hardness.
Material in the maximum ductility range is less hard than that of materials of the same thickness having average ductility. In any ductility range, as the thickness increases, the hardness and minimum bending ratio decreases. As it can be seen from Fig. 1 there is a difference in minimum bend ratio between strips having the same carbon content and the same thickness but different ductility and thickness.

4.3 <u>Stainless Spring Steel</u>

The values given in Fig. 2 for 302525 (En 58 A) from the Draft British Standard [8], BS 1449: Part 4, refer to material under 1.0 mm. thick; for thicker material, the bend test requirements in both directions being less severe.
The Draft BS 1449: Part 4 also specifies bend test requirements for other stainless steel materials in the cold rolled conditions: 301S21 (17/7) and 316S16 (En58J), the data for the latter being the same as for 302S25. BS 1449: Part 2: 1975 [15] also specifies bend test values for 301S21 material for 180° bends, parallel to the direction of rolling, which differ slightly from those given in Part 4, though the specification does not specifically apply to material for spring manufacture.

4.4 <u>Mill Hardened Beryllium Copper</u>

Fig. 3 shows the minimum bend radius data for 90° bends in terms of the tensile strength and hardness of the material. The data from all the sources correlate very closely, with the exception of the data for bends parallel to the direction of rolling in the hardest conditions. Mallory Metallurgical Products Limited [6] state much higher values of minimum bend radii in the extra spring hard condition, but until experimental data has shown otherwise however, it would be unwise to use bend radii below this value for extra spring hard material. Since Skelskey [2], a literature survey quotes the values given by Brush Beryllium [7], no additional data is provided. There is no British Standard Specification for mill hardened beryllium copper.

4.5 Solution Heat Treated and Cold Worked Beryllium Copper

Fig. 4 shows the minimum bend radius data for 90° bends in terms of the tensile strength and hardness of the material. As can be seen from Table III. the material specification of the Associated Spring Corporation [12] states minimum values higher than those given in the British Standard (BS 2870). Since Mallory [6] states values which are almost identical to those in the British Standard and both Skelskey [2] and Brush Beryllium [7] give values below both these it might be argued that the A.S.C. are too conservative.

4.6 Phosphor-Bronze

Fig. 5 shows the minimum bend data from 2 sources for 5% Tin Phosphor-Bronze in terms of its tensile strength and hardness. The data shown for bends parallel to the direction of rolling correlate well but those for bends tangential to the direction of rolling differ by up to 2t. Skelskey [2] states values which are below those in the British Standard (BS 2870) for tangential bends (see Table IV). These results must be treated with caution and their use is not recommended until further work or experience has shown whether or not the data given in the British Standard is conservative.

Additional information is available from the two sources [2] [5] on 8% Tin Phosphor-Bronze but as the material is not widely used in this country, it has not been included in the report.

4.7 70/30 Brass

All the bend radii shown in Fig. 6 are more severe than those given in the British Standard BS 2870(see Table V). However, wide discrepancies exist between the data shown in Fig. 6, and it is advisable to use the data from (5), which are the most conservative until further experimental data is available.

4.8 General Discussion

From examining the recommended ~~minimum~~ forming ratios it is apparent that for many materials there is a large difference between the values quoted by different authorities. Such variation makes it very difficult for this survey to give positive information to the spring industry, the more so as in many instances the methods by which the values have been obtained are not mentioned. Until experimental work has been carried out to provide reliable information it is recommended that where available the values given in the British Standard for the material should be used to determine the minimum forming radius for presswork components.

In general, the differences in stated minimum bend ratios from the various sources can probably be attributed to the following variables.

1) methods and speed of bending
2) surface finish
3) edge condition
4) strip dimensions
5) strip compositions and tempers
6) methods of assessing failure: and
7) inclusion content and distribution, particularly when bending parallel to the rolling direction.

Scovill Manufacturing Company [5] in their Handbook on Bending Copper and Copper Alloys state that the minimum bending radii given apply where bends are made under worst forming conditions (high speed and narrow width) and for severest subsequent service conditions. They also state that if the bending speed is slow, if the width is greater than 8-12t, or if the bend is non-functional, i.e. there is no loading or fatigue stressing, then the minimum bending radii can be reduced; though their method of displaying the data did not enable a value to be placed on this reduction. Sachs [3] also states that the width of the strip has a significant effect on the minimum bend radius. He states that the effect is most pronounced on comparatively narrow parts, while for parts in which the width exceeds the metal thickness by a factor of approximately 8, the minimum bend radius remains nearly constant.

According to several sources the surface finish of the sheet or strip prior to bending is a significant factor affecting the minimum bend radius. Small scratches on the surface or burrs and notches on the edge of the strip act as stress raisers in the bending operation and can seriously increase the permissable minimum forming radius. No surface or edge can be perfectly smooth, increasing the width of the strip therefore reduces the effect of any stress raisers. Increasing the width of the strip also increases the likelihood of the strip not being flat, which can cause the stresses during bending to be increased.

Inclusions can also act as stress raisers, the ductility as measured by bending parallel to the rolling direction varying accordingly to numbers and type of inclusion. In high carbon steels, it has been found that elongated inclusions of the Manganese Sulphide type do reduce bending ductility in proportion to the sulphur content of the steel. This is the main reason for restricting Sulphur levels on high carbon spring strip which will be subjected to "severe" bending, whether as annealed or hardened and tempered strip.

A difficulty encountered when comparing the information presented by the various sources is the method used of evaluating the "minimum bend radius". In the bend tests, specimens are commonly classified as "satisfactory" or "unsatisfactory" by visual examination. In most of the British Standard specifications a test piece is considered satisfactory if the outer convex surface is free from cracks. Scovill (7) however, considered that the surface appearance was of importance since bending operations are followed by finishing processes which often include plating or coating. In their published information, a surface roughening effect, which occurs at a larger radius than cracking, was undesirable and only a minimum was considered acceptable. This factor should be borne in mind when comparing values from different sources and any future experimental work should clearly state the method used for judging the acceptability of the bend.

In their handbook, Scovill(5) also state that using a closed die set the speed at which the deformation stress is applied to the metal will influence the minimum bend radii. Too sudden an application of the force will create high local stresses, especially at the surface of the strip, and will cause failure, either of individual fibres of the metal which will act as stress raisers, or failure of the entire bend.

It is also stated that a slow stroke (less than 50 inches/ second die movement) will permit slightly sharper bend radii than a fast stroke, especially in tempered material.
In two instances [(2),(5)] details are given of minimum bend ratios for bends at 45° to the direction of rolling which show that these are generally mid-way between the values for longitudinal and transverse bends. Hence it would not be unreasonable to assume that approximate linear interpolations can be made to derive forming radii for bends at any angle to the direction of rolling.

5. FURTHER WORK

It is recommended that future work should be carried out with tempered steel strip. The effect of edge conditions and dimensions of the strip on the bending properties of various materials should be assessed and some less detailed tests are needed to assess how conservative are the manufacturers' figures and, in cases where two sources give conflicting information, to decide which is the more accurate.

6. CONCLUSIONS

1. From the results of this literature survey it is apparent that there is no reliable guide to the minimum forming radius that can be used for all materials so that where they exist, the values given in the appropriate British Standard should be used.
2. Minimum bend ratios stated in this report taken from the literature can only be used as an initial guide in bending operations.
3. The survey has shown more detailed information is required on minimum bend ratios for hardened and tempered carbon spring steel and also experimental work to check existing results on several other materials particularly in their hardest condition.
4. The information available at present is insufficient to qualify the effects of spring strip dimensions, surface and edge conditions, and speed of forming on minimum bend ratio.

7. REFERENCES

1. British Standard BS 1449 Part 1:1972. "Carbon Steel Plate, Sheet and Strip".
2. SKELSKEY Jr. J.J. "Designing Strip Parts for Four Slides". Springs, 1965, October, pp. 16-23.
3. SACHS G. "Principles & Methods of Sheet-Metal Fabricating".
4. KNIGHT E.A. & SONS LTD. Knight Strip Precision Metals.
5. SCOVILL MANUFACTURING CO. "Handbook on Bending Copper and Copper Alloys".
6. MALLORY METALLURGICAL PRODUCTS LTD. "Mallory 73 Beryllium-Copper".
7 THE BRUSH BERYLLIUM CO. "Data Sheets on Berrylium Copper 25 & 165 Alloy and Brush 190 Mill Heat-Treated Strip".
8. Draft British Standard Specification for Steel Strip intended for the manufacturer of springs. BS 1449. Part 4. Martensitic and Austenitic Stainless Steel.
9. Draft British Standard Specification for Steel Strip intended for the Manufacture of Springs. BS 1449. Part 3. "Pre-hardened and Tempered Steel".
10. CARSON R.W. "Special Report on Flat Spring Materials" Product Engineering. 1962, June.
11. GUNNAR H.A. "Pretempered vs Annealed Strip for Steel Flat Springs" Product Engineering, 1963, May, pp.111-115.
12. ASSOCIATED SPRING CORPORATION. "Material Specifications".
13. ASSOCIATED SPRING CORPORATION. Design Handbook, Springs Custom Metal Parts.
14. BECKWITH J.B. "Formability of Flat Spring Material" Spring Design & Application, ed. N.P.Chironis
15. British Standard BS 1449. Part 2:1975. "Stainless and Heat Resisting Steel Plate, Sheet and Strip".

TABLE I   MINIMUM BEND RADII FOR ANNEALED COLD ROLLED CARBON SPRING STEEL STRIP

CARBON CONTENT (%)	HARDNESS (HV)	ANGLE & DIRECTION OF BEND	MINIMUM BEND RADIUS			
			SOURCE 1	SOURCE 2	SOURCE 3	SOURCE 4
0.65 - 0.75	185 max.	180° //	1 - 1½t			1 - 1½t
0.7 - 0.8	-	180° ⊥			1 - 2t	
0.7 - 0.8	175 max.	90° //		1.2 - 2t		
0.75 - 0.85	195 max.	180° //	1½ - 2t			1½ - 2t
0.85 - 0.95	210 max.	180° //				1½ - 2t
0.9 - 1.0	210 max.	180° //	1½ - 2t			
0.9 - 1.05	195 max.	90° //		1.5 - 2.5t		
0.9 - 1.05	-	180° ⊥			1 - 3t	
0.95 - 1.05	220 max.	180° //				2 - 2½t

TABLE II   KEY TO GRAPHS

— – —— – —   Bends parallel to the direction of rolling

————————   Bends perpendicular to the direction of rolling

All bends are at 90° unless otherwise stated. The numbers beside each curve refer to the source of the data.

TABLE III: EXTRACTS FROM BS 2870: SOLUTION ANNEALED & COLD WORKED BERYLLIUM COPPER

CONDITION	MINIMUM TENSILE STRENGTH (N/mm^2)	TRANSVERSE BEND		LONGITUDINAL BEND	
		Angle	Radius	Angle	Radius
W	41 5	180	Close	180	Close
W(¼H)	51 0	90	t	180	t
W(½H)	59 0	90	2t	90	t
W(H)	69 5	-	-	90	2t

TABLE IV: EXTRACTS FROM BS 2870: 5% Sn PHOSPHOR BRONZE

CONDITION	MINIMUM TENSILE STRENGTH (N/mm^2)	TRANSVERSE BEND		LONGITUDINAL BEND	
		Angle	Radius	Angle	Radius
0	31 0	180	Close	180	Close
¼H	35 0	180	Close	180	Close
½H	49 5	90	t	180	t
H	59 0	-	-	90	t
EH	64 5	-	-	90	t

TABLE V: EXTRACTS FROM BS 2870: 70/30 BRASS

CONDITION	MINIMUM TENSILE STRENGTH (N/mm^2)	TRANSVERSE BEND		LONGITUDINAL BEND	
		Angle	Radius	Angle	Radius
0	28 0	180	Close	180	Close
¼H	32 5	180	Close	180	Close
½H	35 0	180	t	180	t
H	41 5	90	2t	90	t

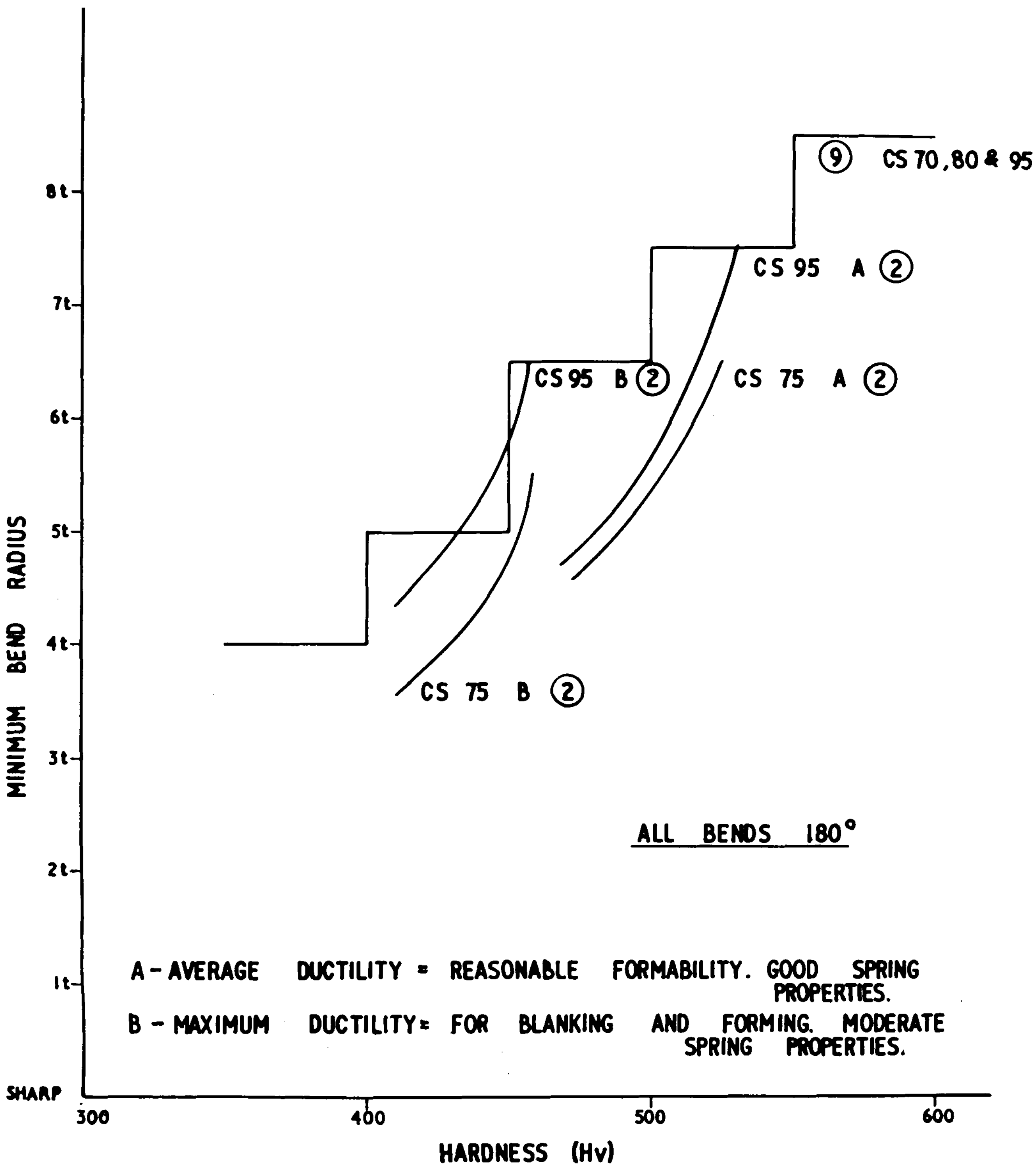

FIG. 1. MINIMUM BEND RADII FOR HARDENED AND TEMPERED CARBON SPRING STEEL.

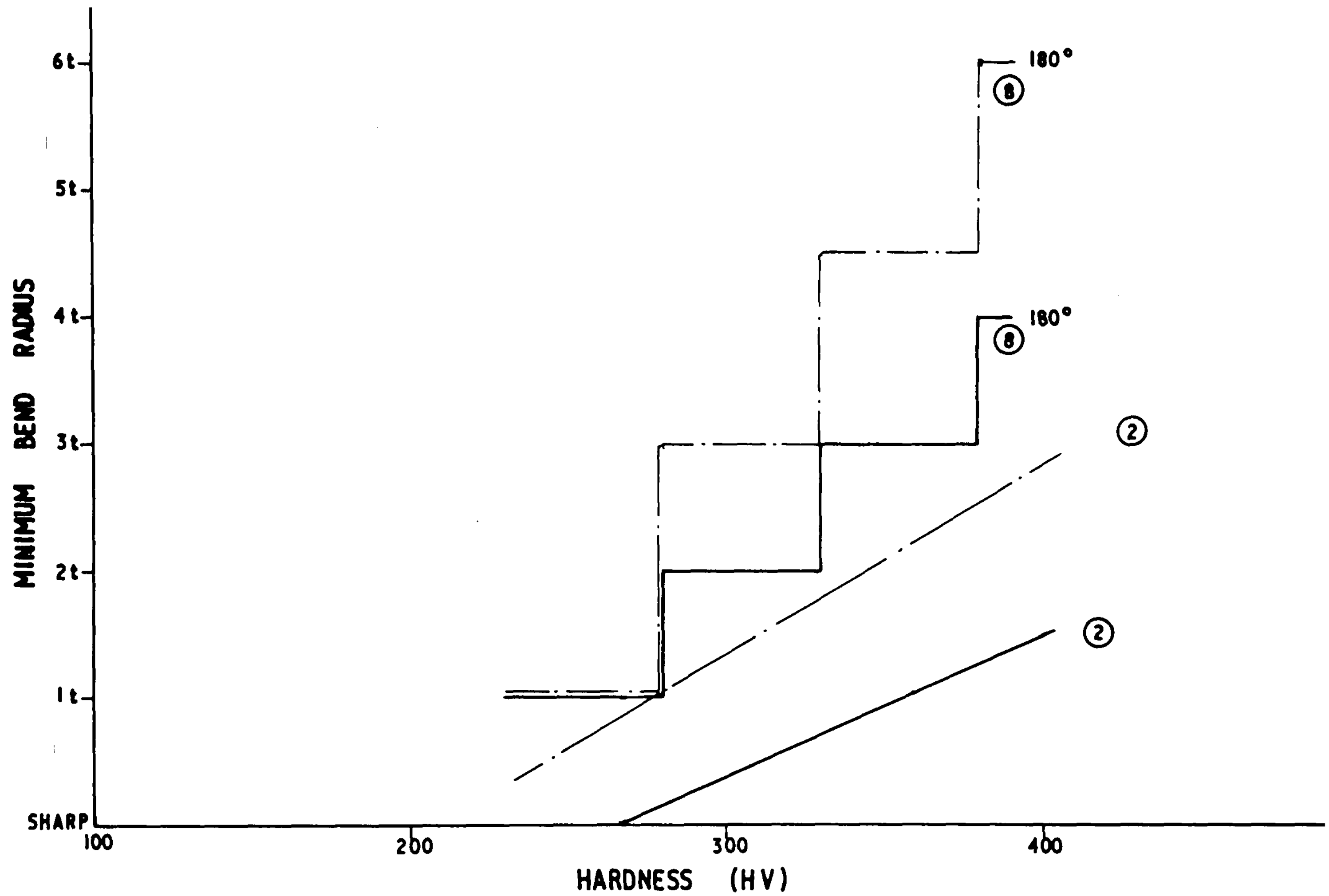

FIG. 2 MINIMUM BEND RADII FOR STAINLESS 18/8 SPRING STEEL (302S25)

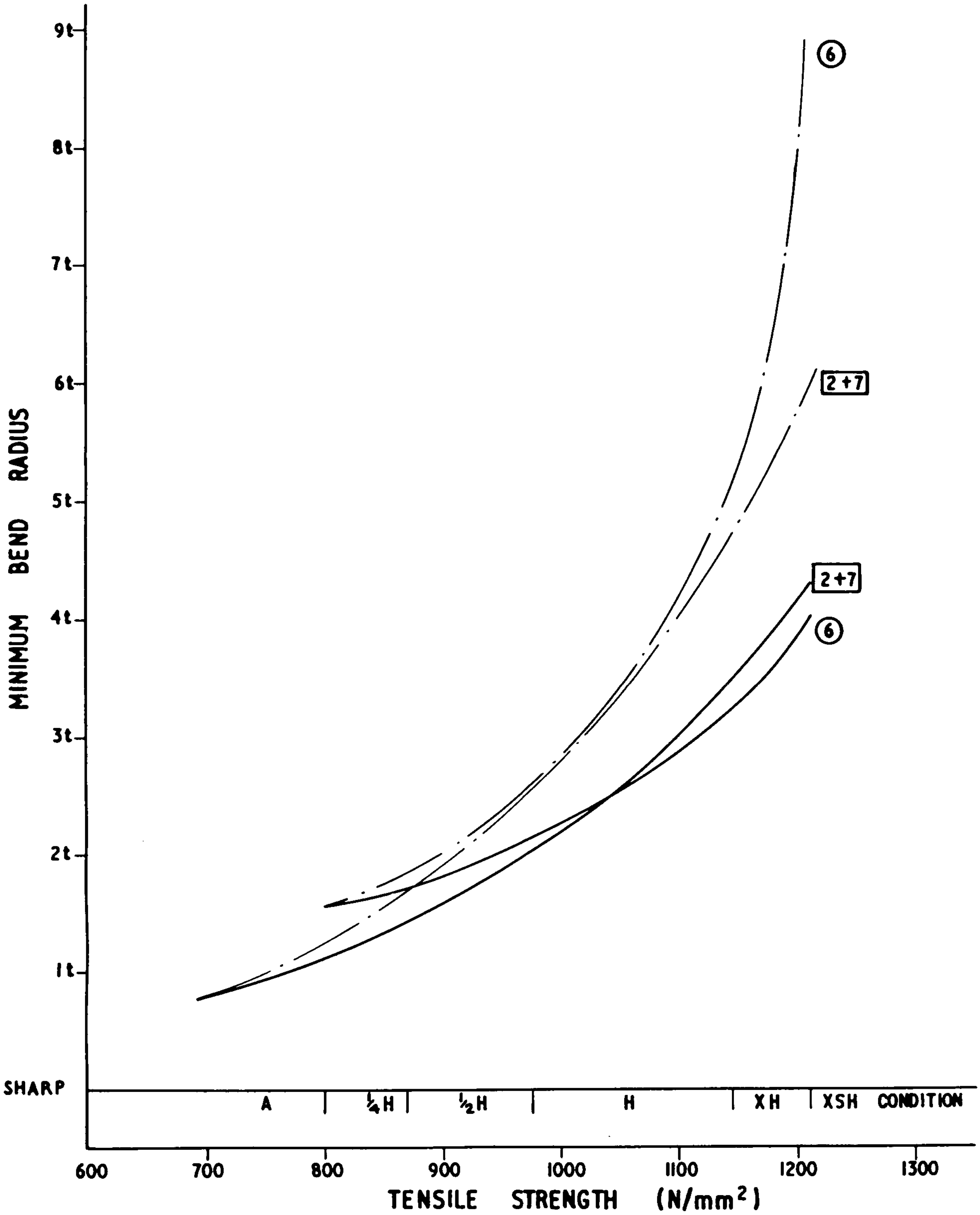

FIG. 3 MINIMUM BEND RADII FOR MILL HARDENED BERYLLIUM COPPER.

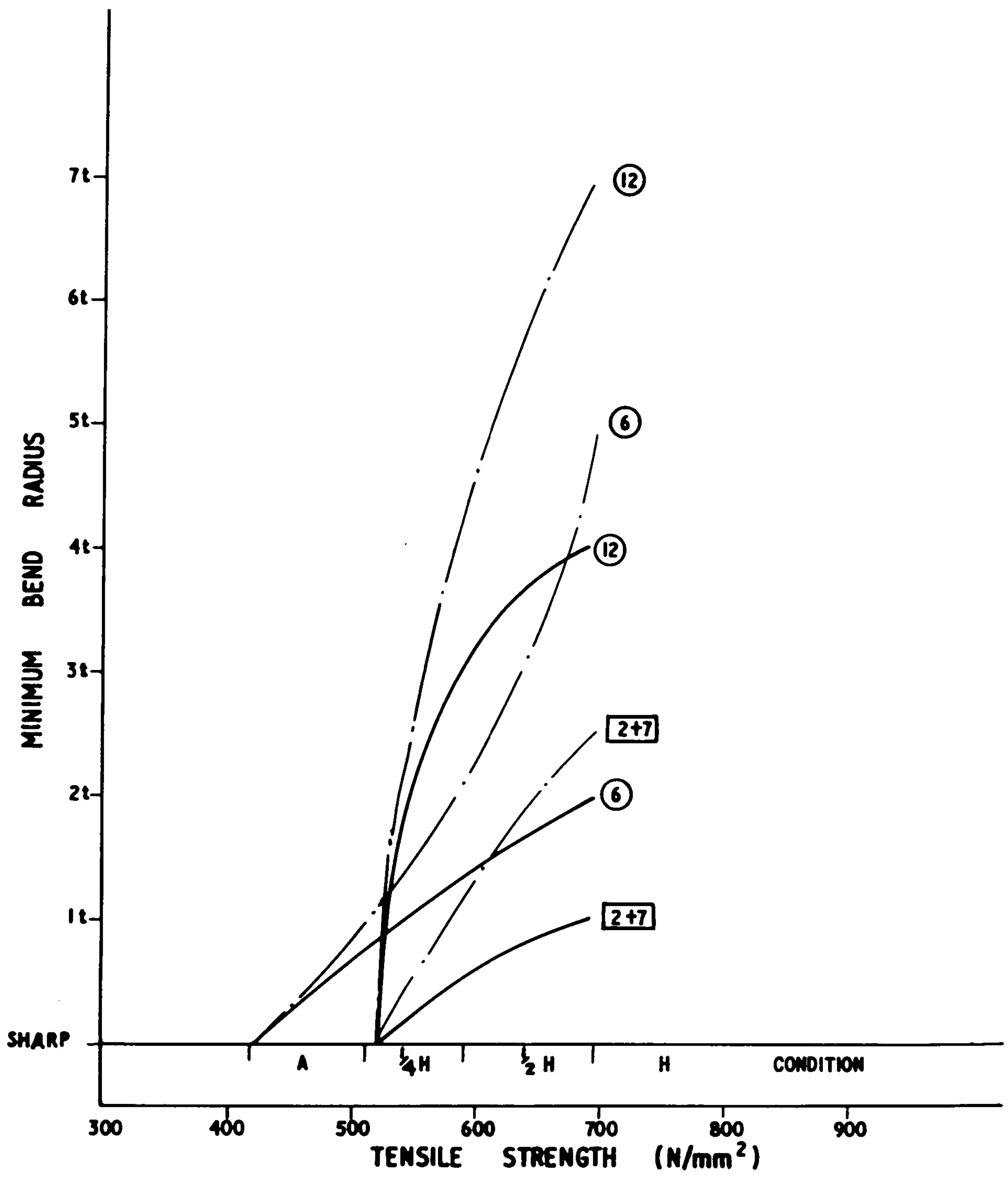

FIG. 4 MINIMUM BEND RADII FOR SOLUTION HEAT TREATED BERYLLIUM COPPER.

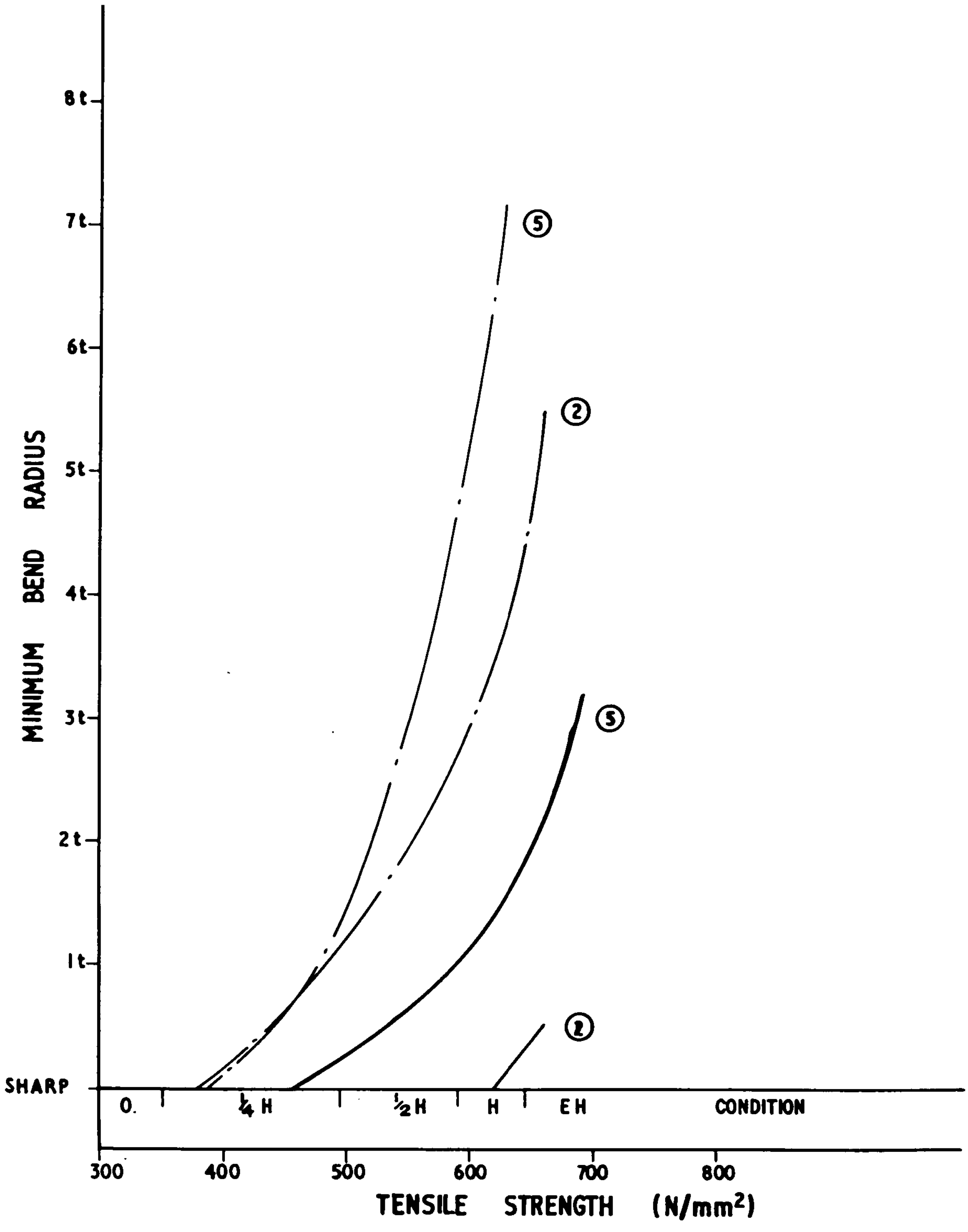

FIG. 5 MINIMUM BEND RADII FOR 5% Sn PHOSPHOR BRONZE.

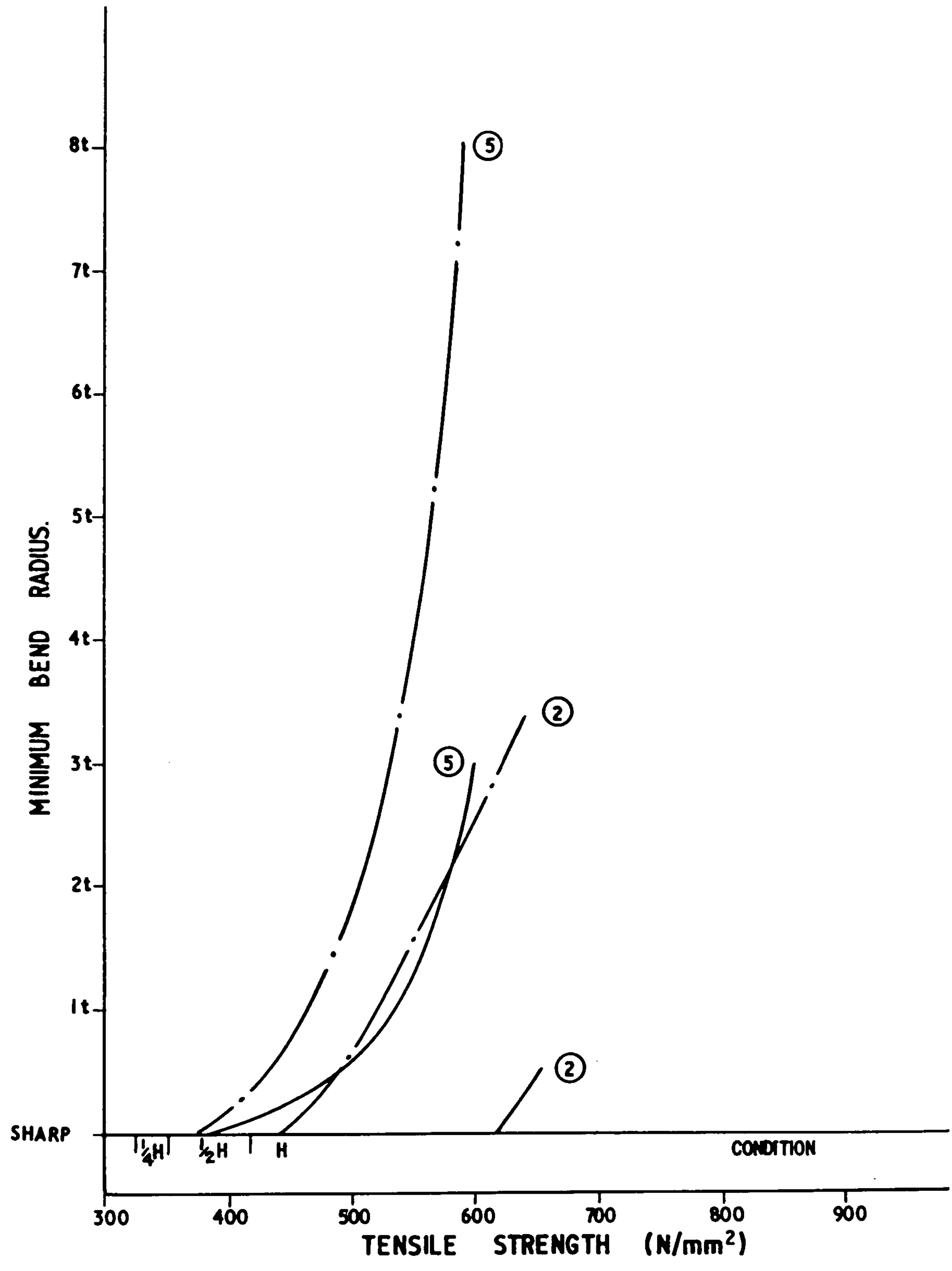

FIG. 6 MINIMUM BEND RADII FOR 70/30 BRASS.