MANUFACTURE OF TURBINE BLADING.

With the high peripheral speeds used in geared turbine installations, which speeds are necessary to obtain a high degree of internal efficiency in the turbine, and to enable also full scope to be given to the saving of space and weight, the blades in these turbines are in many cases highly stressed under working conditions. Having in view the strength of the material specified, an ample margin of blade dimensions is provided, but it should be appreciated that such margin is dependent on the quality of each individual blade, and it may be partially absorbed to an uncertain extent by any deviation from design, or by incorrect workmanship during the machining and constructional stages. As these blades form such a vital feature in a turbine installation, the care necessary at every step in the manufacture and fitting needs no emphasis, and in the first case it is necessary to ensure a very sound material which, besides satisfying the strength requirements, has to possess also resisting power to erosion and corrosion.

The operations of machining and fitting the blading are well known, and it is only intended in this article to deal with the manufacture of the bars before despatch to the machinery contractors for machining and fitting. Phosphor bronze blading has been found very suitable to give the necessary requirements for naval work, and the specifications state that "the material is to be hard-rolled and bright-finished, and to have a tensile strength of not less than 24 tons per sq. in., and an elongation not less than 10 per cent. on a length of 10 ins. The composition of the material is to be as follows :—

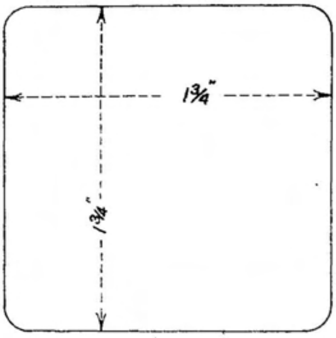
"Copper : not more than 96·9 per cent., and not less than 94·9 per cent.

"Tin : not more than 5·0 per cent., and not less than 3·0 per cent.

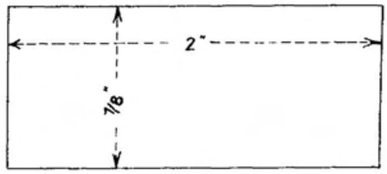
"Phosphorus : not less than ·1 per cent.

"The material to be quite free from lead, zinc and aluminium, and not to contain more than traces of other impurities."

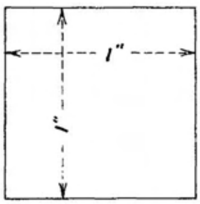
Phosphor bronze is manufactured by melting copper in a crucible and adding tin and copper phosphide in the requisite proportions. The copper phosphide is prepared in the first place by pouring a definite weight of best selected copper directly upon yellow phosphorus, which is placed in a carefully dried crucible



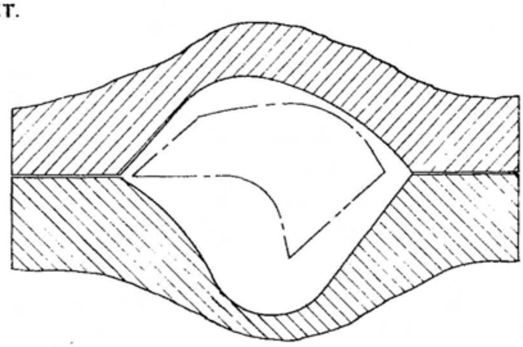
SECTION OF CAST BILLET.



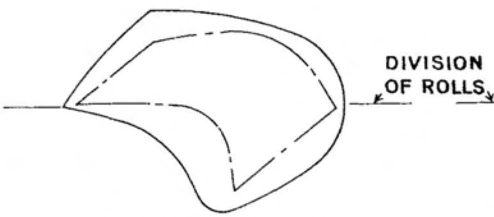
AFTER COLD ROLLING
BEFORE 2ND ANNEALING.



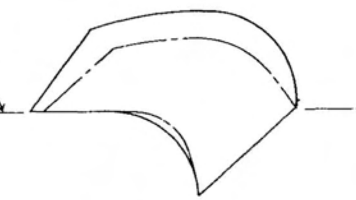
AFTER COLD ROLLING
BEFORE 3RD ANNEALING.



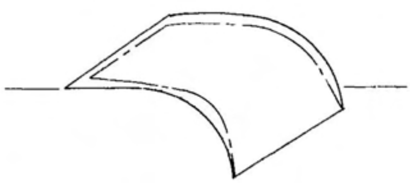
AFTER COLD ROLLING IN SPECIALLY
SHAPED ROLLS, BEFORE 4TH ANNEALING.



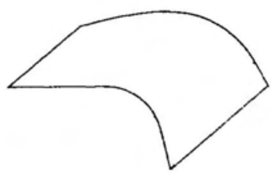
AFTER ROLLING IN
SPECIALLY SHAPED ROLLS
BEFORE 5TH ANNEALING.



AFTER ROLLING IN
SPECIALLY SHAPED ROLLS
BEFORE 6TH ANNEALING.



AFTER 1ST COLD PASS,
THROUGH SOLID DIE, ON
DRAW BENCH, BEFORE
7TH ANNEALING.



FINISHED BLADE AFTER 2ND
COLD PASS THROUGH HIGHLY
FINISHED ACCURATE HARDENED
STEEL DIE IN HALVES.

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contained in a chamber closed except for ventilating arrangements. The crucible in which the re-action takes place is well stirred and agitated till the operation is complete, when the resulting product is poured into shallow trays.

Copper is now melted in a crucible and tin and copper phosphide are added to the molten copper in the order named and according to the desired composition of the blades. It is then cast into ingot moulds which are of cast-iron in halves. These moulds are cleaned inside and dressed with blacklead, and when placed together are secured with a ring and wedges. The cast billet is usually about $1\frac{1}{2}$ to $1\frac{3}{4}$ ins. square, and 6 ft. long. Such billets are large enough after undergoing the necessary subsequent treatment to give the maximum section blades used in Admiralty practice.

The billets are now annealed in a gas furnace and then taken to breaking-down rolls, where they are given successive passes through the rolls until reduced in section. The whole of the subsequent treatment consists of a series of annealing and rolling operations, the annealing at intermediate stages, which is carried out by placing the bars in a muffle at 700° C. for about 1 hour, being necessary owing to the hardening of the material during the rolling operation. The penultimate roll is through a solid steel die which is approximately the required section. At this stage it is carefully examined and gauged, and must show smooth surfaces and be free from rags or roughness at the edges. After annealing, the bar is given its final pass through a very accurate and highly-finished hardened steel die, this die being made in halves to facilitate accurate machining and gauging in the fitting shop. The approaches to the dies are carefully curved, as the result of much experiment, to ensure that cracking does not take place at the thin edges. The bar has now its rough ends cut off, and is straightened either by hand or by drawing through staggered blocks of wood, which give it slight bends in either direction, and so remove all "kinks." The finished bars are now cleaned with paraffin and carefully examined and gauged along their entire length, the necessary gauges being in halves and fitting over the blade.

The successive stages to the final stage are indicated approximately by the sketch, the final section being indicated at various stages to show the gradual approach of the bar to this section.

The general change in quality of the material at the successive stages will be better appreciated by the results of a series of tests carried out on typical bars during manufacture.

The actual analysis in these cases was:—

> Copper, 96·21 per cent.; tin, 3·4 per cent.; phosphorus, ·32 per cent.

The finished blades were of large section, the original billets being $1\frac{1}{2}$ ins. and $1\frac{3}{4}$ ins. square.

Stage of Manufacture.	Dimensions. (Inches.)	Cross-sectional Area (Sq. ins.).	Ultimate tensile (Tons per sq. in.).	Yield Point (Tons per sq. in.).	Elongation per cent. in 2 ins.	Reduction of Area at Fracture, per cent.
Original casting -	$1\frac{3}{4} \times 1\frac{3}{4}$	3·0625	17·4	—	24	24
After 1st rolling and 2nd annealing.	$2\frac{1}{16} \times 1\frac{5}{32}$	2·385	19·6	—	60	59
After 2nd rolling and 3rd annealing.	$1\frac{15}{32} \times 1\frac{1}{4}$	1·836	19·8	—	68	76
After 3rd rolling and 4th annealing.	$1\frac{17}{32} \times \frac{7}{8}$	1·34	19·4	—	75	78
After 4th rolling and 5th annealing.	1×1	1·0	19·6	—	64	82
After 5th rolling and 6th annealing.	$1\frac{3}{8} \times \frac{9}{16}$	·7734	19·6	—	72	83
After 6th rolling and 7th annealing.	$1\frac{1}{8} \times \frac{9}{16}$	·6328	20·0	—	65	86
After 2 draws with subsequent annealing and final draw.	Final Section. 1719c.	·5	25·1	19	31	79

Total reduction of area from original section = 83 per cent. approximately.

Stage of Manufacture.	Dimensions. (Inches.)	Cross-sectional Area (Sq. ins.).	Ultimate tensile (Tons per sq. in.).	Yield Point (Tons per sq. in.).	Elongation per cent. in 2 ins.	Reduction of Area at Fracture, per cent.
Original casting -	$1\frac{1}{2} \times 1\frac{1}{2}$	$2\frac{1}{4}$	18·3	6·8	22	27
After 1st rolling -	$1\frac{9}{16} \times 1\frac{1}{4}$	1·96	29·4	26·6	11	25
Annealed -	$1\frac{9}{16} \times 1\frac{1}{4}$	1·96	19·5	7·4	53	30
After 2nd rolling -	$1\frac{1}{16} \times 1\frac{1}{16}$	1·12	35·5	26·4	12	45
Annealed -	$1\frac{1}{16} \times 1\frac{1}{16}$	1·12	20·1	7·5	68	72
After 3rd rolling -	Irregular section.	—	26·3	22·0	37	73
Annealed -	,,	—	20·3	7·4	65	78
After 4th rolling -	,,	—	26·5	16·2	55	72
Annealed -	,,	—	20·0	7·6	66	80
After 1st drawing -	,,	—	31·9	26·2	25	74
Annealed -	,,	—	21·0	8·3	65	79
After 2nd drawing -	,,	—	26·6	21·1	31	77
Annealed -	,,	—	21·0	8·1	62	81
Final draw -	Section 48 c.	·5	25·1	19·2	34	79

Total reduction of area from original section = 77 per cent. approximately.