(*Paper No. 3423.*)

"Copper Locomotive-Boiler Tubes."

By Francis William Webb, Vice-President Inst. C.E.

Having recently concluded an investigation made with the object of determining the composition of copper tubes most suitable for use in locomotive-boilers, the Author has pleasure in presenting the result, which, he feels sure, will be interesting, and doubtless useful, to engineers engaged in locomotive-work. As mentioned in his Paper[1] on "Locomotive Fire-box Stays," the fire-box stays of the locomotive-boilers on the London and North Western Railway are of copper; the inner casing of the fire-box and the tubes generally are also of that metal, which is found to be more economical than steel, in respect of both durability and evaporative power.

Soon after the general introduction of copper boiler-tubes it was observed that certain tubes had a much longer life than others; in fact the life of tubes by the same maker often varied considerably. Chemical analyses of both good and bad tubes were made from time to time, and it was generally found that the most durable tubes contained some hardening-element, such as arsenic or nickel; and also that the life of a tube depended upon how it had been worked. The tubes usually fail through being worn thin by the corrosive action of the furnace-gases and the abrasion of the cinders, the pressure inside the boiler then causing them to collapse at the corroded part. Others fail by breaking immediately behind the fire-box tube-plate, a result which is often due to brittleness.

In order to ascertain the composition of the copper tubing most suitable for use in locomotive-boilers, a set of tubes (198) by ten different makers, namely, twenty by each of eight makers and nineteen by each of two makers, was put into the boiler of engine

[1] Minutes of Proceedings Inst. C.E., vol. cl. p. 87.

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No. 1,213, "The Queen," a 4-wheels-coupled passenger-engine. Each make of tube was so placed in the tube-plate as to get the same amount of abrasion by cinders and corrosion by furnace-

Fig. 1.

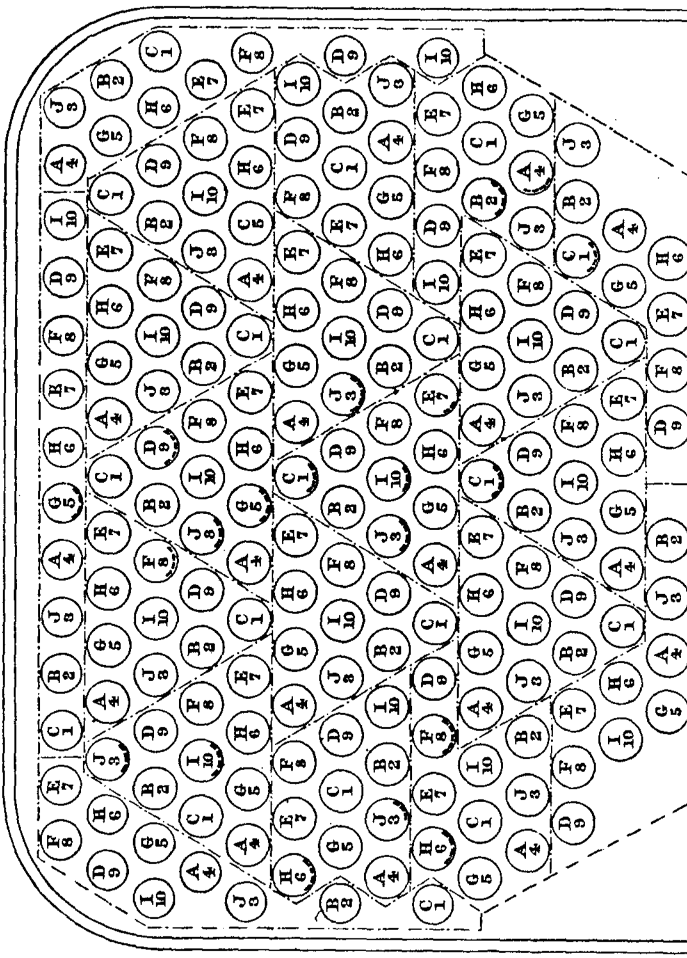

DIAGRAM SHOWING METHOD OF GROUPING TUBES, AND POSITIONS IN THE TUBE-PLATE OF THE TUBES THAT FAILED. THE FAILURES ARE SHOWN THUS:—

gases; this was insured by arranging them in twenty groups, each group containing one tube of each make, with two exceptions, in which nine makers only were represented in each group. The method of grouping is illustrated in *Fig. 1.* The tubes were numbered consecutively 1 to 198, and the different makes were numbered 1 to 10.

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The boiler fitted with the experimental set of tubes commenced work in October, 1898, and finished in December, 1901. During that time the engine ran 142,348 miles. In order to determine the relative merit of each make of tube the following rule was observed. When a tube failed, it was taken out of the boiler and the mileage of the engine was noted; and when a second tube of the same make failed, the whole of the tubes of that make were removed from the boiler and the engine-mileage up to the failure of the second tube was noted. While the experiment was in progress, the tubes were re-rolled and re-ferruled and the ferrules were knocked up several times.

The first tube failed after the engine had completed 34,067 miles, and the second tube of the same make at the end of 40,612 miles; whereas the first and only failure of the make which stood the best did not take place until the engine had completed 123,896 miles. Of the tubes second in order of merit, only one tube failed, and that at the end of 107,507 miles. When the engine had completed 142,348 miles, it was decided to stop the experiment, although the experimental tubes remaining in the boiler, by two makers, were still in fairly good condition.

It was observed that, with one exception, the failure of the tubes was due to their having worn thin from the inside, invariably at the bottom and within 6 inches of the fire-box end of the tube, the pressure inside the boiler causing them to collapse. The one exception was that of a tube which cracked during re-rolling. It is singular that the inside of the tubes should invariably wear thin at the bottom. Doubtless, this unequal wasting of the tube is due either to the sulphurous acids from the sulphur in the coal condensing on the bottom of the tube near the fire-box end during the lighting-up of the boiler, and thus corroding the metal; or to a portion of the cinders striking the top, inside of the ferrule, and being deflected downwards against the bottom of the tube. A typical example showing the unequal wasting of the tube just beyond the ferrule is illustrated in Fig. 2, Plate 5; and the shape and thickness of a typical "burst" tube are shown in Fig. 3, Plate 5.

Chemical analyses of each of the tubes that failed, and of the average of the tubes that did not fail, were made. The results of the analyses, together with the mileage of each make of tube, arranged in order of mileage—and therefore of merit—(A to J) are set out in Table I. of the Appendix, and are shown diagrammatically in *Fig. 4*. It will be observed that there is practically no difference in the chemical composition of tubes of the same

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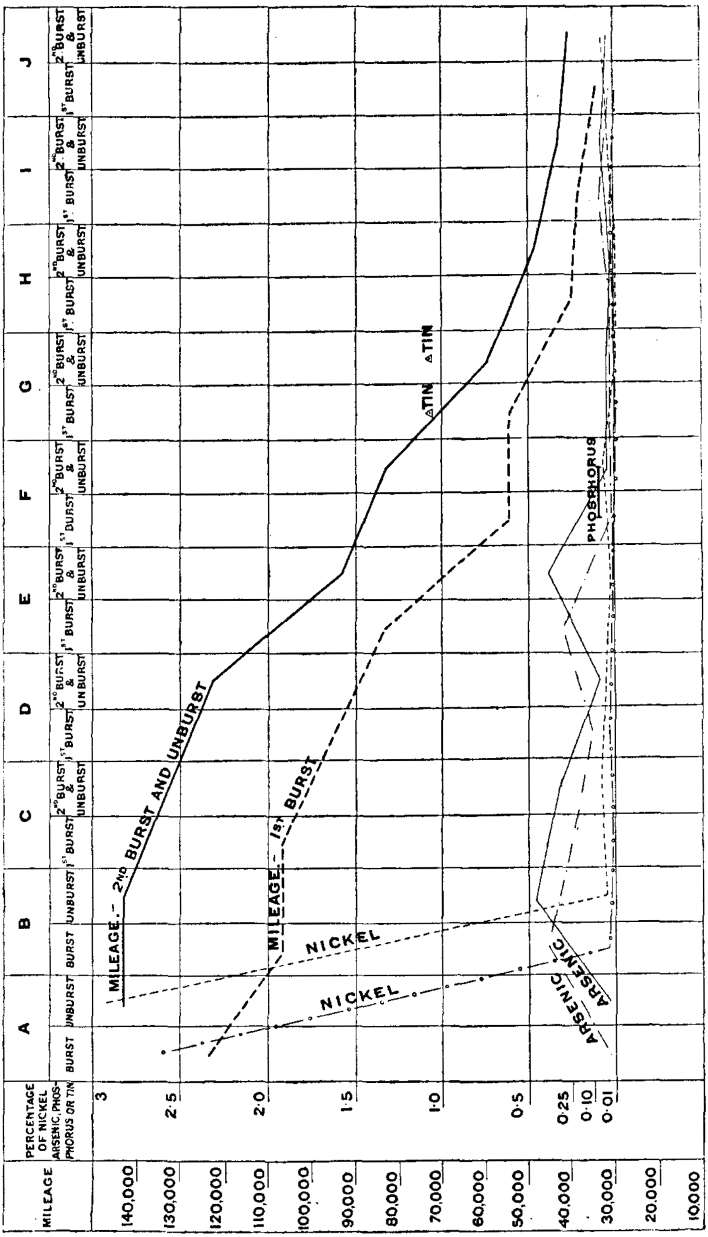
Fig. 4.



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make, whether they failed or not; and that the two makes of tubes which stood the best are hardened with nickel and arsenic respectively. Of the tubes marked C in order of merit, two failed (Nos. 146 and 178) at the same time; hence, three tubes of this make are shown as having failed.

Taking the quantity of arsenic present as determining the hardness of the tube, and the hardness as representing its life, the tubes E in Table I. should, at least, be one place higher in order of merit. However, the make which stood the best is quite different from the others in chemical composition.

The Author thinks it will be agreed, as the result of this investigation, that the most satisfactory copper tubes for locomotives are those containing either 3 per cent. of nickel, or at least 0·5 per cent. of arsenic.

Copper tubes hardened with nickel are now being put into locomotives on the London and North Western Railway, and good results are anticipated from them.

Three samples of seamless copper tubes, said to contain 3 per cent. of nickel, 0·5 per cent. of arsenic and 0·75 per cent. of arsenic, respectively, which have been made as the outcome of the foregoing investigation, have been submitted to the Author. A complete chemical analysis of each of these tubes is given in Table II., and the results of the mechanical tests of the samples in Table III. of the Appendix. These mechanical tests indicate that the tubes are softer than the average of thirty-two samples of ordinary copper tube taken from consignments received from time to time. Nevertheless, on cutting them with a chisel they do not show particularly soft metal, especially in the case of the sample marked N 3.

Some time ago experiments were conducted at Crewe with fluted copper tubes (Figs. 5, Plate 5); but it was found that the ridges inside the tube suffered abrasion, especially at the commencement of the ridges, just beyond the ferrule, which were rather quickly worn through; consequently the use of such tubes had to be abandoned.

An ordinary copper tube which has suffered abrasion rather severely, as will be seen from the corrugated appearance of the inside surface of the tube, is illustrated in cross-section in Fig. 6, Plate 5.

In conclusion, a form of steel ferrule, introduced by the Author at Crewe some time ago, may be mentioned. The ferrules, which are stamped from mild-steel sheet, are, in the fourth of the five operations of manufacture, forced into a die which forms sixteen

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small ridges, $\frac{1}{16}$ inch in width and about $\frac{1}{64}$ inch in depth on the outside. These ferrules, having a taper of 1 in 80, in addition to the ridges, are found to hold better in the ends of the tubes, which are rolled with parallel sides, than the plain turned ferrules with a taper of 1 in 40. An elevation and an end-view of this improved ferrule are shown in Fig. 7, Plate 5.

The Paper is accompanied by two diagrams and six photographs, from which Plate 5 and the Figures in the text have been prepared; and by the following Appendix.

[Appendix.

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APPENDIX.

TABLE I.—CHEMICAL COMPOSITION AND MILEAGE OF A SET OF 198 COPPER LOCOMOTIVE-BOILER TUBES, MADE UP FROM TUBES SUPPLIED BY TEN DIFFERENT MAKERS.

Order of Mileage (A to J).	A		B		C				D			E		
Number of Make	4		2		1				9			7		
Ref. No. on Tube	166[1]	[2]	151[1]	[2]	84[1]	146[1]	178[1]	[2]	33[1]	38[1]	[2]	132[1]	187[1]	[2]
Tin	absent	absent	0·02	trace	trace	absent	absent	absent	absent	absent	absent	absent	mere trace	absent
Antimony	trace	trace	0·016	0·02	0·021	0·019	0·013	0·02	0·01	0·006	trace	0·012	0·017	0·02
Arsenic	0·03	0·05	0·40	0·46	0·25	0·32	0·34	0·34	0·11	0·08	0·095	0·30	0·38	0·43
Lead	absent	absent	absent	trace	absent	trace	0·11	0·03	absent	absent	mere trace	absent	absent	trace
Bismuth	”	”	”	absent	”	absent	trace	mere trace	”	”	absent	”	”	absent
Iron	trace	trace	trace	trace	trace	”	”	trace	”	trace	”	trace	trace	mere trace
Chromium	absent	absent	absent	absent	absent	”	absent	absent	”	absent	”	absent	absent	absent
Aluminium	”	”	”	”	”	”	”	”	”	”	”	”	”	”
Manganese	”	”	”	”	”	”	”	”	”	”	”	”	”	”
Nickel	2·66	2·90	0·04	0·05	0·01	0·08	0·02	0·03	0·02	0·06	0·03	0·02	0·02	0·92
Cobalt	absent	absent	absent	absent	absent	absent	absent	absent	absent	absent	absent	absent	absent	absent
Zinc	”	”	”	”	”	”	”	”	”	”	”	”	”	”
Sulphur	trace	trace	trace	trace	trace	trace	trace	trace	trace	trace	trace	trace	trace	trace
Phophorus	0·033	0·033	absent	mere trace	absent	absent	absent	mere trace	”	”	mere trace	0·006	”	absent
Silver	absent	absent	trace	absent	”	”	”	absent	absent	”	trace	absent	”	mere trace
Copper (by diff.)	97·277	97·017	99·524	99·470	99·719	99·581	99·517	99·580	99·860	99·854	99·875	99·662	99·583	99·530
Total	100·000	100·000	100·000	100·000	100·000	100·000	100·000	100·000	100·000	100·000	100·000	100·000	100·000	100·000
Mileage	123,896	142,348	107,507	142,348	107,507	133,112			95,456	123,896		82,327	93,475	

[1] Analysis of tubes which failed.

[2] Average composition of tubes which did not fail.

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TABLE I.—*continued.*

Order of Mileage (A to J)	F			G			H			I			J		
No. of Make	8			5			6			10			3		
Ref. No. on Tube.	36 [1]	126 [1]	[2]	68 [1]	7 [1]	[2]	77 [1]	124 [1]	[2]	48 [1]	115 [1]	[2]	109 [1]	52 [1]	[2]
Tin	absent	absent	absent	1·05	1·09	1·07	trace	trace	absent	0·03	trace	absent	absent	absent	absent
Antimony	trace	0·01	0·01	0·01	0·008	trace	,,	0·01	trace	0·01	0·005	trace	0·01	0·01	mere trace
Arsenic	0·03	0·04	0·04	0·04	0·03	0·04	0·02	0·03	0·04	0·08	0·06	0·06	0·03	0·04	0·04
Lead	absent	absent	absent	absent	absent	absent	absent	absent	absent	0·03	0·03	0·03	absent	trace	trace
Bismuth	,,	,,	,,	,,	,,	,,	,,	,,	,,	absent	absent	absent	,,	absent	absent
Iron	,,	trace	,,	trace	,,	trace	,,	trace	trace	trace	trace	mere trace	trace	trace	mere trace
Chromium	,,	absent	,,	absent	,,	absent	,,	absent	absent	absent	absent	absent	absent	absent	absent
Aluminium	,,	,,	,,	,,	,,	,,	,,	,,	,,	,,	,,	,,	,,	,,	,,
Manganese	,,	,,	,,	,,	,,	,,	,,	,,	,,	,,	,,	,,	,,	,,	,,
Nickel	0·01	trace	0·04	trace	trace	0·03	trace	trace	0·01	0·02	0·03	trace	,,	trace	0·09
Cobalt	absent	absent	absent	absent	absent	absent	absent	absent	absent	absent	absent	absent	,,	absent	absent
Zinc	,,	,,	,,	,,	,,	,,	,,	trace	,,	,,	,,	,,	,,	trace	,,
Sulphur	trace	trace	trace	trace	trace	trace	trace	,,	trace	trace	trace	trace	trace	,,	trace
Phosphorus	0·095	0·092	0·088	0·021	0·015	0·018	0·041	0·025	0·044	absent	absent	mere trace	absent	absent	,,
Silver	absent	absent	mere trace	absent	absent	absent	absent	absent	absent	,,	trace	trace	,,	,,	absent
Copper (by diff.)	99·865	99·858	99·882	98·879	98·857	98·842	99·939	99·935	99·906	99·830	99·875	99·910	99·960	99·950	99.870
Total	100·000	100·000	100·000	100·000	100·000	100·000	100·000	100·000	100·000	100·000	100·000	100·000	100·000	100·000	100·000
Mileage	55,634	82,327		54,466	59,028		40,612	48,809		39,760	43,230		34,067	40,612	

[1] Analysis of tubes which failed. [2] Average composition of tubes which did not fail.

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Table II.—Three Seamless Copper Tubes.

Chemical Analyses.

—	Sample Marked 1902. ·5	Sample Marked 1902. ·75	Sample Marked 1902. N. 3
	Per Cent.	Per Cent.	Per Cent.
Arsenic	0·58	0·80	trace
Antimony	trace	0·01	,,
Nickel	0·06	0·06	3·10
Iron	trace	trace	0·08
Phosphorus	absent	absent	0·04
Lead	0·08	0·08	absent
Sulphur	trace	trace	trace
Copper (by diff.)	99·28	99·05	96·78
	100·00	100·00	100·00

Table III.—Three Seamless Copper Tubes.

Mechanical Tests.

(1) *Span Test (tube supported on centres* 10 *feet apart, and loaded at middle).*

Mark on Tube.	Diameter.	Thickness.	Load Required to Produce the First Permanent Set.			Load Required to Produce a Permanent Set of $\frac{1}{10}$ inch.		
			Load.	Deflection.	Permt. Set.	Load.	Deflection.	Permt. Set.
	Inch.	Inch.	Lbs.	Inch.	Inch.	Lbs.	Inch.	Inch.
1902. ·5	1·86	0·14	80	0·66	0·01	180	1·56	0·10
,, ·75	1·86	0·14	60	0·51	0·01	225	1·94	0·10
,, N. 3	1·86	0·14	60	0·48	0·01	210	1·68	0·10
Mean of 32 previous tests made with ordinary copper tubes	1·87	0·12	128	1·09	0·01	273	Inches. 2·40	0·10

(2) *Tensile Test (on tubes as received from makers).*

Mark on Tube.	Diameter.	Thickness.	Area.	Breaking Weight.	Contraction of Area.	Extension on 6 Inches.	Remark.
	Inch.	Inch.	Sq. Inch.	Tons per Sq. Inch.	Per Cent.	Per Cent.	
1902. ·5	1·86	0·14	0·756	15·87	61·6	36·3	Extension uniform over the tube.
,, ·75	1·86	0·14	0·756	16·00	57·4	34·8	
,, N. 3	1·86	0·14	0·756	17·39	70·6	31·3	
Mean of 32 previous tests	1·87	0·12	0·660	20·19	50·3	9·8	

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TABLE III.—MECHANICAL TESTS—*continued.*

Drifting Tests.

Mark on Tube.	Diameter. Inch.	Thickness. Inch.	Maximum Diameter, Drifted. Inches.	Increase in Diameter. Inch.	Expansion. Per Cent.	Remark.
(3 A.) *On Tubes as received from Makers.*						
1902. ·5 . .	1·86	0·14	3·04	1·18	63·5	
„ ·75. .	1·86	0·14	3·00	1·14	61·3	
„ N.3 .	1·86	0·14	3·24[1]	1·38	74·2	
Mean of 32 previous tests .	1·87	0·12	2·10	0·23	12·3	
(3 B.) *On Tubes annealed and cooled in Air.*						
1902. ·5 . .	1·86	0·14	3·24[1]	1·38	74·2	
„ ·75. .	1·86	0·14	3·02	1·16	62·4	[1] Did not burst.
„ N.3 .	1·86	0·14	3·24[1]	1·38	74·2	
Mean of 32 previous tests .	1·87	0·12	2·91	1·04	55·6	
(3 C.) *On Tubes annealed and cooled in Water.*						
1902. ·5 . .	1·86	0·14	3·24[1]	1·38	74·2	
„ ·75. .	1·86	0·14	3·24[1]	1·38	74·2	
„ N.3 .	1·86	0·14	3·24[1]	1·38	74·2	
Mean of 32 previous tests .	1·87	0·12	2·84	0·97	51·9	

(4.) *Rolling Test in Tube-Plate.*

Unannealed . . . . . . All three tubes work very well.
Annealed . . . . „ „ „ „ „ „

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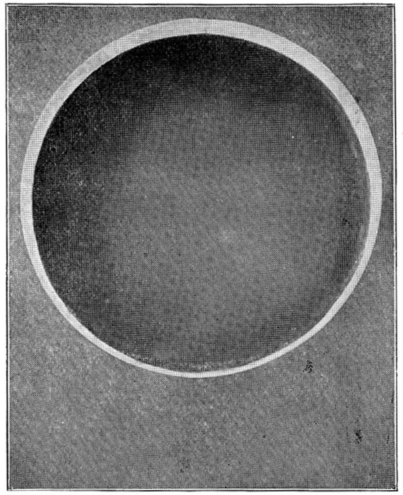
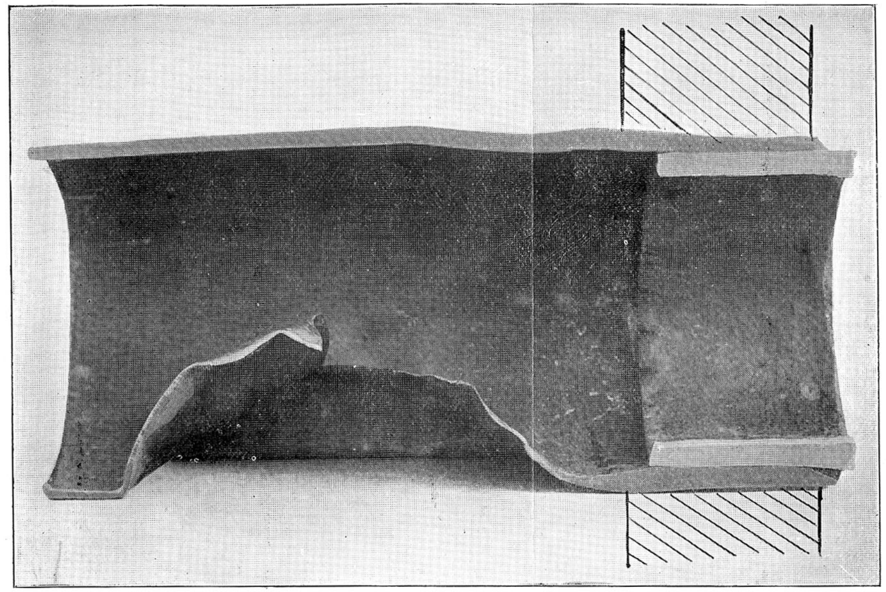
Fig. 2.



CROSS-SECTION OF TUBE SHOWING UNEQUAL WASTING.

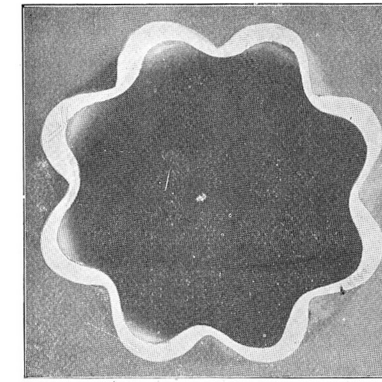
SCALE.—FULL SIZE.

Fig. 3.

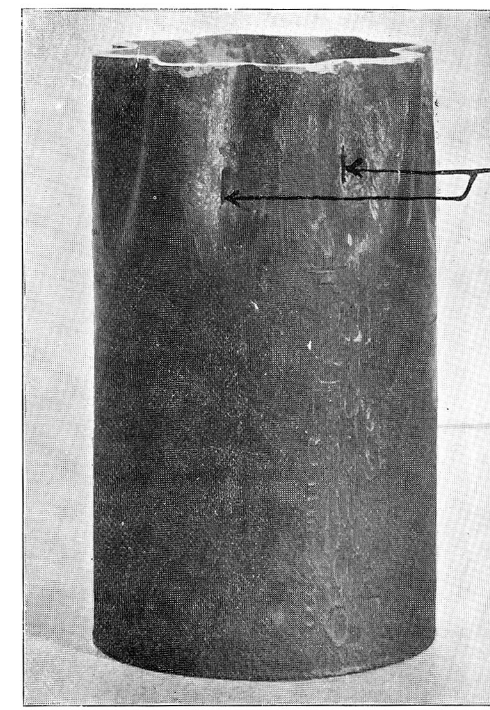


LONGITUDINAL SECTION OF TYPICAL "BURST" TUBE.

Figs. 5.



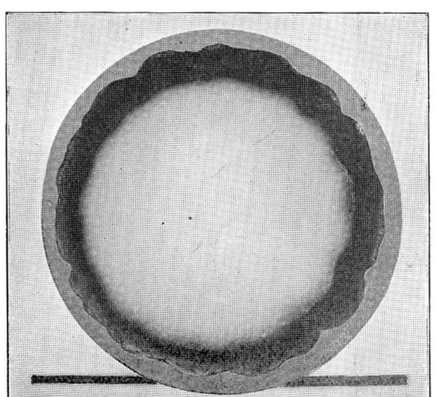
CROSS-SECTION OF WORN FLUTED TUBE.



HOLES.

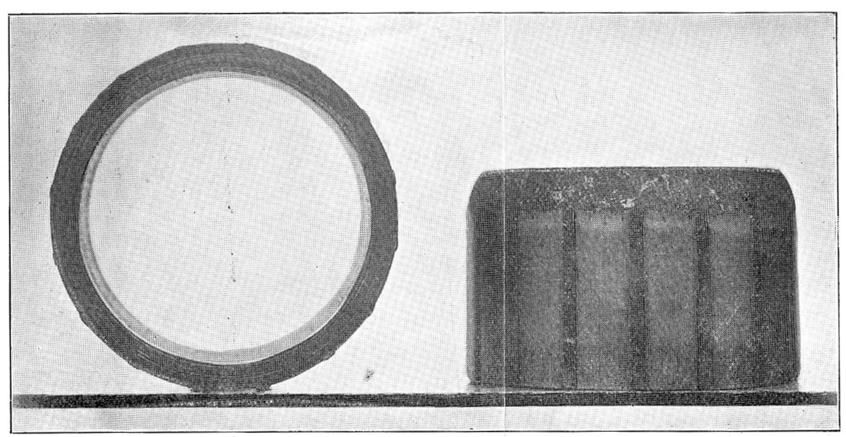
ELEVATION OF END OF WORN FLUTED TUBE.

Fig. 6.



CROSS-SECTION OF WORN ORDINARY TUBE.

Fig. 7.



END VIEW AND ELEVATION OF STEEL FERRULE.

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