TABLE I.

	Analysis.								U.T.S.	Yield.	Elong.	Bend.	Impact.	
	C.	Mn.	P.	S.	Si.	Ni.	Cr.	Mo.					Longl.	Trans.
Original specification	·3	·6	≯·04	≯·04	·15	2·5	·66	·6	56/63	47/53	% 15	° 180	40	30
A1	·32	·65	·036	·033	·207	2·56	·76	·58	59	48·5	20·5	180	28 (aver.)	22 (aver.)
A2	As for A1.								58/59	38/ 38·5	18/22	180	50/51	31/34
B1	·30	·57	·022	·026	·20	3·43	·85	·24	60	45·8/ 52	17/19	180	52	23/33
B2	As for B1.								52·8	37·2	19	180	61/74	35/43
Modified specification	Ni, Cr, Mo, steel. Composition to be stated. C.≮·3 per cent.; S. and P.≯·04 per cent.								55/70	≮38	≮15	180	≮40	≮30

No. 7

SOME RECENT DEVELOPMENTS IN HIGH PRESSURE AIR CYLINDERS

Previous articles in Nos. 12 and 13 issues of these Papers have dealt with the manufacture, history and development of the high-pressure air cylinders used in H.M. ships up to the end of 1932. It is intended here to bring this information up to date in the light of recent experience with these cylinders.

Up to the year 1933, high-pressure air cylinders had for some years been made of ·43 to ·48 per cent. carbon-steel with a U.T.S. of 40 tons/sq. in. Considerations of weight in new construction equipment made the production of a lighter cylinder highly desirable; but it appeared that, in the case of straight carbon-steel cylinders, the low limit of weight for a given air capacity had been reached. The utilisation of an alloy-steel with a U.T.S. in the neighbourhood of 60 tons/sq. in. appeared therefore to offer sufficient advantages to warrant trials being carried out with an experimental cylinder with a view to the adoption of this material in future construction.

Accordingly, in 1932, the first of a series of four experimental cylinders was manufactured and submitted to the Admiralty for trial. In all, four cylinders were produced in the two succeeding years. They were by two different makers and are numbered, for convenience, A1, A2, B1 and B2 in Table I, which gives details of their chemical composition and physical properties.

The cylinders, which were of the submarine type, were all made to the same design, being 20 in. external diameter, 6 ft. long, $\frac{7}{8}$ in. thick, with a capacity of 9·2 cu. ft. and a working pressure of 3,500 lb/sq. in. The average weight of a cylinder was about 1,085 lb. This gave a figure for weight per cubic foot capacity 42 per cent. lower than the 40-ton carbon-steel cylinders previously used.

Manufacture.—The manufacture of A1 and A2 cylinders followed normal lines. The cylinders were punched and hot-drawn, one hemispherical end being formed during the punching process. After annealing they were machined all over and test-rings removed. The open ends were then bottled. All the forging operations were carried out at 1,030° C.

B1 and B2 cylinders were manufactured by a process which differed from any of those normally laid down. The ingots were punched and hot-drawn to a tubular form, being furnace-cooled after the final hot-pass. The tubes were then machined all over, test rings removed and both ends were then bottled.

Heat-treatment.—Table II gives particulars of the heat-treatment given to each cylinder after manufacture.

TABLE II.

	Heat-treatment.
A1	1. Heated to 850° C. Maintained for 1 hour. Cooled in still air. 2. Tempered at 630° C. for 2 hours 40 minutes. Cooled in still air.
A2	As for A1. Cylinder was oil-quenched after first heat.
B1	1. Heated to 850° C. Cooled in still air. 2. Tempered at 600° C. Cooled in still air.
B2	1. Heat treatment as for B1. 2. Heated to 930° C. Maintained for 1 hour. Cooled in air. 3. Re-heated to 850° C. Maintained for 45 minutes. Cooled in air. 4. Tempered at 650° C. for 1¾ hours. Cooled in air.

The test-rings which were removed from the cylinders underwent the same heat-treatment as the cylinders they represented. It was therefore possible to determine the mechanical properties of the latter and tentatively to forecast the behaviour of any cylinder under adverse conditions.

It will be seen that the introduction of oil-hardening (hitherto considered impossible for these cylinders) in the case of A2 cylinder, and the subsidiary heat-treatment in the case of B2 cylinder had, in each case, a beneficial effect on the toughness obtained, which was borne out in the subsequent trials.

Trials.—It was decided to submit A1 cylinder to 100 repeated proof-tests to 5,850 lb./sq. in. in order to discover any liability to permanent set, and subsequently to carry out "rough-handling" trials. These latter were as follows :—

(*a*) *Drop Test.*—The cylinder, charged with air to 3,500 lb./sq. in. to be supported horizontally on two wood blocks on a solid foundation. A half-ton tup, radiused 10 in. at its point of impact, to be dropped from a height of 30 ft. on to the cylinder. (Fig. 1 shows A2 cylinder, together with tup, after the drop test.)

(*b*) *Penetration Test.*—The cylinder, still charged up to 3,500 lb./sq. in., to be suspended vertically and fired at from a range of about 200 yards with a 47 mm. A.P. projectile, impact being normal to the surface of the cylinder.

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FIG. 1.

FIG. 2.

Rough Handling Tests with one Experimental Alloy Steel Cylinder manufactured under Elswick Order No. A.B. 122, for Admiralty, to Elswick Drg. No. 4968.

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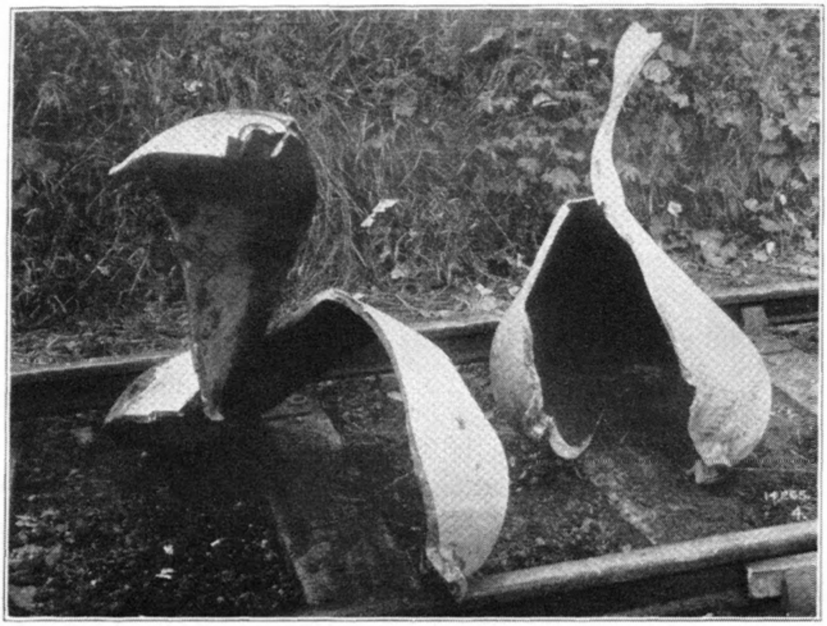

FIG. 3.

Results.—The trials of A1 cylinder took place in February, 1933. The repeated pressure tests produced no permanent deformation, but the low Izod figures obtained from this cylinder made it appear doubtful if either rough-handling test would be withstood. The drop-test was successfully carried out however, as was the case subsequently with the other three cylinders. Only local deformation resulted—in the form of a dent about ·1 in. deep. The firing test resulted in the cylinder fragmenting badly (Fig. 2), the various fragments, large and small, being projected from 50 to 250 yards from the point where the cylinder was suspended.

To determine the relative merits of carbon steel and alloy steel air cylinders under these somewhat severe conditions, a subsidiary trial was next carried out. A standard 20-in. diameter 40-ton carbon steel cylinder was subjected to identical rough-handling tests. The drop-tests produced, in addition to the usual dent, an axial bend of approximately $\frac{1}{4}$ in. Under gunfire, one wall only of the cylinder was penetrated and the latter did not burst. Though at first sight this makes the result of the similar test on A1 referred to above appear disappointing, experience has shown that the bursting of a charged cylinder probably takes place when the projectile strikes the rear wall. In this case the wall thickness, $1\frac{7}{16}$ in., being so much greater than that of an alloy steel cylinder, the residual energy of the shell, having penetrated the front wall, was insufficient to cause rupture on striking the rear wall. Had a projectile with a greater striking energy been utilised the result would probably have been different.

The manufacture and trial of the remaining three cylinders was now proceeded with. Rough handling tests took place, in each case under identical conditions.

The repeated pressure tests applied to A1 cylinder were not carried out, the previous satisfactory results having shown them to be redundant.

The drop test produced similar results in each case to those obtained from A1 cylinder. The effects of the penetration test were, however, of interest.

It will be seen that the Izod figures for A2 cylinder greatly improved upon those recorded for A1, although this result was obtained at the expense of the yield point. This resulted in a much tougher cylinder which, when penetrated, did not fragment but tore asunder axially into two pieces (Fig. 3). This was the most satisfactory trial of the series and indicated the advantages obtained from oil quenching in the avoidance of any grain growth in the structure of the cylinder during heat treatment.

B1 cylinder, under gunfire, gave very similar results to those obtained from A1, the cylinder bursting into 15 fragments. An examination of these latter showed that the thickening at the ends of the cylinder was greater than usual, indeed the thickness was in places as great as 2½ in. The consequent retention of heat in these portions of the cylinder during the lengthy air-hardening process would probably result in a certain degree of grain growth. The transverse Izod figure was also low.

As B2 cylinder had been manufactured concurrently with B1, it was decided to machine the ends as near as possible to the designed thickness of ⅞ in. and to submit the cylinder to a further heat-treatment with a view to increasing the impact figures. Approximately 80 lb. of surplus metal was machined from the ends of the cylinder and the second heat-treatment, shown in Table II, gave very promising test results, the impact figures being notably good although the yield-point was considerably lowered.

On penetration, the cylinder resolved into six pieces, rupture being generally by tearing. In view of the fact that this cylinder, after re-machining, no longer had hemispherical ends, it was considered that the results were satisfactory when compared with A1 and B1 cylinders.

Conclusions.—The stowage position of high-pressure air reservoirs in H.M. ships is such that the chance of a direct hit normal to the surface by a high velocity projectile being registered in action is negligible. When deciding on the rough-handling trials it was therefore considered that the drop-test, as representing possible attack by splinters, constituted the most unfavourable conditions which a cylinder might reasonably be called upon to sustain on service.

The penetration test enabled comparative results of the respective manufacturing processes to be obtained with regard to resistance to penetration, the amount of fragmentation resulting, and the type of fracture, a fracture in the nature of a "tear" being desired with minimum fragmentation.

The results of these trials in general, and particularly in the case of A2 and B2 cylinders, indicate that alloy steel cylinders manufactured by the processes indicated, are suitable for use in H.M. Service. The greatly reduced thickness rendered possible by this more highly stressed material has raised other points of interest. It was realised that corrosion was now a more potential danger than hitherto. Accordingly tests were carried out which showed that under similar conditions the alloy steel used had a resistance to corrosion about 65 per cent. greater than 40-ton carbon steel.