EROSION OF PROPELLERS.

A great deal of light has in recent years been thrown on the subject of the erosion so frequently observed on propeller blades and bosses and the general causes of this erosion may now be considered well understood. The principal conclusions arrived at by independent investigators and by Committees dealing with this question have been published and discussed at various times, but as these conclusions may not be generally known it is proposed in the following article to summarise the findings, and indicate steps that have necessarily had to be undertaken to minimise as far as possible this deteriorating action.

It should be noted that prior to the adoption of the turbine drive, propellers were driven at comparatively low speed, and all observed cases of deterioration in these cases appear to have been traceable generally to chemical corrosion. When, however, the high-speed propellers associated with the direct drive turbine were introduced, numerous instances of extremely rapid deterioration of these fittings were observed. This deterioration bore a superficial resemblance to chemical corrosion but was seen to be much more intense, and moreover of a different nature when carefully examined, and with the adoption of high powers it at first looked likely that the deterioration of the propellers would give a limiting factor to further developments, *e.g.*, in the case of the "Mauretania" and "Lusitania" the first sets of propellers were practically destroyed after three months' running, whilst in certain of the early high-speed turbine torpedo-boat destroyers, it was not unusual to wear out a set of propellers in a single trial run at full speed. Researches taken in hand resulted in the discovery of the erosion-resisting alloys that are now universally used for propellers of high-speed ships, and incidentally these researches established that the erosion was a mechanical effect brought about chiefly by "the action of water broken by evacuated spaces in which no air is present." An opinion that the frictional rub of the water plays a part in this action still persists, but the main cause is that above stated. The frictional rub effect in any case must be practically negligible, as severe erosion frequently takes place at the root of the blades in high-speed propellers whereas at the regions moving with much greater velocity the erosion is often completely absent. Frictional rub can therefore be dismissed as being the direct cause, although its effect in accelerating the erosion set up by the water-hammer action may not be entirely negligible.

Dismissing any chemical and galvanic effects which the investigations have conclusively proved as in no way accounting for the deterioration, the thorough examination of a large number of propellers has rendered it possible to arrive at a series of generalisations in a problem which appeared very complicated and perplexing, owing to its effects as regards the areas in different cases being peculiarly distributed. These generalisations may be divided into different types, each type being traceable to special conditions productive of currents of water, broken by evacuated cavities or vacuum bubbles (to use an apt term) impinging on the areas eroded. This theory of the action is borne out by the fact that the erosion, although varied in different cases, is always similar and in the same places on the blades of the same propeller.

(1) *Erosion due to damage to the propeller.*—Whenever the leading edge of a high-speed propeller is bent or deformed an eroded area results on the blade in the neighbourhood of the damaged edge. The distorted edge when in motion leaves a trail of water broken with evacuated spaces. As this current of broken water sweeps over the blade the vacuum bubbles therein collapse and produce a water-hammer action on the metal of the blade. If the following edge be damaged it will not appreciably affect the parts before the damage, but it will be liable to cause a stream of broken water to impinge on the blade following. The erosion in this case will perhaps be not so severe or concentrated as in the case of damage to a leading edge assuming equal relative damages.

If a lifting hole be left in a blade, it will set up a local action that will cause erosion in the neighbourhood. For this reason lifting holes are either not provided, or are effectively plugged.

(2) *Erosion due to disturbances caused by the propeller itself.*—In high-speed propellers it would appear that the erosion at the faces of the blades in the neighbourhood of the roots is partly due to the centrifugal action caused by the rapid revolution. As a result the water leaves the boss and roots of the blades forming evacuated spaces which, due to the motion of the propeller in disturbed water, continually collapse and re-form.

If the propellers have only a comparatively small clearance from the hull of the ship, the backwash of the water thrown on the hull causes broken water to be thrown on the propeller. Such action would appear to lead to an erosion distributed over the outer portions of the blades.

(3) *Erosion due to the passage of some body forward of the propeller which causes a stream of water broken by evacuated spaces to impinge on the propellers.*—The principal fittings in this connection are of course the "A" brackets and the necessity of maintaining these of the stream-line form and, if possible, not too close to the propeller blades, is self-evident. If any small fittings, such as a lubricating pipe, be led down the "A" bracket to the bearing it requires to be encased to preserve the stream-line formation. The erosion due to this may be distributed over the blades, but may be expected to be more intense near the roots of the blades, due to the greater interference with the stream lines at this position.

The ship itself may send stream lines broken by evacuated spaces towards the propellers.

The erosion was especially very marked in some earlier cases where more than one propeller was mounted on the shaft as the after propellers would work in water disturbed by the action of those in front. Similar disturbances will arise in the case of vessels fitted with multiple screws in which the disc of a propeller overlaps that on another shaft which works in a plane in advance.

Erosion due to these causes is generally distributed and is found on both back and front of the blades, but is likely to be more intense on the driving face which moves forward at high speed and encounters these evacuated spaces.

The correctness of the foregoing causes of erosion is naturally dependent on the fact that the collapse of the evacuated spaces gives rise to forces capable of destroying the surface of the metal and to this effect theoretical and practical investigations were made to obtain some idea of the possible pressures that might be produced by the closing up of vortex cavities. This question was fully dealt with by Mr. S. S. Cook, in a paper read before the Institution of Naval Architects, 1919, in which it was shown that very large pressures might be set up, when vortex cavities are caused suddenly to collapse, by the final concentration of the initial energy upon a small volume of the fluid. It is not necessary to detail the calculations but they showed that when a spherical vortex cavity in the sea closes upon a central nucleus of one-twentieth of the diameter of the original cavity, the instantaneous pressure or blow upon this cavity may reach 68 tons per square inch, and if the diameter of the nucleus is one hundredth of the diameter of the original cavity, the pressure may reach 765 tons per square inch.

It was also shown that the pressure on impact is independent of the size of the cavities and is only a function of the ratio of the initial to the final radii, so that very small cavities may set up erosion. The truth of these calculations was established by simple apparatus in which the evidence of these large forces was shown by the ease with which brass sheet could be punctured by the forces induced by the collapse of a small vacuum cavity. This apparatus and some results of the experiments are dealt with in the paper referred to.

It is often noted that erosion is most severe during the early life of the propeller and proceeds more slowly afterwards. This is not in disagreement with the above theory as it can be accounted for by the erosion carrying the surface beyond the region of the nuclei of pressure. This has also been demonstrated by experiment.

The general steps that can be taken to minimise the influences causing erosion are evident from their nature, but as in the best of cases such influences cannot be entirely eliminated it remains to choose a metal of the best type and structure to resist these erosive effects.

It is several years ago now that the Admiralty decided, after a series of trials, that henceforth all propellers for warships should be manufactured of manganese bronze, an alloy that possesses the valuable properties of strength combined with a certain ductility and is resistive to chemical action. This alloy when in the form of essentially a "beta" structure, *i.e.*, the "alpha" crystals present are embedded in the "beta" crystals, is found also to be a highly resistive to erosive influences.

The study of the structures of the complex brasses and bronzes is a very involved subject but the following remarks will serve to illustrate in broad outline what is signified by the foregoing references.

The industrial brasses are divided conveniently into three categories according to the micro-structure of the metal. These three categories or phases are named respectively "alpha," "alpha-beta," and "beta" structures. In the normal condition, as cast, those brasses having the "alpha" structure represent the weaker alloys, while the "beta" structure alloys represent those of the greatest tensile strength; the "alpha-beta" structure is associated with the alloys of an intermediate strength between those of the "alpha" and of the "beta" structures. Brass of either the "alpha" phase or of the "beta" phase is homogeneous, whereas a specimen in the "alpha-beta" phase is not homogeneous in the true sense as each grain facet under a microscope shows the presence of two constituents, the lighter coloured being the "alpha" and the darker the "beta." The ratio of the "alpha" to the "beta" constituent in any particular alloy, which depends on the treatment received, has a considerable bearing on the ultimate strength of the alloys within the "alpha-beta" range, the higher the ratio of the "beta" constituent, the greater, in general, being the tenacity of the alloy. The type, the distribution and the occurrence of the two constituents, as also the size of the crystal grains, distinctly influence the strength, ductility and resistance to erosion and shock and also the fatigue stresses of the alloy.

Brasses containing from 100 to 50 per cent. copper may be composed of one or more constituents.

Between the compositions 100 per cent. copper and 64 per cent. copper the slowly cooled metals consist entirely of a single solid solution of "alpha" structure. At a composition corresponding to 63 per cent. copper the "beta" constituent appears and between the range 63 to 53 per cent. copper the metals may be either a mixture of "alpha" and "beta" or entirely "beta" according to the temperature of the metal. At ordinary temperatures alloys within this range consist of a mixture of the "alpha" and "beta" constituents.

The analysis of some recent propeller metals, as supplied by the two firms that have made a speciality of their manufacture, shows a composition somewhat as follows :—

Copper - - -	55 to $57\frac{1}{2}$	per cent.
Zinc - - -	39 to $41\frac{1}{2}$	,, ,,
Tin - - -	·75 to 1·25	,, ,,

Lead - - -	·2 to	·35	per cent.
Iron - - -	·76 to	1·2	,, ,,
Aluminium - -	·2 to	·75	,, ,,
Manganese - -	Traces to	·6	,, ,,
Nickel - - -	Traces to	·5	,, ,,

The alloy known as Turbadium, which has been used to some extent, has a lower percentage of copper, about 50, increased zinc, about 44, and also higher percentages of manganese and nickel; about 1½ and 2 per cent. respectively.

The Admiralty specifications demand an ultimate tensile strength of not less than 33 tons per sq. inch, with an elongation in a length of 2 inches of not less than 15 per cent.

It will be noticed that manganese bronze is a copper-zinc alloy and therefore is truly a brass. High-tension brass is the designation actually given in the Admiralty specification and this is the more correct nomenclature as the term bronze was originally applied to those alloys having a copper-tin basis.

The name manganese bronze has become, however, established by long usage.

It might appear strange that a copper-zinc alloy, containing only a trace of manganese and with appreciable proportions of iron, &c., should be designated a manganese bronze. It is, however, the influence of the manganese during the manufacturing operation that enables the superior qualities of the alloy over a brass of approximately similar constituents, but with manganese absent, to be obtained. The iron which assists in strengthening the alloy is usually introduced in the form of ferro-manganese and in this form more easily alloys with the copper and zinc. The manganese acts as a reducer of any oxides in the slag; and to the absence of these dissolved oxides is due largely the improved qualities of the brass. A similar effect is to be noted in the copper-tin basis alloy, phosphor-bronze, which may contain only a trace of phosphorus in the final form.

The foregoing remarks show that the successful compounding of a high-tension brass to give the qualities desired in a propeller can only be accomplished after a skilful and systematic study, combined with a complete control by chemical and micrographic analysis during the manufacture.

Correct appreciation and elimination as far as possible of the influences causing erosion, combined with the care taken to produce a satisfactory propeller metal in the foundry, have considerably reduced the deterioration due to this effect and cases of propellers being renewed in a few months have not arisen in recent years. The introduction of the geared turbine has been all in favour of minimising the effect but even with the direct drive turbine reasonable life of the propellers had been obtained.