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ALUMINIUM IN SHIPBUILDING

Synopsis: The paper reviews the uses of aluminium alloys with regard to the Shipbuilding Industry. No attempt has been made to go into details but some general principles are discussed and some achievements described. Some aspects of the working and using of Aluminium Alloys in the Shipyard are also examined.

INTRODUCTION

Although Aluminium is a relatively new metal, its production rate in terms of volume ranks second only to that of steel at present, when considering industrial metals.

The metal was unknown before about 1830 and was not produced industrially until nearly 1890. As is often the case, the evident uses of the metal were small until better production methods became available. The pure metal itself is not strong enough for most commercial purposes, but early researchers, notably Wilm, discovered that certain alloys containing copper and magnesium were amenable to heat-treatment and attained high strengths with ageing and the first patent for Duralumin was taken out in 1909.

Later, in the 1920's, the magnesium aluminium alloys were developed and these proved to be extremely resistant to corrosion. It is these latter alloys which form the basis of the materials used for marine construction and this is entirely due to the corrosion resisting properties they possess.

While it is not the place of this paper to describe the manufacturing processes, the operation is a complex electrolytic one which is the chief cause of the high cost of aluminium as a structural material as compared with steel. It is worthy of note that the aluminium normally so produced is greater than 99.0% pure and is commonly of 99.5% and 99.8% purity.

The aluminium is cast as slabs and billets which are then rolled or extruded into plate and bar sections. The high ductility of the metal allows the latter extrusion process which in turn affords the production of special shapes and sections which could not be rolled.

Forging and casting are operations which do not greatly concern the present discussion.

The specification of the various alloys, has in the past, lead to much confusion but the best method of designation appears to be that of the British Standards Institution. The various alloys are described as follows:-

For wrought materials -

Prefix	N	Non heat - treatable
"	H	Heat - treatable
"	S,T,P,E, etc.	Sheet, tube, plate, extruded section etc.,
Suffix	O,H,WP etc.	Soft, hard, fully heat treated etc.
"	M	Non heat treatable, as manufactured.

Thus, the designation NS3-H indicates hard-rolled sheet of non-heat-treatable alloy 3, while HT 10-WP indicates fully heat-treated tube in heat-treatable alloy 10. The aluminium industry and the various B.S.S. should be consulted as to the exact details of the various alloys.

The principal alloying metals used are copper, magnesium, silicon, manganese, iron, nickel and zinc, and the alloys of most interest to the ship-builder are the 3-6% magnesium alloy known as N.6, and the heat-treatable aluminium-magnesium-silicide alloy H.10.

Lloyds require ultimate tensile strengths of 17 tons per sq.inch and these alloys are readily produced to meet this requirement.

Certain points should be noted in dealing with some of these alloys.

For example, it is possible to attain a strength of 17 tons per sq. inch in plate material (NP5/6) using 5% Magnesium in the as manufactured state; alternatively, the same strength may be attained using only 3% Magnesium and subjecting the plate to cold work. However, the latter plate would then be less valuable where welding was required due to the annealing effect of the welding, process.

THE USE OF ALUMINIUM ALLOYS ON BOARD SHIPS

The uses of these alloys may be divided into three major sections:-

(1) Minor parts of no structural importance. These would include minor bulkheads, small deckhouses and decks, interior fittings etc.

(2) Local strength members, including deck girders and pillars, hatch beams and covers etc.,

(3) Main structural Parts, such as large superstructures. These require special treatment and are beyond the scope of this paper. Many references are available on this subject, notably those by Dr. W. Muckle.

SOME FACTORS INFLUENCING THE USE OF ALUMINIUM ALLOYS

There are many such factors which must be taken into account in deciding whether any advantage is to be gained in using Aluminium Alloys in ship Construction. Some of these are general and affect the whole basis of planning while others can be dealt with as design progresses, once general concepts are established.

(A) ECONOMIC CONSIDERATIONS

These are probably the most important of all the factors, as no-one is likely to be convinced of the advantages of using Aluminium unless some overall increase in return can be promised, and probably the primary reason for the slow development of the use of such alloys is the high first cost of the raw material available to the shipbuilder. However, there are other points to be considered when looking at the financial side and which demonstrate that in many cases a great deal is to be gained by the judicious use of light alloys. The shipowner stands to gain by the use of light alloys for two reasons.

First, due to the low specific gravity of the new material, worthwhile saving in weight can be made for equal structural strength.

Secondly, owing to the high corrosion resistance of the alloys, maintenance and upkeep is very likely to be reduced compared with that for other materials.

The displacement of the ship is made up of the lightweight and the deadweight. Of the lightweight items, the structural weight is always the largest part. Any appreciable reduction in this weight means an increased cargo weight for the same displacement and therefore, a greater weight of cargo can be moved per trip for the same speed and power.

Apart from light alloy considerations, structural weight has been (and is being) considerably reduced owing to the great progress made in welding. Naturally, with lighter materials, the saving in weight will be much greater especially if the same welding progress can be made with alloys as has been the case with steel.

The weight of the light alloys is just greater than one third that of steel, and despite the fact that alloy scantlings must be slightly greater than those of the steel parts they replace, the nett saving in weight is often of the order of 50%.

Light alloys cost much more per ton than steel and although less weight is required, the cost of a light alloy structure will be greater in the first place. This means that the shipowner must invest more capital in his ship and since the capital cost is increased, additional annual charges have to be met, viz: loss of interest on additional capital expenditure and higher depreciation, if it is assumed that the life of the vessel is the same as that for a normal vessel. Further, marine insurance will be increased and all these expenses have to be met by the increased earnings of the vessel using light alloys. All the above considerations tacitly assume that there are no other increases in expenditure incurred by the use of light alloys such as increased shipyard working costs and increased upkeep.

In the case of the cargo vessel, which has an increased cargo-carrying capacity and where the freight-rate is so much per ton, a greater amount will be earned. Obviously, each extra ton of cargo carried must earn a certain minimum per annum in order to meet the additional expenditure. If the prevailing freight-rate causes the amount per ton per annum to exceed this figure, then the excess represents the additional profit to the shipowner. In turn, the amount earned per ton of cargo-deadweight per annum for a given freight-rate depends on the number of voyages made by the vessel. A fast vessel will make more voyages per annum than a slow one and therefore the speedier ship will earn more per ton of cargo deadweight per annum for the same freight-rate. Thus the faster vessel stands to gain more by the use of light alloys.

In making the above remarks, it must be assumed that there is always sufficient cubic capacity available on board to accommodate this extra deadweight. On the other hand, where the rate is on a cubic capacity basis, and there is still space on board when the ship is down to her marks, then the use of light alloys allows this wasted space to be made use of in enabling the ship to carry more deadweight to bring her down to her marks. It will be seen that there is no economical advantage to be gained in a vessel which has all its cargo spaces filled before the vessel is down to her marks.

While increased cargo-capacity is the best means of employing weight reduction in a cargo vessel, there are alternative advantages offering for other types of ships.

It is generally true to say that light alloys are used and contemplated in the upper works of ships, such as superstructures, and any weight-saving in these regions automatically produces an increase in stability resulting from lowered centre of gravity.

In certain cases, such as intermediate and large liners, the stability is a difficult problem and the use of light alloys allows the following modifications in design.

(1) As a result of reduced top-weight, the centre of gravity is lowered and a reduction in beam becomes possible while retaining the same initial stability.

(2) The reduction in beam is followed by a reduction in displacement and if this is greater than the weight saving due to the use of light alloys, the actual form of the ship can be made finer.

(3) The gains made in item (2) lead to a reduction in power necessary for a given speed.

(4) reduced power means reduced machinery and/or fuel weights, which allow further reductions in displacement.

For any vessel in which the above advantages apply, the annual fuel cost will be reduced and this reduction in cost must pay for the additional expenses referred to. As a smaller point, the finer form and reduced dimensions may lead to a reduced tonnage.

To amplify some of the above points, Fig. 1 (shown later) gives an indication of the increase in stability which can be gained for a typical passenger/cargo ship of about 15,000 tons displacement.

The foregoing remarks will apply to a greater or less degree to all types of ships but the advantages to be gained apply most forcibly to two particular cases:-

(1) vessels whose structural weight forms a large proportion of the total displacement and where a reduction in structural weight leads to an appreciable reduction in displacement.

(2) vessels which use a large amount of fuel per annum and where even a small reduction in fuel used leads to a worthwhile saving

Ships which fall into these categories are fast vessels of the Cross-Channel type having high speed-length ratios and large Atlantic liners of extremely high total horse power.

A further benefit from weight-saving can come from increased passenger accommodation in ships where this is important, the improved stability allowing the addition of extra passenger space high up where space is very valuable. Thus the earning power is increased for the same driving power. This fact was made use of in the design of the liner "Bergensfjord".

Alternatively, reduced displacement can allow reduced draft which may be advantageous for shallow water craft.

Finally, and apart from the major advantages listed above, there are many lesser ways in which aluminium alloys may be used to advantage, as for instance in the manufacture of life-boats, davits, masts, derricks, hatch covers and beams, side-lights, doors etc., Such items, because of their reduced weight, are much more readily handled as well as helping to save overall weight.

STRESSES IN ALUMINIUM STRUCTURES

(B) This aspect is one which must be carefully studied in ships of composite construction. Where the alloy is limited to minor structural parts such as beams, pillars, small houses and so on, the problem is simple and suitable scantlings may readily be determined by ordinary methods of structural analysis.

However, where, the aluminium structure is expected to form a main part of the vessel's hull girder, the investigations will be more complex. Dr. W. Muckle (and others) have made the most thorough researches into the problems involved and the main problems are well understood.

In some structural problems, the fact that Young's modulus for aluminium is only one third that for steel is troublesome, as large deflections may result, but generally, the low modulus may be used to advantage in large superstructures, since the strains transmitted from the steel to alloy result in stresses roughly one third those in the corresponding steel superstructure. Experiments show that the actual stresses are rather more than one third those in steel structures. Such low stresses can lead to the elimination of expansion joints in long superstructures with consequent reduction in constructional difficulties.

A further note on stresses is due with regard to the subject of temperature stresses. Without discussing the problem further, it will be appreciated that a bi-metallic girder must suffer some degree of stressing due to temperature gradients, especially where the aluminium upperworks are subject to direct sunlight and the steel hull immersed largely in water. Dr. Corlett has very thoroughly examined this problem.

Note: The alloy has a co-efficient of expansion approximately double that of steel.

FIRE PROTECTION

(C)

At first sight, the low melting point of aluminium alloys appears to be a serious disadvantage but experiments and practice have revealed that the problem can be satisfactorily solved, partly due to the high heat conductivity of the alloy and its high reflectivity when polished and used in foil form in conjunction with asbestos sheeting. It is significant to note that the liner "United States" contains over 2,000 tons of structural alloy and yet the American Marine fire regulations are (or were) the most rigid in the world.

CORROSION PROBLEMS

(D) As stated earlier, the 3% to 5% Magnesium alloys are highly resistant to corrosion, especially in a marine atmosphere and are, in general, only bettered by stainless steel.

It should be noted here that the reverse is the case with some aluminium alloys and the author is aware of one case in which a launch propeller made of a copper-bearing alloy largely vanished in a matter of a few days.

The high corrosion resistance is generally due to the film of aluminium oxide always present on the metal surface. This safeguard may be enhanced by electrolytically thickening the film or by painting with suitable and approved paints. It is worth noting that where the paint film is damaged, the attack and corrosion products do not spread beneath the remaining paint as with other materials.

The most serious problem under this heading is the corrosion which can result from bi-metallic contact in a marine atmosphere. This problem requires an immense amount of thought, especially in a large liner where the super-structure is of alloy, lift and stair trunks of steel, service piping of steel, copper and iron, cable trays and an infinite number of fittings of many different metals, and so on. The outstanding example is the structural joint where the steel hull meets the alloy superstructure. This joint must be suitably insulated, self-draining and, in addition, carry the shear along the joint. The commonest type is shown later in Fig. 2. The rivets are often packed in "Neoprene" tubes, with "Neoprene" sheet and/or zinc chromate paint separating the plating. As far as the author is aware, this method was generally used on the "Bergensfjord".

HYGIENE

(E) This may be a small point, but experience has shown that linings of the corrosion-resistant alloys in chambers carrying perishable food is particularly effective.

This provides another use for aluminium and such is the case in ships carrying fish, fruit, ice-cream etc.,

ELECTRICAL CHARACTERISTICS

(F) Aluminium alloys have an electrical conductivity 60% that of copper and may very effectively be used in the form of conductors like busbars. In addition, being non-magnetic, the alloys may be used to advantage in the construction of wheel-houses and binnacles.

THERMAL INSULATION

(G) As mentioned earlier, the high heat-reflectivity of aluminium may be made use of not only from the point of view of fire-protection, but also as a heat insulation. The commonest method appears to be either the use of thin sheet as a retaining skin for powdered cork, or in the use of foil alone. It is noteworthy that the heat transfer rate of aluminium foil in a 1 inch air-space is comparable with those of glass silk, slab cork, slag wool and expanded ebonite.

THE WORKING OF ALLOYS IN THE SHIPYARD

(H) This is the phase of aluminium in shipbuilding of most interest to the shipbuilder and shipowner. If complications arise in the actual working and forming of the alloys in the shipyard, there will be an automatic increase in costs which must necessarily be passed on, adding to the capital cost of the ship and reducing the economic argument in favour of the use of these alloys.

At the outset, it is safe to say that no such complications arise in general, so that existing shipyard plant or simple modifications thereof, can be readily used.

One initial precaution to be taken in handling the alloys in the yard is the differentiation between the various alloys, but as previously indicated this resolves itself into separating only about 3 alloys and in particular, distinguishing between heat-treatable and non-heat-treatable alloys.

With regard to forming, the non-heat-treatable $3\frac{1}{2}\%$-5% magnesium alloys behave very well, since they may be heated under control with a top limit of 400°c without any loss of strength; they are as easily cold worked as cold steel.

The heat-treatable alloys can only be cold worked and are less easily formed than the other alloys but being somewhat stronger and usually cheaper, are very useful where the forming required is not excessive.

In general, the cutting, machining, shearing planing etc., of these alloys can be carried out as for steel although some modifications may be needed with regard to speeds, feeds, tool-shapes and so on.

The flame-cutting of aluminium alloys is not a particularly satisfactory process even using iron-powder or electric-arc systems but the author's knowledge on these points is rather out of date and may be open to correction.

Riveting presents no serious problems, the usual material being the 5% magnesium alloy. Rivets may be closed cold or hot under favourable conditions. With hot riveting, fairly close temperature control is required and thermostats will generally be necessary.

The welding of aluminium has a relatively short history but one which has been crammed with remarkable developments and achievements, so that it is now a well-established fact with some relatively simple techniques. These remarks apply to the various argo gas-shielded processes rather than to the older fluxed electrode methods, which are tedious due to corrosive nature of the fluxes.

In this respect, capital outlay will be required as the argon processes are unique in that they are self-contained and cannot be adapted from conventional welding plant. The two main processes are generally well-known and require no elaboration here; they are the tungster-arc-filler-rod and the consumable electrode techniques and both have their place, although the latter is the more valuable, being capable of heavy welding in all positions and at very high speeds.

Welding out of doors can be troublesome due to disturbance of the argon atmosphere, but effective screening allows work to proceed under reasonable conditions.

The welding of the heat-treatable alloys presents a problem as their properties may be damaged, but even this disadvantage can be overcome by judicial location of welds near neutral axes and away from highly stressed regions. A common example of this is the welding of H 10 section to NP 5/6 plating, using 5% magnesium wire. The weld would normally be at the junction of section toe and plating i.e. near the neutral axis and the most highly stressed part would then be the table of the higher strength H 10 bar, well away from the weld.

The stud-welding of aluminium is also an accomplished fact.

In general, pre-fabrication is easier using aluminium, since weights are roughly halved, so that if space is available, units twice the size of their steel counterparts can be prepared.

The making of joints watertight is readily accomplished but preference should be given to metal-to-metal joints where this is possible, as packings can deteriorate and harbour moisture. Caulking is satisfactory but care is needed as the alloys are much softer than steel.

It is usually recommended that timber should not be placed directly in contact with aluminium in exposed places as corrosion can set in as a result of timber acids or the accumulation of salts.

A layer of bituminous compound between the two materials is recommended especially for wood decking.

Painting is common and often desirable but lead-based paints must not be used. Self-etching primes or zinc chromates make good priming paints but advice should be sought in such matters, especially to ensure compatibility between primes and finishing coats.

Anti-fouling coats must be of specially prepared material and are usually based on organic poisons. Those containing copper or mercury should on no account be used. Deck compositions are available in forms prepared with particular reference to aluminium.

It is hoped that above very brief summary will demonstrate the advances and possibilities with regard to the marine uses of aluminium alloys. No attempt has been made to go into any detail but it is hoped that appetites may have been whetted or healthy curiosities roused. A reference list is appended, covering some of the major aspects mentioned, with adequate details for those who may wish to proceed further.

Some diagrams and photo-graphs are added to complete this paper and to help illustrate a few of the points.mentioned.

The Author wishes to thank the Branch Committee for the honour they have done in inviting him to present this paper and tenders his sincere apologies for his unavoidable absence.

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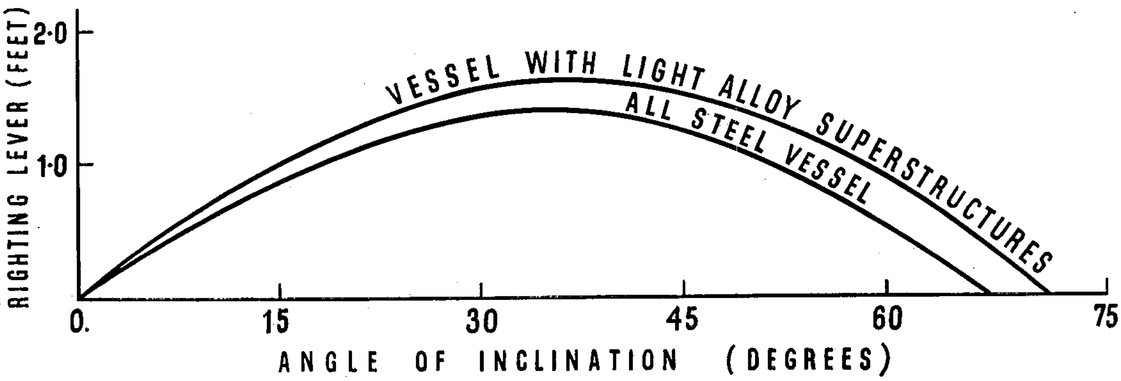
See also the various A.D.A. Information Bulletins, particularly No.18, the Working of Aluminium in the Shipyard.

LIST OF FIGURES.

FIG. 1



THIS DIAGRAM REFERS TO A PASSENGER/CARGO VESSEL, 460 FT. IN LENGTH, OF APPROXIMATELY 15,000 TONS DISPLACEMENT. IT ILLUSTRATES THE EFFECT OF A LIGHT-ALLOY SUPERSTRUCTURE IN LOWERING THE CENTRE OF GRAVITY OF A VESSEL AND INCREASING THE RANGE OF STABILITY

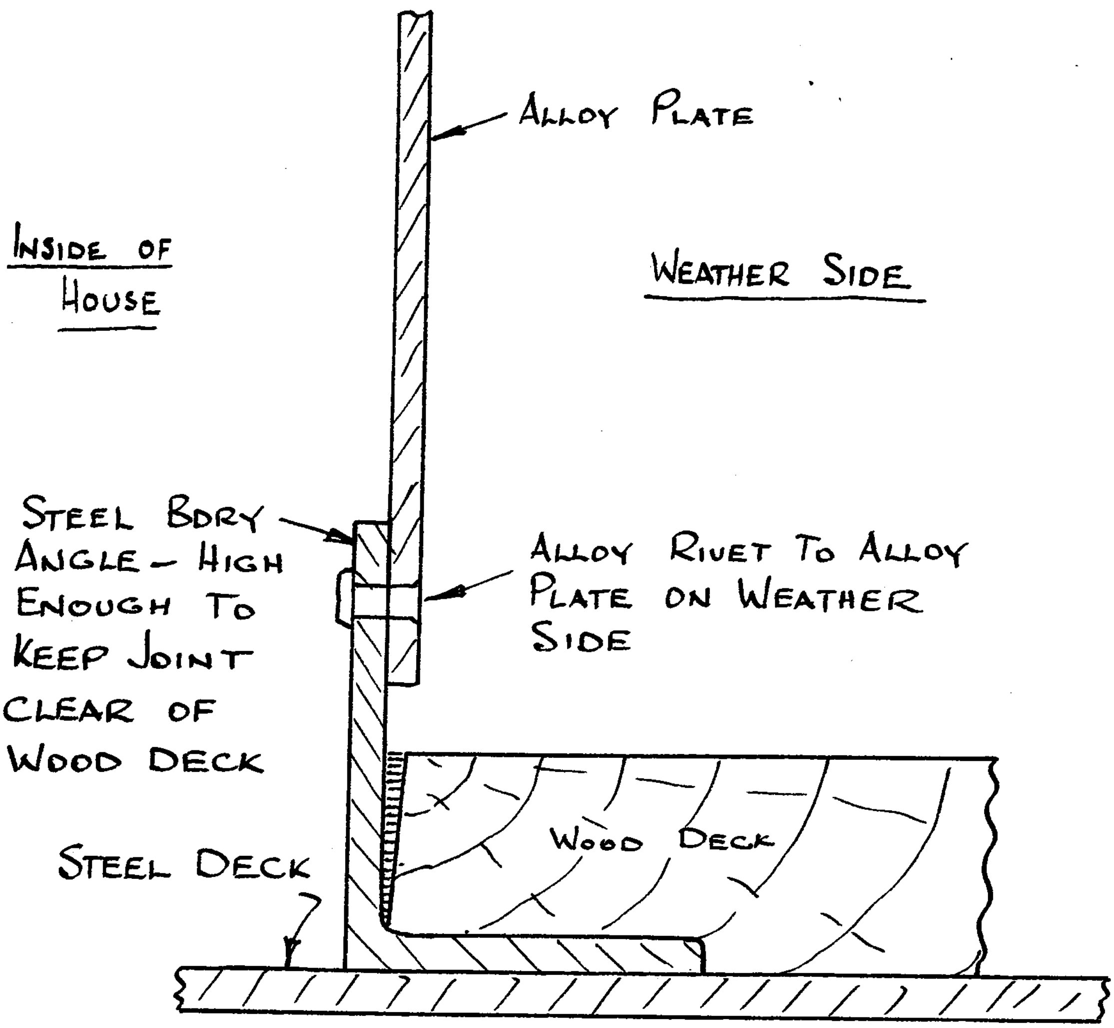


FIG. 2.

FIG. 3

(*Courtesy: Associated Press Ltd.*)

"UNITED STATES"

THE 53,330-TON FLAGSHIP OF THE UNITED STATES LINES, LAUNCHED IN 1951, WON THE ATLANTIC BLUE RIBAND ON HER MAIDEN VOYAGE. THE VESSEL INCORPORATES OVER 2,000 TONS OF ALUMINIUM: 1,000 TONS IN THE 600 FT. SUPERSTRUCTURE INCLUDING DECKS AND INTERIOR BULKHEADS, 400 TONS IN FUNNELS AND LIFEBOATS, AND 600 TONS IN WINDOWS AND FITTINGS

FIG. 4

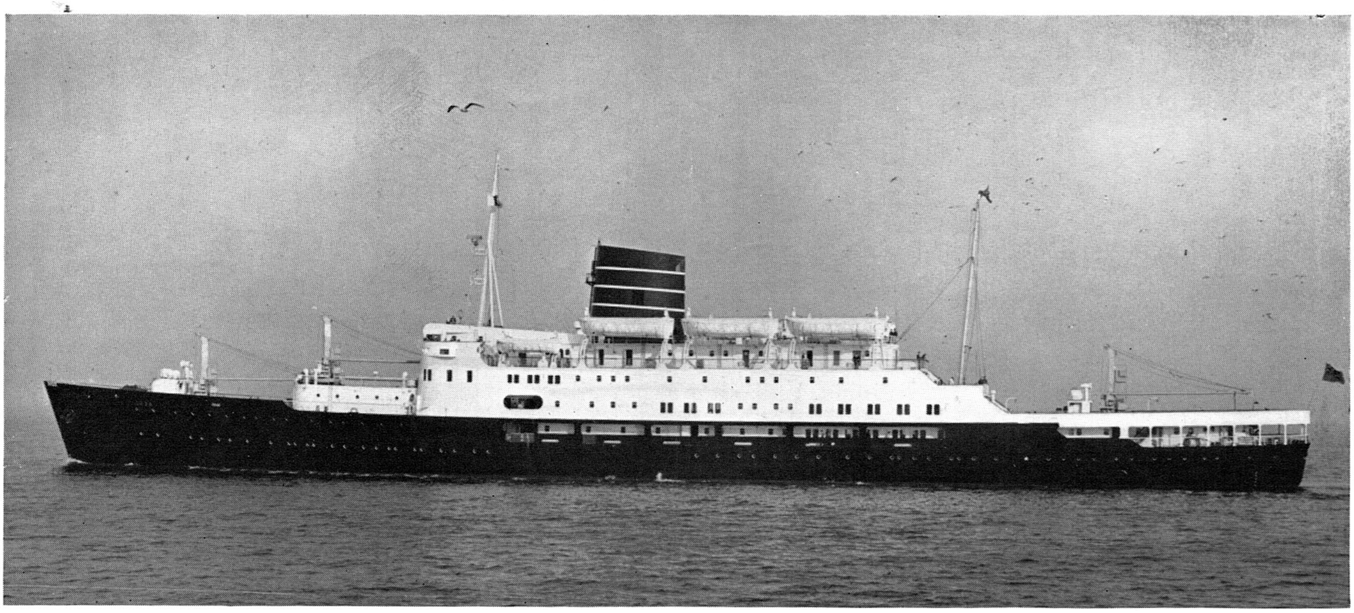
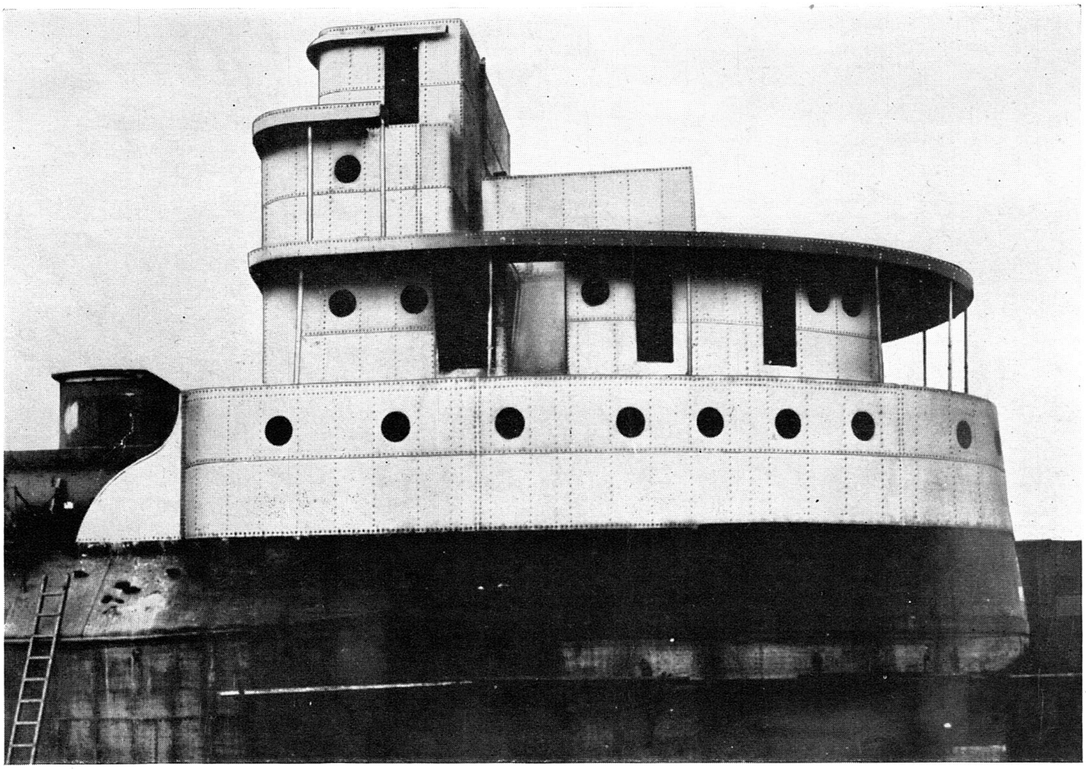


FIG. 5



"REDFERN"

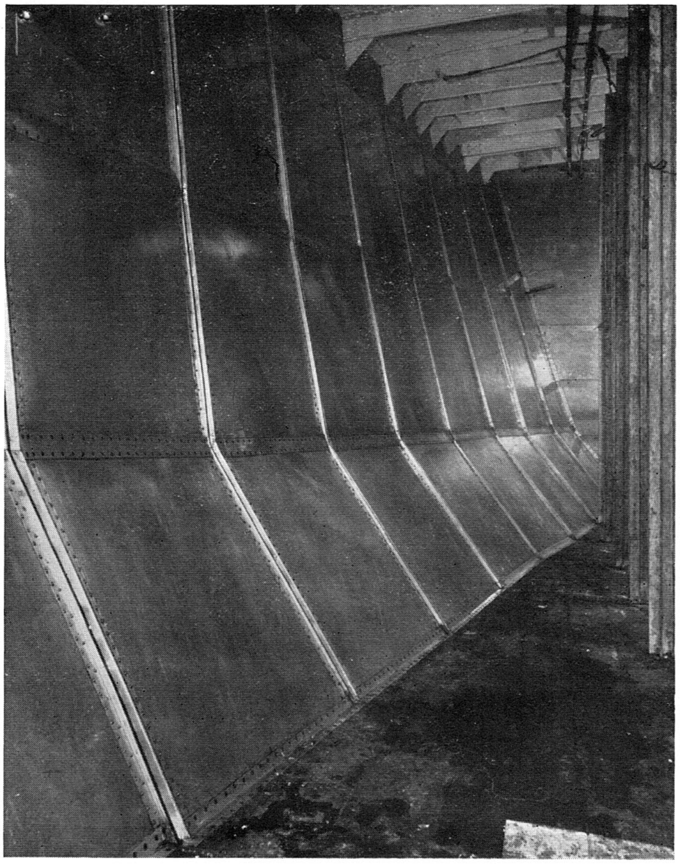


FIG. 6

FIG. 7

F[redacted]. *Internal view of "Morag Mhor." (By courtesy of the British Aluminium Co. Ltd.)*

FIG. 8.