EARLY WELDING FOR THE ROYAL NAVY

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ABSTRACT

Both the British and US design departments took a keen interest in arc welding during World War I and, in collaboration, made considerable advances. Little was achieved in UK warship building yards during the twenties or early thirties but an increasing amount of welding was used in cruisers, particularly in Chatham and, more, in the *Ark Royal* at Birkenhad. In 1936 the first all-welded ship for the RN, *Seagull*, was built at Devonport.

During the war, progress was more rapid and both Chatham and Vickers made considerable advances in submarine prefabrication. The LOCH Class frigates were designed for prefabrication which was successful though there was still considerable opposition to welding.

Beginnings[1]

It was discovered early in the nineteenth century that an electric arc could generate very high temperatures and, in 1865, a Mr White was granted a UK patent, seen as the genesis of arc welding. Oscar Kjellberg developed a coated electrode in 1907 which was used to a limited extent for boiler repairs. In 1909, Strohmenger, a scientist working for an asbestos company, discovered, almost by chance, the use of asbestos as a coating for electrodes and also introduced the use of alternating current. A well known company took its name from this discovery since it was said that AC produced only a 'Quasi-Arc'.

World War I

As suitable transformers and electrodes became available, welding came into use for emergency repairs. Some such work was heroic. The cast steel, stern post of a battleship was found to be cracked in two places and, initially, it was thought that a new post would be needed, putting the ship out of action for a long time. Gard, then Constructive Manager, Malta, proposed a welded repair and d'Eyncourt, the Director of Naval Construction, approved it[2,3]. The work took six weeks, involving the deposition of six hundredweight of weld metal. After 21 months at sea the repair was still sound. Gard also describes welded repairs to a steel stern casting, the shaft bracket of a destroyer and re-inforcement of worn shall plating. It would seem that *Dolphin*'s first welding set dates from this period, c. 1917.

Not all such repairs were successful and Gard[2] lists some failures but, overall, welding seemed so promising that a series of tests were carried out in Portsmouth Dockyard, starting in August 1917, and intended to lead to an all welded ship. It was realized that the performance of the weld depended on the environmental conditions and, even more, on the skill of the welder and every effort was made to fabricate the test pieces under realistic rather than ideal conditions.

Electrodes from different manufacturers were tried and welds were made in all positions; not surprisingly, downhand was found to give the best results and it was noted that the design of welded structure should cater for this position. The tensile strength of the joints was satisfactory but ductility in bend tests was much inferior to the parent plate. Some samples were immersed in sea water before test to study the effect of corrosion.

These Portsmouth tests were followed with great interest and their conclusions were known as the 'Portsmouth Rules'. The tests were attended by some shipbuilders and by Lloyd's Register who carried out further tests of their own on fatigue properties. Portsmouth then applied the lessons of these tests to the construction of a 20 foot length of anti-torpedo bulge. The main difficulty was in assembly and a single row of widely spaced rivets was used to hold the plates in place while the lap joint was welded, a procedure which Gard saw as transitional.

Gard[2] summed up the position in 1919 as follows:

> It will be necessary to train designers and draughtsmen to so frame ship structures as to simplify the welding operation by producing the best conditions to make it reliable, to devise a practical means of detecting inferior welds or to ensure that none shall exist, to considerably increase the electric power available, to overcome the difficulties of assemblage to suit welded structures, to suitably protect welders and workers in the vicinity, to increase the sources of supplies of electrodes, &c., before we can carry out any large amount of electric welding work at the shipyard. These and other considerations lead to the opinion that the realisation of the all-welded ship will necessarily be a slow process and only attained by careful thought and consideration and attention to details, for which but little time is likely to be available in the near future without special effort.

The cynical may feel that the position described was very similar to that 30 years later.

Washington and Goodall

From December 1917, the Assistant Naval Attaché in Washington was a constructor, S. V. Goodall, later Sir Stanley and Director of Naval Construction (DNC), who reported directly to the then DNC, d'Eyncourt. Welding formed a major topic of their correspondence[4] with a constant exchange of information. Goodall was invited to become a member of the Electric Welding Committee of the Emergency Fleet Corporation though Admiral D. W. Taylor 'advised me not to be carried away by the enthusiastic air, which, I gather, surrounds the committee'. He thought there were too many electrical engineers who belittled the difficulties. Goodall ignored this advice and became a lifelong enthusiast for welding. To summarize this lengthy exchange, it would seem that the UK was ahead in development but the USA more adventurous in the use of welding.

The Twenties

The results of the tests by Portsmouth and Lloyds were used in the building of a barge, *AC1320*, at Richborough in 1918, with claimed savings of 20–25% in time and materials[5]. This experience contributed to Lloyds' first rules for welded ships, issued in 1920.

Cammell Lairds had installed welding equipment in 1917 and the following year began the construction of the first British, all-welded ship, the coaster *Fullagar*, launched in 1920. There is a half block, plating model in the Science Museum showing that her plate seams were joggled and lap welded. Her adventurous life proved the strength of welded construction; in 1924 she ran aground and her bottom was set up by 11 inches over 1500 square feet. Not only did she remain watertight, but it was found possible to straighten the bottom using jacks. Later, she hit a cliff at full speed and suffered only localized damage. This historic ship was finally sunk in collision in 1937[6].

There were a number of technical advances in the twenties, but there was little use of welding in warship construction anywhere and none for the RN, surprising in the light of the emphasis placed on weight saving after the Washington Treaty. Weight saving was sought by the use of high tensile (D Quality) steel and aluminium, both almost impossible to weld at the time. Conservative shipbuilders (and owners), demarcation rules and the depression seem to be among the other causes.

The Thirties

The new decade saw an increasing use of welding in production work (FIG. 1). By 1931, Cammell Lairds were welding the main transverse bulkheads of the cruiser *Achilles*. Chatham Dockyard extended the use of welding in the cruiser *Arethusa*, under two assistant constructors, Sims and Sherwin, both later to rise to high rank. Initially, welding was carried out by shipwrights but later welders were recruited from unskilled men. They were given very limited training before starting production.

Sherwin is often said to have been the 'White Knight', fighting the cause of welding in a reactionary world but, just before his death, he told the author that this picture was false. There were very few opponents; most people saw that the future lay with welding but there were a number of problems, many apparently trivial, but time-consuming, to be overcome. Chatham even had to make their own electrodes for minor structure. At the same visit, he confirmed that his well-known INA paper[3] was largely based, with permission, on his predecessor's (Sims) notes.

It is likely that much of the unusually large scatter in the 'as completed' displacements of the LEANDER & ARETHUSA Classes is due to the extent of welding adopted. Sherwin lists the welding used at Chatham as:

- Shell and strength deck for the forward 80 ft.
- Other decks throughout and superstructure.
- Framing in the double bottom, bulkheads and much minor work.

Distortion was seen as a difficult, though soluble problem.

FIG. 1—HMS 'ARETHUSA' UNDER CONSTRUCTION AT CHATHAM IN 1933, SHOWING WELDING IN PROGRESS

reproduced by courtesy of K. A. Slade

In the discussion of Sherwin's paper, Lillicrap, in charge of cruiser design, made two important points. Firstly, Sherwin had said that the cost/ton of welded work differed little from riveted but, since there was a substantial weight saving due to welding, there was a real cost saving. Secondly, he qualified the statement that 'D' quality (high tensile) steel could be welded; though some satisfactory welds had been achieved, there were too many unexplained failures for designers to have confidence of welding in D steel.

From 1932 onwards, when the destroyer *Wishart* was repaired at Shanghai, increasing use was made of welding to repair corroded tail shafts. Portsmouth repaired the shafts of the submarine *L20* in 1933 and an investigation was carried out by the Admiralty Engineering Laboratory in 1934 into the best methods to use. From then on such repairs became fairly common, though only formalized by Admiralty Fleet Order in 1945.

Overseas Naval Developments

Some other navies were more courageous in their use of welding in the thirties but a few, at least, had cause to regret it. The Dutch cruiser *De Ruyter* (1933–36) was all-welded, apparently without problems, while the Germans welded about 90% of the structure of their pocket battleships. The weight saving so obtained helped to limit their displacement to 'only' 1700 tons above that permitted in the Treaties. There was a fair amount of cracking in this welded structure but not of a serious character.

Japan built the depot ship *Taigei* with an all-welded hull in 1933, saving about 15% in weight. As a result the MOGAMI Class of large cruisers was also designed with a virtually all-welded hull in DS steel. MOGAMI suffered serious cracking on trial and again in a typhoon in September 1935. The whole of the shell plating had to be removed and replaced with riveted DS amidships and with welded mild steel at the ends[7].

Ark Royal

The Admiralty and Cammell Lairds agreed to the extensive use of welding in the large aircraft carrier, *Ark Royal*[8]. When she was designed by Forbes it was hoped that the 1936 London Naval Treaty would limit new aircraft carriers to 22,000 tons and *Ark Royal* was designed to that figure, making weight saving most important. The treaty finally set the limit at 23,000 tons, too late for *Ark Royal*, and even this limit was not generally ratified.

About 500 tons was saved by welding, equal to about half the weight of her armament. Some 65% of the structure was welded, including transverse and longitudinal bulkheads, decks, shell plating above the lower hangar deck and the whole of the forward 100 feet. 150 welders were employed on the ship and 50 on the ground using 7 million feet or 260 tons of electrodes. Stiffeners and beams were generally of T bars to save cutting. The upper hangar deck was plated transversely with an edge butt at every deep girder, 8–12 feet apart.

A welding shop was built at the head of the slip equipped with a 10 ton travelling crane. The skids supporting the weldments were five feet high so that welders could work underneath when necessary. The main problem was distortion and 1 in 96 was allowed for contraction which seems to have prevented any serious overall movement, though bowing of plates between stiffeners proved expensive to rectify.

During the discussion, a Mr John for the builders said that though there was a saving in plate preparation, and a larger saving in water testing, welded construction was still slightly more expensive than riveted work.

Ark Royal had an elaborate torpedo protection system with a welded holding bulkhead of two thicknesses of D1 plate each ¾ inch thick[9]. A full size replica of this protection was tested on Job 74 and, though full records cannot be found, it

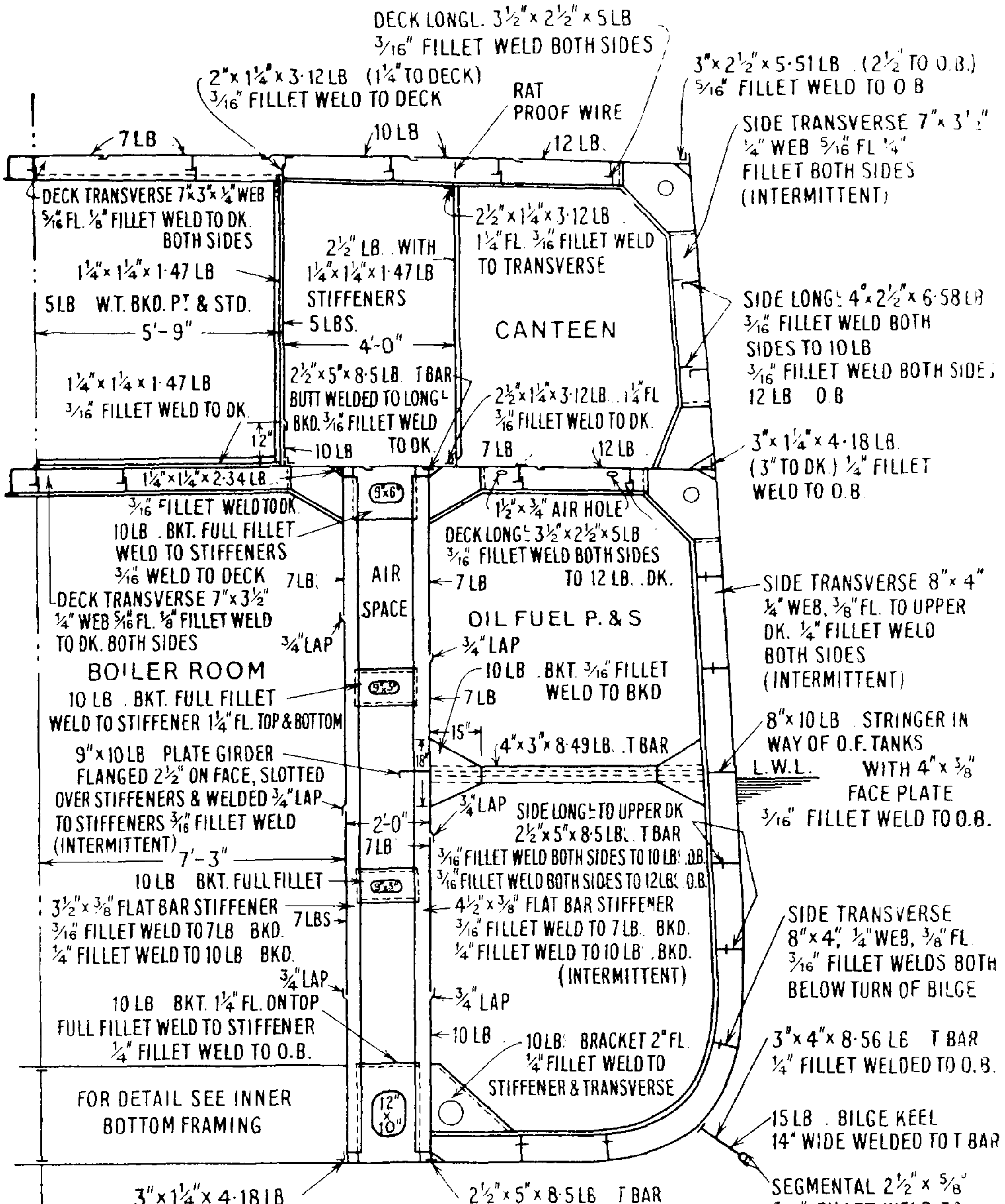

FIG. 2—THE WELDED LONGITUDINALLY FRAMED HULL OF HMS 'SEAGULL'. SECTION AT FRAME 51, LOOKING FORWARD

seems from the Goodall diaries that there was a serious failure of the holding bulkhead and that it was too late to alter that in the ship. When she was torpedoed Goodall was concerned that her loss might be due to a failure in this bulkhead and was later relieved to find that this was not so.

The extent of welding in the KING GEORGE V Class battleships was similar to that outlined earlier for cruisers, and the protection system and principal structure were riveted. During the late thirties, Swan Hunter built some tankers of welded construction but in general there was little welded shipbuilding in the UK.

Seagull

In 1936 it was decided to make a detailed comparison of the weight, cost and problems of building an all-welded minesweeper with those of a similar riveted ship. Commercial shipbuilders were still reluctant to weld, particularly with the light scantlings involved, so Devonport Dockyard was asked to build the welded *Seagull* alongside the *Leda*, which was riveted except for welded bulkheads[10].

The structure of *Seagull*, designed by R. Baker (FIG. 2), was totally different from that of *Leda* (FIG. 3), with longitudinal framing in place of transverse and flush welded butt joints in place of riveted laps; the details being worked out in conjunction with the Dockyard. The material, all mild steel, had already been ordered as for a riveted vessel which imposed a few constraints on the design.

The number of welders employed averaged 20 with a peak of 41. Great attention was paid to the selection and training of welders and, even more important, their supervisors, and careful records were kept of individual's

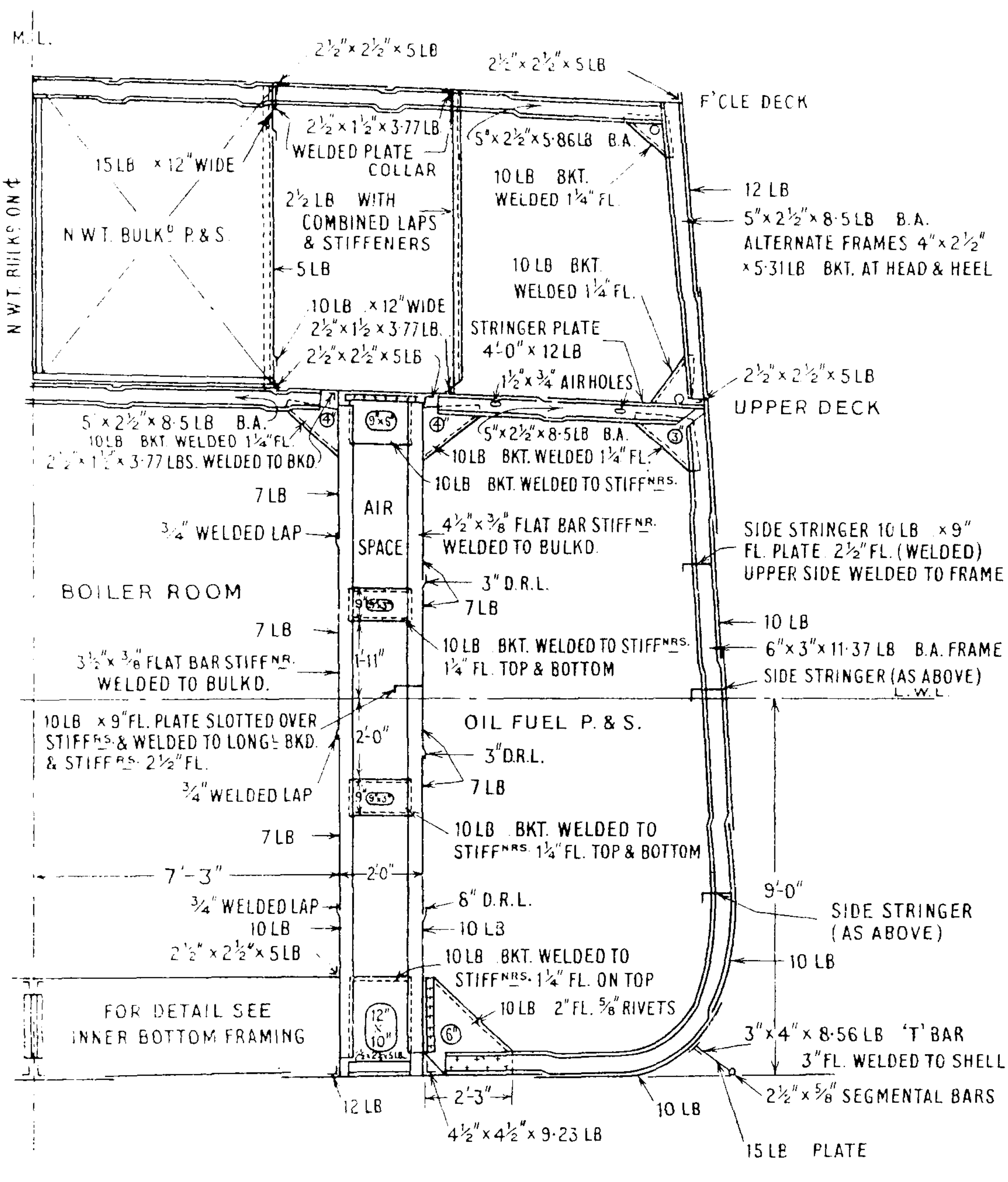

FIG. 3—THE RIVETED HULL OF HMS 'LEDA'. SECTION AT FRAME 51, LOOKING FORWARD

performance. To maximize downhand welding, the double bottom units were fabricated, upside down, in units which were quite large for the day but limited by the 2½ ton derricks on the slip.

From the start, it was realized that distortion would have to be controlled but that contraction was inevitable and must be allowed for, ½ inch in 30 feet being expected for a bulkhead. The measures taken were generally satisfactory and at launch, when the structure was complete (313 tons) the ship was only ¼ inch less than the design length and the forefoot had lifted 1¾ inches.

TABLE I—*Comparison of building the all-welded 'Seagull' and the mainly riveted 'Leda'*

		Seagull	*Leda*
Time to launch	weeks	37	30
Weight of structure	tons	311	345*
Direct labour cost	£	13 998	14 248

* Leda's bulkheads were welded, reducing the advantage of Seagull

The time taken to build the *Seagull*'s structure was a little longer than for her riveted sister but weight and cost were saved even on this first example of a relatively unfamiliar method of construction (TABLE I). (Note that Nicolls[10] compares costs on direct labour, without oncosts. The welding school, which must have been fairly costly, should have been charged to *Seagull*.) A big advantage in cost lay in water testing where *Seagull* showed a 45% advantage.

In summing up, Nicholls[10], the Constructive Manager, said that this trial had shown that there were no insuperable problems in welded construction. Weight savings of 10% had been demonstrated and more would be possible in an unconstrained design. There would be no increase in cost or building time if welders and supervisors were efficient. Even with *Seagull*'s light scantlings, distortion had been controlled but great care was needed. Welded construction was eased by longitudinal framing.

The Commanding Officer, Commander T. W. Marsh, spoke in the discussion, starting with his initial fears over his novel ship. however, once at sea, he found that she was free of the minor leaks which afflicted riveted ships and of their creaks and groans in waves while vibration was greatly reduced. She floated 3 inches higher in the water due to the weight saving and this, combined with the reduced resistance from her smooth flush shell made her faster than her riveted sisters and greatly reduced her fuel bill. Her simpler structure made it much easier to clean the bilges.

While earlier papers were optimistic over the future of welding, they did draw attention to the problems still to be overcome. Nicholls's paper strikes a different note, success had been achieved; there were no remaining problems.

Seagull spent much of the war in the Arctic and there are no reports of problems with her hull.

World War II

Nicholls's paper on *Seagull* was read in the spring of 1939, leaving little time to build on this success before war broke out. During the war, opportunities for change were limited as the shipyards were laid out and manned for riveted construction and, with a few exceptions, production could not be interrupted while a change was made. Goodall's diaries, however, were full of complaints over the reactionary attitudes of many shipyard managers and even a few of his own senior staff. Welding development for the Admiralty was in the hands of W. G. John, RCNC, and Goodall noted '. . . a treat to see a young man getting on with it'[11].

Samuel White's yard at Cowes was severely bombed and, on re-building, it was laid out for welded pre-fabricated construction. The big fabrication shop enabled work to continue in the blackout or in bad weather, improved working conditions and made supervision easier while making possible greater use of machine welding with less distortion[12]. The first ship built in the new facility, *Contest*, was launched by Lady Lillicrap, a fine tribute to her husband's encouragement of welding[13].

The LOCH Class frigates were designed for welded pre-fabrication using a very simple structural style so that most of the work could be carried out by bridge builders, away from the shipyards. The object of getting the ships built quickly was achieved though, due to the simple style, the man-hours worked were greater than in similar ships of riveted construction.

A minor but valuable wartime development was the freelance design of a stud welding machine in Portsmouth, later improved by Chatham.

Submarine Construction

Some welding of submarine components, such as pipe flanges and ventilation trunking had been carried out in Chatham Dockyard during World War I and in the first post-war boat some welding was used on flats exposed to test pressures less than 50 lb/in^2. This boat, *Oberon*, had an intricate cast steel forward bulkhead to the pressure hull where the torpedo tubes and their operating gear passed though. Several castings proved defective, two recognized only after being built into the ship. For the next submarine, *Odin*, it was decided to use a welded fabrication rather than a casting and this was so successful that similar fabrications were used in all later submarines at Chatham.

Submarines were a special case, as a welded hull was inherently stronger and would not leak while the weight saving, particularly the change from Z to T frames, could be put into thicker shell plating and increase the diving depth. The high strength steel used before the war (HST) was unsuitable for welding and it was some time before the more tolerant S quality became available. There was also some reluctance to change on the part of the builders. It was found possible to increase plating thickness by ⅛ inch in welded boats, giving 50 feet extra diving depth.

When S quality became available in 1943, the Chatham drawing office undertook a substantial redesign of the structure to take advantage of welded fabrication and to permit the maximum use of downhand work. The T Class submarines had a cylindrical section 110 feet in length, 16 feet diameter. This was divided into 9 sections, each section being built with two semicircular plates. The seams were staggered to avoid 4-way junctions[14].

After the first boat, the fore and after ends were further redesigned so that each plate was part of a frustrum of a cone and so could be rolled to shape. The building slip was completely enclosed and served by one 15 ton and two 10 ton cranes. During fabrication the sections were supported on rollers and slowly turned by motors to permit downhand welding of the plates and the T bar frames. The AC welding plant could support 60 welders at 300 amps or 39 at 600 amps.

In erecting each section, the bottom plate would be positioned on the rollers with the edges planed for welding and the complete ring frames clamped in place. The top plate would then be clamped in position before a manual back run was made on the seams. The outer runs of welding to the seams were applied, downhand, by a Unionmelt machine after which the back runs were gouged out and rewelded. The frames were tacked in place and then fully welded by the machine which was supported on a gantry while the section rotated past it. All T intersections of seam and butt welds were X rayed as were many other sample positions. Special rollers were made for the conical ends but their geometry forced the use of manual welding for the frames. The external hull and superstructure were also welded.

The A Class of submarines was the only wartime design and was designed for welded construction. The principal builders, Vickers and Chatham Dockyard, introduced their own prefabrication methods of which they were proud, both being claimed as superior to the methods used in Germany for the Type XXI.

Wartime Problems

There was still considerable suspicion of welded ships, fired by the many failures in the structure of Liberty ships, blamed, not entirely with justice, on welding. Of 2710 such ships there were problems, mainly minor, in about 1000[1]. Many of these were due to the poor design of details leading to stress concentrations which initiated cracking. There were similar problems in US-built excort carriers used by the RN in the extreme cold of the Arctic, so that the operationally inferior, but riveted, British built carriers were preferred for the Murmansk run. Cracks would still start but would usually, though not always, stop at a riveted seam. In a welded structure cracks could run indefinitely.

Failures in Liberty ships also came from lack of supervision and poor quality control with welders pay depending on the number of electrodes used per shift. It is no wonder that there were some cases of joints filled with whole electrodes lightly buttered over with weld metal. These problems were comparatively rare and should not obscure the great achievement of the Liberty ship programme which contributed so much to victory in the Atlantic. The building time for later ships averaged 41 days with a record of 17 days.

Goodall was irritated by such suspicions and would not accept that even mild steel could behave in brittle fashion in welded ships; just for once he was wrong. He was also angry—and right—on 29 May 1944 when Sir John Thornycroft complained about welding in destroyers. Goodall replied 'If you decide to stick to riveting or to riveting combined with 50% welding, my view is that Thornycroft's days as a builder of light, fast craft is over'[11].

The Admiralty also contributed greatly to the satisfactory introduction of welding in merchant ships. Reference 6 is a collection of lectures given at a course in Glasgow, organized by the Admiralty, to encourage and improve the use of welding. The Admiralty issued a series of memoranda covering topics such as welding, examination of welds, repairs to welded ships and others. They set up the Admiralty Ship Welding Committee which supported applied research, culminating in full-scale trials to measure the relationship between loading and strain on the welded tanker *Neverita* in still water and the cargo ship *Ocean Vulcan* in rough seas. The Naval Construction Reasearch Establishment tested and advised on electrodes, while the Admiralty took control of non-destructive testing.

One real problem was what has been called 'the march on, chip out and weld up brigade'. Cracks would be welded up without any attempt to discover the cause and, as these were usually associated with stress concentrations, a new and bigger crack would soon appear. Such work discredited the value of welding in properly considered repairs.

Comment

In World War I, the UK and particularly the Admiralty were, with the USA, world leaders in welding technology and usage. During the twenties there seems to have been little work on the technology and even less on the application of welding. As well as the usual and justifiable excuses of lack of staff and funds, of reactionary management and labour problems, it must be accepted that the

Washington Treaty led to a much greater use of high tensile steel (and aluminium), then unsuitable for welding.

The cautious progress in the thirties may be justified in the light of over-ambitious work elsewhere but it was a decade too late. Inevitably, development was fragmented during the war and, with a backward industry, was probably all that could be expected; it was as good as that achieved in Germany but trivial in comparison with US naval work. On the evidence available, which may well be incomplete, it would seem to be a typical British saga of successful innovation followed by failure to implement.

Note

The history of welding up to 1945 for the Royal Navy is not well documented. There are a few detailed technical papers but, other than some frustrated comments in Sir Stanley Goodall's diaries[11], there is little personal background. It is hoped that this article, which deals with the use made of welding rather than the technology, will provoke comment and enable a fuller account to be written.

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