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EXAMINATION OF WELDED JOINTS IN SAMPLE FROM HULL OF C.C.G.S. 'SIR HUMPHREY GILBERT'

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PHYSICAL METALLURGY DIVISION

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SUMMARY OF RESULTS

A visual examination was made of short sections of a longitudinal and a transverse weld (a seam and a butt weld) and representative sections from both welds were examined microscopically. Sections were also examined from locations of grooves in the hull plating where alignment members had been welded on during the construction of the hull.

Portions of weld deposits, not refined by subsequently deposited weld metal, had been subjected to slightly greater attack by sea-water than were the refined portions of the deposits. This explains the appearance of longitudinal ridges on the welds after a period of service.

The preferential attack along both edges of the longitudinal weld and the forward edge of the transverse weld is related to the presence of unrefined weld metal but also may be related to increased erosive action of sea water due to weld profile and undercutting.

The grooves where alignment members had been welded on during construction are due to preferential corrosion of the weld metal remaining after removal of the members. It is likely that the welds were single pass deposits and thus unrefined metal with its higher corrosion rate would have been present.

In view of the severe general corrosion found on ice-breaker hulls, it is considered that concentrating attention on developing weld deposits having improved corrosion resistance should be secondary to developing a system for overall protection of the hulls.

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INTRODUCTION

During a visit[1] by Dr. G. J. Biefer and the writer on October 18, 1966 to examine the corrosion on the hull of the C.C.G.S. "Sir Humphrey Gilbert" it was agreed that a laboratory examination of a small section of a welded joint could be performed for the Department of Transport. Dr. Biefer and the writer stated that the examination should be made only if it was necessary to remove a plate from the hull for repair purposes. The sample was subsequently flame-cut from an area that included the junction of a transverse and a longitudinal weld on the starboard side of the hull towards the bow at a location where a plate had been bulged inward. Dr. Biefer and the writer were told that the bulged plate would have to be replaced.

The ship was stated to have been built in 1958 by Davie Shipbuilding Co. Ltd. The steel in the hull was stated to vary from 1/2 in. to 1-1/4 in. thick and to have been specified to ASTM A131 Grade C. This requires a ladle analysis of 0.24% C max., 0.60-0.90% Mn, 0.04% P max, 0.05% S max and 0.15-0.30% Si. It was stated that E7018 low-hydrogen type electrodes were employed in fabricating the hull plates, but that any subsequent welding repairs on drydocking were made using E6010 electrodes for replacement of plates and E6012 electrodes for repair of corroded areas.

It is understood that the submitted sample was from an area that had not been repaired in any way but rather represented original welds as affected by subsequent operation.

VISUAL EXAMINATION

Both the inner and outer surfaces of the weld and plate showed general corrosive attack. The transverse weld was more nearly flush with the surface of the plate than was the longitudinal weld. Several pronounced crests, parallel to the weld length, were seen on the longitudinal weld. The crests were less pronounced on the transverse weld. No traces of the weld ripple appearance remained on any of the welds on the sea-water side of the joint. There were grooves about 3/64 in. in maximum depth at each edge of the longitudinal weld on the sea-water side. A groove was present only along the forward edge of the transverse weld on the sea-water side and this groove was about 1/16 in. in maximum depth.

Two grooves on the sea-water side of the surface of the plate intersected the longitudinal weld on its upper side. These grooves, each about 1/16 in. deep and about 1/2 to 5/8 in. wide, were caused by attack along a line where alignment pieces had been fillet-welded to the hull during fabrication.

MICROSCOPICAL EXAMINATION

Sections removed across each of the two welds and the two grooves were polished and finally etched in 2% nital. Figures 1-3 inclusive illustrate the section from the longitudinal weld and Figures 4-6 inclusive illustrate sections from the transverse weld.

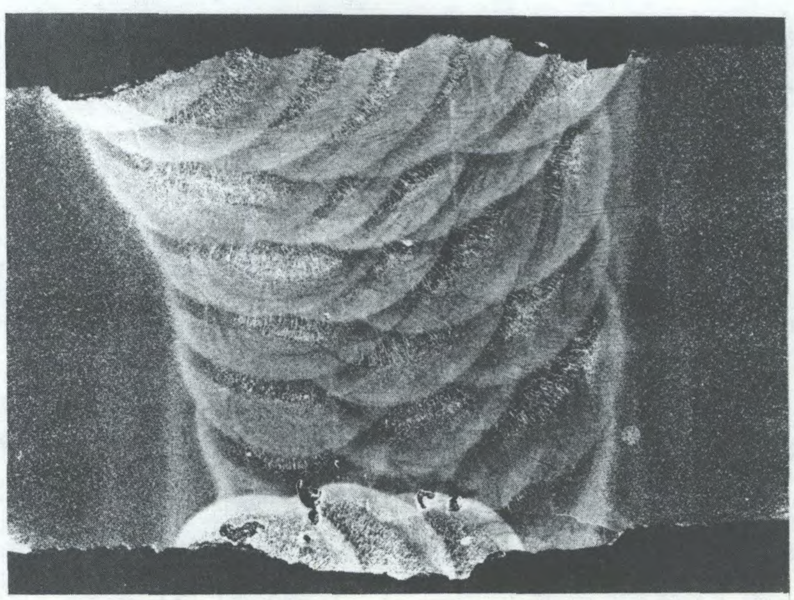

Figure 1. Section from longitudinal weld in the hull. The lower edge of the weld when located on the ship is at the right and the sea-water side is at the top. Mag. X2.

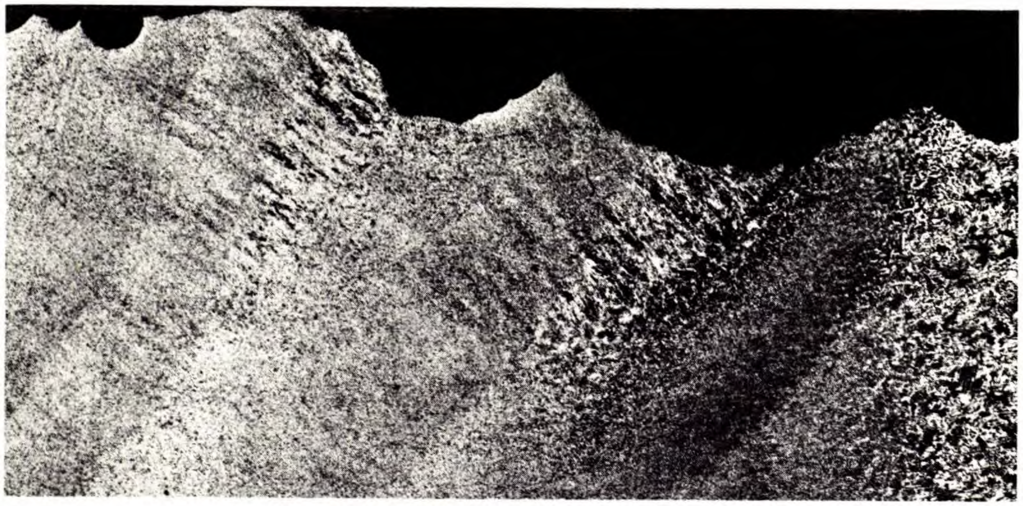

Figure 2. At lower edge of longitudinal weld, on sea-water side. Mag. X11.

Figure 3. At upper edge of longitudinal weld, on sea-water side. Mag. X11.

Figure 4. Section from transverse weld with forward edge of the weld when located on the ship at the left and the sea-water side at the top. Mag. X2.

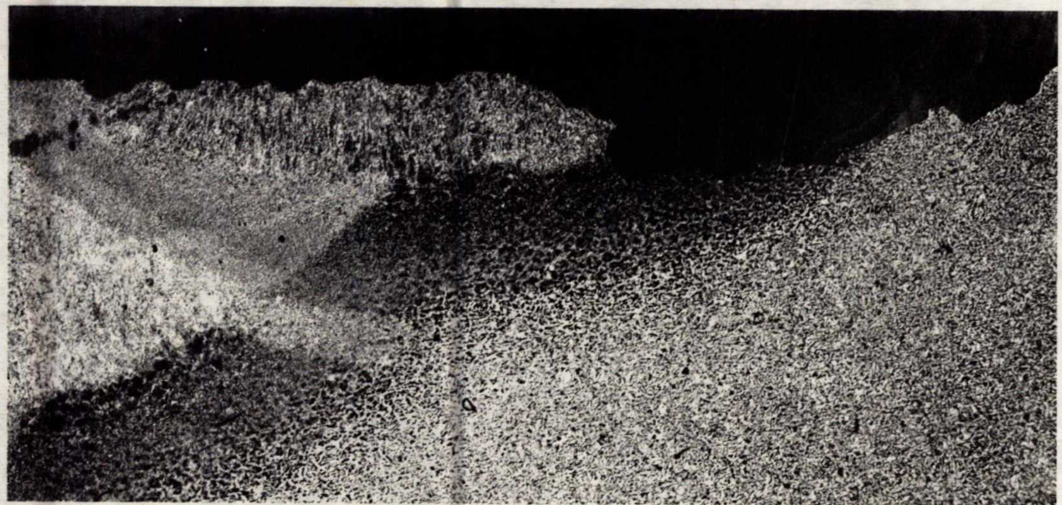

Figure 5. At forward edge of transverse weld, on sea-water side. Mag. X11.

Figure 6. At rear edge of transverse weld, on sea-water side. Mag. X11.

In Figures 1 and 4 it can be seen that the refined grain portions of the weld deposit corroded at a slightly slower rate than the coarser, columnar portions of the weld. This accounts for the appearance of the longitudinal crests on the welds.

Figures 1-3 inclusive show that there has been greater loss of metal at each edge of the longitudinal weld, with the greatest loss being on the upper edge (Figure 3). This is at least partly due to the fact that the last bead deposited was at the upper edge of the joint, thus leaving exposed a greater portion of coarse, columnar weld metal than would be present in any of the beads deposited earlier. Only the last bead would remain entirely in the as-deposited condition. All other beads would have portions of their areas refined by the heat of subsequent deposits. It is evident from Figure 3 that most of the columnar cast structure of the last bead has been lost by corrosion. The outer surface of the darker etching zone is only slightly below the original fusion line of the last bead.

On the transverse joint, a comparison of Figures 5 and 6 shows that there has been a greater attack on the forward edge. Again, the last bead was at the forward edge and much of this coarser columnar deposit had been corroded away.

Figure 7 shows the structure at the base of the corroded grooves in the plate where alignment members had been welded onto the hull plating.

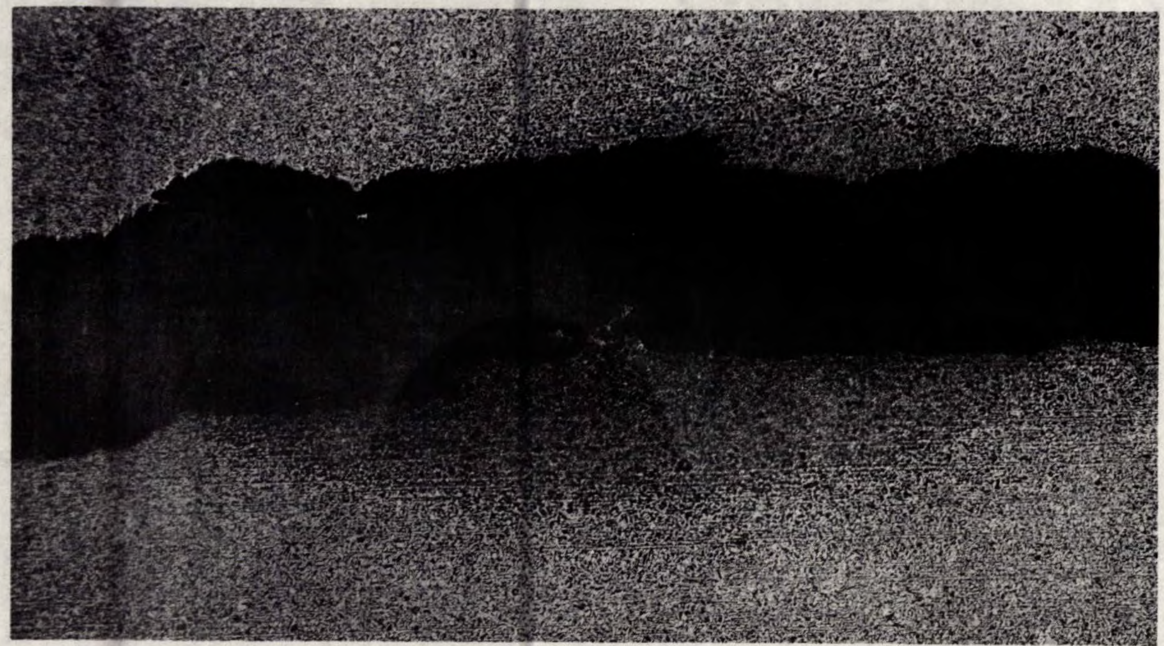

Figure 7. Showing the appearance at the bottom of each of the two grooves in the hull plate. Mag. X11.

In the lower specimen, only a small bit of weld metal remains and corrosion has extended into the heat-affected zone. In the upper specimen, corrosion has extended almost completely through the heat-affected zone.

DISCUSSION

The original welding of butts and seams (transverse and longitudinal joints) in the hull is said to have been done using E7018 (low-hydrogen) electrodes. Subsequent building up of corroded welds is said to have been with E6012 (rutile) electrodes, with E6010 (cellulosic) electrodes being used for butt welding insert plates into the hull.

According to some published data[2] by European investigators, weld deposits from low-hydrogen electrodes are generally more susceptible to attack than deposits made with electrodes having coatings classed as iron oxide or rutile types. No information was given concerning deposits from cellulosic type electrodes of the E6010 or E6011 classes.

British investigators[3] found that six of seven brands of low-hydrogen electrodes tested produced deposits having corrosion rates $1\frac{1}{2}$-3 times those of deposits from rutile electrodes. The other low-hydrogen electrode produced deposits having a corrosion rate equivalent to the rutile electrode. A limited study by electron microscopic and electron diffraction methods was made on deposits from a rutile electrode having a slower corrosion rate and from two low-hydrogen electrodes, one of which had a high corrosion rate and the other a lower rate, i.e. about equivalent to the rutile deposit. Deposits from the rutile electrode and the low-hydrogen electrode having similar corrosion rates were found to have significantly smaller volume fractions of $FeO-Fe_3O_4$ type precipitates than the deposit from the low-hydrogen electrodes having $1\frac{1}{2}$ - 3 times the corrosion rate. The investigators concluded that there was a strong indication that increased weld corrosion was associated with a higher volume fraction of $FeO-Fe_3O_4$ precipitates. Unlike other investigators, they did not find that the silicon content was an important factor in the corrosion of weld metals.

Dutch investigators[2] decided that it would be desirable to develop a low-hydrogen electrode that would not have inferior corrosion resistance. After conducting a series of tests, they concluded that adequate resistance to sea water would be provided by an electrode whose deposit contained about 0.06°C, 0.90% Mn, 0.75% Si and 1.75% Ni. Surprisingly, their tests indicated that less satisfactory results were obtained with an electrode whose deposit composition was similar except for a nickel content of 2.0-2.3%. The investigators concluded also that the rutile electrodes produced deposits no more resistant to corrosion than those from normal low-hydrogen deposits. This is contrary to the conclusions of other investigators previously discussed.

An enquiry was made to the U.S. Naval Research Laboratory to determine if they had any information on this subject. Evidently no useful information is available and it appears that this preferential weld corrosion is not considered to be a major problem in U. S. Navy vessels.

It is not possible to state definitely that Canadian or American-produced low-hydrogen and rutile type electrodes will behave generally in a similar fashion to that indicated by European investigators. It was shown that variations were found in corrosion-resisting qualities among European-produced electrodes. Thus, it cannot be stated with assurance that the corrosion rate will always be lower if rutile rather than low-hydrogen type electrodes are used for making the finish deposits on hull welds. Also, it should be pointed out that the rutile class electrodes, supplied to Canadian and American electrode specifications, produce weld deposits that can have significantly lower tensile ductility and notch ductility than electrodes such as E6010, E6011, E6015, E6016, or E7018 classes. The specification covering the original hull fabrication excluded the use of the rutile type E6012 and E6013 electrodes for welds subjected to major stresses. Thus the use of E6012 electrodes for building up of corroded welds could be considered contrary to the intent of the original fabrication requirements.

A variable pattern of corrosion was found at the joints in the hull of the "Sir Humphrey Gilbert". Some welds had corroded so that their top surfaces were below the surfaces of the adjacent plates while other adjacent welds had suffered much greater attack at the edges.

Preferential attack along the edges of some of the welds is related to the presence of unrefined weld metal deposits. However, it is likely that other factors are involved, such as excessive undercutting at the time of welding. It is possible that the profile of the weld may have some influence upon erosive attack and some investigators have recommended that welds be ground flush with the plate surfaces.

It was stated by Mr. Harvey, a representative of Lloyd's Register of Shipping, that numerous alignment members which had been fillet welded to the hull were knocked off during construction rather than being removed by flame-cutting and grinding as is considered best practice. He stated that the removal practice caused some metal to be torn from the hull plating. Grooves resulting from such a practice would be expected to corrode somewhat faster than the adjacent plate. Even if no mechanical grooves had resulted from the removal procedure, the presence of even a small layer of the coarse columnar weld deposit (i.e. resulting from penetration into the plate) would be expected to accelerate corrosion. Numerous locations were observed on the hull of the "Sir Humphrey Gilbert" where accelerated corrosion had occurred at the former locations of alignment members. As the welds involved would likely be single pass deposits, there would be no refined zones and therefore corrosion would be expected to be more rapid than in a multi-pass weld.

In view of the extensive corrosion wherever weld metal was deposited on the hull of the "Sir Humphrey Gilbert" it would seem to be desirable when welding hulls of icebreakers to use electrodes producing deposits less susceptible to attack by sea water. For example, the electrode developed by N. V. Philips Gloeilampenfabrieken(2) could be tested by making some repairs on icebreaker hulls. An evaluation of Canadian or U. S.-produced electrodes for resistance to sea-water corrosion could be undertaken in a laboratory but this would be rather time-consuming.

Considerable general corrosion occurs on the plating of icebreakers due to the fact that it is not possible to protect the hulls effectively by any system of paint or epoxy coating employed to date. Thus it would seem that the most effective methods would be a cathodic protection system using permanent anodes or possibly by metallizing with aluminum or by the two in combination. It is recommended that such systems be evaluated prior to the consideration of an extensive program for the evaluation or development of electrodes producing weld deposits of improved corrosion resistance.

CONCLUSIONS

(1) General corrosion has taken place over the surfaces of the plate and the longitudinal and the transverse welds examined. The unrefined zones of the weld were corroded to a greater extent by the sea water than the refined zones.

(2) Grooves were produced at both edges of the longitudinal weld and at the forward edge of the transverse weld as a result of greater corrosion rates possibly aided by increased erosive action.

(3) Grooves were produced at locations where welds had been made to attach alignment members to the hull during construction.

(4) For the present, methods for the overall protection of icebreaker hulls should be sought rather than concentrating attention upon the weld deposit. However, some weld repairs could be made using special electrodes that have been developed and these could be examined after a period of service.

REFERENCES

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