SR-12

PROGRESS REPORT

on

CLEAVAGE FRACTURE OF SHIP PLATE
HATCH CORNER TESTS

by

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under Navy Contract NObs-31222

COMMITTEE ON SHIP CONSTRUCTION
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PREFACE

The Navy Department through the Bureau of Ships is distributing this report to those agencies and individuals that were actively associated with this research program. This report represents a part of the research work contracted for under the section of the Navy's directive "to investigate the design and construction of welded steel merchant vessels".

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S. M. Boyd 6/13/58

July 24, 1946

Chief, Bureau of Ships
Navy Department
Washington 25, D. C.

Dear Sir:

Attached is Report Serial No. SSC-1, entitled "Cleavage Fracture of Ship Plate: Hatch Corner Tests". This report has been submitted by the contractor as a progress report on the work done under Contract NObs-31222 between the Bureau of Ships, Navy Department, and the University of California.

The report has been reviewed and acceptance recommended by representatives of the Committee on Ship Construction, Division of Engineering and Industrial Research, NRC, in accordance with the terms of the contract between the Bureau of Ships, Navy Department and the National Academy of Sciences.

Very truly yours,

Frederick M. Feiker
Chairman, Division of Engineering
and Industrial Research

Enclosure

PROGRESS REPORT

U.S. Navy Research Project NObs-31222

CAUSES OF CLEAVAGE FRACTURE IN SHIP PLATE

Hatch Corner Tests

September 1, 1945 to March 1, 1946

From:

University of California
Department of Engineering
M. P. O'Brien, Technical Representative

Report prepared by:

E. Paul DeGarmo
J. L. Meriam
R. C. Grassi
J. W. Harman

ABSTRACT

Six full scale specimens, similar in design to a hatch corner of a ship, were constructed from a low carbon, ship quality, semi-killed steel and tested to failure. One tested at 120° F gave a shear type fracture. All others tested at room temperature failed with cleavage type fractures. Two which were welded with preheat at 400° F showed superior performance, both in strength and energy absorption. Two which were fabricated by riveting gave inferior performance.

An investigation was conducted to determine the effects of preheat and a comparison made with the effects of 1000° F postheat treatment for 8 hours.

Studies were made of quarter scale symmetrical and asymmetrical hatch corner models to determine which type of specimen would best duplicate the stress condition existing in actual ships.

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INTRODUCTION

Starting November 1, 1944, a program of research was undertaken by the University of California under a contract with the NDRC having as its title "Cleavage Fracture of Ship Plate as Influenced by Design and Metallurgical Factors (NS-336)." Work under this project continued up to August 31, 1945, and was divided into two parts as follows:

A. A determination of the influence of metallurgical factors and temperature on the cleavage fracture of ship plate containing internal notches.

B. The determination of the effect of variation of material and temperature on the tendency for cleavage fracture of welded structural specimens containing a discontinuity, such as hatch corners.

Part B of this project involved the design and testing of full scale ship sections in order to:

a. Obtain a specimen approximating an actual section of a ship, wherein restraint to plastic flow is provided by the inherent geometry of the structure rather than by artificially induced notches.

b. Correlate the effects of temperature, steel, and stress relief on these specimens with results obtained on flat plate tests by other investigators.

Since September 1, 1945, this work has been continued by the University of California under a contract with the United States Navy, Contract NObs-31222.

In previous reports,[1,2] published by the Office of Scientific Research and Development, accounts were given of the development of a hatch corner type specimen which contained a corner which had considerable restraint to plastic flow. Prior to September 1, 1945, thirteen of these large specimens were constructed and tested. Five different steels were used in constructing the various specimens.

This report covers further tests made on six additional full scale hatch corner type specimens and an investigation of the effect of preheating upon the hardness of welds and the adjacent heat affected zones.

Some questions regarding the full scale hatch corner specimen design had been raised due to the fact that the longitudinal stress distribution across a transverse section opposite the corner of the hatch and the accompanying ratios of maximum to minimum stress were not quite the same as those which had been measured on two Liberty ships, the SS. David Bushnell and SS. Philip Schuyler. It also appeared that due to the asymmetry of the specimen some distortion would occur which might not exist in the actual ship hatch corner. It had not been intended that the existing full scale specimen should duplicate exactly conditions existing in actual ships but, rather, it was to be a laboratory specimen which contained a severe design notch due to inherent geometry and construction. This was to be in contrast to notches artificially introduced by saw cuts, holes, or the like.

However, to aid in the possible interpretation of the full scale hatch corner specimen results for direct ship design purposes, it was

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1,2 See Bibliography.

agreed that an attempt should be made, using quarter scale models, to obtain a design which more closely approached ship conditions. The models would enable comparison of the relative merits of a symmetrical versus asymmetrical specimen with respect to stress distribution, stress ratios, distortion, and adaptability to further full scale design tests. These model studies are also covered in this report.

PART I

Full Scale Specimens

Procedure

The design of the welded full scale hatch corner type specimens is shown in Fig. 1. The details of specimens 16 and 19, which were riveted, are shown in Fig. 2. In these riveted specimens an attempt was made to keep the general configuration as nearly as possible the same as for the welded specimens so as to make the only variable that of method of fabrication. For the welded specimens the welding sequence is shown in Table I.

Fig. 3 shows several views of one of the welded specimens during construction. In fabricating the riveted specimens all holes were drilled and reamed. Fig. 12 shows two views of one of the riveted specimens.

In making specimens 15 and 18, preheat was used in making all welds within two feet of the corner. Heating torches were utilized to raise the temperature of the plates within three inches of the welds to 400° F. The temperature was not allowed to fall below this value until welding was completed.

Five different steels were available for tests carried out in this project. These steels, their chemical analyses and tensile properties are shown in Tables II and III. For the six specimens discussed in this report only Steel C was used.

After construction of the specimens was completed, in order to provide transverse restraint, 3 in. x 3 in. bars were welded to the two edges of the specimens as shown in Fig. 4. Three transverse restraining beams were then attached by means of wedges between their ends and the 3 in. x 3 in. bars. These restraining beams were made of 6 in. channels with special strongbacks to prevent buckling. The wedges at the ends were driven tight until strain gages placed on the beams showed a compressive strain of 50 micro-inches per inch. It was recognized that the transverse restraint offered by these bars was not as severe as exists in ships. However, since cleavage type fractures were being obtained it was decided that the system should be used throughout the series of tests in order to keep the conditions constant.

Type SR-4 electrical resistance strain gages were attached to all specimens, except number 19, at the locations indicated in Figs. 5 and 6. Since specimen 19 was a repeat of number 16, it was not felt that it was necessary to use strain gages on this specimen. Since specimen 18 was similar to several others the gages were not read.

With the exception of number 17, over-all energy absorption was determined by taking pin-to-pin strain measurements as indicated in Fig. 7. Integration of the load-strain curves gave the energy absorbed.

For all the specimens except number 17, readings of the various gages were taken at loads of 0; 100,000; 200,000; 300,000; 600,000; 1,000,000; and 1,200,000 pounds. Beyond 1,200,000 pounds the readings of four gages were followed continuously up to failure, or until the gages became inoperative.

The purpose of testing specimen number 17 was to determine whether the strain concentrations at various locations would change if loading was repeated. Therefore, in testing this specimen the following loading schedule was used: 0; 100,000; 0; 100,000; 200,000; 0; 200,000;

300,000; 0; 300,000; 500,000; 0; 500,000; 800,000; 0; 800,000; 1,200,000; 0; 1,200,000 pounds and then to failure.

Results

The major results obtained from the tests of the full scale specimens are shown in Table IV. For convenience in comparing results Table V gives similar data for the first thirteen specimens. Photographs of the various specimens after failure are shown in Figs. 8 to 24, inclusive.

The failure of specimen 14, tested at 120° F, with a shear type fracture verified expectations, based upon previous tests, that such a fracture could be obtained in this type of specimen with Steel C if the test was conducted above 112° F.[2] It should be noted that the energy absorbed by this specimen was more than double that obtained with any previous specimen made from this steel and for which cleavage type fractures had been obtained. However, the nominal breaking stress was very nearly the same as had been obtained with cleavage type failures.

The results obtained from specimens 15 and 18 were by far the most outstanding obtained in these tests to date. The breaking stress of these specimens was about 33 per cent higher than the average breaking stress of all previous specimens, and nearly 10 per cent better than the best previous specimen (number 9) which had been given a high temperature stress relief after welding. In spite of the fact that cleavage type fractures were obtained in specimens 15 and 13, the energy absorption was very high, being more than twice as much as was measured on any previous specimen.

The performance of the welds on these preheated specimens was particularly noteworthy, In the welded specimens which were made without preheat there was always rather general failure of the welds adjacent to the fracture. This was particularly true of the weld connecting the longitudinal girder to the hatch end beam and the fillet weld between the deck and doubler plate. In these preheated specimens there was almost no failure in the welds. This is shown very clearly in Fig. 21 where the longitudinal girder plate was fractured but the weld was almost intact. In order to obtain a better picture of the reason for this superior performance the studies discussed in Part II of this report were made.

The behaviors of specimens 16 and 19 were not anticipated until load was applied. The "working" of the joints was very considerable even at low loads. This resulted in the angle at the corner opening up to quite an extent. This opening was very apparent while in welded specimens it was difficult to observe any change. The difference in the rigidity of the riveted and welded specimens was striking to all who had observed both types under load.

Fig. 25 shows the load-strain curves from which the energy absorption of the various specimens was computed. The superior performance of the two preheated specimens is apparent in this figure.

The results obtained from the test of specimen 17 by repeated loading are shown in Figs. 26, 27, and 28. As shown in Fig. 26, for loads greater than 300,000 lbs. there was, in general, less strain increment for the second application of a given load than for the first application. This was due to the permanent strain resulting from plastic flow which occurred during the first application of load. This resulted in a redistribution of stresses. As a result there was a decrease in the strain concentrations as shown in Fig. 27. The fact that strain concentrations measured in these tests are greater than those found in actual ships[1,3] may be due in part to the fact that this specimen was not as rigid as an actual hatch corner in a ship and as a result some opening of the corner angle resulted, and that both elastic and plastic strains were measured whereas in the case of at least one of the series of measurements made on ships only elastic strains were recorded.

Fig. 28 shows the behavior of gage 19H (Fig. 26) during the test. This indicates that the material at this point exhibited elastic behavior upon unloading and for reloading up to the previously applied load. As indicated, this gage failed, in that it ceased to function normally, at a load just above 800,000 pounds. The strain concentration is also indicated by the slopes of the two curves in this Figure. For example, using the slopes corresponding to the 800,000 pound load a strain concentration of approximately 8 is shown for gage 19H as compared with the average of the outboard gages.

[1,3] See Bibliography.