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Characteristics of welding induced initial deflections in welded aluminum plates

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Abstract

It is well known that welding-induced initial deflections, among other factors, significantly affect the ultimate strength behavior of welded plate structures. This means that it is of vital importance to identify the features of plate initial deflections prior to the plate ultimate strength computations. The aim of the present paper is to investigate the characteristics of initial deflections that occur during welding fabrication of aluminum plates used for marine applications. A total of 78 single and multi-bay stiffened plate prototype aluminum structures which are full scale equivalent to sub-structures of an 80 m long all aluminum high speed vessel are constructed by metal inert gas (MIG) welding. Initial deflections of plating between stiffeners are then measured. A statistical analysis of the measured database is performed to determine mean and coefficient of variation (COV) of the plate initial deflection. The insights developed from the present study will be very useful for reliability analyses and code calibrations of ultimate limit state strength and fabrication quality control for welded aluminum plate structures.

Keywords: High speed marine vessels; Aluminum stiffened plate structures; Plate initial deflections; Ultimate limit state strength; Reliability analyses; Code calibrations; Design database; Fabrication quality control

1. Introduction

During the last decade, high strength aluminum alloys have been increasingly applied for the design and construction of high speed vessels; and over the same time the size of high speed vessels has grown and their operation has moved into increasingly harsher environments. Subsequently, the design and building process to ensure the structural safety of aluminum high speed vessels has become more complex in terms of strength or reliability analysis and fabrication quality control [1].

In terms of ultimate strength analysis for welded aluminum plate structures, fabrication-related initial deflection of plates is one of primary parameters of influence. In contrast to welded steel plate structures where the necessary information is plentiful [2,3], lack of information on fabrication related initial deflections of aluminum plates can in particular make the design and building process for aluminum vessels relatively more uncertain [4,5].

The aim of the present paper is to obtain the statistical database of welded aluminum plate initial deflections that can occur during welding fabrication of aluminum stiffened plate structures for marine applications.

The studies related to initial deflection surveys for welded aluminum structures have mostly been performed in conjunction with mechanical collapse test programs. In the early 1980s, a series of collapse tests were carried out on aluminum unstiffened plates made of 5083 and 6082 alloys, by Mofflin [6] and Mofflin and Dwight [7] at the University of Cambridge, UK; and these are regarded as perhaps one of the largest and most relevant test programs for the collapse strength of aluminum plating until now. After TIG (tungsten inert gas) welding in the longitudinal direction and MIG (metal inert gas) welding in the transverse direction, weld-induced initial deflections were measured.

In the late 1980s, Clarke and Swan [8] and Clarke [9] at the Admiralty Research Establishment (ARE), UK carried

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out the buckling collapse testing on a total of five aluminum stiffened plate structures made of 5083 alloy. This was one of the earliest collapse test programs to use ship-shaped aluminum stiffened plate structures using full scale prototype models of all-welded construction with multiple frame bays.

Over a decade after the ARE tests, several collapse test programs on aluminum stiffened plate structures constructed by welding were carried out together with various surveys of weld induced initial imperfections [10–17]. The material of most test structures was 5083 aluminum alloy for plating and 6082 aluminum alloy for stiffeners. Except perhaps for those by Tanaka and Matsuoka [12] and Matsuoka et al. [13], which were full scale prototype models with multiple frame bays, most of these test structures were small scale models with single bay.

Through the present study, it is hoped that some more database is developed on fabrication-related initial deflections of welded aluminum plates which can be used for reliability analysis or code calibrations in terms of ultimate limit state assessment of welded aluminum plate structures. It is evident that there are various types of initial imperfections in welded aluminum stiffened plate structures such as initial distortions of plating and stiffeners, residual stresses and softening in the heat-affected zone [18], but the present paper is focused on the initial deflections of plating between stiffeners.

A total of 78 ship-shaped full scale prototype aluminum structures which are equivalent to sub-structures of a 80 m long all aluminum high speed vessel are constructed by MIG (metal inert gas) welding. The material of plating and stiffeners is varied among 5083-H116 (rolled), 5383-H116 (rolled), 5383-H112 (extruded) and 6082-T6 (extruded) aluminum alloys which are today the most popular for marine applications.

The statistics of weld-induced initial deflections in plating between stiffeners are obtained by direct measurements of the prototype structures. A statistical analysis of measured database is performed to determine mean and coefficient of variation (COV) of the plate initial deflection. Three (slight, average and severe) levels of the plate initial deflection are then obtained.

2. Design and construction of full scale prototype structures

A total of 78 prototype aluminum structures which are full scale equivalent to sub-structures of an 80 m long all aluminum high speed vessel are considered. They are designed in terms of single and multi-bay stiffened plate structures as those shown in Fig. 1. While various methods for fabricating aluminum ship structures are today relevant, the present test program adopts the MIG welding technique, which is now one of the most popular methods of welding in aluminum ship construction.

Table 1 indicates the overall dimensions of prototype structures. To cover the possible diverse range of in-service aluminum marine structures representative of various collapse failure modes, a variety of structural dimensions, material types, plate thicknesses, stiffener types and stiffener web heights are considered as follows (see Fig. 2 for the nomenclature):

- panel width: $B = 1000$ mm;
- stiffener spacing: $b = 300$ mm;
- panel length: 1000 mm (one-bay structure), 1200 mm (one-bay structure), 3000 mm (three-bay structure of 1000 mm length);

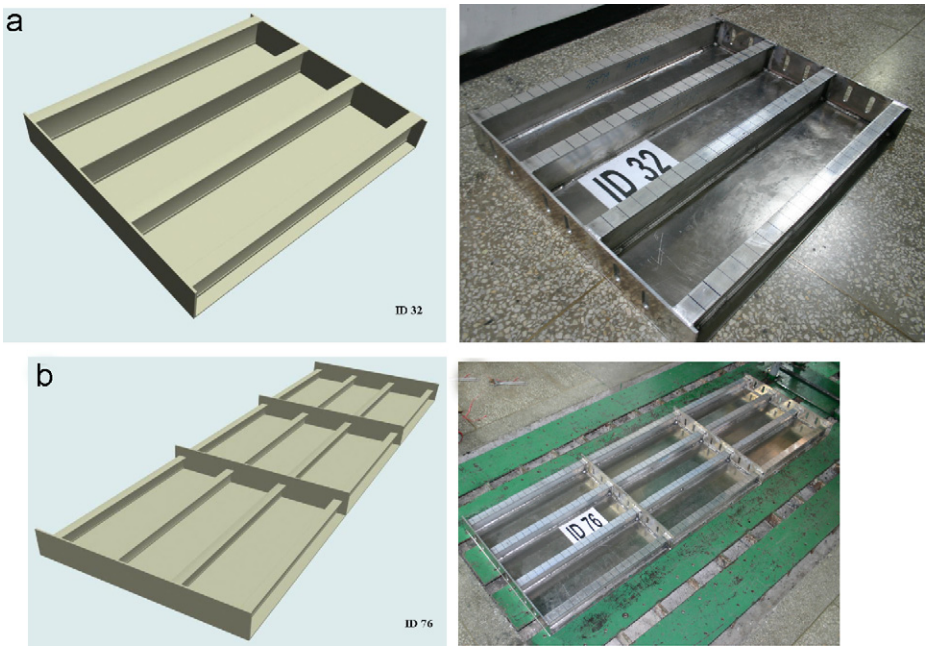

Fig. 1. (a) One-bay prototype structure. (b) Three-bay prototype structure.