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Empirical formulations for predicting the ultimate compressive strength of welded aluminum stiffened panels

Jeom Kee Paik*

Department of Naval Architecture and Ocean Engineering, Pusan National University, Busan 609 735, Republic of Korea

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Abstract

The present study was undertaken by the support from Ship Structure Committee (http://www.shipstructure.org), a North American-based interagency research and development committee, in association with SR-1446 project, and also from Alcan Marine, France. Empirical expressions are developed for predicting the ultimate compressive strength of welded aluminum stiffened panels used for marine applications. Existing data of the ultimate compressive strength for aluminum stiffened panels experimentally and numerically obtained by the SR-1446 project is used for deriving the formulations which are expressed as functions of two parameters, namely the plate slenderness ratio and the column (stiffener) slenderness ratio. The formulae implicitly include the effects of weld induced initial imperfections, and softening in the heat affected zone.

Keywords: Welded aluminum stiffened panels; Ultimate compressive strength; Initial imperfections; Nonlinear finite element method; High-speed vessels

1. Introduction

In recent years, high-strength aluminum alloys have increasingly been used for building high-speed vessels, and other types of weight-critical structures. In such structures, stiffened panels are the basic strength members. In this case, the calculation of collapse strength of stiffened panels in deck and bottom structures is required for structural design and safety assessment.

The stiffened panels of ship structures are generally subjected to combined loads arising from hull girder actions, but a primary load component is axial compression. Theoretically, possible collapse modes of a stiffened panel subject to predominantly axial compressive loads can be categorized into the following six types [1,2], namely

- *Mode* I: Overall collapse after overall buckling.
- *Mode* II: Collapse of plating between stiffeners without failure of stiffeners which may typically occur under biaxial compression.
- *Mode* III: Collapse as a beam-column, i.e.,plate-induced or stiffener induced failure of stiffeners together with attached plating.
- *Mode* IV: Buckling of stiffener web.
- *Mode* V: Torsional-flexural buckling or tripping of stiffeners.
- *Mode* VI: Gross yielding.

The collapse of stiffened panels will occur at the lowest value of ultimate loads calculated from each of the above six collapse patterns, although some interactions between the various collapse patterns may exist in some cases. A number of theoretical and numerical methods have been suggested in the literature for predicting the ultimate strength of stiffened panels made of steel [3]. The numerical methods take an "implicit form" where numerical computer programs or procedures have been provided. However, it is often desirable to use closed-form expressions for the calculation of ultimate strength of stiffened panels, because they can be more useful in terms of design formulae, or failure functions for reliability analysis [4,5], although some precautions must be paid to adjust factors of safety in association with uncertainties and deviations due to the strength modeling.

*Tel.: +82 51 510 2429; fax: +82 51 512 8836.
E-mail address: jeompaik@pusan.ac.kr.

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In contrast to steel stiffened panels, the related study in aluminum stiffened panels is limited at least for marine loading intensities and geometries [6], although some useful formulations of the ultimate compressive strength of aluminum stiffened panels have been found in the literature [7–11]. Some benchmark studies between the existing formulations are undertaken by Collette [6] and Paik et al. [12].

The present study was undertaken by the support from Ship Structure Committee, a North American-based interagency research and development committee (http://www.shipstructure.org), in association with SR-1446 project titled "Mechanical collapse testing on aluminum stiffened panels for marine applications" [13], and also from Alcan Marine, France.

The aim of the present study is to derive closed-form expressions for predicting the ultimate compressive strength of stiffened panels used for marine applications. The formulae are developed by the regression analysis of existing data on ultimate compressive strength of welded aluminum stiffened panels, experimentally and numerically obtained by the SR-1446 project [13]. The present paper is a sequel of the author's two papers previously published in the literature [11,14].

The yield stress (at 0.2% offset) is denoted by σ_{Yp} for plating and σ_{Ys} for stiffeners. The ultimate tensile stress of material is σ_{T} and fracture strain is ε_{f}. The elastic modulus is E and the Poisson ratio is ν. The entire length of a stiffened plate structure is denoted by L; and the spacing of longitudinal girders, transverse frames and longitudinal stiffeners are B, a and b, respectively, as shown in Fig. 2.

The thickness of plating is denoted by t. The panel has n_{s} stiffeners in the longitudinal direction. Unlike steel stiffeners that are usually built up from rectangular sections, aluminum stiffeners are extruded into optimized shapes as shown in the inset to Fig. 1, where the extruded stiffener is attached to the plate with fillet welds, while an integrated extrusion may sometimes be applied as well.

In specific cases, it is to be recommended that all dimensions and properties specific to a plate and stiffener combination with an extruded stiffener geometry be obtained from the manufacturer. For the present study purpose, the geometry of stiffeners will be idealized into one of three types as indicated in Fig. 3, where the height and thickness of the stiffener web are h_{w} and t_{w},

2. Nomenclature: aluminum stiffened panels

Fig. 1 shows a stiffened plate structure for marine applications, composed of plating and support members (longitudinal stiffeners, longitudinal girders and transverse frames), typical for aluminum high-speed vessel structures. Due to the relatively low stiffness of aluminum as compared to steel, and in consideration of response to global hull bending loads, most aluminum vessels are longitudinally stiffened, that is, the plating between longitudinal girders and transverse frames is rigidified with a number of extruded sections in the longitudinal (ship's length) direction.

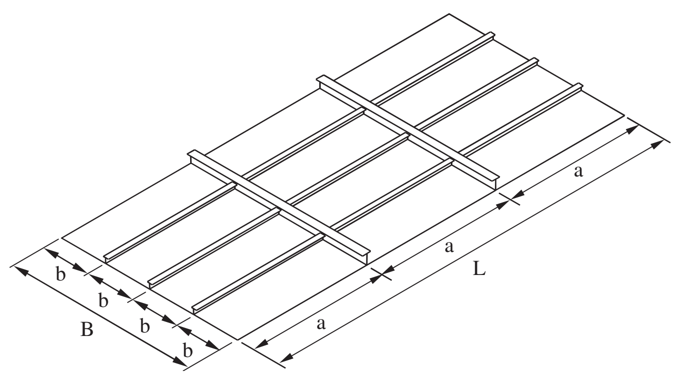

Fig. 2. Nomenclature for a stiffened plate structure.

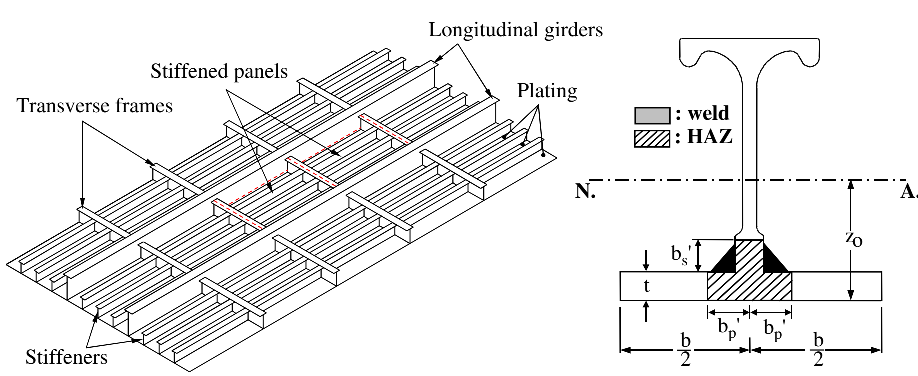

Fig. 1. A profile of typical aluminum stiffened plate structure with schematic of an extruded stiffener welded to plating, for marine applications (N.A. = neutral axis).