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Ultimate compressive strength design methods of aluminum welded stiffened panel structures for aerospace, marine and land-based applications: A benchmark study

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Abstract

The high strength-to-weight advantage of aluminum alloys has made it the material of choice for building airplanes and sometimes for the construction of land-based structures. For marine applications, the use of high-strength, weldable and corrosion resistant aluminum alloys have made it the material of choice for weight sensitive applications such as fast ferries, military patrol craft, luxury yachts and to lighten the top-sides of offshore structures and cruise ships. And while, over the last two decades, the ultimate limit state (ULS) design approach has been widely adopted in the design of aerospace and land-based (steel) structures, it is just recently being considered as a basis for the structural design and strength assessment of ships and offshore structures. Practical ULS methods or design codes are available in the aerospace and civil engineering industries, but they are just now being developed for use by the marine industry. The present paper compares some useful ULS methods adopted for the design of aerospace, marine and land-based aluminum structures.

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A common practice for aerospace, marine and civil engineering welded stiffened panel applications is discussed.

Keywords: Aluminum stiffened panel structures; Aerospace structures; Marine structures; Land-based structures; Buckling; Post-buckling; Ultimate limit state design; Ultimate strength

1. Introduction

There exist common issues in the structural design of airplanes, ships and land-based structures that usually are addressed differently. Most of the issues are different due to the inherent nature of the structures in themselves and in particular due to the loads, structural response, geometries and fabrication practices for each of these types of structures.

However, ships, airplanes and some land-based structures share a common aspect in that they use the stiffened panel as the building block of the primary load-carrying structure. The design of large parts of ship and airplane structures is primarily driven by compressive strength, where for civil transport aircraft the structural response of the upper wing and the lower fuselage shell may be likened to the structural behavior of a ship's hull girder (bottom, deck and side shells).

The structural stability of these thin-walled structures subjected to compressive loads is dependent on the buckling strength of the structure as a whole and of each structural member. For stiffened aerospace panels (high span-to-thickness ratio), the onset of buckling usually takes place in the skin, i.e., plating between stiffeners.

Marine stiffened panels are designed with sturdier stiffeners (e.g. bulb-flats or tees) so that they may meet other modes of failure rather than elastic panel buckling [1]. In both cases, the stiffness of the panel as a whole is significantly reduced after buckling, where the ultimate strength of the panel has normally not yet been reached since the panel enters into a post-buckling regime, a complex inelastic process being better described as panel failure or collapse. The final collapse state called the ultimate limit state can be formed by a combination of local buckling phenomena for plating and stiffeners or by a global 'folding' (or overall buckling) of the panel. In any case, the ultimate strength is not reached until the load versus end-shortening curve reaches its maximum, at which point several local buckling phenomena can already be active.

The design of aerospace stiffened panels under compressive loads needs methods which can predict buckling, post-buckling and ultimate strength behavior. These methods are based on Euler's column buckling analysis and Timoshenko's theory on the elastic stability of plates and shells [2].

These aerospace methods, where needed, combined with a correction for material plasticity, can easily predict the onset of buckling of perfect panels. While it may be possible to consider geometric imperfections as parameters of influence in these methods, it is not straightforward to take into account other types of imperfections such as thermo-mechanically affected zones (TMAZ, also described as HAZ, heat affected zones) and residual stresses from welding.

Marine structural design analysis has historically been simplified and experience-based. This is due to the intrinsic nature of ships, being hand crafted, generally one-off,