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Full-field analysis of AL/FE explosive welded joints for shipbuilding applications

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ABSTRACT

Nowadays explosion weld is widely used in marine structures, thanks to its reliability. AL/FE explosive welded joints, used in shipbuilding applications, were investigated in this research activity. Static and fatigue bending tests were carried out on rectangular specimens made of ASTM A516 low carbon steel, clad by explosion welding with A5086 aluminum alloy and provided with an intermediate layer of pure aluminum. Two full-field techniques were applied during the bending tests: Digital Image Correlation and Infrared Thermography. The digital image correlation technique allowed determining the displacement and strain fields showing that the aluminium side has a higher strain with respect to the steel side, and Infrared Thermography was used to detect the superficial temperature of the specimen allowing the determination of the fatigue limit. The fatigue limit values, predicted using the Thermographic Method during static and fatigue tests, are in good agreement with the experimental values of the fatigue limit.

1. Introduction

The use of dissimilar metals is of fundamental importance for ship or offshore structures as the need to have good properties in terms of cost, weight, producibility, marine corrosion, fatigue, fire resistance, vibration and sound damping. Unfortunately, many dissimilar metals cannot be welded by traditional methods and require mechanical joining solutions, such as bolting or riveting. The major problem that may arise with mechanical joints is the presence of both crevice and galvanic potential differences, which tend to produce corrosion at bolted or riveted joints after a relatively short service life.

Aluminium/steel welded joints have been widely adopted in different industries, but they find their main application in the shipbuilding industry [1]. Explosion welding [2] provides a solution for shipyard fabrication of reliable aluminium-steel structures. The explosion welding (EXW) process is a solid state welding process that uses the high energy of explosives to cold weld two dissimilar metal components. The metals are welded due to plastic deformations that occur at the collision front of the metals surface by means of a chemical explosive charge. Interface morphology and weld strentgth strongly depend from impact velocity and impact angle [3] and it is very common to use an intermediate plate due to the difficulty of welding directly alluminium alloy and steel [4,5]. In 1962 DuPont patented the explosion welding process after developing it in the 1950s. Working with the US Navy, DuPont developed the Detacouple® Transition joint concept for making aluminium-steel welds. Currently, EXW process is used extensively in the marine and shipbuilding industry (ferries, cruise ships, naval vessels and offshore structures) for its ability to make a metallurgical joint between highly dissimilar metals with an adequate corrosion resistance. The galvanic corrosion can be totally avoided only by complete electrical insulation of the metal components; a solution almost impossible to achieve. Galvanic corrosion problems are significantly increased when the components are mechanically joined, as rivets and bolts can create gaps in which crevice corrosion

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develops. EXW replaces the mechanical joints, solving the problem of crevice corrosion. Absent of the crevice, traditional paint and other common coatings provide reliable control of galvanic corrosion.

Findik reviewed the recent developments in explosive welding [6], while an example of connection of aluminium superstructure to steel deck was reported in Ref. [7]. In this way, the aluminium and steel structures can be welded to the respective surfaces of the transition joints, made of the same metal, using conventional fusion welding processes. The corrosion resistance and mechanical properties of explosion welded joints were investigated in Ref. [8]. An extensive battery of tests was conducted in the past [8] and experimental investigations of explosive welding of aluminium to steel were reported in Refs. [9,10].

It is necessary to bear in mind that weight minimization of the superstructures achieved with a material, as aluminium alloys, characterized by a low Young modulus leads to more flexible structures, proner to dynamic effects and consequently to possible fatigue collapse. Thus, the fatigue analysis becomes of the utmost importance especially for welded joints, that are intrinsically weak, due to the presence of crack-like defects along with high stress concentration effects and tensile residual stresses caused by the thermal welding process itself. It is also necessary to point out that light alloys are in general less resistant than steel to cyclic loads, and moreover that the effect of fusion welding on lowering the fatigue limit is greater for such alloys.

In order to meet the ever growing request of more efficient ships, the shipbuilding industry is engaged in the design and construction of ships quite different from the traditional ones, and conceived according to the “lightweight design” philosophy. Therefore, new materials and technologies have been adopted, and, as a consequence, a lack of experiences concerning the fatigue behaviour of many structural details has become apparent.

As the engineering practice of using various joint geometries and new welding techniques finding increased use, it's possible that some welded details are not considered by any codes. In particular, it is necessary to acquire a better knowledge concerning the fatigue behaviour of structural details built up resorting to new technologies like bimetallic joints obtained through the Explosion Welding technique. The above-mentioned need for more reliable data is indeed recognized both by the shipbuilders and by the Classification Societies.

The aim of this paper is to investigate the static and fatigue behaviour of exploded welded joints, used for shipbuilding applications, in order to give designers information regarding the static strength and fatigue curve of the mentioned type of explosive welded joint, using full-field techniques: Digital Image Correlation (DIC) and Infrared Thermography (IR).

Full-field techniques were already applied by some of the authors for the assessment of different materials used for marine structures: aluminum T-shaped welded joints under high cycle fatigue loading [11], steel T-shaped welded joints under low cycle fatigue loading [12], and Iroko wood under static loading [13,14].

2. Materials and methods

Static and fatigue bending tests were carried out on explosive welded specimens, which are produced by TRICLAD for shipbuilding applications. Fig. 1 shows the investigated specimens. Table 1 reports the mechanical properties of the three metals involved, which are made of three layers: a 19,5 mm thick lower layer of ASTM A516 Gr55 structural steel, an intermediate layer of AA 1050 commercial pure aluminum with a thickness of 9.5 mm, and an external upper layer of 6 mm made of AA 5086 aluminum alloy. As visible from Fig. 1, the interface between the pure aluminium and aluminium alloy is wavy, while the interface between the steel and pure aluminium is straight. The interface between two metals can vary from wavy to straight, due to the impact energy and the metals involved in the process.

The static three points bending tests were performed at a displacement rate of 4 mm/min using a servo-hydraulic load machine (*INSTRON 8854*). The support span L was set equal to 300 mm. The fatigue bending tests were carried out using cyclic loads at a frequency f = 5 Hz and at a load stress ratio R = 0.1. The support span L was set equal to 280 mm. The fatigue tests were performed using an *ITALSIGMA* servo-hydraulic load machine with a 25 kN capacity. For each specimen, the tests were carried out with a constant value of the load range till failure. Specifically, different levels were applied in order to obtain the S-N curves. If failure did not occur within 5 million cycles, the test was suspended. The *ARAMIS 3D 12M* system was used for the Digital Image Correlation

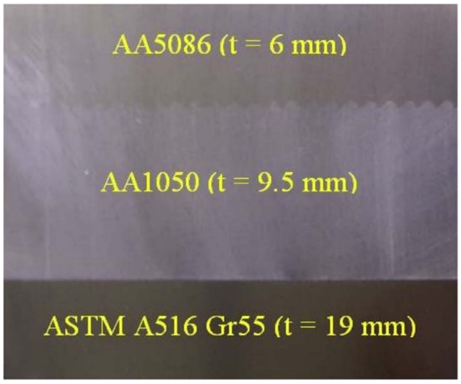

Fig. 1. TRICLAD explosive welded joints.