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On the fatigue durability of clad 7075-T6 aluminium alloy bonded joints representative of aircraft repair

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ABSTRACT

The fatigue durability of bonded joints representative of repairs to aircraft structure with and without the presence of a clad layer was investigated by testing aluminium alloy 7075-T6 double lap shear joint specimens. This was done by changing the bonding interface of the outer strap. The joint geometry, central adherend material, adhesive and surface preparation method were all kept the same. On two of the specimen types, the strap material was clad 7075-T6, with one type fabricated with the clad layer left on prior to surface preparation, and the other with the clad layer removed. On the last specimen type, the strap material was unclad 7075-T6. The test results showed that the fatigue durability was lowest when the clad layer was left in-situ, followed closely by those with the clad layer removed. The unclad specimens achieved a fatigue life one order of magnitude greater than those with the clad layer physically removed. Under constant amplitude loading, adhesive fatigue cracking was observed at the location of peak load transfer, which progressed to the interface. Analysis showed that the cracking caused a substrate stress concentration which may have caused the clad fracture. Further analysis, supported by test observations, showed that once a small notch had formed at the interface, damage progression through the outer strap was rapid.

1. Introduction

Bonding to clad aluminium interfaces for aircraft repair has been a contentious issue for many years. Lap shear testing after exposure to a salt fog environment [1] confirmed that joints bonded without the removal of the clad performed worse than the samples with the clad layer removed. It was also shown more recently [2] that repair joints with considerable Mode I or peel stress in the adhesive exhibited crack growth near to the clad interface, which was not observed for the unclad aluminium samples.

Other studies showed that the differential between clad and clad-removed lap-shear samples in a salt-fog environment could be mitigated through the use of chromate bond primers [3]. In other words, the clad layer became less critical in harsh operating environments, provided the adherends were protected with the chromate bond primer. In a recent study examining the performance of the surface treatment of clad and unclad aluminium 7075-T6 alloy using the Boeing wedge test in a hot wet environment [4], the clad joint was actually shown to have a higher fracture toughness.

To further examine the influence of either leaving the clad layer in situ, or removing it in preparation for a bonded patch repair, clad, clad removed and unclad 7075-T6 aluminium joints were prepared that represented the critical region of a typical repair. The joints were tested under constant amplitude fatigue loading in room temperature ambient conditions. The testing revealed some unexpected fatigue failure modes which were subsequently investigated with fractograpy. Fractography was used to examine the modes of failure, including identification of the path of the cracking and the relative speed of the crack progression, of each of the three specimen types. Finite Element Analyses (FEA) was performed to investigate the role of the clad layer in the progression of cracking within the joint, and to develop a methodology to account for the clad layer in the design of adhesively bonded joints.

2. Experimental method

The fatigue specimens were designed to represent typical aircraft repair joints, with symmetry used to prevent excessive bending and peel stress in the adhesive. The specimens were prepared in 205 mm × 250 mm plates, and then cut into 38 mm wide specimens. The design of the specimen is shown in Fig. 1. The edges of the specimens were machined square, and then polished with 1000 grit emery paper. The plates were bonded

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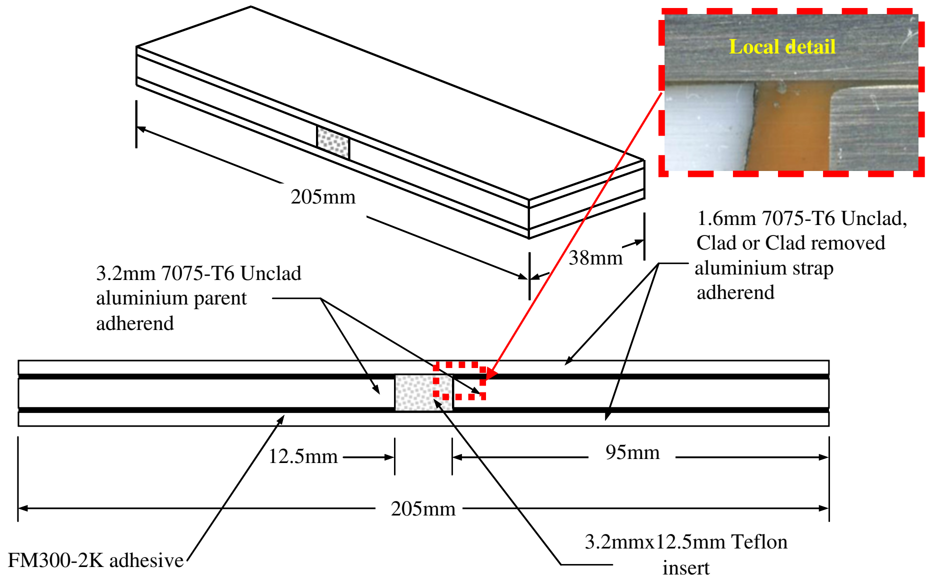

Fig. 1. Schematic of the representative joint specimen.

Fig. 2. Aluminium alloy 7075-T6 dog-bone specimen with edges treated with the Australian grit-blast silane surface preparation procedure.

Table 1
Specimen type descriptor definition.

Descriptor	Specimen type description
Unclad	Specimens with the outer adherend straps fabricated from 7075-T6 bare sheet.
Clad	Specimens with the outer adherend straps fabricated from 7075-T6 clad sheet.
Clad removed	Specimens with the outer adherend straps fabricated from 7075-T6 clad sheet after the clad layer had been removed.

together with FM300-2K adhesive from Cytec with an areal density of 488 g/m^2, and cured for 2 h at 120 °C in an autoclave with 100 kPa positive pressure Fig. 2.

Three different outer strap adherends were used in the manufacture of the specimens. The strap material was 7075-T6 sheet, with one set of specimens fabricated with clad material, one with the clad layer physically removed and one with no clad layer. The clad layer itself was identified as 7072-0 condition material and measured to be between 0.10 and 0.20 mm thick. The clad layer is metallurgically bonded on the core material during fabrication to provide corrosion protection. The descriptors used to denote each of the specimen types throughout the remainder of the report are provided Table 1. The clad was removed by mechanically abrading the surface with a 3M Scotch-brite^{TM} pad (Type 7447). The complete removal of the clad was verified by dropping small amounts of sodium hydroxide diluted with distilled water. The sodium hydroxide solution dissolves the clad aluminium producing a colour change. Mechanical abrasion was continued until the sodium hydroxide solution test was passed. The Australian "grit-blast silane" method of surface treatment [5] was used to prepare each of the adhering surfaces for bonding. No bond primer was used in the surface preparation procedure.

In addition, dog-bone specimens were fabricated from the same sheet used to fabricate the outer straps, and were obtained from unclad bonded joint specimens. The purpose of these specimens was to examine whether the surface preparation procedure unduly influenced the durability of the strap adherend, isolated from the effect of it being in a bonded joint configuration or coated with a clad layer. Previously prepared bonded joint specimens were submerged in liquid nitrogen to weaken the adhesive, and then separated. The outer straps were shaped into a dog-bone, and then tabs were attached. The edges of the test section were degreased with methyl–ethyl–ketone (MEK), abraded with a Scotchbrite^{TM} pad (Type 7447), and then grit-blasted. These specimens are referred to as "*strap only*".

Fatigue testing was conducted on a servo-hydraulic machine (MTS Systems Corporation, USA, Model 318.10, force capacity = 100 kN, USA) under constant amplitude loading at a frequency of 5 Hz Previous fatigue test studies [6] with a lower performing adhesive (FM73) showed the fatigue life had no frequency dependence in the range 2–10 Hz. A stress ratio of 0.1 was selected, which is defined as the maximum stress divided by the minimum stress. The peak applied stress levels chosen for fatigue testing of the bonded joints and the "strap only" are provided in Table 2. Note that the average stress in the outer strap of the bonded joint specimen at the mid point is double what it is near the specimen ends. The axial stress in the strap removed from the central region is referred to as the far field stress of the bonded joint specimen. The axial stress in the outer strap at the mid-point is referred to as the reference stress of the bonded joint specimen. The axial stress in the mid-point of the "strap only" specimens is referred to as the reference stress for these