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Some contraindications of hole expansion in riveted joints

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ABSTRACT

Comparable fatigue tests were carried out on aluminium alloy 7475-T7351 double butt joints with untreated and with cold expanded holes. Surprisingly, the behaviour of the specimens having cold expanded holes was worse than that of specimens with untreated holes. This result was attributed to the surface upset which was present in cold expanded holes. Several hypotheses were formulated and experimentally verified to overcome this problem, such as deeper hole deburring, rivet diameter, joint design and grip material, steel instead of aluminium alloy.

Additional tests demonstrated that the problem was not present in sealed joint as the surface upset was hidden in the sealant thickness. Sealants have detrimental effects in the fatigue resistance of riveted joints, as they increase the load transferred by rivet bearing. The hole expansion is beneficial in this condition, while in un-sealed joints its effect must be accurately evaluated.

Other authors too highlighted possible problems due to surface upset, up to suggest to eliminate it. Only in a very few cases, a reduction of fatigue life as a consequence of hole expansion was observed.

1. Introduction

Cold expansion is a technique typically used in aerospace field to improve the fatigue resistance of rivet holes, Fig. 1. The process is mainly used to recover fatigue problems manifested in-service; less commonly, the cold expansion is used in new designs to improve the resistance of fatigue critical components. The cold expansion principle consists of introducing, at the fatigue critical hole, a compressive residual stress field, which, when combined with the stresses due to fatigue loading, results in a lower mean value of the local stress, with beneficial effects for the fatigue resistance.

Even if the process is intended to mitigate fatigue problems in rivet installation holes, a large part of the relevant bibliography concerns the behaviour of holes not having a rivet installed, commonly referred as "open holes". These papers, limiting our attention to some of the most recent, deal with the numerical or the experimental evaluation of the residual stresses introduced by cold expansion [1–7], the nucleation or the propagation of fatigue cracks in cold expanded holes [8,9]. One paper is concerned with a new technique for hole expansion [10], whose efficiency is evaluated by fatigue tests performed on open hole specimens.

The activity described in the present paper originated as a prosecution of a previous larger research activity performed at the Department of Aerospace Engineering of the University of Pisa, (now Department of Civil and Industrial Engineering,

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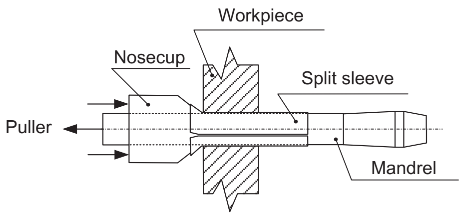

Fig. 1. Split sleeve cold expansion.

DICI) in cooperation with Agusta-Westland (Cascina Costa di Samarate) on the fatigue behaviour of cold expanded holes. A riveted joint was designed by starting from the geometry of an actual component which manifested fatigue problems in practice. Surprisingly, the fatigue resistance of the joints worsened after the cold expansion of the holes. A first review of the available references put in evidence a paper [11] where the fatigue worsening was ascribed to the presence of a surface upset in cold expanded holes; this effect was named "volcano effect".

Surface upset is a surface protrusion, having a volcano shape, which is produced as a consequence of the hole expansion, both on the entry and on the exit sides of the mandrel. Cold expansion is typically performed using FTI (Fatigue Technology Inc., Seattle) tools. FTI manuals [12] discuss the formation of the surface upset. It is believed that most of the surface upset is removed during hole reaming, and that in any case its presence is not harmful to the fatigue resistance. According to the results of the present activity, this statement does not seem applicable to the different combinations of materials and geometries.

Coming back to the technical literature, a limited number of papers deal with riveted joints; often the necessary information about surface preparation and rivet installation are not given, (see for instance [13,14]). In some cases the information given show test conditions not representative of the surface preparation of aerospace joints; for instance, in [15], discussing of a high load transfer joint, the author notes that, in absence of interference fit in the fastener installation, there is no significant influence of cold expansion on fatigue life. Surfaces were polished with a 800 grade paper in the longitudinal direction and the polished faces were clamped together, after degreasing, without any interface treatment. This preparation is not representative of aerospace riveted joints. Similarly in [16] the specimens, after machining and creating the hole, were polished using various grits of fine and ultra-fine sand papers to eliminate surface scratches. The specimen was a double shear lap joint; the results obtained show the equivalence, from the fatigue point of view, between the hole expansion and the interference fit installation of the rivets. Actually rivets used were pins, not clamped on the specimens. Also this situation is not representative of aerospace joint preparation.

Particularly interesting from the point of view of the present work is a forty years old paper [17]; the author observes that surface upset in expanded holes produces localised bearing and high contact pressure; these events are unfavourable for fretting. The shape and the dimensions of the surface upset are given both at the exit and the entry faces. To overcome the problems connected to the surface upset the author used "micarta shim, 0.254 mm thick" inside the joints. This stratagem improved the fatigue resistance; the same goal was obtained by removing the surface upset before the specimen assembly. In our experience, information given in this paper is very important and practically unknown for most researchers.

The present paper is inserted in this context; the activity started to quantify the beneficial effect of hole expansion in a high transfer load joint, while in reality has come to identify some possible limitations of the method. In particular, the fatigue results relevant to specimens having cold expanded holes were worse than those relevant to specimens with untreated holes. Several hypotheses were formulated and experimentally verified to overcome this problem, without appreciable results. The actual cause of the result obtained was identified in the surface upset which was present in cold expanded holes. Additional tests demonstrated that the problem disappears in sealed joint as the surface upset is hidden in the sealant thickness. As a consequence the hole expansion in joints that for some reasons are not sealed must be accurately evaluated.

2. Materials, geometry and preparation of riveted specimens

The material under examination was an aluminium alloy, 7475-T7351, thickness 5 mm. Metal sheets were treated by Alodine and painted by epoxy-primer Akzo Nobel 37076; these operations were performed at Agusta-Westland, so to guarantee industrial quality standards. Specimen machining and final assembly was performed at DICI.

The specimen was a double-butt joint Fig. 2, connected by one threaded aerospace fastener HL20PB70-6-6 (type HL20; PB: cadmium plated; collar: HL70; diameter: 6/32 in.; grip length 6/16 in.). Grain direction was longitudinal in all the specimens. The main dimensions of the specimens, i.e. rivet diameter and specimen width, which is equal to the pitch in a multi-rivet joint, were established on the basis of the design of an actual helicopter structure, which manifested unexpected fatigue cracks.

The specimen was design to minimise, as soon as possible, the number of fatigue critical locations; for this reason, only one rivet is present. The final hole diameter after reaming was 4.83 mm; as a consequence rivets were assembled by clearance, being their nominal diameter equal to 4.76 mm. This choice, certainly open to criticism, is common in aerospace