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Technical Report

An experimental investigation of the bolt clamping force and friction effect on the fatigue behavior of aluminum alloy 2024-T3 double shear lap joint

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ABSTRACT

In this article, the effect of bolt clamping force on the fatigue life of bolted double shear lap joints was investigated. To do so, fatigue tests were carried out on the bolt clamped double shear lap joint specimens made of aluminum alloy 2024-T3. These fatigue tests were conducted with applied torques of 0.25, 2 and 4 N m at different cyclic longitudinal load levels in un-lubricated and lubricated states. From these tests the stress–life (S–N) data for different clamping forces for un-lubricated and lubricated states were obtained. The results show that clamping force increases fatigue life compared to clearance fit specimens. In general, at higher tightening torque higher fatigue lives were achieved, however, below a certain load level the life improvement was discontinued because of fretting phenomenon. Also lubricating the parts of the specimens reduces the advantage of clamping force or torque tightening.

1. Introduction

The attachment of mechanical components is a crucial part of every design process especially in aerospace industries. An optimum choice of a connection method has to guaranty maximum durability, low cost, simplicity and above all the safety of the design. The need to design a proper joint becomes more imperative for components under cyclic loadings. Detachable joints such as fastener bolts and location pins have been widely used for these purposes. High durability and the ease of detachment are the primary features of these joints which render them as a popular joining technique in assembly of airframe structures. Nevertheless, the inherent problem with these joints is employment of drilled holes which create convenient sites for crack initiation during cyclic loading. Accordingly, numerous attempts have been made to devise an applicable method to improve the load carrying capacity and fatigue life of these joints. Among the highly recommended methods are cold expansion and interference fit, in which compressive residual stress and pre-stress are created around the fastener hole to make the joint more resistant to cyclic load damage [1–6]. The bolted joints, due to their proven superior performance under static and cyclic loading [7], have been widely utilized for connecting key components in the structure of modern aircrafts. An important advantage associated with using bolted joints as compared with other detachable joints such as riveted ones is due to the possibility of creating a clamping force, i.e. pre-tension in the bolt, by means of torque tightening. This would in effect, lead to friction induced beneficial division of any longitudinally applied load between the plate and the bolt shank with the division ratio primarily depending on the amount of applied load. However, due to the oscillatory motion during cyclic loading, the friction between the bolt tightened plates renders the joint prone to fretting fatigue especially when high tightening torques are employed. Nevertheless, bolt clamping force not only alleviates the detrimental tensile longitudinal stress around the hole but also reduces the stress intensity factor of any fatigue crack emanating from the hole [8–10].

In addition to metallic material joints, bolt clamping effect has been studied in composite material joints as well. To design composite structures containing bolt hole and open holes, stress analysis was carried out for laminated composite using different failure criteria to predict failure in a bolted laminated composite material [11]. An experimental study conducted on bolt clamping effects on the tensile strength of composite plates with a bolted hole showed that for bolted joints which failed in a tension mode, clamping improved the joint strength regardless of the ply orientation [12]. The bearing strength and failure mode in glass fiber reinforced epoxy laminated composite plate were investigated experimentally and it was shown that bearing strengths increase by increasing bolt pre-load [13].

Experimental and numerical investigation carried out on single cold expanded holed plate made from 7075-T6 aluminum alloy shows that bolt clamping the cold expanded hole improves the compressive tangential residual stress by increasing its magnitude and making its distribution uniform thus enhancing fatigue life [14]. A research on the structural fatigue and joint degradation in single lap riveted joint made of Al-alloy 2024-T3 concluded that

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