Engineering Failure Analysis 45 (2014) 406–420

Contents lists available at ScienceDirect

Engineering Failure Analysis

journal homepage: www.elsevier.com/locate/engfailanal

Investigation of bolt clamping force on the fatigue life of double lap simple bolted and hybrid (bolted/bonded) joints via experimental and numerical analysis

F. Esmaeili *, T.N. Chakherlou, M. Zehsaz

Faculty of Mechanical Engineering, University of Tabriz, P.O. Box 51666-14766, Tabriz, Iran

A R T I C L E   I N F O

Article history:
Received 22 January 2014
Received in revised form 13 July 2014
Accepted 15 July 2014
Available online 23 July 2014

Keywords:
Torque tightening
Clamping force
Hybrid joint
Fatigue life
Bonded joint

A B S T R A C T

In this research, the effect of bolt clamping force on the fatigue life of double lap simple bolted and hybrid (bolted/bonded) joints have been studied both experimentally and numerically. To do so, two kinds of joints, i.e. double lap simple and hybrid (bolted/bonded) joints were studied. For each kind of the joints, three sets of specimens were prepared and subjected to tightening torque of 1, 2.5 and 5 N m and then fatigue tests were carried out at different cyclic longitudinal load levels. Experimental tests revealed that the hybrid joints have higher fatigue life in comparison with the simple bolted joints. In the numerical method, finite element code was used to obtain stress distribution in the joint plates due to clamping force and longitudinal applied loads. Numerical simulation and experimental results showed that the fatigue life of specimens was improved by increasing the clamping force due to compressive stresses created around the hole. In addition, the investigation revealed the positive role of clamping force resulting from torque tightening on the fatigue life of both simple and hybrid joints.

1. Introduction

Detachable joints such as bolted, riveted or pined ones are frequently used in aerospace industry for connecting various parts. Among the mentioned detachable joints, bolted joints are the most important elements in aerospace structures. However, the existence of geometrical discontinuity in these joints due to essential hole drilling process causes stress concentration and thus increases the tendency of early fatigue crack initiation and grow under cyclic loading [1–4]. On the other hand, easy dismantling that simplifies repairs and permits replacing of damaged components makes these types of joints favorite for extensive use in aerospace structures. Therefore, it is of great importance to reduce the effect of stress concentration and attain enhanced fatigue life [5]. According to results of previous researches, bolted joints have higher tensile and fatigue strengths than welded, riveted and pinned joints [6,7].

An alternative method to mechanical fastening is adhesive bonded joints. In order to perceive the advantages of adhesive bonding in fatigue, two fundamental differences are important between the two types of lap joints. First, in a mechanical joint, the overlapping areas are attached to one another at discrete points only, i.e. by the fasteners. Obviously, severe stress concentrations should occur. However, if the connection is made continuously in the full overlapping area by adhesive bonding, these stress concentrations do not occur. Because, the adhesive bonded joints do not need to the fasteners and fastening

* Corresponding author. Tel.: +98 411 3392492.
E-mail address: f.esmaeili@tabrizu.ac.ir (F. Esmaeili).

http://dx.doi.org/10.1016/j.engfailanal.2014.07.014
1350-6307/

holes. Therefore, the stress distributions in the joint are relatively uniform compared with those in the mechanical joint. Secondly, metallic direct contact between the two sheets does not happen in the adhesively bonded joints [7].

In order to employ the advantages and avoid the disadvantages of adhesive bonding, and mechanical joints, and therefore, to obtain high performance joints, a combination of mechanical joints (riveted, bolted, etc.) and an adhesive, namely hybrid joints, are used [8–11]. Hybrid joints are used in many engineering application such as aerospace, automotive, and naval industries because of their better performance compared to simple joints such as adhesively bonded, welded and mechanically fastened joints [12,13]. Hybrid joints have also been used for the repair and improvement of damage tolerance [14,15].

Several researchers [15–20] have investigated the hybrid joints. An analytical investigation was conducted by Hart-Smith [11] on a hybrid joint with stepped lap joints. The strength of hybrid joints was found to be the same as well-designed bonded joints. Chan and Vedhgiri [16] conducted experiments with composite joints as well as a parametric study using finite element analysis to study the stacking sequence effect on joint strength. Barut and Madenci [18] developed a semi-analytical solution method for stress analysis of a hybrid joint and they revealed that the adhesive, despite the fact it has low modulus compared to the bolt, transfers most of the load. Kweon et al. [21] detected a similar phenomenon in their experiments, where a double lap hybrid joint was employed using composite and aluminum adherends.

Pirondi and Moroni [28] compared the hybrid weld-bonded, rivet-bonded, clinch-bonded, and simple joints under various conditions, via experimental analysis. The effect of the material, geometrical factors, and environment on static strength and energy absorption were evaluated through the analysis of variance.

In other investigation, Gomeza et al. [13] proposed a mechanical model to reproduce the mechanical behavior of a hybrid (riveted-bonded) joint.

A similar investigation conducted by Schvechkov [29] on the effects of adhesive mechanical properties on the fatigue strength of hybrid (riveted-bonded) joints by means of experimental analysis.

In separate investigations, Kelly [17,30] studied the static and fatigue strength of the hybrid (bonded–bolted) hybrid single lap using different modulus adhesives. The results of studies, revealed that, the hybrid joints with lower modulus adhesives allowed for load sharing between the adhesive and the bolts.

Imanaka [31] showed that the fatigue strength of the adhesive joint can be improved through combination with a rivet whose fatigue strength is at least the one of the corresponding bonded joint.

A similar investigation conducted by Fu and Mallick [9]. They experimentally showed that the hybrid (bolted–bonded) single lap joints have a higher static and fatigue strength in comparison with only adhesively bonded joints.

In the hybrid joint, mechanical fastening is added to the bonded joint. The hybrid joint uses mechanical fastening in addition to bonding in an effort to overcome the potential weaknesses of adhesive bonding.

The hybrid joints may include weld-bonded, clinch-bonded and rivet-bonded connections [22–27]. It is important to note that, even though some limited research have been conducted on the analysis of hybrid joints, still static and fatigue strength data for the hybrid joint are lacking.

When a nut and bolt are used to join mechanical members together, the nut or bolt can be pre-tensioned by applying tightening torque using a torque wrench and then the bolt and nut are pulled toward each other. Pre-tension or clamping force is the technical term for the tension caused by tightening the nut that holds the assembled part together [32–38].

Previous works revealed that the clamping force can reduce the stress concentration at the bolted hole region, and therefore improve the strength of the joint considerably [32,39]. Collings [39] investigated the effects of bolt clamping pressure on the strength of bolted joints in CFRP laminates. Stockdale and Matthews [40] investigated the effect of clamping pressure on bolt bearing load in glass fiber-reinforced plastics experimentally. Deng and Hutchinson [38] investigated the residual clamping stress exerted by the rivets on the joint. The relation between the clamping and applied force was analyzed using finite element methods in the small strain framework.

In this research, the effects of clamping force on the fatigue strength of double lap simple bolted and hybrid (bolted/bonded) joints have been investigated both experimentally and numerically. To do so, two kinds of joints, i.e. double lap simple and hybrid (bolted/bonded) joints were studied. For each kind of the joint, three sets of specimens were prepared and subjected to tightening torque of 1, 2.5 and 5 N m and then fatigue tests were carried out on them at different cyclic longitudinal load levels. In the numerical method, finite element ANSYS code was used to obtain stress distribution in the joint plates due to clamping force and longitudinal applied loads.

2. Experimental procedures

The specimens employed in this investigation were made from 2024-T3 aluminum alloy with thickness of 2 mm. Table 1 lists the mechanical properties of the aluminum alloy obtained from tension (static) tests, while Table 2 presents the chemical compositions of the used aluminum alloy.

Table 1
Mechanical properties of 2024-T3 aluminum alloy.

Young's modulus (GPa)	Yield stress (MPa)	Tensile strength (MPa)	Poisson's ratio	Elongation (%)
72	315	550	0.33	18