JCAMECH

Vol. 49, No. 2, December 2018, pp 415-429
DOI: 10.22059/jcamech.2018.269612.342

A review on stress distribution, strength and failure of bolted composite joints

*Mohammad Shishesaz * and Mohammad Hosseini*

Department of Mechanical engineering, Shahid Chamran University of Ahvaz, Ahvaz, Iran

ARTICLE INFO

Article history:
Received: 2 November 2018
Accepted: 12 December 2018

Keywords:
Plated bolted joints
Nonlinear behavior
Design, fatigue strength and failure

ABSTRACT

In this study, analytical models considering different material and geometry for both *single* and *double-lap* bolted joints were reviewed for better understand how to select the proper model for a particular application. The survey indicates that the analytic models selected for the adhesively *single* or *double* bolted *lap* joints, as well as *T*, *scarf, and stepped* joints, with linear material properties are mostly two dimensional and the studies on stress distribution and/or failure of the joint are performed either experimentally, analytically or by finite element method. The results seem to be generally accurate and adequate. Additionally, it was shown that any increase in the bolt-hole clearance leads to an increase in bolt rotation, as well as a decrease in bolt-hole contact area, and hence, a reduction in joint stiffness. Moreover, studies on hybrid joints have revealed that the proper choice of adhesive material in conjunction with bolts or rivets in a joint, allows for significant increase in the static and fatigue strength compared to similar pure bonded joints. Additionally, the results on hybrid scarf joints showed that it is vital to place fasteners closer to the ends of the overlap to suppress the peak peeling stresses and hence, delay the effects of early crack initiation in the adhesive layer. Experimental studies on fatigue behavior and strength of bolted joints have shown that compared to clearance fit specimens, clamping force increases the fatigue life of a bolted joint. Moreover, higher tightening torque, in general, results in higher fatigue lives in bolted joints.

1. Introduction

In past decades, bolted joints have been extensively used as a mean for joining parts together. Parts can be joined by different means forming a *single* or a *double lap* joint or other possible forms [1]. Based on the different materials used for the adherends, numerous analytical models have been proposed in bolted or hybrid joints (a combination of bolt/rivet and adhesive) to predict the joint strength and/or failure. The results would help one to have a better understanding on stress distribution in the joint while using a suitable joint for any specific action. Bolted and riveted joints are subjected to two basic types of stresses; shear and bearing stresses. The stress distribution can be obtained either by a three dimensional or two-dimensional finite element analysis, whichever is suitable, or by a closed-form solution, if applicable. The method which is most attractive to an engineer is to set up a series of differential equations to describe the state of stress and strain in a unit width of the joint. The governed differential equations which are based on the selected material behavior of the selected model can be solved analytically, or numerically when a closed-form solution is out of reach. Sometimes, finite element procedure may be adopted to seek the solution. Consequently, the design engineer is confronted with a long list of models and may face a difficulty in finding the most appropriate one for a particular application. The objective of this work is to review the analytical and numerical models, based on the material behavior and type of joint type, to provide a guideline for selection of proper model for prediction of stress distribution and/or failure of the bolted or hybrid joints.

Typically, bolted or riveted joints can be divided into the

* Corresponding Author(s): mshishehsaz@scu.sc.ir

following basic types shown in Fig. 1, although some other structural joint configurations may be possible.

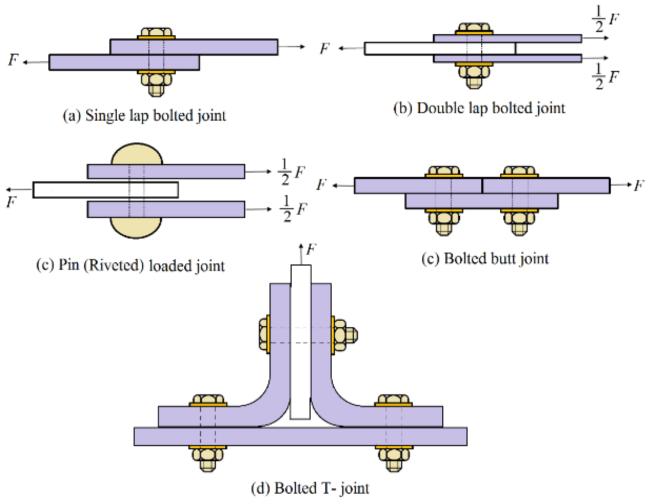

Figure 1: Some basic bolted and pin joints

Stress distribution in the bolted/riveted or hybrid joints depends on the joint geometry and mechanical properties of the adhesive and adherends. Among the main parameters affecting the stress field in the joint one may point to the gripping force, number of bolts/rivets, adherend thicknesses and properties, and stress-strain relations in the adherend layers and properties of the adhesive in hybrid joints. Different models, based on different material behaviors and geometries have been proposed to investigate the displacement and stress fields produced in the joint as a result of a tensile and/or shear loads, as well as torsional and bending moments. In the sequel, these analyses are subdivided into a few groups to mainly study the stress distribution as well as failure of analyses of these joints.

2. Stress analysis in composite bolted/riveted joints

References [2-13] cover the pin or bolt effect on stress distribution in composite joints. Reference [2] investigates the effect of fiber arrangements on stress distribution around a pin in a laminated composite joint. In this reference, it was assumed that all fibers lie in one direction while loaded by a force P_o at infinity (see Fig. 2). Square and hexagonal arrangements of fibers were postulated in the models. However, in Ref. [3], experiments and finite element simulation were used to investigate the influence of geometric parameters on stress distribution and failure response of bolted *single-lap* composite joints. The stacking sequence of the laminate was considered to be $[0/0/+45/-45/0/90/0/+45/-45/0]_s$. Excellent agreement between the experimental and finite element results was observed. In addition, finite element method was applied to perform the studies in Refs. and [3] and [5] as well as Refs. [6] and [8]. Reference [6] examines the three-dimensional contact stress in a *double lap* joint (for carbon fiber reinforced plastic). The initially selected stacking sequence was $[45/0/-45/90]_s$. Moreover, in Ref. [8], A preliminary numerical and experimental investigation of shear stress distribution in multi-row bolted FRP joints was performed using Finite element technique. Similar work on stress distribution in bolted double-lap joints using 3-D finite element analysis was performed in Ref. [9]. The numerical results were compared with available closed-form equations. It was found that the results based on 3-D finite element model were more reliable than simplistic 2-D closed form solution. The effects of bolt-hole clearance on mechanical behavior of bolted composite (graphite/epoxy) joints were studied.

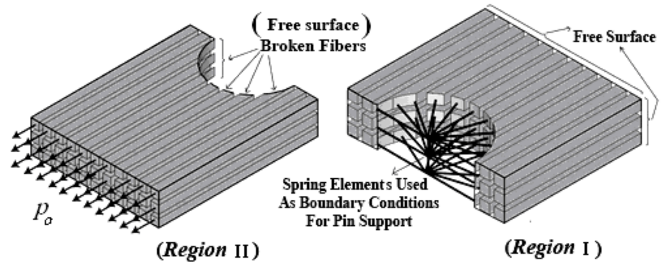

Figure 2: Composite pin joint subjected to tensile load [2].

The response of a bolted joint subjected to preload as well as loaded in bending and torsion was studied by Hissam and Bower [9] and Cavatorta *et al.* [11]. They used finite element modelling to extract their results which were supported by experimental observations. The selected material was a hybrid glass-carbon non-woven fabric in epoxy matrix. The manufacturing technology was hand lay-up with vacuum bagging. In another study, Ref. [14], the two-dimensional semi-analytical solution method for stress analysis of bolted composite lap joints under general in-plane loading was found by Barut *et al.*. In Ref. [14], metal to composite bolted joint behavior, evaluated at impact rates of loading, was investigated by VanderKlok *et al.* They tested 4142 alloy steel-E glass ply epoxy resin composite bolted joint under impact load, using a split Hopkinson tension bar. They found that as the joint overlap length increases, an asymptotic region of maximum bearing strength is attained. In a numerical and experimental work by Camanho *et al.* [15], the strength and efficiency of single-shear composite bolted joints were explored. The single bolt was surrounded by a metallic insert followed by the epoxy adhesive which was used to bond the inserts into the composite laminate. The tensile properties of the adhesive layer were determined using ASTM D683-72 standard. The proposed model was able to predict the stress redistribution in the joint as well as yielding of the adhesive layer.

Stress distribution in bolted joints has been also investigated by other authors (Refs. [16-31]). Reference [16] presents an overview on the behavior and analysis of bolted connections and joints in pultruded fiber reinforced polymers. In Ref. [17], McCarthy and Gray developed an analytical approach for modelling the load distribution in multi-bolt composite joints. The bolts and laminates were represented by a series of springs and masses where the effect of static friction between laminates was taken into account. The method was validated against experimental results (where possible) and three-dimensional finite element models. The joint geometries included single-bolt, *single-lap* joint as well as a three-bolt, *single-lap* joint. Additionally, load sharing in *single-lap* bonded/bolted composite joints was studied by Bodjona *et al.* and Bodjona and Lessard in Refs. [18] and [19] respectively. A combination of a bonded and bolted joint was used to result in a joint that was stronger and more durable than either constituent separately. The objective of the sensitivity analysis was to quantify the relative importance of the different joint design parameters (factors) in load sharing. It was shown that adhesive yield strength was mainly the most important factor, while other factors, namely the joint E/D ratio, adhesive thickness, and adhesive hardening slope were found to be other significant factors influencing load sharing (D was the bolt diameter and E represented the distance between free end of the substrate to bolt centerline). A similar analysis on improving the load sharing in hybrid bonded/bolted composite joints using an interference-fit bolt was performed by Raju *et al*. [20]. In a related study, Mara *et al.* in Ref. [21] investigated the performance improvement of the bolted joints in fiber reinforced composite structures using metal inserts. Their study showed that the bolt tension relaxation was minimized and the joint efficiency was increased in terms of joint stiffness and strength.

A simplified stress analysis of hybrid (bolted/bonded) joints was performed by Paroissien *et al.* in Ref. [22]. Their investigation allowed for the analysis of hybrid (bolted/bonded) joints made of dissimilar laminated or monolithic adherends, as well as the introduction of non-linear material behavior for both the adhesive layer and the fasteners. It was shown that the proper choice of adhesive material allows for significant increase in static and fatigue strength compared to similar a pure bolted or bonded joint. In a separate study, Taheri-Behrooz (Ref. [23]) investigated the effects of material nonlinearity on load distribution in multi-bolt composite joints. It was shown that increasing the degree of material nonlinearity of the members causes a decrease and an increase in the amount of the load transferred by the inner and outer bolts of the joint, respectively. The effect of temperature on composite bolted joints for aeronautical applications was discussed by Santiuste *et al.* in Ref. [24]. A numerical model based on finite element method was developed to evaluate the stresses in the bolt and composite plates. The objective of the article was to avoid damage due to the cross-effect of temperature and the torque when designing the composite bolted joint. Results showed the significant effect of temperature combined with torque level on the joint behavior. In a separate study by Olmedo *et al.*, an analytical model was developed to study the secondary bending prediction in *single-lap* composite bolted joints in Ref. [25]. Their model was validated through comparison of the predicted load-displacement curve with the literature data as well as the conducted experimental tests. A parametric study was also performed to analyze the influence of main joint parameters on the load-displacement curve. An experimental investigation on the behavior of single lap composite bolted joint under traction loading was performed in Ref. [26]. The experiments were designed to identify the effects of stacking sequence of the layers, bolt diameter, and loading rate on the joint the properties.

Reference [27] discusses the influence of lateral displacement of the grip on the behavior of *single lap* composite-to-aluminum bolted joints, via a novel model, using the finite element method. Tensile tests on the joint were also conducted, while the lateral displacement of the grip as well as the tensile displacement, out-of-plane displacement, and surface strains were measured. The novel model predicted 13 % smaller joint stiffness than the traditional model, causing a delay in failure load of the joint due to lateral displacement of the grip. In the study performed by Kratochvil and Becker [28], the structural behavior of composite bolted joints was analyzed using the complex potential method. In this work, the problem of a pin-loaded hole in a symmetric composite plate was considered using classical laminate theory. The analysis was performed using the Lekhnitskii complex potential method. Their approach presented an efficient method for the calculation of displacements and stresses in the neighborhood of the hole where failure is likely to occur.

Evaluation of opening-hole shapes for rivet connection of a composite plate, as well as fastener effects on mechanical behaviors of *double-lap* composite joints and the effect of end geometry and pin-hole effects on axially loaded adhesively bonded composite joints were discussed in Refs. [29-31]. In Ref. [29], a comparative evaluation was presented to analyze the influence of opening-circular, elliptical, and racetrack hole shapes on structural stress concentration in a composite plate. The finite element (FE) models of the specimens with the three shapes for the rivet holes were constructed. The stress distributions in finite element models under tensile loading were analyzed to compare the stress concentration factor for the foregoing hole shapes. It was found that the elliptical and racetrack-shaped holes, produce smaller stress concentration compared to the circular hole. A picture showing the three hole shapes is shown in Fig. 3. However, the experimental and numerical studies performed in Ref. [30] revealed the effect different fasteners on mechanical behaviors of composite bolted joints. Experimental tests were performed to depict the differences in the joint strength, stiffness and failure mode between protruding head joint and countersink joints. A similar study on the effects of pin hole geometry, adherend thickness and joint type, on the joint behavior was examined in Ref. [31]. Results showed that increasing the sample thickness improves the joint performance in composite single lap joints as well as in scarf joints. Additionally, the taper in *single lap* joints provided a significant advantage over the simple *single lap* joints, in terms of axial tensile strength.

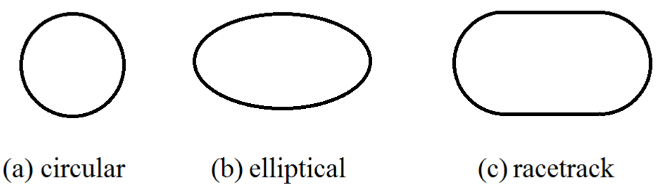

Figure 3: A picture of the three hole shapes used in Ref. [30].

References [14, 32-35] study the composite bolted joint behavior subjected to dynamic loads. In Ref. [32], the response of bolted carbon fiber composite joints (and structures) subjected to constant dynamic loading rates between 0.1 m/s and 10 m/s was studied. The experimental results showed that the tested joints exhibit only minor loading rate dependence when loaded in the pull-through direction but when loaded in bearing at or above 1 m/s, there was a significant change in failure mode. However, below a loading rate of 1 m/s, the failure mode consisted of initial bolt bearing followed by bolt failure. Additionally, for a loading rate of 1 m/s and above, the bolt failed in a tearing mode. A similar study on the dynamic behavior of bolted joints under heavy loadings was performed by Daouk *et al.* in Ref. [33]. They designed a dynamic test bed, based on a bolted structure, and performed the modal tests. The configuration of the bolted joint and the level of the loading were the relevant parameters that were considered in this study. Pearce *et al.* (Ref. [34]) proposed a stacked-shell finite element approach for modelling the dynamically loaded composite bolted joints under in-plane bearing loads. The onset of failure modes, damage and the ultimate load of the joint were able to be predicted by the models. In a separate study by VanderKlok *et al*., Ref. [14], on the behavior of metal to composite bolted joints under impact loading rates, quasi-static measurements were conducted to distinguish the operational modes of failure as well as the maximum bearing strength, corresponding to different edge distance to hole diameter (e/d) ratios. Such joints form an integral part of a majority of structural components used in aircraft and automobile industries, where they can be subjected to either static or time-dependent loadings. Results showed that the dynamic response of a metal-composite bolted joint was significantly higher than its static counterpart. Additionally, the asymptotic region of failure mode alteration was observed to be dependent on loading rate transfer in the joint. Reference [35] investigates the stress distribution in multi-bolted joints for FRP pultruded composite structures. Distribution of shear stresses among different bolts by varying the number of rows of bolts as well as the number of bolts per row was examined. The effect of any change in washer diameter on bearing stresses was also included in the analysis. According to the results of this study, in multi-bolt joints, the load was not distributed equally due to varying bolt position, bolt-torque or tightening of the bolt, bolt-hole clearance, and friction at washer-plate interface. A side view of the joint geometries used in Ref. [35] is shown in Fig. 4. A similar experimental and simulation continuous twice-impacts analysis of Ultra-High Molecule Weight Polyethylene laminate which was fixed by four bolted joints was performed in Ref. [36]. The experimental results of the first impact test were used to verify the numerical model, in which a solid blunt projectile penetrated the laminate with a velocity of 216 m/s.

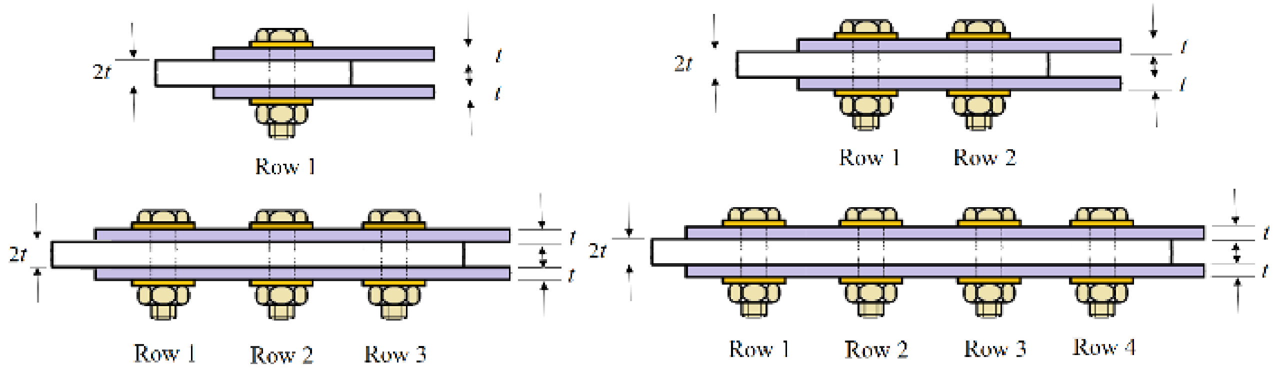

Figure 4: Side view of the bolt arrangements used in ref. [35].

Experimental and numerical studies, as well as new designs on laminated composite joints were discussed in Refs. [37, 38]. Additional studies on static and dynamic behavior of composite riveted joints in tension as well as static and dynamic torque characteristics of composite co-cured *single lap* joints were discussed in Refs. [39, 40]. In Ref. [39], seven joint configurations for aircraft application were tested based on three types of loading conditions. The joint specimens were made of carbon fiber reinforced plastic in a number of lay-ups of unidirectional tapes and woven fabrics. It was shown that the effect of tensile loading rate on variation of tensile strength is negligible for the tested composite riveted joint specimens.

In addition to some of the previously mentioned studies, Refs. [41-46] adopt finite element method to investigate the behavior of bolted joints. Stocchi *et al.* (Ref. [41]), performed a detailed finite element investigation on *single lap* composite bolted joints with countersunk fasteners under static load. In their study, in addition to the analysis of contact evolution between the bolts and the holes, stress distribution in carbon fiber reinforced plastic plate and titanium bolts were discussed, while the numerical results were compared to experimental data. Five different stages were identified in the joint behavior: (i) No-Slip, (ii) Slip, (iii) Full Contact, (iv) Damage and (v) Final Failure. According to the results of their study, the joint stiffness is higher in the No-Slip stage than in the Full Contact stage. This was independent of coefficient of friction and bolt clamping force. In Ref. [42], a simple homogenization scheme for 3D finite element analysis of composite bolted joints was presented by Mandal and Chakrabarti to determine the basic mechanical behaviors of a laminated composite joint with significantly lesser computational effort. To takes into account the effect of transverse shear deformation in composite laminates, their formulation was based on Mindlin–Reissner plate theory. Their method was able to find equivalent homogeneous model for laminated composite joints having any type of lamination scheme. Reference [43] introduces the finite element modelling of blind bolted composite joints. In this study, a detailed three-dimensional finite element model was developed to study the behavior of blind bolted endplate composite joints that connect composite beams to a concrete-filled steel tubular column. Each part of the study was modeled using proper element. The parametric studies were also carried out to investigate the effects of shear studs and reinforcement ratio, as well as column sections and thickness ratios, as well as blind bolt types and diameters on the joint performance.

Experimental and finite element studies on bolted, bonded and hybrid step lap joints of thick carbon fiber/epoxy panels which are used in aircraft structures showed that the finite element models are well capable of predicting the bonded, bolted and hybrid joint strengths with a high accuracy [44]. According to the results based on strain energy release rate, it is vital to place fasteners closer to the ends of the overlap to suppress the peak peeling stresses and hence, delay the effects of early crack initiation. A schematic diagram of the hybrid joint is shown in Fig. 5.

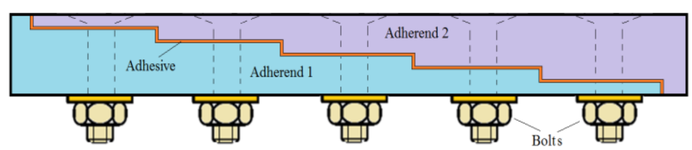

Figure 5: A diagram of the hybrid step joint used in Ref. [44].

A similar experimental and finite element analysis of glass fiber reinforced plastic composite laminates with combined bolted and bonded joints is performed in Ref. [45]. A highly efficient user-defined finite element for load distribution analysis of large-scale bolted composite structures was developed by Gray and McCarthy [46]. The method was a combination of analytical/numerical approach and was capable of representing the full non-linear load-displacement behavior of the bolted composite joints up to and including, joint failure. A related study by the same authors on a global bolted joint model for load distributions in multi-bolt composite joints based on finite element analysis was presented in Ref. [47]. They stated that their new model was found to be robust, highly efficient and accurate, with time savings of up to 97% over the full three-dimensional finite element models.

References [48-51] concentrate on the design of bolted and/or hybrid joints. In Ref. [48], Zhou *et al.* proposed a novel design of out-of-plane π joints to increase the load carrying capacity of the joint. This type of joint uses bolts to connect the joint to other structural components. Static experiments performed on the novel bolted composite π joint and an aluminum counterpart showed that the bolted carbon/epoxy composite π joint exhibits a larger load carrying capability with a massive weight reduction compared to its aluminum counterpart. Additionally, based on the numerical simulation, the progressive damage process and failure mechanism of the bolted composite π joint showed that the novel design not only enhances the positive factors of composite and substantially strengthens the composite π joint, but also it eliminates the potential weaknesses in deltoid fillers. A schematic diagram of the π joint is shown in Fig. 6.

In a related study by Cheng *et al.* [49], a novel design scheme was proposed which mainly improved the layup design in the composite bolted π-joint. In Ref. [50], the effects of several factors on the strength of hybrid joints were examined using the Design of Experiments methodology. The studied factors included adhesive modulus, adhesive thickness, adherend thickness, bolt-hole clearance and clamping area. It was found that the hybrid joints were stronger than the bolted or bonded joints, and they have a better crack arrest capability due to the hybridization effect. More investigations on bolted and hybrid joints can be found in Ref. [51]. Three-dimensional stress analysis of bolted single-lap composite joints was investigated in Ref. [52] using a three-dimensional finite element model which was developed to determine non-uniform stress distributions through the thickness of composite laminates in the vicinity of a bolt hole.

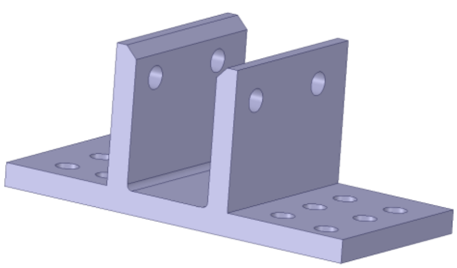

Figure 6: Schematic diagram of a π- joint used in Ref. [48].

3. Strength analysis of composite bolted/riveted joints

References [53-62] deal with strength analysis of bolted/pinned (riveted) joints. In Ref. [53], a parametric finite element analysis was performed to investigate the effect of the material property degradation rules and failure criteria on the tensile behavior and strength of bolted joints in a *single-lap* single-bolt graphite/epoxy composite laminate. The predicted load-displacement curves and failure loads were compared with experimental results for different laminate stacking sequences and joint geometries. The authors proposed a combination of failure criteria and material property degradation rules that led to an accurate strength prediction of the joint. The numerical results obtained on deformations, strains, and bolt loads were validated with experimental findings. In another study, bearing strength and failure behavior of bolted composite joints was investigated by Yi Xiao and Takashi Ishikawa in Refs. [54, 55]. To evaluate the effect of resin properties on bearing response, two different types of polymer–matrix-based Carbon Fiber Reinforced Plastic laminates were selected. In the first stage, their experimental observations showed that the bearing failure can be outlined as a process of compressive damage accumulation, which can be divided into the following four stages: damage onset; damage growth; local fracture; and finally, structural fracture. In the second stage, an analytical model was developed to simulate the bearing failure and response characteristics of each bolted composite joint. Their proposed model accounted for the contact conditions at the pin/hole interface, as well as the finite deformation, progressive damage, and nonlinear behavior of the material.

An analytical model for strength prediction in multi-bolt composite joints at various loading rates was proposed by Sharos *et al.* in Ref. [56]. The analytical model was used to quickly determine the complete load-displacement curve of single- and multi-fastener composite joints. The loading rate effects, as well as bearing damage, were included via a novel conic damage approximation function. Their method was validated against experimental data.

In Part I of the study performed by McCarthy *et al.* (Ref. [57]), a Three-dimensional finite element models were developed to study the effects of bolt–hole clearance on the mechanical behavior of single-bolt, *single-lap* graphite/epoxy composite joints. The validated model was used in Part II of the study (Ref. [58]), to investigate the effects of bolt–hole clearance on the joint stiffness, stress state and failure initiation. It was shown that any increase in the bolt-hole clearance leads to an increase in bolt rotation, as well as a decrease in bolt-hole contact area, and hence, a reduction in joint stiffness. The analytical model presented by Gray and McCarthy in Ref. [59] for prediction of through-thickness stiffness in tension-loaded composite bolted joints was the extension of a spring-based method. Their proposed model accounted for the stiffness of the clamped region of the joint due to bolt torque, as well as bolt extension, flexural stiffness, and the anticlastic curvature within the laminates. Three-dimensional finite element models of the bolted composite plates were used to validate the method.

In the study performed by Zaroug *et al.* (Ref. [60]), experimental and numerical investigation were used to seek the effects of adherend material and thickness on the strength of bolted, bonded, and hybrid *single lap* joints. In their study, the mechanical performance of bonded, bolted, and hybrid *single lap* joints subjected to tensile loading was examined using three different adherend thicknesses and two different adherend materials with different mechanical behaviors. Force-displacement curves, failure history, and the amount of absorbed energy by each configuration were analyzed to clarify the strength of various joints. In a separate study, Zhao *et al.* in Ref. [61] used a probabilistic model to analyze the strength of a double lap single-bolt composite joint. Static tensile tests were performed on fifteen composite *double lap* single-bolt joints, made of T800 carbon/epoxy composites. The probabilistic failure load of the joint which was obtained from the proposed model was in good agreement with the results of conducted experiments. It shows that although the statistical parameters of the probabilistic failure loads were slightly influenced by the probability distribution type of random variables, the proposed model was not sensitive to this distribution. Additional studies on strength analysis of composite bolted joints can be found in Refs. [62-84].

4. Damage, fatigue and failure of bolted/riveted joint

Based on the nonlinear finite element approach, Nerilli and Vairo [85] investigated the progressive damage of composite bolted joints. In another study, the progressive bearing damage of composite bolted joints under quasi-static shear loads was studied by Nezhad *et al.* [86]. He and Ge [87] used a numerical scheme in the framework of coupled continuum damage mechanics to predict failure of composite multi-bolted joints. On the other hand, Zhou *et al.* [88] proposed a three-dimensional finite element model for damage estimation of *single-lap* and *multi-lap* joints. Du et al. [89] used finite element method to investigate the progressive damage of pultruded fiber reinforced polymer bolted joints. In another study, Hühne *et al.* [90] performed an investigation on the effect of liquid shim layers on the progressive damage of composite bolted joints using finite element method. A similar analysis on the progressive damage analysis of multi-bolt composite joints in the framework of characteristic length method was performed by Zhang *et al.* [91]. However, Kolks and Tserpes [92] suggested a progressive damage model for predicting the mechanical behavior of titanium lamella in a *double-lap* composite bolted joint subjected to tensile loading. Chishti *et al.* [93] performed experimental tests for studying progressive damage characteristics and strength of bolted joints of composite laminates. Based on a continuum damage model, Zhou *et al*. [94] introduced a damage model for *double-lap* and *multi-bolt* composite joints under quasi-static loads. Additional studies on damage analysis of composite bolted joints can be found in Refs. [95, 96].

The analytical and experimental studies performed by Awadhani and Bewoor [97] reviled the effect of geometrical parameters such as edge distance to diameter ratio or width to diameter ratio, on the failure behavior of *single-lap* bolted joints between metal and GFRP under axial tensile loads. Applying a tensile load on the single bolted single lap joint, the failure modes were determined experimentally. According to the results of this study, increasing the edge distance, changed the failure mode form cleavage or net tension to bearing failure. It was also concluded that the joint strength was increased with an increase in edge distance. Hu *et al.* [98] used finite element method to investigate the progressive failure in *single-lap* bolted joints of woven fiber reinforced composites subject to high bearing strains. Using explicit finite element analysis along with material nonlinearity, the bearing failure characteristics of the bolted joint, as well as the crushing of the composite material due to the rotation of the bolt head were determined. The finite element results were in agreement with experimental observations. Cheng *et al.* [99] employed failure envelopment method and utilized the three-dimensional finite element analysis to predict the failure behavior of multi-bolt composite joints. Tensile experiments of two- and three-bolt joints were conducted to obtain the failure modes and other joint properties. Experimental findings were in agreement with 3D finite element results. Warren *et al.* [100] introduced a three-dimensional model in order to investigate progressive damage of single-bolt and double-shear joints of woven composites. The modeled joint is commonly used in many aerospace structures. The Hashin failure criteria and the Matzenmiller-Lubliner-Taylor damage model as well as the unique morphology of three-dimensional woven composites were included in the study. The onset of damage the model were found to be in agreement with previous experimental findings. Bearing failure of Carbon-Epoxy composite bolted joints under uniaxial and biaxial quasi-static loads was examined experimentally by Kapidžić *et al.* [101]. In this work, uniaxial and biaxial quasi-static bearing failure experiments were performed on carbon–epoxy laminate specimens at elevated temperatures. The experiments were also simulated by 3D, explicit, finite element analyses, which included intralaminar damage and delamination. Results of the study showed that the experimental and simulated bearing failure loads differed by 1.7% in the uniaxial case and 2.1% in the biaxial case.

Liu *et al.* [102] performed a numerical analysis and experimental study on bearing failure of *single-lap* composite joints with countersunk. In this study, tensile experiments were conducted on *single-lap* bolted joint with a countersunk fastener. Finite element models were also prepared using cohesive elements to predict the interlaminar damage in model I. In mode II, 8-node reduced integration solid elements were selected to model all the parts with 3D Hashin-type initiation criteria and Camanho degradation law. The results simulated by both models were able to accurately predict the elastic loading response and the overall damage profile compared with the experimental results. Based on the Huang's criterion, Nerilli *et al.* [103] modeled the progressive damage in multi-bolted joints connecting structural elements made up of fiber-reinforced polymers composite laminates. Differences in failure mode and values of ultimate-load were numerically investigated. In the case of single-bolted joints, the use of carbon-FRP laminates showed the best mechanical properties. Ozen and Sayman [104] performed numerical and experimental study on the failure behavior of pinned joints of glass-fiber-reinforced composites containing two serial holes. Experimental tests involved variations in a number of parameters such as the distance between the center of two holes-to-hole diameters (K/D), the edge distance-to- upper hole diameter (E/D), and the width of the specimen-to-hole diameter (W/D). Results showed that the immersion of test specimens into sea water causes a decrease in failure load without a preload moment. Additionally, test specimens under preload moments produced nearly the same bearing strength as unimmersed specimens. Khashaba *et al.* [105, 106] reported the effects of stacking sequences and of pin–hole clearance on the failure behavior of pinned-joints composite laminates. Theoretical models were developed to predict the characteristic bearing strength, as well as lower bound bearing strength. Four configurations for stacking sequences were studied: $[0/90]_{2s}$, $[15/75]_{2s}$, $[30/60]_{2s}$, and $[45/45]_{2s}$. Results showed that specimens with $[0/90]_{2s}$ stacking sequence had the ultimate failure stress and maximum failure displacement compared with the other stacking sequences. However, based on the first-peak criterion, specimens with $[45/45]_{2s}$ stacking sequence showed the maximum failure displacement and bearing capacity.

Wang *et al*. [107] utilized extended finite element method to identify the progressive failure of bolted *single-lap* composite joints. In their study, the extended finite element method (XFEM) was used to predict the progressive failure of *single-lap* bolted joints. The failure load in the joint, simulated by XFEM, was compared with the experimental results in the literature. the influences of two geometric parameters, namely plate width-to-hole diameter ratio (W/D) and the edge-to-hole diameter ratio (E/D), on the failure load of single bolt *single-lap* composite joint was also included in the study. In Ref. [108], Liu *et al.* proposed a failure envelopment method (based on the conventional failure envelope method presented by Hart-Smith) to predict the final failure mode and strength of multi-bolt composite joints. In a separate study, Soykok *et al*. [109] performed an experimental analysis to investigate the effects of thermal conduction and tightening torque on the failure of *single lap* double serial fastener glass fiber-epoxy composite joints. It was observed that, the load-carrying capacity of the joint gradually decreases by an increase in temperature. The maximum decrease in failure loads occurred at 70 ºC and 80 ºC due to the heat damage to the resin matrix. Additionally, it was observed that the tightening torque (which contributes to the joint strength) is effective not only at room temperature, but also at elevated temperatures. A three-dimensional method presented by Ataş *et al.* [110] for prediction of *double lap* bolted joint strength in composite laminates showed that although the in-plane failure mode of each individual layer in $[0^o/90^o/\pm45^o]_{2s}$ carbon fiber reinforced plastic laminates was predicted to happen around the fastener hole, the X-ray radiographs indicated that delamination failure is particularly dominant around the washer's outer edge. Lu *et al*. [111] suggested a three-directional explicit finite element method for failure prediction of single-shear and double-shear composite joints. A linear damage propagation law based on the fracture energy and the characteristic length was adopted. The predicted mechanical behavior was in good agreement with experimental results.

Using experimental tests, Lee and Ahmad [112] studied the effects of bearing stress, lay-up and plate aspect ratio on the failure life of *double-lap* woven fabric kenaf fiber reinforced polymer hybrid bonded-bolted joints. The effects of lay-up types, different normalized plate width (plate width/hole diameter, *W/d*), and bolt loads were incorporated into their study. The bearing stress at failure increased with increments in *W/d* ratio. Zhao *et al.* [113] determined stress concentration relief factor via tensile tests on open-, filled- and loaded-hole laminates, failing in tensile mode, respectively. This factor was used for determination of failure life in composite multi-bolt joints. High-stress concentration level was found in loaded hole, while the filled-hole had slightly higher stress concentration than that of the open-hole. In another study, Zhang *et al.* [114] performed numerical analysis and experimental tests to indicate the effects of end distances on failure life of composite bolted joints. Using trial-and-error method, a group of material degradation factors were presented to establish the three-dimensional progressive damage models of the bolted joints. According to the progressive damage analyses, the predicted results on load-displacement curves, failure patterns of bolted joints with different end distances, and failure loads, were in good agreements with corresponding experimental findings. Olmedo and Santiust [115] proposed a new set of failure criteria to predict the composite failure in *single-lap* bolted-joints. The advantage of their criteria with respect to the other three-dimensional failure criteria was the consideration of non-linear shear stress-strain relationship. In a separate work by Fun *et al*. [116], bending behavior of a novel composite bolted π-joints was investigated using experimental and numerical studies. The details of their proposed novel π-joint and its components are shown in the non-scaled Fig. 7. The L and U-shaped preforms were made of quasi-isotropic T300/6808 warp-knitting multi-layer fabrics while the base preform was composed of composite plain cloth (G814/6084) with a total thickness of 3 mm. The results of this study showed that delamination of the fillet region in L-preform was the π-joint's failure mode. The hygrothermal effect on fatigue characteristics of jagged pin-reinforced composite *single-lap* joints was studied by Ko *et al.* [117]. Three environmental test conditions, namely, room temperature and dry, elevated temperature and dry, and elevated temperature and wet were considered. Results indicated that under all test conditions, the joint strength was improved while reinforced with the z-pins. However, when jagged z-pins were used under the elevated temperatures and wet conditions, compared with the corresponding values for an unpinned joint, the static and fatigue strengths at a million cycles were increased by 32.2% and 65.8%, respectively.

An experimental study was performed by Giannopoulos *et al.* [118] to investigate the effects of bolt torque tightening on strength and fatigue behavior of airframe FRP laminate bolted joints. Results showed that for relatively heavily torqued pre-tightened joints, failure took place mainly on the specimen part after the washer. Based on the continuum damage mechanics, Sun *et al.* [119] investigated the elastic-plastic fatigue and fretting fatigue characteristics of *double-lap* bolted joints. Result showed that the predicted fatigue lives agree well with the experimental results (available in the literature). In a separate study, Scarselli *et al.* [120] presented a model for prediction of failure loads in bolted laminated composite joints subjected to cyclic loading.

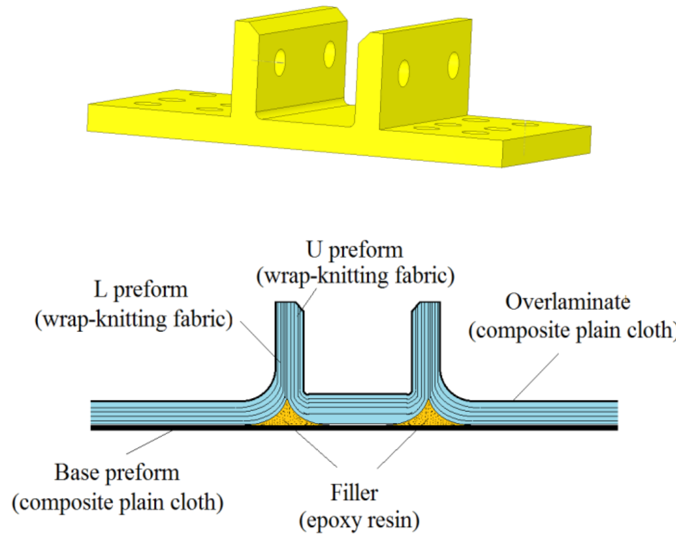

Figure 7: A non-scaled picture of the novel π-joints (with its details) used in Ref. [116].

Gathering the data through experimental activities, they proposed a constitutive relationship between stress and strain. Using finite element method in conjunction with Tsai-Hill criteria, Zhou *et al.* [121] suggested a model for prediction of multi-axial fatigue behavior of composite bolted joints. Their study adopted the modified S-N fatigue life curve fitted by unidirectional laminate S-N curve which takes the ply angle and stress ratio into consideration, to determine fatigue life of composite bolted joint. Kapidžić *et al.* [122] studied the effects of biaxial load and thermal loads on the fatigue life of bolted joints. In their study, two-bolts, *double-lap* joints with quasi-isotropic carbon–epoxy composite specimens were subjected to uniaxial and biaxial cyclic loading at 90 ºC. The influence of biaxial load and bearing fatigue failure process were investigated on the joint failure. Results showed that the biaxial loading results in a longer fatigue life that the uniaxial loading. Experimental and numerical study on the mechanical behavior of blind bolted end plate joints as well as experimental tests for static and dynamic failure behavior of bolted joints in carbon fiber composites can be found in Refs. [123] and [124]. One can also find additional work on failure of bolted/riveted joints in Refs. [97, 98, 112, 125-137] and [138-142].

In 1980, a strength review analysis of *mechanically fastened* fiber reinforced plastic joints was presented by Godwin and Matthews [143]. They discussed the effects of material, fasteners, and design parameters in their report. In a related work, Agarwal [144], studied the static strength prediction of bolted joints in composite materials. He presented a new method for predicting the strength of double-shear single-fastener composite joints. He used finite element method to calculate the stress distribution around a fastener hole, as well as predicting the various modes of laminate failure through some modifications applied to the average stress criterion. Choi *et al.* [65], studied the strength of a composite laminated bolted joint subjected to a clamping force using the *failure area index* method. Using this method, the strengths of different geometric shapes and dimensions were predicted and compar[129]ed with experimental results. It was shown that using failure area index method, the strength of a given laminated composite bolted joint subjected to a clamping force can be predicted within a fairly acceptable accuracy. In Ref. [145], Lin and Jen worked on failure analysis of *single-lapped* bolted and bonded mixed-composite joints. They performed numerical and experimental studies to generate their data. Two kinds of stacking sequences in the adherends were tested: quasi-isotropic and cross-ply. The adhesive layers included thermal-setting and thermal-plastic types. Various multi-bolt and bonded joints were made and tested. Two types of lay-ups were considered for the adherends; cross-ply and the quasi-isotropic laminates. Three-dimensional finite element analysis was used to obtain the stress and strain fields within each specimen. Additionally, the C-scan technique was adopted to determine the damage zone and failure mechanism of the joint.

Other authors have also worked on the fatigue behavior, development, damage and failure of composite bolted joints [146-167]. Smith *et al*. [146], studied the behavior of *single-lap* bolted joints in CFRP laminates. The strengths of *single-lap* bolted joints were presented as functions of width and end distance in two carbon fiber reinforced composite laminates. Comparing the results with those of others, they showed that due to the joint bending effect, the ultimate strength of a *single-lap* joint is lower than that of a *double-lap* joint. On the other hand, experimental studies on fatigue behavior and strength of bolted joints in Ref. [147] showed that compared to clearance fit specimens, clamping force increases the fatigue life of a bolted joint. According to Ref. [148], higher tightening torque, in general, results in higher fatigue lives in bolted joints, Moreover, the numerical simulation as well as experimental results showed that an increase in clamping force, improves the fatigue life of *double lap* bolted joints due to presence of compressive stresses around the hole. Additionally, in Ref. [149], the effect of tightening torque as well as the effect of plate thickness on the fatigue life of a *single* and *double lap* joints were studied. The objective of the fatigue tests was to demonstrate the failure trends for each material thickness, joint type, and torque loading.

The development of fatigue damage around fastener holes in the thick graphite/epoxy composite laminates was studied by Saunders *et al.* [150]. Performing experiments on bolted composite laminates subjected to fatigue loading, they discussed the mechanisms by which the damaged area develops and eventually grows around countersunk fastener holes. In Refs. [151] and [152], stresses distribution around fasteners due to cheese-head and countersunk bolts in composite structures in flexure, and their effect on fatigue damage initiation was fully discussed. Comparison of the results on experimental and theoretical models made it possible to predict the location of fatigue damage initiation. In another study, using nondestructive examination techniques, Persson *et al*. [153], investigated the propagation of hole machining defects in the pin-loaded carbon/epoxy laminates. They applied KTH-method (a machining method which gives holes with no detectable defects using non-destructive examination technique) and two other traditional methods for machining holes. The samples were subjected to uniaxial tension fatigue loading. Among their other results, they concluded that the KTH specimens yielded the longest fatigue life. An additional study on the effects of hole machining defects on the strength and fatigue life of composite laminates was performed by Persson *et al*. in Ref. [154]. In Ref. [155], the theory of micro-mechanics of failure was extended to analyze the progressive fatigue damage of carbon fiber reinforced polymer (CFRP) composites and to predict the strength of bolted joint structures. Fatigue behavior of mechanically fastened joints (bolted joints) was also discussed in Refs. [156-160]. In these studies, the effects of protruding and countersunk-bolt heads, as well as the quasi-isotropic and highly orthotropic lay-ups and fastener systems, on the joint strength and fatigue performance were studied. Fractographic SEM and optical microscopy were used to explore the fracture and damage which was developed in the joint system during static and fatigue testing. Results showed a linear dependence between the number of bolt rows and the fatigue life of the corresponding joints. Additionally, the specimens joined by protruding-head bolts showed better static and fatigue performance compared to the other joints bolted by countersunk fasteners. According to the load-transfer calculations results, different bolt rows transfer slightly different amounts of load. According to the fractographic observation, the severe damage in the bolted joints subjected to fatigue loading occurred around the bolt holes. The experimental study of fatigue behavior of $[0/90]_{4s}$ *double-lap* bolted joints was explored by Smith and Pascoe [161]. This study also covered the effect of bolt clamp-up torque on fatigue behavior of the laminate. The fatigue resistance of composite joints with countersunk composite and metal fasteners, as well as protruding-head bolts were also discussed in Refs. [162] and [163].

In Ref. [164], fatigue behavior of multiple-row bolted joints in carbon/epoxy laminates was discussed by Persson and Eriksson. In their study, the ranking order of factors affecting the strength and fatigue life of multiple-row bolted composite laminates were investigated. Eight different factors related to the geometry, material properties, laminate configuration, hole quality, environmental conditions, and fastener type were considered. Additionally, in the studies performed in Refs. [165-167], the effect of secondary loads on the common failure modes of composite aircraft structures, fatigue characteristics of bolted joints for unidirectional composite laminates, and the effect of repeated tensile loading on bearing damage evolution of a pinned joint in CFRP laminates were discussed, respectively.

Several other authors have also worked on the failure analysis of composite bolted joints [107, 168-171]. In the study performed by Wilson and Tsujimoto [168], they addressed the concepts used in formulation of strength models and compared the capabilities of some used failure criteria. According to their results, the differences in predicted strengths based on the examined models were insignificant. On the other hand, Wang *et al.* [169], extended the finite element method to investigate the failure load prediction of bolted *single-lap* composite joint. To investigate the effect of ply angle on the failure response of a bolted composite *single-lap* joint, a three-dimensional model was developed by Zhou *et al*. [170]. Their model could predict the failure load and failure mode of the joint with arbitrary ply angle. A related study similar to those outlined in Refs. [169, 170] is performed in Ref. [107]. One can also find studies on failure of bolted and riveted joints in Refs. [73, 171-173].

5. Conclusions

A literature review on the behavior of different bolted *single* and *double-lap* joints (as well as others) has been made to assist a designer to select the proper model for a particular application. The survey shows that the analytic models selected for the bolted bonded joints (*single* or *double*), as well as other types of joints (i.e. *tee, scarf, and stepped*), with linear material properties are mostly two dimensional where the solutions for stress distribution and/or failure of the joint are investigated either experimentally or by finite element method. The results seem to be generally accurate and adequate. A combination of a bonded joint and bolted joint resulted in a joint that was stronger and more durable than either constituent separately. It was shown that the adhesive yield strength is singularly the most important factor in these type of joints, while other factors, namely the joint *E*/*D* ratio, adhesive thickness, and adhesive hardening slope were found to be the other significant factors influencing load sharing (*D* was the bolt diameter and *E* represented the distance between the free end of the substrate to bolt centerline). Additionally, studies show that the use of metal inserts in the bolt tension relaxation is minimized and the joint efficiency is increased in terms of joint stiffness and strength by using metal inserts in fiber reinforced composite bolted joints structures. The use of material nonlinearity on load distribution in multi-bolt composite joints showed that increasing the degree of material nonlinearity of the members causes a decrease and an increase in the amount of the load transferred by the inner and outer bolts of the joint, respectively. The study of lateral displacement of the grip on single lap composite-to-aluminum bolted joints showed that the influence of lateral displacement of the grip of the joint results in 13 % smaller joint stiffness than the traditional model, causing a delay in failure load of the joint due to lateral displacement of the grip. However, the study on the effects of pin hole geometry, adherend thickness and joint type, showed that increasing the adherend thickness improves the joint performance in composite single lap joints as well as in scarf joints. Additionally, taper in single lap joints provided a significant advantage over the simple single lap joints in terms of axial tensile strength. According to a detailed finite element investigation on a single lap carbon fiber reinforced plastic composite bolted joints with countersunk fasteners under static load five different stages were identified in the joint behavior: (i) no-slip, (ii) slip, (iii) full contact, (iv) damage and (v) final Failure. Studies performed on the bolted carbon/epoxy composite π joints showed a larger load carrying capability with a massive weight reduction compared to its aluminum counterpart. Additionally, the bolted composite π joint and its aluminum counterpart showed that the bolted composite π joint exhibits a larger load carrying capability with a considerable weight reduction. Furthermore, it was shown that any increase in the bolt-hole clearance leads to an increase in bolt rotation, as well as a decrease in bolt-hole contact area, and hence, a reduction in joint stiffness.

References:

[1] D. M. Gleich, Stress analysis of structural bonded joints, Delft University Press, 2002, pp. 122.

[2] M. Shishesaz, M. M. Attar, H. Robati, The Effect of Fiber Arrangement on Stress Concentration Around a Pin in a Laminated Composite Joint, in *ASME, 10th Biennial Conference on Engineering Systems Design and Analysis ESDA2010-24587*, 2010, pp. 153-161.

[3] S. Zhou, Z. Wang, J. Zhou, X. Wu, Experimental and numerical investigation on bolted composite joint made by vacuum assisted resin injection, *Composites Part B: Engineering*, Vol. 45, pp. 1620-1628, 2013.

[4] *Load Development and Automation for Composite Bolted Joint Bearing and Bypass Analysis*, 2010 (American Institute of Aeronautics and Astronautics).

[5] M. Keikhosravy, R. Hashemi Oskouei, P. Soltani, A. Atas, C. Soutis, Effect of geometric parameters on the stress distribution in Al 2024-T3 single-lap bolted joints, *International Journal of Structural Integrity*, Vol. 3, No. 1, pp. 79-93, 2012.

[6] W.-H. Chen, S.-S. Lee, J.-T. Yeh, Three-dimensional contact stress analysis of a composite laminate with bolted joint, *Composite Structures*, Vol. 30, pp. 287-297, 1995.

[7] T. J. Whitney, E. V. Iarve, R. A. Brockman, Singular stress fields near contact boundaries in a composite bolted joint, *International Journal of Solids and Structures*, Vol. 41, pp. 1893-1909, 2004.

[8] F. Ascione, A preliminary numerical and experimental investigation on the shear stress distribution on multi-row bolted FRP joints, *Mechanics Research Communications*, Vol. 37, No. 2, pp. 164-168, 2010/03/01/, 2010.

[9] M. H. Ahmad, Stress distribution in composite double-lap bolted joints incorporating with clamp-up, *Applied Mechanics and Materials*, Vol. 660, pp. 152-156, 2014.

[10] *Analysis of a Preloaded Bolted Joint in a Ceramic Composite Combustor*, 2003 (American Institute of Aeronautics and Astronautics).

[11] M. P. Cavatorta, D. S. Paolino, L. Peroni, M. Rodino, A finite element simulation and experimental validation of a composite bolted joint loaded in bending and torsion, *Composites Part A: Applied Science and Manufacturing*, Vol. 38, pp. 1251-1261, 2007.

[12] *An experimental investigation of composite bonded and/or bolted repairs using single lap joint designs*, 1997 (American Institute of Aeronautics and Astronautics).

[13] *An Analytical Method for Evaluating Bolted Joint Repairs in Composite Structures*, 2011 (American Institute of Aeronautics and Astronautics).

[14] A. Vander Klok, A. Dutta, S. A. Tekalur, Metal to composite bolted joint behavior evaluated at impact rates of loading, *Composite Structures*, Vol. 106, pp. 446-452, 2013.

[15] P. P. Camanho, C. M. L. Tavares, R. de Oliveira, A. T. Marques, A. J. M. Ferreira, Increasing the efficiency of composite single-shear lap joints using bonded inserts, *Composites Part B: Engineering*, Vol. 36, pp. 372-383, 2005.

[16] A. M. Girão Coelho, J. T. Mottram, A review of the behaviour and analysis of bolted connections and joints in pultruded fibre reinforced polymers, *Materials & Design*, Vol. 74, pp. 86-107, 2015/06/05/, 2015.

[17] C. T. McCarthy, P. J. Gray, An analytical model for the prediction of load distribution in highly torqued multi-bolt composite joints, *Composite Structures*, Vol. 93, No. 2, pp. 287-298, 2011/01/01/, 2011.

[18] K. Bodjona, K. Raju, G.-H. Lim, L. Lessard, Load sharing in single-lap bonded/bolted composite joints. Part I: Model development and validation, *Composite Structures*, Vol. 129, pp. 268-275, 2015.

[19] K. Bodjona, L. Lessard, Load sharing in single-lap bonded/bolted composite joints. Part II: Global sensitivity analysis, *Composite Structures*, Vol. 129, pp. 276-283, 2015.

[20] K. P. Raju, K. Bodjona, G.-H. Lim, L. Lessard, Improving load sharing in hybrid bonded/bolted composite joints using an interference-fit bolt,

Composite Structures, Vol. 149, pp. 329-338, 2016.

[21] V. Mara, R. Haghani, M. Al-Emrani, Improving the performance of bolted joints in composite structures using metal inserts, *Journal of Composite Materials*, Vol. 50, No. 21, pp. 3001-3018, 2016.

[22] E. Paroissien, F. Lachaud, S. Schwartz, A. Da Veiga, P. Barrière, Simplified stress analysis of hybrid (bolted/bonded) joints, *International Journal of Adhesion and Adhesives*, Vol. 77, pp. 183-197, 2017/09/01/, 2017.

[23] F. Taheri-Behrooz, A. R. Shamaei Kashani, R. N. Hefzabad, Effects of material nonlinearity on load distribution in multi-bolt composite joints, *Composite Structures*, Vol. 125, pp. 195-201, 2015/07/01/, 2015.

[24] C. Santiuste, E. Barbero, M. Henar Miguélez, Computational analysis of temperature effect in composite bolted joints for aeronautical applications, *Journal of Reinforced Plastics and Composites*, Vol. 30, No. 1, pp. 3-11, 2011.

[25] A. Olmedo, C. Santiuste, E. Barbero, An analytical model for the secondary bending prediction in single-lap composite bolted-joints, *Composite Structures*, Vol. 111, pp. 354-361, 2014/05/01/, 2014.

[26] L. Awadhani, A. Bewoor, Behavior of single lap composite bolted joint under traction loading: Experimental investigation, in *Proceeding of*, AIP Publishing, pp. 020124.

[27] S. W. Wang, X. Q. Cheng, X. Guo, X. Li, G. Chen, Influence of Lateral Displacement of the Grip on Single lap Composite-to-Aluminum Bolted Joints, *Experimental Mechanics*, Vol. 56, No. 3, pp. 407-417, March 01, 2016.

[28] J. Kratochvil, W. Becker, Structural analysis of composite bolted joints using the complex potential method, *Composite Structures*, Vol. 92, No. 10, pp. 2512-2516, 2010/09/01/, 2010.

[29] Y. Zhou, Q. Fei, Evaluation of opening-hole shapes for rivet connection of a composite plate, *Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science*, Vol. 231, No. 20, pp. 3810-3817, 2017.

[30] T. Qin, L. Zhao, J. Zhang, Fastener effects on mechanical behaviors of double-lap composite joints, *Composite Structures*, Vol. 100, pp. 413-423, 2013/06/01/, 2013.

[31] I. F. Soykok, End geometry and pin-hole effects on axially loaded adhesively bonded composite joints, *Composites Part B: Engineering*, Vol. 77, pp. 129-138, 2015/08/01/, 2015.

[32] G. M. Pearce, A. F. Johnson, R. S. Thomson, D. W. Kelly, Experimental Investigation of Dynamically Loaded Bolted Joints in Carbon Fibre Composite Structures, *Applied Composite Materials*, Vol. 17, No. 3, pp. 271-291, June 01, 2010.

[33] S. Daouk, F. Louf, C. Cluzel, O. Dorival, L. Champaney, S. Audebert, Study of the dynamic behavior of a bolted joint under heavy loadings, *Journal of Sound and Vibration*, Vol. 392, pp. 307-324, 2017/03/31/, 2017.

[34] G. M. K. Pearce, A. F. Johnson, A. K. Hellier, R. S. Thomson, A Stacked-Shell Finite Element Approach for Modelling a Dynamically Loaded Composite Bolted Joint Under in-Plane Bearing Loads, *Applied Composite Materials*, Vol. 20, No. 6, pp. 1025-1039, December 01, 2013.

[35] L. Feo, G. Marra, A. S. Mosallam, Stress analysis of multi-bolted joints for FRP pultruded composite structures, *Composite Structures*, Vol. 94, No. 12, pp. 3769-3780, 2012/12/01/, 2012.

[36] Z. Shen, D. Hu, Y. Zhang, Q. Cai, X. Han, Continuous twice-impacts analysis of UHMWPE laminate fixed with bolted joints, *International Journal of Impact Engineering*, Vol. 109, pp. 293-301, 2017/11/01/, 2017.

[37] M. Y. Tsai, J. Morton, An investigation into the stresses in double-lap adhesive joints with laminated composite adherends, *International Journal of Solids and Structures*, Vol. 47, pp. 3317-3325, 2010.

[38] M. Y. Tsai, J. Morton, F. L. Matthews, Experimental and Numerical Studies of a Laminated Composite Single-Lap Adhesive Joint, *Journal of Composite Materials*, Vol. 29, pp. 1254-1275, 1995.

[39] Q. M. Li, R. A. W. Mines, R. S. Birch, Static and dynamic behaviour of composite riveted joints in tension, *International Journal of Mechanical Sciences*, Vol. 43, pp. 1591-1610, 2001.

[40] S. W. Lee, D. G. Lee, K. S. Jeong, Static and Dynamic Torque Characteristics of Composite Cocured Single Lap Joint, *Journal of Composite Materials*, Vol. 31, pp. 2188-2201, 1997.

[41] C. Stocchi, P. Robinson, S. T. Pinho, A detailed finite element investigation of composite bolted joints with countersunk fasteners, *Composites Part A: Applied Science and Manufacturing*, Vol. 52, pp. 143-150, 2013/09/01/, 2013.

[42] B. Mandal, A. Chakrabarti, A simple homogenization scheme for 3D finite element analysis of composite bolted joints, *Composite Structures*, Vol. 120, pp. 1-9, 2015/02/01/, 2015.

[43] H.-T. Thai, B. Uy, Finite element modelling of blind bolted composite joints, *Journal of Constructional Steel Research*, Vol. 112, pp. 339-353, 2015/09/01/, 2015.

[44] N. M. Chowdhury, W. K. Chiu, J. Wang, P. Chang, Experimental and finite element studies of bolted, bonded and hybrid step lap joints of thick carbon fibre/epoxy panels used in aircraft structures, *Composites Part B: Engineering*, Vol. 100, pp. 68-77, 2016/09/01/, 2016.

[45] L. Prabhu, V. Krishnaraj, S. Sathish, V. Sathyamoorthy, Experimental and Finite Element Analysis of GFRP Composite Laminates with Combined Bolted and Bonded Joints, *Indian Journal of Science and Technology*, Vol. 10, No. 14, 2017.

[46] P. J. Gray, C. T. McCarthy, A highly efficient user-defined finite element for load distribution analysis of large-scale bolted composite structures, *Composites Science and Technology*, Vol. 71, No. 12, pp. 1517-

1527, 2011/08/19/, 2011.
[47] P. J. Gray, C. T. McCarthy, A global bolted joint model for finite element analysis of load distributions in multi-bolt composite joints, *Composites Part B: Engineering*, Vol. 41, pp. 317-325, 2010.
[48] L. Zhou, D. Zhang, L. Zhao, X. Zhou, J. Zhang, F. Liu, Design and analysis of a novel bolted composite π joint under bending load, *Materials & Design*, Vol. 98, pp. 201-208, 2016/05/15/, 2016.
[49] X. Cheng, J. Fan, S. Liu, X. Guo, Y. Xu, T. Zhang, Design and investigation of composite bolted π-joints with an unconventional configuration under bending load, *Composites Part B: Engineering*, Vol. 85, pp. 59-67, 2016/02/01/, 2016.
[50] P. Lopez-Cruz, J. Laliberté, L. Lessard, Investigation of bolted/bonded composite joint behaviour using design of experiments, *Composite Structures*, Vol. 170, pp. 192-201, 2017/06/15/, 2017.
[51] A. Vassilopoulos, 2014, *Fatigue and fracture of adhesively-bonded composite joints*, Elsevier,
[52] T. Ireman, Three-dimensional stress analysis of bolted single-lap composite joints, *Composite Structures*, Vol. 43, No. 3, pp. 195-216, 1998/11/01/, 1998.
[53] K. I. Tserpes, G. Labeas, P. Papanikos, T. Kermanidis, Strength prediction of bolted joints in graphite/epoxy composite laminates, *Composites Part B: Engineering*, Vol. 33, No. 7, pp. 521-529, 2002/10/01/, 2002.
[54] Y. Xiao, T. Ishikawa, Bearing strength and failure behavior of bolted composite joints (part I: Experimental investigation), *Composites Science and Technology*, Vol. 65, No. 7, pp. 1022-1031, 2005/06/01/, 2005.
[55] Y. Xiao, T. Ishikawa, Bearing strength and failure behavior of bolted composite joints (part II: modeling and simulation), *Composites Science and Technology*, Vol. 65, No. 7, pp. 1032-1043, 2005/06/01/, 2005.
[56] P. A. Sharos, B. Egan, C. T. McCarthy, An analytical model for strength prediction in multi-bolt composite joints at various loading rates, *Composite Structures*, Vol. 116, pp. 300-310, 2014/09/01/, 2014.
[57] M. A. McCarthy, C. T. McCarthy, V. P. Lawlor, W. F. Stanley, Three-dimensional finite element analysis of single-bolt, single-lap composite bolted joints: part I—model development and validation, *Composite Structures*, Vol. 71, pp. 140-158, 2005.
[58] C. T. McCarthy, M. A. McCarthy, Three-dimensional finite element analysis of single-bolt, single-lap composite bolted joints: Part II—effects of bolt-hole clearance, *Composite Structures*, Vol. 71, pp. 159-175, 2005.
[59] P. J. Gray, C. T. McCarthy, An analytical model for the prediction of through-thickness stiffness in tension-loaded composite bolted joints, *Composite Structures*, Vol. 94, No. 8, pp. 2450-2459, 2012/07/01/, 2012.
[60] M. El Zaroug, F. Kadioglu, M. Demiral, D. Saad, Experimental and numerical investigation into strength of bolted, bonded and hybrid single lap joints: Effects of adherend material type and thickness, *International Journal of Adhesion and Adhesives*, Vol. 87, pp. 130-141, 2018/12/01/, 2018.
[61] L. Zhao, M. Shan, F. Liu, J. Zhang, A probabilistic model for strength analysis of composite double-lap single-bolt joints, *Composite Structures*, Vol. 161, pp. 419-427, 2017/02/01/, 2017.
[62] H.-L. Ma, Z. Jia, K.-t. Lau, X. Li, D. Hui, S.-q. Shi, Enhancement on mechanical strength of adhesively-bonded composite lap joints at cryogenic environment using coiled carbon nanotubes, *Composites Part B: Engineering*, Vol. 110, pp. 396-401, 2017/02/01/, 2017.
[63] A. Othman, K. J. Jadee, M.-Z. Ismadi, Mitigating stress concentration through defense hole system for improvement in bearing strength of composite bolted joint, Part 1: Numerical analysis, *Journal of Composite Materials*, Vol. 51, No. 26, pp. 3685-3699, 2017.
[64] H. Li, Z. Lu, Y. Zhang, Probabilistic strength analysis of bolted joints in laminated composites using point estimate method, *Composite Structures*, Vol. 88, No. 2, pp. 202-211, 2009/04/01/, 2009.
[65] J. H. Choi, Y. H. Lee, J. H. Kweon, W. S. Che, Strength of Composite Laminated Bolted Joint Subjected to a Clamping Force, *Key Engineering Materials*, Trans Tech Publ, 2006, pp. 1777-1780.
[66] H.-S. Chen, The static and fatigue strength of bolted joints in composites with hygrothermal cycling, *Composite Structures*, Vol. 52, No. 3, pp. 295-306, 2001/05/01/, 2001.
[67] Y. Ling, An estimation method of bearing strength of bolted joints in fibre reinforced composite, *Applied Mathematics and Mechanics*, Vol. 7, No. 1, pp. 103-109, January 01, 1986.
[68] Y. Pekbey, The bearing strength and failure behavior of bolted e-glass/epoxy composite joints, *Mechanics of Composite Materials*, Vol. 44, No. 4, pp. 397-414, July 01, 2008.
[69] T. Katsumata, Y. Mizutani, A. Todoroki, R. Matsuzaki, Study of high-strength CFRP bolted joints with failure-monitoring cone washers, *Frontiers of Mechanical Engineering*, Vol. 6, No. 3, pp. 272, August 20, 2011.
[70] T. Collings, 1977, *The strength of bolted joints in multi-directional CFRP laminates*, Citeseer,
[71] G. Kretsis, F. L. Matthews, The strength of bolted joints in glass fibre/epoxy laminates, *Composites*, Vol. 16, No. 2, pp. 92-102, 1985/04/01/, 1985.
[72] H. Ahmad, A. D. Crocombe, P. A. Smith, Strength prediction in CFRP woven laminate bolted double-lap joints under quasi-static loading using XFEM, *Composites Part A Applied Science and Manufacturing*, Vol. 56, pp. 192–202, 2014.
[73] A. Ataş, C. Soutis, Strength prediction of bolted joints in CFRP composite laminates using cohesive zone elements, *Composites Part B: Engineering*, Vol. 58, pp. 25-34, 2014.
[74] F. Esmaeili, M. Zehsaz, T. N. Chakherlou, Experimental Investigations on the Effects of Torque Tightening on the Fatigue Strength of Double-lap Simple Bolted and Hybrid (Bolted/Bonded) Joints, *Strain*, Vol. 50, No. 4,

pp. 347-354, 2014.
[75] O. Sayman, R. Siyahkoc, F. Sen, R. Ozcan, Experimental Determination of Bearing Strength in Fiber Reinforced Laminated Composite Bolted Joints under Preload, *Journal of Reinforced Plastics and Composites*, Vol. 26, No. 10, pp. 1051-1063, 2007.
[76] P. D. Herrington, M. Sabbaghian, Effect of Radial Clearance between Bolt and Washer on the Bearing Strength of Composite Bolted Joints, *Journal of Composite Materials*, Vol. 26, No. 12, pp. 1826-1843, 1992.
[77] F. Esmaeili, M. Zehsaz, T. N. Chakherlou, S. Hasanifard, Experimental and Numerical Study of the Fatigue Strength of Double Lap Bolted Joints and the Effect of Torque Tightening on the Fatigue Life of Jointed Plates, *Transactions of the Indian Institute of Metals*, Vol. 67, No. 4, pp. 581-588, August 01, 2014.
[78] H. Ahmad, A. D. Crocombe, P. A. Smith, Strength prediction in CFRP woven laminate bolted single-lap joints under quasi-static loading using XFEM, *Composites Part A: Applied Science and Manufacturing*, Vol. 66, pp. 82-93, 2014/11/01/, 2014.
[79] L. Liu, J. Zhang, K. Chen, H. Wang, Influences of assembly parameters on the strength of bolted composite-metal joints under tensile loading, *Advanced Composite Materials*, Vol. 22, No. 5, pp. 339-359, 2013/10/01, 2013.
[80] J. H. Walter, R. R. Schmitt, Influence of Clamp-Up Force on the Strength of Bolted Composite Joints, *AIAA Journal*, Vol. 32, No. 3, pp. 665-667, 1994/03/01, 1994.
[81] F. X. Irisarri, F. Laurin, N. Carrere, *6 - Strength prediction of bolted joints in carbon fibre reinforced polymer (CFRP) composites*, in: P. Camanho, L. Tong, *Composite Joints and Connections*, Eds., pp. 208-244: Woodhead Publishing, 2011.
[82] S. Nilsson, Increasing Strength of Graphite/Epoxy Bolted Joints by Introducing an Adhesively Bonded Metallic Insert, *Journal of Composite Materials*, Vol. 23, No. 7, pp. 642-650, 1989.
[83] F. Gamdani, R. Boukhili, A. Vadean, Tensile strength of open-hole, pin-loaded and multi-bolted single-lap joints in woven composite plates, *Materials & Design*, Vol. 88, pp. 702-712, 2015/12/25/, 2015.
[84] H. Ahmad, M. A. Abed, Strength Prediction of Double-Lap Bolted Joints of Woven Fabric CFRP Composite Plates Using Hashin Formulations, in *Proceeding of*, Trans Tech Publ, pp. 290-294.
[85] F. Nerilli, G. Vairo, Progressive damage in composite bolted joints via a computational micromechanical approach, *Composites Part B: Engineering*, Vol. 111, pp. 357-371, 2017/02/15/, 2017.
[86] H. Yazdani Nezhad, B. Egan, F. Merwick, C. T. McCarthy, Bearing damage characteristics of fibre-reinforced countersunk composite bolted joints subjected to quasi-static shear loading, *Composite Structures*, Vol. 166, pp. 184-192, 2017/04/15/, 2017.
[87] B. He, D. Ge, Coupled continuum damage mechanics and failure envelope method for failure prediction of composite multi-bolt joints, *Journal of Reinforced Plastics and Composites*, Vol. 36, No. 8, pp. 563-578, 2017.
[88] Y. Zhou, H. Yazdani Nezhad, C. Hou, X. Wan, C. T. McCarthy, M. A. McCarthy, A three dimensional implicit finite element damage model and its application to single-lap multi-bolt composite joints with variable clearance, *Composite Structures*, Vol. 131, pp. 1060-1072, 2015/11/01/, 2015.
[89] A. Du, Y. Liu, H. Xin, Y. Zuo, Progressive damage analysis of PFRP double-lap bolted joints using explicit finite element method, *Composite Structures*, Vol. 152, pp. 860-869, 2016/09/15/, 2016.
[90] C. Hühne, A. K. Zerbst, G. Kuhlmann, C. Steenbock, R. Rolfes, Progressive damage analysis of composite bolted joints with liquid shim layers using constant and continuous degradation models, *Composite Structures*, Vol. 92, No. 2, pp. 189-200, 2010/01/01/, 2010.
[91] J. Zhang, F. Liu, L. Zhao, Y. Chen, B. Fei, A progressive damage analysis based characteristic length method for multi-bolt composite joints, *Composite Structures*, Vol. 108, pp. 915-923, 2014/02/01/, 2014.
[92] G. Kolks, K. I. Tserpes, Efficient progressive damage modeling of hybrid composite/titanium bolted joints, *Composites Part A: Applied Science and Manufacturing*, Vol. 56, pp. 51-63, 2014/01/01/, 2014.
[93] M. Chishti, C. H. Wang, R. S. Thomson, A. C. Orifici, Experimental investigation of damage progression and strength of countersunk composite joints, *Composite Structures*, Vol. 94, No. 3, pp. 865-873, 2012/02/01/, 2012.
[94] Y. Zhou, H. Yazdani-Nezhad, M. A. McCarthy, X. Wan, C. McCarthy, A study of intra-laminar damage in double-lap, multi-bolt, composite joints with variable clearance using continuum damage mechanics, *Composite Structures*, Vol. 116, pp. 441-452, 2014/09/01/, 2014.
[95] G. Lampeas, N. Perogamvros, Analysis of composite bolted joints by a macro-modelling approach, *International Journal of Structural Integrity*, Vol. 7, No. 3, pp. 412-428, 2016.
[96] A. Ataş, C. Soutis, Subcritical damage mechanisms of bolted joints in CFRP composite laminates, *Composites Part B: Engineering*, Vol. 54, pp. 20-27, 2013/11/01/, 2013.
[97] L. V. Awadhani, A. K. Bewoor, Analytical and experimental investigation of Effect of geometric parameters on the failure modes in a single lap single bolted metal to GFRP composite bolted joints subjected to axial tensile loading, *Materials Today: Proceedings*, Vol. 4, No. 8, pp. 7345-7350, 2017/01/01/, 2017.
[98] X. F. Hu, A. Haris, M. Ridha, V. B. C. Tan, T. E. Tay, Progressive failure of bolted single-lap joints of woven fibre-reinforced composites, *Composite Structures*, Vol. 189, pp. 443-454, 2018/04/01/, 2018.
[99] X. Cheng, S. Wang, J. Zhang, W. Huang, Y. Cheng, J. Zhang, Effect of damage on failure mode of multi-bolt composite joints using failure envelope method,

Composite Structures, Vol. 160, pp. 8-15, 2017/01/15/, 2017.

[100] K. C. Warren, R. A. Lopez-Anido, S. S. Vel, H. H. Bayraktar, Progressive failure analysis of three-dimensional woven carbon composites in single-bolt, double-shear bearing, *Composites Part B: Engineering,* Vol. 84, pp. 266-276, 2016/01/01/, 2016.

[101] Z. Kapidžić, H. Ansell, J. Schön, K. Simonsson, Quasi-static bearing failure of CFRP composite in biaxially loaded bolted joints, *Composite Structures,* Vol. 125, pp. 60-71, 2015/07/01/, 2015.

[102] P. Liu, X. Cheng, S. Wang, S. Liu, Y. Cheng, Numerical analysis of bearing failure in countersunk composite joints using 3D explicit simulation method, *Composite Structures,* Vol. 138, pp. 30-39, 2016/03/15/, 2016.

[103] F. Nerilli, M. Marino, G. Vairo, A Numerical Failure Analysis of Multi-bolted Joints in FRP Laminates Based on Basalt Fibers, *Procedia Engineering,* Vol. 109, pp. 492-506, 2015/01/01/, 2015.

[104] M. Ozen, O. Sayman, Failure loads of mechanical fastened pinned and bolted composite joints with two serial holes, *Composites Part B: Engineering,* Vol. 42, No. 2, pp. 264-274, 2011/03/01/, 2011.

[105] U. A. Khashaba, T. A. Sebaey, K. A. Alnefaie, Failure and reliability analysis of pinned-joints composite laminates: Effects of stacking sequences, *Composites Part B: Engineering,* Vol. 45, No. 1, pp. 1694-1703, 2013/02/01/, 2013.

[106] U. Khashaba, T. Sebaey, K. Alnefaie, Failure and reliability analysis of pinned-joint composite laminates: Effects of pin–hole clearance, *Journal of Composite Materials,* Vol. 47, No. 18, pp. 2287-2298, 2013.

[107] Z. Wang, S. Zhou, J. Zhang, X. Wu, L. Zhou, Progressive failure analysis of bolted single-lap composite joint based on extended finite element method, *Materials & Design,* Vol. 37, pp. 582-588, 2012.

[108] F. Liu, L. Zhao, S. Mehmood, J. Zhang, B. Fei, A modified failure envelope method for failure prediction of multi-bolt composite joints, *Composites Science and Technology,* Vol. 83, pp. 54-63, 2013/06/28/, 2013.

[109] I. F. Soykok, O. Sayman, M. Ozen, B. Korkmaz, Failure analysis of mechanically fastened glass fiber/epoxy composite joints under thermal effects, *Composites Part B: Engineering,* Vol. 45, No. 1, pp. 192-199, 2013/02/01/, 2013.

[110] A. Ataş, G. F. Mohamed, C. Soutis, Progressive failure analysis of bolted joints in composite laminates, *Plastics, Rubber and Composites,* Vol. 41, No. 4-5, pp. 209-214, 2012/06/01, 2012.

[111] F. Lu, D. a. Cai, J. Tang, W. Li, J. Deng, G. Zhou, Bearing failure of single-/double-shear composite bolted joints: An explicit finite element modeling, *Journal of Reinforced Plastics and Composites,* Vol. 37, No. 14, pp. 933-944, 2018.

[112] S. Y. Lee, H. Ahmad, Bearing Stress at Failure of Double-Lap Hybrid Joints in Woven Fabric Kenaf Fiber Composite Plates under Quasi-static Loading, *MATEC Web Conf.,* Vol. 103, pp. 02008, 2017.

[113] L. Zhao, T. Qin, J. Zhang, M. Shan, B. Fei, Determination method of stress concentration relief factors for failure prediction of composite multi-bolt joints, *Journal of Composite Materials,* Vol. 49, No. 14, pp. 1667-1680, 2015.

[114] J. Zhang, F. Liu, L. Zhao, J. Zhi, L. Zhou, B. Fei, Influence of end distances on the failure of composite bolted joints, *Journal of Reinforced Plastics and Composites,* Vol. 34, No. 5, pp. 388-404, 2015.

[115] Á. Olmedo, C. Santiuste, On the prediction of bolted single-lap composite joints, *Composite Structures,* Vol. 94, No. 6, pp. 2110-2117, 2012/05/01/, 2012.

[116] J. Fan, X. Cheng, S. Wang, X. Guo, T. Zhang, Experimental and numerical investigation of composite bolted π-joint subjected to bending load, *Composites Part B: Engineering,* Vol. 78, pp. 324-330, 2015/09/01/, 2015.

[117] M.-G. Ko, J.-H. Kweon, J.-H. Choi, Fatigue characteristics of jagged pin-reinforced composite single-lap joints in hygrothermal environments, *Composite Structures,* Vol. 119, pp. 59-66, 2015/01/01/, 2015.

[118] I. K. Giannopoulos, D. Doroni-Dawes, K. I. Kourousis, M. Yasaee, Effects of bolt torque tightening on the strength and fatigue life of airframe FRP laminate bolted joints, *Composites Part B: Engineering,* Vol. 125, pp. 19-26, 2017/09/15/, 2017.

[119] Y. Sun, G. Z. Voyiadjis, W. Hu, F. Shen, Q. Meng, Fatigue and fretting fatigue life prediction of double-lap bolted joints using continuum damage mechanics-based approach, *International Journal of Damage Mechanics,* Vol. 26, No. 1, pp. 162-188, 2017.

[120] G. Scarselli, E. Castorini, F. W. Panella, R. Nobile, A. Maffezzoli, Structural behaviour modelling of bolted joints in composite laminates subjected to cyclic loading, *Aerospace Science and Technology,* Vol. 43, pp. 89-95, 2015/06/01/, 2015.

[121] S. Zhou, Y. Sun, J. Ge, X. Chen, Multiaxial fatigue life prediction of composite bolted joint under constant amplitude cycle loading, *Composites Part B: Engineering,* Vol. 74, pp. 131-137, 2015/06/01/, 2015.

[122] Z. Kapidžić, H. Ansell, J. Schön, K. Simonsson, Fatigue bearing failure of CFRP composite in biaxially loaded bolted joints at elevated temperature, *Composite Structures,* Vol. 127, pp. 298-307, 2015/09/01/, 2015.

[123] J. Wang, N. Zhang, S. Guo, Experimental and numerical analysis of blind bolted moment joints to CFTST columns, *Thin-Walled Structures,* Vol. 109, pp. 185-201, 2016/12/01/, 2016.

[124] S. Heimbs, S. Schmeer, J. Blaurock, S. Steeger, Static and dynamic failure behaviour of bolted joints in carbon fibre composites, *Composites Part A: Applied Science and Manufacturing,* Vol. 47, pp. 91-101, 2013/04/01/, 2013.

[125] J. Zhang, F. Liu, L. Zhao, B. Fei, A novel characteristic curve for failure prediction of multi-bolt composite joints, *Composite Structures,* Vol. 108, pp. 129-136,

2014/02/01/, 2014.

[126] G. M. K. Pearce, A. F. Johnson, A. K. Hellier, R. S. Thomson, A study of dynamic pull-through failure of composite bolted joints using the stacked-shell finite element approach, *Composite Structures*, Vol. 118, pp. 86-93, 2014/12/01/, 2014.

[127] A. Fontanelli, P. Diaz Montiel, S. Venkataraman, *Bearing Failure Predictions of Composite Bolted Joints using Continuum Damage Models*, AIAA SciTech Forum in: *2018 AIAA/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference*, Eds.: American Institute of Aeronautics and Astronautics, 2018.

[128] F. Sen, M. Pakdil, O. Sayman, S. Benli, Experimental Failure Analysis of Glass-Epoxy Laminated Composite Bolted-Joints with Clearance Under Preload, *International Journal of Damage Mechanics*, Vol. 20, No. 2, pp. 163-178, 2011.

[129] W. J. Paulson, C. Oskay, Failure Prediction of Countersunk Composite Bolted Joints Using Reduced Order Multiple Space-Time Homogenization, in *Proceeding of*.

[130] A. P. K. Joseph, P. Davidson, A. M. Waas, *Intra-inter Crack Band Model (I2CBM) for Progressive Damage and Failure Analysis of Joints*, AIAA SciTech Forum in: *58th AIAA/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference*, Eds.: American Institute of Aeronautics and Astronautics, 2017.

[131] B. Mandal, A. Chakrabarti, Numerical failure assessment of multi-bolt FRP composite joints with varying sizes and preloads of bolts, *Composite Structures*, Vol. 187, pp. 169-178, 2018/03/01/, 2018.

[132] J. B. Bai, R. A. Shenoi, X. Y. Yun, J. J. Xiong, Progressive damage modelling of hybrid RTM-made composite Π-joint under four-point flexure using mixed failure criteria, *Composite Structures*, Vol. 159, pp. 327-334, 2017/01/01/, 2017.

[133] J. H. Stockdale, F. L. Matthews, The effect of clamping pressure on bolt bearing loads in glass fibre-reinforced plastics, *Composites*, Vol. 7, No. 1, pp. 34-38, 1976/01/01/, 1976.

[134] T. Sawa, T. Kobayashi, The Strength of Joints Combining an Adhesive with a Bolt, *The Journal of Adhesion*, Vol. 25, No. 4, pp. 269-280, 1988/06/01, 1988.

[135] L. Yao, Q. Feng, D. Wan, L. Wu, K. Yang, J. Hou, B. Liu, Q. Wan, Experiment and finite element simulation of high strength steel adhesive joint reinforced by rivet for automotive applications, *Journal of Adhesion Science and Technology*, Vol. 31, No. 14, pp. 1617-1625, 2017/07/18, 2017.

[136] M. Y. Solmaz, T. Topkaya, Progressive Failure Analysis in Adhesively, Riveted, and Hybrid Bonded Double-Lap Joints, *The Journal of Adhesion*, Vol. 89, No. 11, pp. 822-836, 2013/11/02, 2013.

[137] G. Marannano, B. Zuccarello, Static strength and fatigue life of optimized hybrid single lap aluminum–CFRP structural joints, *The Journal of Adhesion*, Vol. 94, No. 7, pp. 501-528, 2018/06/07, 2018.

[138] G. Qin, J. Na, W. Tan, W. Mu, J. Ji, Failure prediction of adhesively bonded CFRP-Aluminum alloy joints using cohesive zone model with consideration of temperature effect, *The Journal of Adhesion*, pp. 1-24, 2018.

[139] T. Tannert, H. Zhu, S. Myslicki, F. Walther, T. Vallée, Tensile and fatigue investigations of timber joints with glued-in FRP rods, *The Journal of Adhesion*, Vol. 93, No. 11, pp. 926-942, 2017/09/19, 2017.

[140] A. M. Pereira, P. N. B. Reis, J. A. M. Ferreira, Effect of the mean stress on the fatigue behaviour of single lap joints, *The Journal of Adhesion*, Vol. 93, No. 6, pp. 504-513, 2017/05/12, 2017.

[141] S. O. Olajide, E. Kandare, A. A. Khatibi, Fatigue life uncertainty of adhesively bonded composite scarf joints – an airworthiness perspective, *The Journal of Adhesion*, Vol. 93, No. 7, pp. 515-530, 2017/06/07, 2017.

[142] T. Vallée, T. Tannert, S. Fecht, Adhesively bonded connections in the context of timber engineering – A Review, *The Journal of Adhesion*, Vol. 93, No. 4, pp. 257-287, 2017/03/21, 2017.

[143] E. W. Godwin, F. L. Matthews, A review of the strength of joints in fibre-reinforced plastics: Part 1. Mechanically fastened joints, *Composites*, Vol. 11, pp. 155-160, 1980.

[144] B. L. Agarwal, Static Strength Prediction of Bolted Joint in Composite Material, *AIAA Journal*, Vol. 18, pp. 1371-1375, 1980.

[145] W.-H. Lin, M.-H. R. Jen, The Strength of Bolted and Bonded Single-Lapped Composite Joints in Tension, *Journal of Composite Materials*, Vol. 33, pp. 640-666, 1999.

[146] P. A. Smith, K. J. Pascoe, C. Polak, D. O. Stroud, The behaviour of single-lap bolted joints in CFRP laminates, *Composite Structures*, Vol. 6, pp. 41-55, 1986.

[147] T. N. Chakherlou, M. J. Razavi, A. B. Aghdam, B. Abazadeh, An experimental investigation of the bolt clamping force and friction effect on the fatigue behavior of aluminum alloy 2024-T3 double shear lap joint, *Materials & Design*, Vol. 32, pp. 4641-4649, 2011.

[148] F. Esmaeili, M. Zehsaz, T. N. Chakherlou, Investigation the effect of tightening torque on the fatigue strength of double lap simple bolted and hybrid (bolted–bonded) joints using volumetric method, *Materials & Design*, Vol. 63, pp. 349-359, 2014.

[149] J. M. Mínguez, J. Vogwell, Effect of torque tightening on the fatigue strength of bolted joints, *Engineering Failure Analysis*, Vol. 13, pp. 1410-1421, 2006.

[150] D. S. Saunders, S. C. Galea, G. K. Deirmendjian, The development of fatigue damage around fastener holes in thick graphite/epoxy composite laminates, *Composites*, Vol. 24, pp. 309-321, 1993.

[151] B. Benchekchou, R. G. White, Stresses around fasteners in composite structures in flexure and effects on fatigue damage initiation part 1: cheese-head bolts, *Composite*

Structures, Vol. 33, pp. 95-108, 1995.

[152] B. Benchekchou, R. G. White, Stresses around fasteners in composite structures in flexure and effects on fatigue damage initiation part 2: countersunk bolts, *Composite Structures,* Vol. 33, pp. 109-119, 1995.

[153] E. Persson, I. Eriksson, P. Hammersberg, Propagation of Hole Machining Defects in Pin-Loaded Composite Laminates, *Journal of Composite Materials,* Vol. 31, pp. 383-408, 1997.

[154] E. Persson, I. Eriksson, L. Zackrisson, Effects of hole machining defects on strength and fatigue life of composite laminates, *Composites Part A: Applied Science and Manufacturing,* Vol. 28, pp. 141-151, 1997.

[155] W. Li, H. Cai, C. Li, K. Wang, L. Fang, Micro-mechanics of failure for fatigue strength prediction of bolted joint structures of carbon fiber reinforced polymer composite, *Composite Structures,* Vol. 124, pp. 345-356, 2015.

[156] *Experimental investigation of fatigue behaviour in composite bolted joints*, 1999.

[157] A. Lanciotti, L. Lazzeri, M. Raggi, Fatigue behaviour of mechanically fastened joints in composite materials, *Composite Structures,* Vol. 33, pp. 87-94, 1995.

[158] R. Starikov, J. Schön, Local fatigue behaviour of CFRP bolted joints, *Composites Science and Technology,* Vol. 62, pp. 243-253, 2002.

[159] R. Starikov, Fatigue behaviour of mechanically fastened aluminium joints tested in spectrum loading, *International Journal of Fatigue,* Vol. 26, pp. 1115-1127, 2004.

[160] R. Starikov, J. Schön, Quasi-static behaviour of composite joints with protruding-head bolts, *Composite Structures,* Vol. 51, pp. 411-425, 2001.

[161] P. A. Smith, K. J. Pascoe, Fatigue of bolted joints in (0/90) CFRP laminates, *Composites Science and Technology,* Vol. 29, pp. 45-69, 1987.

[162] R. Starikov, J. Schön, Fatigue resistance of composite joints with countersunk composite and metal fasteners, *International Journal of Fatigue,* Vol. 24, pp. 39-47, 2002.

[163] R. Starikov, J. Schön, Experimental study on fatigue resistance of composite joints with protruding-head bolts, *Composite Structures,* Vol. 55, pp. 1-11, 2002.

[164] E. Persson, I. Eriksson, Fatigue of multiple-row bolted joints in carbon/epoxy laminates: ranking of factors affecting strength and fatigue life, *International Journal of Fatigue,* Vol. 21, pp. 337-353, 1999.

[165] A. M. Rubin, Common failure modes for composite aircraft structures due to secondary loads, *Composites Engineering,* Vol. 2, pp. 313-320, 1992.

[166] T. S. Lim, B. C. Kim, D. G. Lee, Fatigue characteristics of the bolted joints for unidirectional composite laminates, *Composite Structures,* Vol. 72, pp. 58-68, 2006.

[167] S. Seike, Y. Takao, W.-X. Wang, T. Matsubara, Bearing damage evolution of a pinned joint in CFRP laminates under repeated tensile loading, *International Journal of Fatigue,* Vol. 32, pp. 72-81, 2010.

[168] D. W. Wilson, Y. Tsujimoto, On phenomenological failure criteria for composite bolted joint analysis, *Composites Science and Technology,* Vol. 26, pp. 283-305, 1986.

[169] Z. Q. Wang, S. Zhou, J. F. Zhang, X. Q. Wang, Failure Load Prediction of Bolted Single-Lap Composite Joint Based on XFEM, *Advanced Materials Research,* Trans Tech Publ, 2011, pp. 742-745.

[170] S. Zhou, Z. Q. Wang, J. F. Zhang, Y. G. Xie, Influence of Ply Angle on Failure Response of Bolted Composite Joint, *Advanced Materials Research*, Trans Tech Publ, 2012, pp. 7128-7132.

[171] T. Sadowski, M. Kneć, P. Golewski, Experimental investigations and numerical modelling of steel adhesive joints reinforced by rivets, *International Journal of Adhesion and Adhesives,* Vol. 30, pp. 338-346, 2010.

[172] M. Grassi, B. Cox, X. Zhang, Simulation of pin-reinforced single-lap composite joints, *Composites Science and Technology,* Vol. 66, pp. 1623-1638, 2006.

[173] A. Ataş, C. Soutis, Application of cohesive zone elements in damage analysis of composites: Strength prediction of a single-bolted joint in CFRP laminates, *International Journal of Non-Linear Mechanics,* Vol. 66, pp. 96-104, 2014.