Research Article

Numerical Shear Buckling Investigation of GLAREs with Initial Delamination

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1. Introduction

Fibre metal laminates (FMLs) consist of metal (typically, high strength aluminium alloy) sheets bonded to fibre-reinforced composite laminates. They supply an excellent mixture of metals and composites that results in a material, which merges the advantages of composites and metals. FMLs present significant weight savings relative to metallic structures [1]. There are three main kinds of FML, including ARALL (Aramid-Reinforced Aluminium Laminate), CARALL (Carbon Reinforced Aluminium Laminate), and GLARE (Glass Reinforced Aluminium Laminate) [2]. GLARE is the most common FML in aerospace structures. AKZO introduced the first patent on GLARE in 1987 (see Table 1) [3]. According to the standard classification, GLAREs are variants in the thickness of the aluminium layer and the number of layers. This variation is presented in a standard classification system in the form of GLARE A-B/C-D, where the sign A implies the grade of GLARE, B and C show the number of aluminium layers and composite layers, respectively, and D indicates the thickness of the aluminium layer [4]. For example, GLARE 3-3/2-0.3 specifies three aluminium plies with a thickness of 0.3 mm, two layers of composite with a layout of [0/90], and a thickness of 0.25 mm.

FMLs, particularly GLAREs, are widely employed in the aerospace industry because of their high strength-to-weight ratio, impact resistance, and resistance to crack propagation [5, 6]. Hence, GLARE structures are applied in aerospace structures, for example, the fuselage skin structures of Airbus A380 [7–9].

Several studies have already been carried out to determine the novel properties of FMLs [10–15]. Besides, many researchers have directed their efforts toward overcoming the weaknesses and limitations of this material [16–20]. To increase the performance of FMLs, it is necessary to
recognize their failure mechanisms under different loading conditions. The main failure modes in FMLs are delamination, matrix cracking, and fibre breakage. Delamination, as one of the main common failures of FMLs, can be started by stress concentrations, interfacial voids, or transverse matrix cracks [21]. To date, several studies have been carried out related to the failure of FMLs [22–28]. To this end, Curiel Sosa et al. [22] analysed the delamination of GLAREs by the Extended Finite Element Method (XFEM). They investigated the crack propagation of a double cantilever beam (DCB) made of GLARE and compared the obtained results with the experimental data. In another study, Nowak [23] sought to address some failure modes of GLARE regarding the delamination by defining an Elastic-plastic behaviour for aluminium layers. Also, the effect of the alloy plasticity on the mechanical performance of the composite structure was evaluated by Nowak [23]. Zhu et al. [24] established a nonlinear finite element model based on the continuum damage mechanics. They explored the damage modes and collapse mechanisms of carbon-fibre-reinforced aluminium laminates under the high-velocity impact. Jin et al. [25] introduced a 3D constitutive model to analyse the mechanical behaviour under tensile and bending states. They calculated the ductile damage of alloy layers, failure of composite layer, and interface delamination by 3D criteria. Also, they examined the effect of fibre orientation on mechanical properties. Bie nias et al. [26] employed an End Notch Flexure (ENF) test for the delamination growth rate of fibre metal laminates. They demonstrated that glass-fibre laminates are more resistant to delamination growth than carbon-fibre laminates. Banat and Mania [28] calculated the progressive damage and failure behaviour of thin-walled GLARE columns constrained by in-plane compressive loading. Recently, Xu et al. [27] described the mechanical responses of hybrid FML joints under quasi-static uniaxial tension load. They determined the effect of joint geometry on the propagation of some damage, including matrix cracking, debonding of the adhesive layer, metal fracture, and fibre breakage.

The stability of GLAREs is a common concern, and the situation becomes even more critical when there is initial damage [28–30]. Up to the present time, countless research has already been devoted to specifying the compression buckling of FMLs [31–40]. For example, Bi et al. [34] evaluated the influences of the primary deflection, the loading state, and the geometric parameters on the elasto-plastic compression buckling and postbuckling of fibre metal laminates. Mania et al. [35–37] investigated the stability of FMLs from different perspectives. In this way, they improved a finite element method (FEM) model for the compression buckling and postbuckling response of 3/2 FML open cross-section profiles [35]. In another attempt, they also analytically examined the effect of the various fibre alignments on the compression buckling and postbuckling response of the FMLs, via a finite element analysis (FEA) [36], Al-Azzawi et al. [39] studied the delamination of GLARE laminate containing internal splice and doubler joints under compression buckling by an experimental approach. In another work, they also considered the relationship between the start of buckling and speedy progress in cumulative acoustic emissions (AEs) energy by implementing cohesive elements and a numerical method. The outcomes showed that all the damage, plasticity mechanisms, load eccentricity, and geometry imperfections affected the FEA [38]. Muddappa et al. [40] determined the effect of fibre orientation on the vibration and compression buckling behaviour under the action of partial edge loads employing the FEM.

Shear buckling is a very common phenomenon in aerospace structures that occurs when a laminate is subjected to a shear load along the four edges and is commonly the preliminary failure in thin panels [41–44]. Once a member begins to shear buckle, the plate starts wrinkling, and any further load will cause significant and unpredictable deformations, leading to complete loss of the load-carrying capacity of the member [41]. To date, the shear buckling response of different types of GLARE in the presence of delamination has not been evaluated yet. The present study is conducted based on two main objectives. Firstly, the effect of metal thickness of different types of GLARE on their shear buckling behaviour with and without initial delamination has been investigated. Secondly, this work refers to the impact of the delamination dimension and its position on the stability of GLAREs subjected to the shear loads. In this way, numerical analysis is applied using the application of the finite element software, ABAQUS. The Cohesive Zone Element of FM94 is also selected to investigate the delamination growth between delaminated layers. FM94 is a practical adhesive for bonding metallic and composite structures [45].

### Table 1: Commercially available GLARE grades [3].

| GLARE grade | Aluminium layers | Fibre layers |
|-------------|-----------------|--------------|
|             | Material | Thickness (mm) | Layout | Thickness (mm) |
| GLARE 1     | 7475-T76      | 0.3–0.4        | [0/0] | 0.25            |
| GLARE 2     | 2024-T3       | 0.2–0.5        | [90/90] | 0.25   |
| GLARE 3     | 2024-T3       | 0.2–0.5        | [0/90]  | 0.25   |
| GLARE 4     | 2024-T3       | 0.2–0.5        | [0/90/90/0] | 0.375 |
| GLARE 5     | 2024-T3       | 0.2–0.5        | [0/90/90/0] | 0.5   |
| GLARE 6     | 2024-T3       | 0.2–0.5        | [+45/-45] | 0.25  |

2. Description

As already mentioned, the work evaluates the shear buckling of different types of GLARE, consisting of three aluminium layers and two prepreg plies. The layouts and the thickness of laminates in this study which are based on the AKZOO patent [3] are presented in Table 2. It should be noted that GLARE 1 contains only two different metal thicknesses (0.3 mm and 0.4 mm), while other grades of GLARE have variant thicknesses from 0.2 mm to 0.5 mm.

In all cases, the GLARE laminate is a square plate, 160 mm in length. For the material of the metal layer,
aluminium alloys Al 2024-T 3 and Al 7075-T 61 are considered, while as a prepreg layer, the glass-epoxy fibre-reinforced prepreg is implemented.

In all cases, simply supported boundary conditions are applied on all edges. Both shear buckling load and simply supported boundary conditions are implemented in numerical modelling according to Figure 1. The initial circular delamination, varying in radius (10mm, 20mm, and 30mm), is located at the centre of the laminate and is considered in two different positions through the model thickness, shown in Figure 2. Accordingly, parametric studies are conducted to investigate the response of GLAREs to shear buckling load and delamination failure.

The present work is carried out through the following steps: (1) linear shear buckling analysis of the different types of GLARE and (2) postbuckling analysis and the delamination propagation of GLARE 3 with different metal thicknesses and two different positions of the delamination.

### 3. Methodology

This study is performed by a numerical method using ABAQUS, a finite element commercial software. The buckling analysis is carried out in two steps. The first step is a linear static analysis which calculates the stresses for a given reference set of loads. The second step is an eigenvalue analysis in which the results are given in terms of load factors (eigenvalues) and mode shapes (eigenvectors). It is worth mentioning that considering the mode shapes from an eigenvalue analysis is helpful to be employed as postulated imperfections to perform an iterative nonlinear postbuckling analysis. In this method, the first mode shape is scaled by a small amplitude (less than 0.0001), and then the geometry of the laminate is updated by using the scaled mode shape as an imperfection. Cohesive Zone Elements of FM94 are introduced to numerically simulate the propagation of the delamination in the laminate. In practice, FM94 is an adhesive with a service temperature of 220°F, designed for bonding metallic and composite structures. This adhesive offers a unique combination of high-temperature performance, toughness, and moisture resistance [45]. In Table 3, the mechanical properties of FM94 are presented.

In this study, the 8-node reduced-integration continuum shell element (SC8R) with 3 degrees of freedom at each node has been chosen for the modelling procedure. To establish the optimal mesh density, a mesh convergence study was performed on the GLARE configuration by changing the mesh density within the plane and through the thickness of the model. Accordingly, a highly refined mesh of 0.5mm in the thickness direction is generated using linear elements. Moreover, to preserve the accuracy of the results and accelerate the numerical analysis, the mesh size in the x-direction and y-direction varies from 0.2mm (at the discontinuous delamination front) to 2mm (at the distant area from the delamination zone). The schematic view of the meshing is shown in Figure 3.

Additionally, the hard contact element is employed between the layers to prevent overlapping layers while deforming, where there is initial delamination. In addition, both the aluminium layer and the prepreg one are supposed to be homogeneous. The prepreg layer has orthotropic material properties. Table 3 summarizes all materials properties used in GLARE constituents [46].

| Type of GLARE | Lay out of composite | Thickness of fibre layer | Total layout of GLARE | Thickness of metal layer | Total thickness of GLARE |
|---------------|----------------------|--------------------------|-----------------------|--------------------------|--------------------------|
| GLARE 1       | [0/0]                | 0.25                     | Al/[0/0]/Al/[0/0]/Al  | 0.3                      | 1.4                      |
|               |                      |                          |                       | 0.4                      | 1.7                      |
| GLARE 2       | [90/90]              | 0.25                     | Al/[90/90]/Al/[90/90]/Al | 0.2                      | 1.1                      |
|               |                      |                          |                       | 0.3                      | 1.4                      |
|               |                      |                          |                       | 0.4                      | 1.7                      |
|               |                      |                          |                       | 0.5                      | 2                       |
| GLARE 3       | [0/90]               | 0.25                     | Al/[0/90]/Al/[0/90]/Al | 0.2                      | 1.1                      |
|               |                      |                          |                       | 0.3                      | 1.4                      |
|               |                      |                          |                       | 0.4                      | 1.7                      |
|               |                      |                          |                       | 0.5                      | 2                       |
| GLARE 4       | [0/90/0]             | 0.375                    | Al/[0/90/0]/Al/[0/90/0]/Al | 0.2                      | 1.35                     |
|               |                      |                          |                       | 0.3                      | 1.65                     |
|               |                      |                          |                       | 0.4                      | 1.95                     |
|               |                      |                          |                       | 0.5                      | 2.25                     |
| GLARE 5       | [0/90/90/0]          | 0.5                      | Al/[0/90/90/0]/Al/[0/90/90/0]/Al | 0.2                      | 1.6                      |
|               |                      |                          |                       | 0.3                      | 1.9                      |
|               |                      |                          |                       | 0.4                      | 2.2                      |
|               |                      |                          |                       | 0.5                      | 2.5                      |
| GLARE 6       | [+45/-45]            | 0.25                     | Al/[+45/-45]/Al/[+45/-45]/Al | 0.2                      | 1.1                      |
|               |                      |                          |                       | 0.3                      | 1.4                      |
|               |                      |                          |                       | 0.4                      | 1.7                      |
|               |                      |                          |                       | 0.5                      | 2                       |
4. Validation of the Methodology

The numerical approach is initially validated for modelling (1) GLARE laminates, (2) buckling and postbuckling analysis, and (3) delamination growth. The validation is performed in two steps: (I) shear buckling of a fibre metal laminate containing initial delamination and (II) postbuckling and delamination growth of a composite plate.

4.1. Validation 1: Shear Buckling of FMLs Containing an Initial Delamination. In this section, an FML laminate containing three aluminium sheets interleaved with carbon-fibre/epoxy composite plies is under a uniform shear buckling load. The structure of the laminate is according to Table 4 and Figure 4. In addition, composite ply orientation and the considered initial delamination diameter are variants as 0°, 45°, and 90° and 10, 20, and 40 mm, respectively. The rest of the
assumptions, including the boundary condition, are according to the work by Obdržálek and Vrbka [47]. The calculation of two different positions of the delamination, Interface A (between ply numbers 1 and 2) and Interface B (between ply numbers 3 and 4), is reported in Table 5. As shown in Table 5, the deviation between currently obtained results and reference data is less than 1% in all cases, showing a promising agreement between the developed methodology and available ones.

4.2. Validation 2: Postbuckling and the Delamination Growth of a Composite Laminate. In the next step, the compression postbuckling response of an HTA/6376C rectangular plate with dimensions of 300 mm × 150 mm, containing initial delamination with a diameter of 60 mm, is calculated. All assumptions, including geometry, layout, boundary conditions, and material properties, are according to literature [48]. In this analysis, modelling of delamination growth is performed by using the Cohesive Zone Element. The obtained results are presented in Figure 5, which shows good compatibility of the proposed approach with the available results of [48].

5. Results and Discussion

5.1. Buckling. After the validation of the methodology, the influence of metal thickness and diameter and the position of initial delamination on the linear shear buckling behaviour of different types of GLARE are examined. In the first step, the buckling load of the lowest buckling mode shape is calculated. The delamination is located at two different interfaces, including Interface 1 ([Al/Com/Al/Com/Al]) and Interface 2 ([Al/Com/Al/Com/Al]). The sign // indicates the delamination location of the laminate (see Figure 2). The obtained results are presented in Figure 6, showing different shear buckling capacities of various grades of GLARE.

In general, it can be observed from the results of Figure 6 that metal thickness has a significant effect on the shear buckling capacity of each grade of GLARE. As a result, by reinforcing the metal layer, which increases the overall stiffness and thickness of the specimen, the specimen bears more load until shear buckling occurs. Having a detailed look at Figure 6 reveals that, by reinforcing the metal thickness from 0.2 mm to 0.4 mm, the critical shear buckling load of GLARE 1, GLARE 2, GLARE 3, and GLARE 6 grows about 2.6 times, while the buckling capacity of GLARE 4 and GLARE 5 increases 2.4 and 2.1 times, respectively. Therefore, the effect of the metal layer reinforcing on the shear buckling capacity of GLARE 1, GLARE 2, GLARE 3, and GLARE 6 is higher than GLARE 4 and GLARE 5.

The critical shear buckling load of GLARE 1, GLARE 2, GLARE 3, and GLARE 6, which has been presented in Figures 6(a)–6(c) and Figure 6(f), respectively, has the same
trend and also close results over the delamination propagation from a radius of zero to 30 mm. The internal delamination (Interface 2) has more influence on the shear buckling load than the external one in GLARE 1, GLARE 2, GLARE 3, and GLARE 6 laminates. For example, by increasing the radius of internal delamination (Interface 2) of GLARE 1 from 0 to 30 mm, critical shear buckling load decreases from 18 MPa to 14.5 MPa (metal thickness is 0.3 mm) and from 28 MPa to 22.5 MPa (metal thickness is 0.4 mm), while for GLARE 1 in which the delamination is located in the external position (Interface 1), the buckling load remains almost constant over increasing delamination radius from 0 to 30 mm.

The reduction of shear buckling capacity of different types of GLARE, while the initial delamination radius increases from 0 to 30 mm, is also presented in Table 6. According to obtained results, the initial delamination of Interface 1 (external position) only affects the shear buckling capacity of GLARE 5 and GLARE 4. In detail, external initial delamination with a radius of 30 mm causes a shear buckling capacity reduction between 1.2% (the metal thickness is 0.5 mm) and 42.5% (the metal thickness is 0.2 mm) of GLARE 5. Additionally, it decreases the critical shear buckling load of GLARE 4, 11% (the metal thickness of 0.2 mm) and 1.1% (the metal thickness of 0.3 mm). However, all grades of GLARE are affected by internal initial delamination (Interface 2), and their shear buckling capacity is reduced significantly. In detail, according to Table 6, by increasing the radius of initial delamination of Interface 2 from 0 to 30 mm, the stability of GLARE 1, GLARE 2, GLARE 3, and GLARE 6 is reduced by about 20%, while the buckling capacity reduction of GLARE 4 and GLARE 5 decreases on average by only 11% and 4%, in turn.

### Table 5: Buckling loads of laminate containing initial circular delamination compared with [47].

| Ply angle | Diameter of the delamination (mm) | Interface A | Interface B |
|-----------|-----------------------------------|-------------|-------------|
|           | Present results ($\times 10^3$N)  | Reference [47] ($\times 10^3$N) | Deviation (%) | Present results ($\times 10^3$N) | Reference [47] ($\times 10^3$N) | Deviation (%) |
| $\theta = 0^\circ$ | 10 | 23.1 | 23.2 | 0.4 | 23.25 | 23.3 | 0.2 |
|           | 20 | 23 | 23.1 | 0.4 | 23.2 | 23.4 | 0.8 |
|           | 40 | 21.45 | 21.6 | 0.6 | 21.86 | 22 | 0.6 |
| $\theta = 45^\circ$ | 10 | 22.97 | 23.1 | 0.5 | 22.86 | 22.9 | 0.1 |
|           | 20 | 23.16 | 23.3 | 0.6 | 22.8 | 23.1 | 1 |
|           | 40 | 21.98 | 22.2 | 0.9 | 21.52 | 21.6 | 0.3 |
| $\theta = 90^\circ$ | 10 | 22.88 | 23 | 0.5 | 22.76 | 22.9 | 0.6 |
|           | 20 | 22.66 | 22.8 | 0.6 | 22.62 | 22.9 | 1 |
|           | 40 | 19.82 | 19.9 | 0.4 | 21.82 | 22 | 0.8 |

**Figure 5:** Postbuckling of HTA/6376C plate compared with [48].
Figure 6: Critical shear buckling load of (a) GLARE 1-3/2-D, (b) GLARE 2-3/2-D, (c) GLARE 3-3/2-D, (d) GLARE 4-3/2-D, (e) GLARE 5-3/2-D, and (f) GLARE 6-3/2-D.
5.2. Postbuckling. After parametric studies of different grades of GLARE, the postbuckling analysis of GLARE 3, with different metal thicknesses, in which there is initial circular delamination with a radius of 20 mm, is performed. The cohesive Zone Element of FM94 is used to calculate the delamination growth. For postbuckling analysis, an imperfection equal to $10^{-4}$ times the deformation of the first mode is applied. In the following figures, the effect of delamination position on the load-displacement behaviour of sublaminate and base-laminate has been presented. The sign $w$ indicates the midplane displacement of the laminate through the thickness. The lay-up sequence of the sublaminate and base-laminate for GLARE 3 in which the delamination is located in the external position (Interface 1) is a single layer of aluminium and $[\{0/90\}/Al/[0/90]/Al]$, respectively. Analogously, when the delamination is within the internal position (Interface 2), the sublaminate and base-laminate are $[Al/[0/90]]$ and $[Al/[0/90]/Al]$, in turn. Figures 7–10 show the postbuckling behaviour and delamination growth of GLARE 3-3/2 with different metal thicknesses of 0.2, 0.3, 0.4, and 0.5 mm, respectively.

The outcome of Figure 7(a) compares the postbuckling behaviour of GLARE 3-3/2-0.2 with different positions of delamination. It reveals that, by applying the same shear buckling load, the laminate with internal delamination (Interface 2) has higher movement compared to the laminate in which there is external delamination. In addition, a detailed look at Figure 7(b) reveals that, by applying a pure shear loading of about 20 MPa to GLARE 3-3/2-0.2, the delamination with the location in the internal position (Interface 2) grows about 0.4 mm, from an initial radius of

| Metal thickness (mm) | GLARE 1 | GLARE 2 (%) | GLARE 3 (%) | GLARE 4 (%) | GLARE 5 (%) | GLARE 6 (%) | Interface 1 | GLARE 1 | GLARE 2 (%) | GLARE 3 (%) | GLARE 4 (%) | GLARE 5 (%) | GLARE 6 (%) | Interface 2 |
|----------------------|---------|-------------|-------------|-------------|-------------|-------------|-------------|---------|-------------|-------------|-------------|-------------|-------------|-------------|
| 0.2                  | —       | 0.4         | 0.3         | 11          | 42.5        | 0.3         | 22.7       | 24.1    | 8.3         | 3.7         | 24          |
| 0.3                  | 0.49%   | 0.3         | 0.4         | 1.1         | 29.8        | 0.3         | 19.5%      | 21.9    | 9.5         | 1.6         | 21.3        |
| 0.4                  | 0.22%   | 0.8         | 0.2         | 0.2         | 8.5         | 0.3         | 18.7%      | 20.8    | 13.2        | 5.4         | 20.5        |
| 0.5                  | —       | 0.1         | 0.1         | 0.01        | 1.2         | 0.3         | —          | 20.8    | 12.9        | 6.4         | 19          |

Figure 7: (a) Postbuckling behaviour of GALRE 3-3/2-0.2 and (b) delamination growth of GALRE 3-3/2-0.2.

Figure 8: Contour plots of delamination growth of GLARE 3-3/2-0.2 in different shear load conditions.
Figure 9: (a) Postbuckling behaviour of GALRE 3-3/2-0.3 and (b) delamination growth of GALRE 3-3/2-0.3.

Figure 10: Contour plots of delamination growth of GLARE 3-3/2-0.3 in different shear load conditions.

Figure 11: (a) Postbuckling behaviour of GALRE 3-3/2-0.4 and (b) delamination growth of GALRE 3-3/2-0.4.
20 mm to a radius of 20.4 mm. In comparison, the laminate with external position (Interface 1) starts to grow at a shear loading of about 22.2 MPa. Figure 8 also shows the delamination propagation of GLARE 3-3/2-0.2 with different positions of initial delamination and various shear buckling loads. The graphs indicate that internal delamination grows more than external delamination by applying the same shear load.

Analogously, Figures 9(a) and 9(b) present the postbuckling response and delamination propagation of GLARE 3-3/2-0.3. Again, the laminate with internal delamination is more affected by shear buckling load compared to that in which the laminate contains external delamination. The delamination propagation of the former is only 24 MPa, while the growth initiation of the latter is about 28 MPa. Figure 10 also demonstrates the delamination spread of GLARE 3-3/2-0.3 with different locations of initial delamination and several shear loads.

Finally, Figures 11 and 12 demonstrate the postbuckling behaviour as well as the delamination propagation of GLARE 3-3/2-0.4 and GLARE 3-3/2-0.5, respectively. According to Figure 11, by importing 50 MPa of shear buckling load to GLARE 3-3/2-0.4, the delamination of the laminate in which it has the internal position (Interface 2) grows about 0.4 mm, two times the laminate with the external one (Interface 1). Also, a more detailed look at

![Figure 12: (a) Postbuckling behaviour of GALRE 3 3/2 0.5 and (b) delamination growth of GALRE 3 3/2 0.5.](image)

![Figure 13: Contour plots of delamination growth of GLARE 3-3/2-0.4 in different shear load conditions.](image)
Figure 11 indicates that GLARE 3-3-2-0.4 with internal delamination starts to grow at 30 MPa of shear buckling load, while the one with external delamination propagates at 33 MPa of shear loading. Similarly, Figure 12 illustrates that the GLARE 3-3-2-0.5 with external (Interface 1) and internal (Interface 2) delamination has the growth initiation at shear loading of 40 MPa and 33 MPa, respectively. In addition, by importing a shear buckling load of 70 MPa, the internal delamination grows 1.4 mm, while the external delamination extends only by 0.4 mm. Figures 13 and 14 reveal the delamination growth of GLARE 3-3-2-0.4 and GLARE 3-3-2-0.5 with different locations of initial delamination and some shear buckling loads.

6. Conclusions

In this study, the buckling and postbuckling behaviour of GLARE as a practical member of FMLs, containing initial circular delamination located in two different positions, were analysed. Six different grades of GLARE, containing three aluminium layers and two prepreg plies, were examined numerically to obtain the shear buckling load. The cohesive zone interface elements of FM94 are considered to evaluate the delamination growth.

Generally, the comparison of the results produced in this study can encourage designers to select appropriate GLARE based on the intended application (i.e., shear loading condition, material costs, and available raw material). In addition, the obtained results indicate that the thickness of the aluminium layer affects the buckling behaviour of the GLAREs considerably. In this way, by reinforcing the aluminium layer, the overall stiffness and thickness of the specimen increase, resulting in significant shear buckling capacity improvement. In particular, the shear buckling of GLARE 1, GLARE 2, GLARE 3, and GLARE 6 of this study has higher sensitivity to metal thickness in comparison to GLARE 4 and GLARE 5. In addition, the negative effect of delamination, particularly its location, on the shear buckling capacity of each grade of GLARE can be understood. For instance, in this study, GLARE 5 with external delamination of 20 mm experiences about a 42% reduction of shear buckling load, while in the case of internal delamination, the deterioration of shear buckling is only about 4%.

In GLARE 3-3/2-D (D is aluminium thickness varying from 0.2 to 0.5 mm) with initial delamination of 20 mm, the shear loading of delamination propagation increases by changing the position from the internal interface (Interface 2) to the external interface (Interface 1). In this case, internal delamination starts to propagate in 18, 25, 30, and 36 MPa of shear buckling load in which the metal thickness is 0.2, 0.3, 0.4, and 0.5 mm, respectively, while in the external case with the same condition, the equivalent shear buckling load is 22, 29, 32, and 41 MPa. Additionally, the results reveal that the metal layer reinforcement of the GLARE increases the resistance to delamination growth of the specimen. For instance, with the same shear loading condition, GLARE 3, with a metal thickness of 0.2 mm, grows more than a state with a metal thickness of 0.5 mm.

Data Availability

The numerical data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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