AN EXPERIMENTAL INVESTIGATION ON DAMAGE LOADS OF BUTTERFLY JOINTS IN COMPOSITE STRUCTURES

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ABSTRACT

This study is performed experimentally to investigate damage forces formed on glass-fibre laminated composite plates that are jointed with a component in the shape of butterfly. Pressing it into the mould in a hot press machine produced a glass fibre-epoxy composite plate. Specimens and locking parts in the shape of butterfly were cut using water jet. Experiments were performed in different values of the ratio of the end width of butterfly to the width of the specimen (w/b), the ratio of the middle width of butterfly to the end width of butterfly (x/w) and the ratio of the half-length of butterfly to the width of the specimen (y/b). Using these values, the effects of joint geometry parameters were evaluated. To be able to see the effect of material variations as well, the joint lock in the shape of butterfly was made up of both metal and composite materials. Although the loading capacity of the composite butterfly is lower than that of the metal butterfly, it carries loads for much longer times. Before a composite structure develops damage, damage occurred in the composite butterfly can be seen and, with the repair of the butterfly lock, the life of the composite structure can be extended.

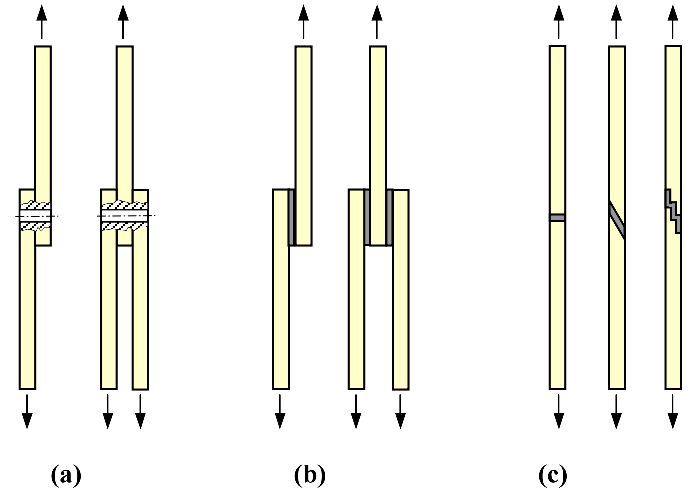
Keywords: Butterfly joint; Composites; Damage load; Joint types.

1. INTRODUCTION

Composite materials are preferred in industrial sectors such as aviation, navigation and automotive since they are light. Most large structures are composed of one or more joints. The aim here is to transfer force from the main structure by joining two or more materials. The most important problem in composite structures is the weakness in the joint areas. Damage force, initial damage's direction and production style of composite material are all of importance in the joint places of composite structures. For this reason, there have been many studies on joining of composite materials [1-9].

Composite structures are joined in general by means of mechanic or adhesive joints. As seen in Fig. 1 (a), mechanic joints are constructed using bolts or pins in the way that they become single or double sided. It is also seen from the studies that in joining areas, there are three types of damage modes. These are net-tension, shear-out and bearing damage modes. Net-tension and shear-out damage are more dangerous than bearing damage [1,2]. In net-tension and shear-out damages, as soon as damage occurs, force decreases instantaneously. On the contrary, in bearing damage, force decreases slowly when it reaches the maximum load that the composite structure can carry. Therefore, designer needs to achieve an optimum geometric design in the way that it prevents damage that instantaneously occurs. Joining of composite structures using adhesive methods can be done in several ways as seen in Fig. 1 (b) and (c) [3-7]. There are various factors that affect load carrying capacity. These include harmony between composite material and adhesive used; type of the joint geometry and adhesive thickness. An adhesive type joint can be subjected to loads such as tension, shear and peeling: While the strength of the adhesive are low with respect to stress distribution that is created by the effect of peeling load, their strength are much better with respect to stress distribution that is created by tension and shear loads [8-10].

Joining in composite structures is carried out using mechanical or adhesive techniques with commonly single or double lap. Especially, when thickness of the composite structure that is to be jointed using adhesives increases, single or double lap joint affects the strength of the whole composite structure. With the increase in the value of axial width, high stress on



(a) Mechanic joints, **(b)** Adhesive lap joints, **(c)** Adhesive butt joints

Fig. 1: Joint types.

adhering surfaces is formed and the strength of the structure gets lower [11]. In laminated structure elements jointed in this way, damage generally occurs at the upper layer. That is, loading capacity goes down due to the fact that axial width goes up. In mechanical joints, increase in axial width causes bolt or pin damage. That is why in thick composite structures, butt, bevel and step joint types are mostly preferred as shown in Fig. 1 (c). In butt joining, adhesive joining along the thickness are mostly used. In this kind of joining, to avoid peeling stress, bevel or step joints rather than simple butt joints are most preferred. Although different joining types are used in butt joining, in any case peeling stress affects the joining life negatively.

In this study, mechanical butt joints with joint lock in the shape of butterfly are offered to replace adhesively bonded butt joints. Joint lock components in the shape of butterfly to fasten composite plates face to face are used in mechanic butt joint with tight fitting procedure. As seen in Fig. 2 specimens used in the experiments are cut out of these plates. Effects of variations of material and geometric parameters of joint lock components on maximum load carrying capacity are considered.

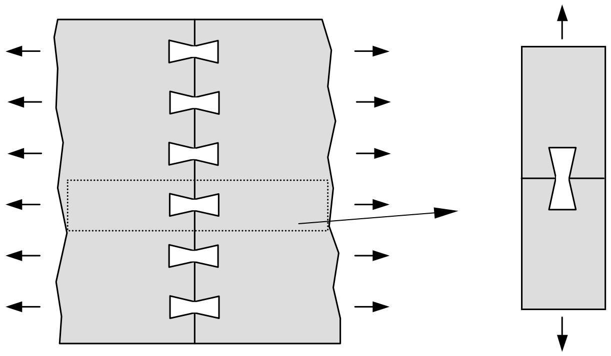


Fig. 2: Butterfly joint.

2. MATERIAL PRODUCTION AND MECHANICAL PROPERTIES

Glass fibre-epoxy composite material used in this study was produced by means of hot pressing in the company called Izoreel Composite Isolate Materials. Glass fibre order were chosen as one sided. Epoxy resin used as matrix material consists of the mixture of CY225 epoxy resin and HY225 hardening material in the rate of 100/80. A wet composite material with 16 layers was obtained by applying the mixture of epoxy resin and hardening material to each glass fibre layer in the mould. Then, the wet material was put under hot press to let it cure and to get a minimum thickness. The glass fibre epoxy composite material was cured under the pressure 14 MPa at the temperature 120°C. Keeping it at this temperature, it had been pressed for two hours. The laminated composite plate with 16 layers was taken out of the press and let to cool to the room temperature. The thickness of the composite plate was reduced to 3.5 mm after a trimming procedure at a volume fraction of 59%.

The mechanical properties of glass epoxy-fibre composite material were characterized under tension, compression and in plane shear by using three specimens for the each mechanical property and the

Table 1: Mechanical properties of glass fibre-epoxy composite material.

E_1/ MPa	E_2/ MPa	G_{12}/ MPa	ν_{12}/	X_t/ MPa	Y_t/ MPa	X_c/ MPa	Y_c/ MPa	S/ MPa
44150	12300	4096	0.20	775	130	305	80	95

average properties were determined. The mechanical properties of composite material were tabulated in Table 1. Tensile properties such as longitudinal modulus (E_1), transverse modulus (E_2), Poisson's ratio (ν_{12}), longitudinal tension strength (X_t) and transverse tension strength (Y_t) were measured by static tension according to the ASTM D3039-76 standard test method. Compressive properties such as longitudinal compression strength (X_c) and transverse compression strength (Y_c) were measured by static compression on unidirectional specimens according to the ASTM D3410-75 standard test method. An important problem in the measurement of shear strength properties is to obtain a pure shear stress in the gauge section of specimens. Iosipescu shear test method was used to define the shear strength (S) according to the ASTM D5379 standard test method. Shear modulus (G_{12}) was determined by a specimen whose principal axis on 45° according to the ASTM D3518-76 standard test method. Shear modulus was calculated by measurement of the strain in the tensile direction [12].

All specimens of experiments were trimmed from manufactured composite plates. Composite butterfly material used in the experiments is the same with composite plate and it is also 16 layered. Metal butterfly material was chosen as St37 steel.

3. SPECIMEN PREPARATION AND EXPERIMENTAL PROCEDURE

Using water jet, specimens were cut out of composite plates produced with different geometric parameters. A snapshot of the specimen preparation procedure at the stage of water jet cutting is shown in Fig. 3.

As seen in Fig. 4, specimen dimensions were chosen as follows: specimen width b=40 mm, total specimen length L=180 mm and specimen thickness t=3.5 mm. Keeping constant the specimen's main dimensions (b,L,t) that are joined in mechanic butt joint, the end width (w), middle width (x) and half the length (y) of the joint lock in the shape of butterfly were changed.

To see the effects of geometric parameters on damage loads, several experiments were performed by changing the ratio of the end width of butterfly to the width of the specimen (w/b) and the ratio of the middle width of butterfly to the end width of butterfly (x/w) from 0.2 to 0.8. In these experiments, the ratio of the half-length of butterfly to the width of the specimen (y/b) was chosen as 0.2, 0.4 and 0.6. The dimensions of butterfly joint components are given in Table 2. Half specimens are jointed with butterfly joint components by using tight fitting. Butterflies used as joining components were made up of both metal and composite materials. Therefore, the effect of the butterfly material on damage load was considered as well.

Fig. 3: Specimen cutting with using water jet.

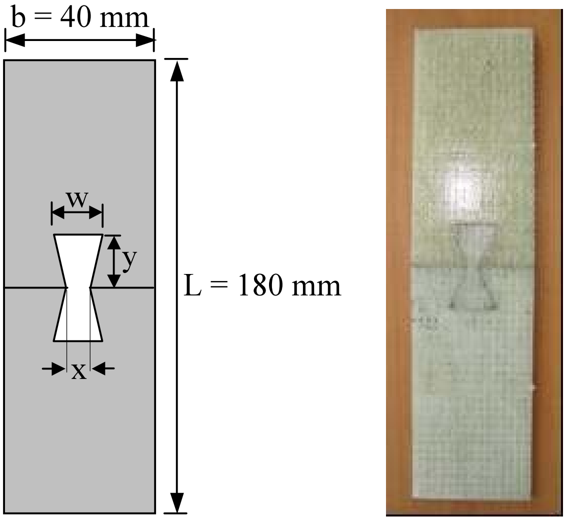


Fig. 4: Laminated composite specimen geometry.

Table 2: Butterfly joining component dimensions.

Dimension ratio		w/b				Dimension/ mm
		0.2	**0.4**	**0.6**	**0.8**	
		8	*16*	*24*	*32*	**w**
x/w	**0.2**	*1.6*	*3.2*	*4.8*	*6.4*	**x**
	0.4	*3.2*	*6.4*	*9.6*	*12.8*	
	0.6	*4.8*	*9.6*	*14.4*	*19.2*	
	0.8	*6.4*	*12.8*	*19.2*	*25.6*	
y/b	**0.2**	*8*				**y**
	0.4	*16*				
	0.6	*24*				

Tensile tests were carried out in Instron 8801 test equipment with 50 kN load capacity (Fig. 5). All the specimens were loaded with 1 mm/min constant jaw speed. Damage load-butterfly displacement graphics were drawn for each model. The experiment was ended as soon as a small amount of drop in the force applied was observed. When the load applied reached the damage load level, damage breaks started to occur on the composite butterfly or on the composite structure around the butterfly. In the case of metal butterfly, damage occurred only on the composite structure around the butterfly. To be able to understand damage shapes, experiments for the same specimens were repeated until the specimens were broken. Therefore, the effects of the butterfly geometry were taken into account.

Fig. 5: Tensile test equipment.

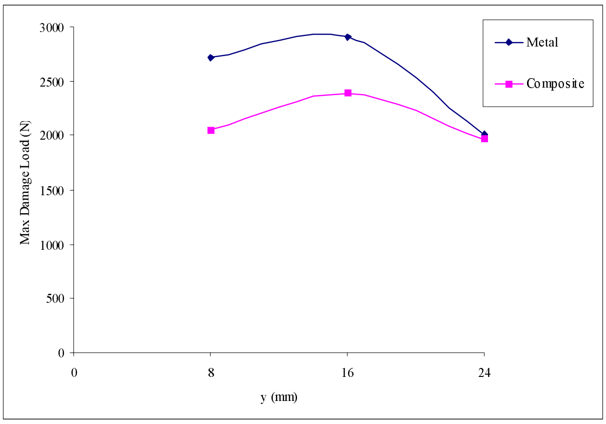


Fig. 6: Maximum damage load versus butterfly half length.

4. RESULTS AND DISCUSSIONS

The joint lock components in the shape of butterfly used in the experiments were made up of both metal and composite materials. In this work, load carrying capacity of the specimens was investigated by observing changes in geometric parameters of butterfly joining components as well as changes in their materials. For different butterfly half-length values, variations in maximum damage load of metal and composite butterfly joints are shown in Fig. 6. Damage load for butterfly half-length y=16 mm was determined to be maximum for both metal and composite butterflies. For this reason, in this work, the half-length of the butterfly joining component was chosen as y=16.

Variations in load carrying capacities of the joints made by metal and composite butterfly, for half length of butterfly y=16 mm, were shown in Fig. 7. As seen from the figure, metal butterflies carried more load than composite butterflies. However, metal butterfly specimens suffered damage more quickly than composite ones. In the specimens joined by metal butterflies, damage always occurred in the composite part.

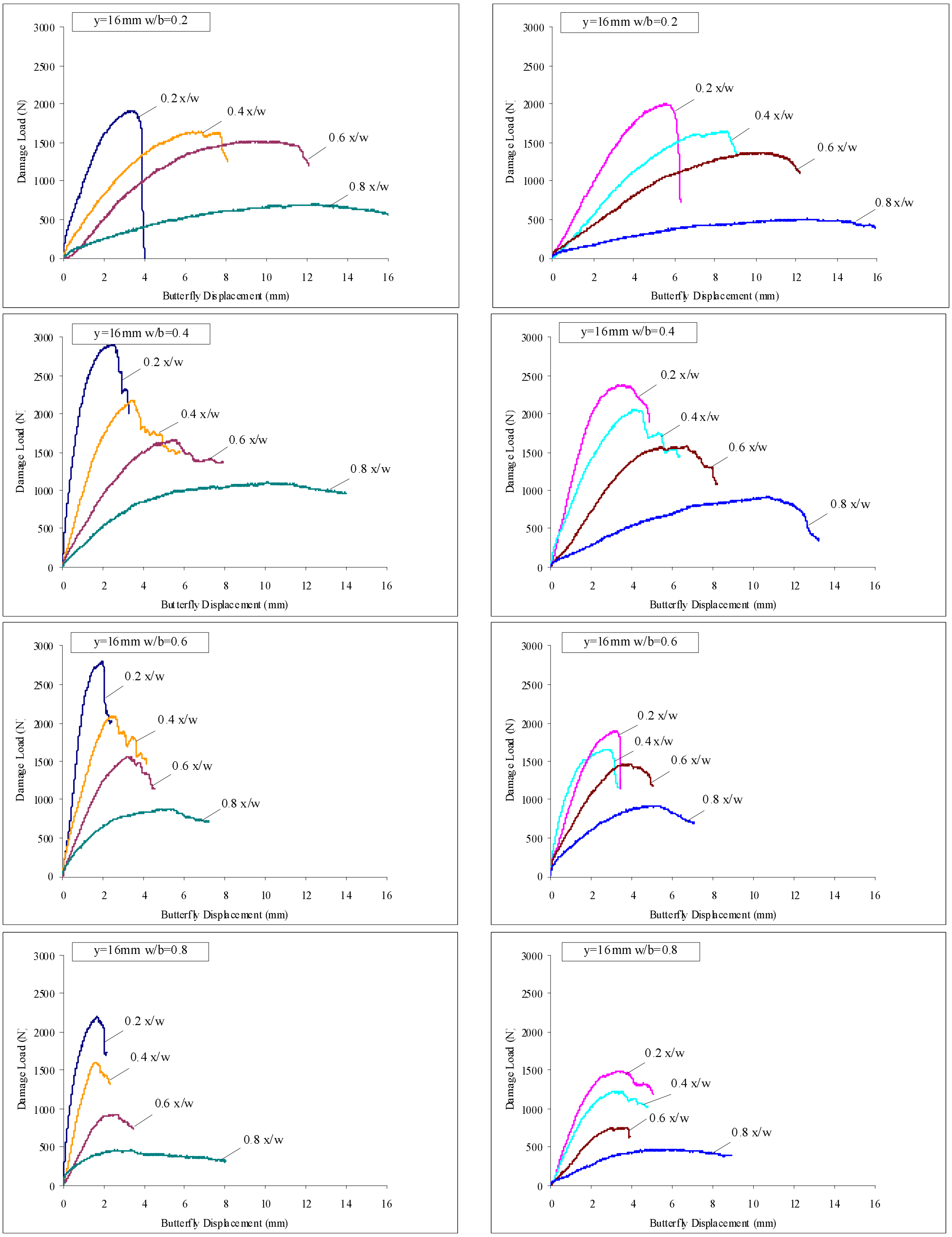
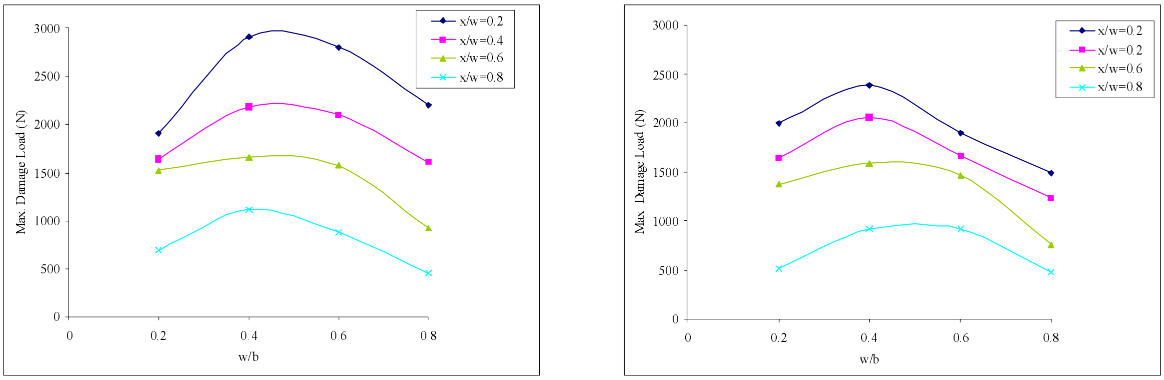


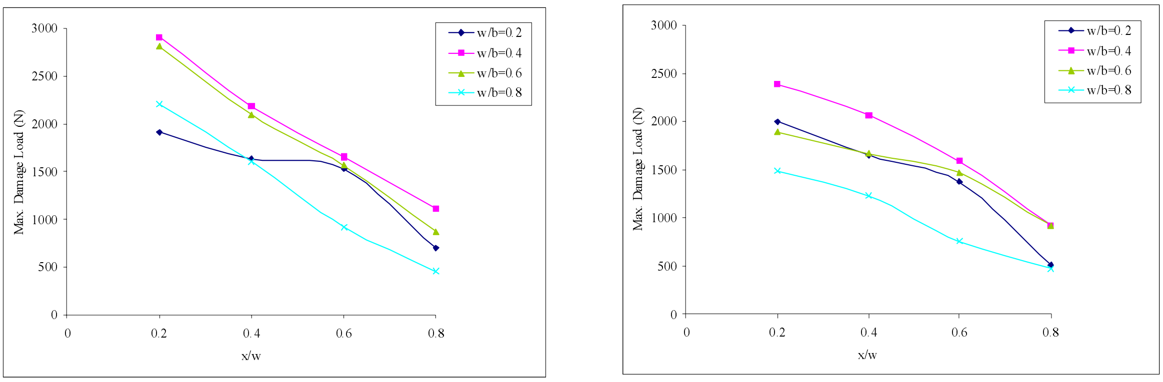
Fig. 7: Displacement versus load that butterfly joining component can carry for Butterfly half length y=16 mm.

It is concluded from the experiments that although specimens in the shape of butterfly suffered damage, they can carry loads for longer times and damage occurred mostly in composite butterfly rather than composite plate. This fact gives us an advantage. Service life of the plate can be extended by just replacing the damaged butterfly lock. While the ratio of butterfly middle width to butterfly end width (x/w) increases, butterfly displacement increases too. As a result of this, increase in sliding amount results in decrease in load carrying capacity. While the ratio of butterfly end width to butterfly width (w/b) increases, at maximum loads, it is observed that butterfly displacement decreases. When the ratio of butterfly



(a) Metal butterfly **(b)** Composite butterfly

Fig. 8: The ratio of (w/b) versus damage load for butterfly half length *y*=16 mm.



(a) Metal butterfly **(b)** Composite butterfly

Fig. 9: The ratio of (*x/w*) versus damage load for butterfly half length *y*=16 mm.

end width to butterfly width (*w/b*) is 0.4, at all of the ratios of (*x/w*), it is determined that the specimen carries maximum load and while the ratio of (*w/b*) goes up, load carrying capacity slowly goes down. In a specimen that has a constant width *b*, when butterfly end width rises, it suffers damage from the weakened area at both sides of butterfly joint component and its load carrying capacity decreases. When load carrying capacity of the specimen whose (*w/b*) ratio is 0.2 is compared with others, it falls between 0.6 and 0.8. This is because, when *w/b*=0.2, since the butterfly geometry is small, damage occur mostly on the butterfly. If the butterfly is metal, then damage occurs on the composite part. It is concluded that maximum joint load is obtained when the ration of (*w/b*) is 0.4 and (*x/w*) is 0.2.

Variations in load carrying capacity of the specimens made with various ratios of (*x/w*) of butterfly joint components with respect to the ratio of (*w/b*) are shown in Fig. 8. As seen from the figure, load carrying capacity depends on the ratio of (*w/b*). When the ratio of (*x/b*) is equal to 0.2 and the ratio of (*w/b*) is usually equal to 0.4, load carrying capacity of both metal and composite butterflies become maximum. Nevertheless, in the case of metal butterfly, this ratio goes up to 0.5. It is observed that when (*w/b*) is lower than 0.4, damage occurs mostly on butterfly. On the contrary, when (*w/b*) is higher than 0.4, damage occurs mostly on composite plate. As a result of this, it can be concluded that regarding load carrying capacity choosing butterfly end width is quite important.

Variations in damage loads with respect to the ratio of (*x/w*) are shown in Fig. 9. When the ratio of (*w/b*) is equal to 0.4 and the ratio of (*x/w*) is equal to 0.2, load carrying capacity of both metal and composite butterflies become maximum. Decrease in maximum damage load with increase in the ratio of (*x/w*) shows the importance of butterfly middle width. When butterfly middle width increases (that is, the ratio of (*x/w*)), the shape of butterfly joint component start to resemble a square or rectangular. Butterfly joint component starts to lose its locking feature resulting in decreasing its load carrying capacity. When (*x/w*) is equal to 1, the shape of butterfly joint component becomes a square or rectangular. It means that butterfly joint component cannot carry load any more. In such a case, to be able to achieve joining, adhesive techniques should be employed.

4. CONCLUSIONS

In this study, effects of joints in the shape of butterfly, butterfly materials (metal or composite) and geometric parameters on damage loads were all considered experimentally. Glass fibre-epoxy composite plate used in the experiments was produced using hot pressing technique. Here are the results obtained from this experimental study:

- At high values of the ratio of the middle width of butterfly to the width of butterfly (*x/w*), joint load decreases gradually. When (*x/w*) reaches 1, since angled surface disappears, it carries no load. Therefore, in such cases, adhesive techniques should be preferred.
- In the cases where the butterfly material is the same as the specimen material, damage occurs first on the butterfly and then while the ratio of (*x/w*) increases, damage occurs on the specimen. If the strength of butterfly material is greater than that of specimen material, damage occurs first on the specimen.
- Compared with specimens with composite butterflies, specimens with metal butterflies reach maximum load with smaller displacement. This can be regarded as a disadvantage since the specimen is quickly damaged. However, in the case of composite butterfly, although load carrying capacity is a bit low, it carries load for longer times.
- Before composite structure develops damage, damage on the butterfly may be repaired and this can be seen as an advantage. This means longer service life for the composite structure.
- While the ratio of (*w/b*) increases, it is concluded that load carrying capacity decreases gradually. In a specimen that has a constant width b, when butterfly end width rises, it suffers damage from the weakened area at both sides of butterfly joint component and its load carrying capacity decreases. While the ratio of (*w/b*)can become 0.5 for metal butterflies, this ratio should be chosen as 0.4 for composite butterflies.
- Mechanic butt joining technique can be used either uniquely or together with adhesive technique. Therefore, negative effects on adhesive joints can be reduced to a minimum if not completely eliminated.
- It is also possible to have different joint load carrying capacities by changing the shape of butterfly locks.

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References:

1. **Karakuzu R., Gülem T., İçten B.M.,** “Failure analysis of woven laminated glass-vinylester composites with pin-loaded hole”, Composite Structures, **72** (2006), 27-32.
2. **İçten B.M., Karakuzu R., Toygar M. E.,** “Failure analysis of woven Kevlar fibre reinforced epoxy composites pinned joints”, Composite Structures, **73** (2006) 443-450.
3. **Kumar S.B., Sridhar I., Sivashanker S., Osiyemi S.O., Bag A.,** “Tensile failure of adhesively bonded CFRP composite scarf joints”, Materials Science and Engineering B, **132** (2006), 113-120.
4. **Ishii K., Imanaka M., Nakayama H., Kodama H.,** “Fatigue failure criterion of adhesively bonded CFRP/ metal joints under multiaxial stress conditions”, Composites Part A, **29**/A (1998), 415-422.
5. **Kim J.H., Park B.J., Han Y.W.,** “Evaluation of fatigue characteristics for adhesively-bonded composite stepped lap joint”, Composite Structures, **66** (2004), 69-75.
6. **Yang C., Huang H., Tomblin J.S., Sun W.,** “Elastic-plastic Model of Adhesive-bonded Single-lap Composite Joints”, Journal of Composite Materials, **38** (2004), 293-302.
7. **Kweon J.H., Jung J.W., Kim T.H., Choi J.H., Kim D.H.,** “Failure of carbon composite-to-aluminum joints with combined mechanical fastening and adhesive bonding”, Composite Structures, **75** (2006), 192-198.
8. **Silva L.F.M., Adams R.D.,** “Techniques to reduce the peel stresses in adhesive joints with composites”, International Journal of Adhesion and Adhesives, **27** (2007), 227-235.
9. **Zou G.P., Shahin K., Taheri F.,** “An analytical solution for the analysis of symmetric composite adhesively bonded joints”, Composite Structures, **65** (2004) 499-510.
10. Loctite Global Design Handbook, Loctite European

Group Germany.

11. **Gunnion A.J., Herzberg I.,** “Parametric study of scraf joints in composite structures”, Composite Structures, **75** (2006), 364-376.
12. **Jones RM.,** Mechanics of Composite Material. Philadelphia: Taylor& Francis; 1999.