Study of buckling behavior of FRP corrugated- core sandwich plates

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Abstract—

Fiber-reinforced plastic corrugated core sandwich panels were tested for buckling in uni-axial compression. Three types of corrugation i.e. sinusoidal, square and triangle of different thickness core of epoxy based were tested. The sandwich panels were fabricated using the hand layup method process. The two short edges of the sandwich panels were clamped, while the two long edges were simply supported for testing. A Bifurcation in the load versus engineering strain curve was noted in all cases. For all sandwich panels tested using corrugation core, the type of failure was easily identified as face sheet delamination followed by core shear failure. In the failed core panels there was little or no evidence of core remaining on the FRP face sheet, however, lower strain rate in the PVC foam core panels there were ample amounts of foam left on the FRP face sheet. It was concluded that although the buckling loads for the sinusoidal corrugated core panels showed very high buckling strength.

***Keywords*—**Buckling, Corrugated sandwich, Damage mechanism, FRP.

I. NTRODUCTION

Aircraft wing structures are strongly required to be stiff in order to withstand aerodynamic forces, while structural flexibility is preferable in morphing wings. This discrepancy makes it a great challenge to realize the morphing aircraft [1]. Many researchers found solution for this problem is to adopt fiber reinforced plastics (FRP) that act flexible in the chord direction and stiff in the span direction [2-3]. But FRP has low resistance against compressive instability in the fiber direction and thus low bending strength. In this direction many researchers [4] propose corrugated-form composites as a candidate for morphing wings structure. The significant feature of corrugated core sandwich structure is its high strength-to-weight ratio. The corrugated core keeps the face sheets apart and stabilizes them by resisting vertical deformations, and also enables the whole structure to act as a single thick plate as a virtue of its shearing strength. This second feature imparts outstanding strength to the sandwich structures [5]. Rao [6] extended this work to shear buckling of

Sinusoidal plates made of composites. Early work on the wrinkling and buckling of sandwich panels can be attributed to Natacha et al. [7], Langdon [8] and Raijun [9], among others. The early buckling of plates stiffened by discrete stiffeners can be attributed to Amir Shahdin [10], and Hui Wang et al. [11], among others. Recent work in this journal includes an article on the bending and buckling unstiffened and hat-stiffened plates by Kumar P Dharmasena et al. [12]. Corrugated core sandwich structure can considerably increase wrinkling strength of uniaxially compression loaded lightweight sandwich structures, which has been numerically and experimentally shown by Sadighi et al. [13]. The corrugations may also be used to carry some of the shear load of a sandwich, as outlined by Xinzhu etl al. [14]. The objective of the paper feasibility study on the application of corrugated core sandwich structure to wing structures is carried out by investigation of the buckling load (edge compression) of corrugated sandwich structure.

II. EXPERIMENTAL STUDY

Sandwich preparation

The corrugated core sandwiches of various thicknesses (0.5mm, 0.75mm, 1mm) and shape (sinusoidal, square, and triangular) were fabricated using epoxy and glass fiber by hand layup technique.

Edgewise compression

Edgewise compression test is carried out according to ASTM 364 – 99 standards in order to find the compressive properties of the sandwich structure in the direction parallel to the face sheet plane. This test provides a basis for judging the load carrying capacity. The sandwich column, no matter how short, usually is subject to a buckling type of failure unless the facings are so thick that they themselves are in the short column class. The failure of the facings manifests itself by wrinkling of the facing, in which the core deforms to the wavy shape of the facings; by dimpling of the facings into the core; or by bending of the sandwich, resulting in crimping near the ends as a result of shear failure of the core or failure in the facing-to-core bond. Specimens of three types of core geometry and thickness were tested. The dimensions of the specimens are shown in Table 1; three specimens of each type were tested. The test is done using a UTM of 10 tone capacity manufactured by Kalpak Instruments and Controls, Pune, INDIA.

Table 1. Dimensions details of specimens for edge wise compression test.

Profile	Sinusoidal			Square			Triangle		
Thickness of core in mm	0.5	0.75	1.00	0.5	0.75	1.00	0.5	0.75	1.00
Total length l in mm	152.4	152.4	152.4	152.4	152.4	152.4	152.4	152.4	152.4
Width b in mm	52	52	52	52	52	52	52	52	52
Height d in mm	15.2	15.45	15.7	15.2	15.45	15.7	15.2	15.45	15.7

III. RESULT AND DISCUSSION

Effect of corrugation thickness on buckling behavior

The typical load-deformation response of edge wise compression of the specimens is presented in Fig. 1 and 2. Typical load-displacement plots of sinusoidal corrugation, square corrugation and triangular corrugation sandwich panels subjected to in-plane compression (for strain rate of 0.5 mm/min, 0.75 mm/min and 1 mm/min) are shown in Fig. 1(a), (b) and (c) respectively. The buckling load vs. deflection for strain rate of 0.5 mm/min, 0.75 mm/min and 1 mm/min (sinosidula corrugation, square corrugation and triangular corrugation) shown in Fig. 2(a), 2(b) and 2(c) respectively. The plots show similar pattern of behavior in the three regions identified: 1) steep increase, 2) steep decrease and 3) zigzag pattern to complete failure. In the first region, the load increases steeply until the peak (F_{max}) at which failure is initiated. The specimens behave like stable structures conforming to some instability mode when they reach corresponding critical loads (F_{max}). In the second region the specimens undergo buckling following which the load falls to a level at which the failure is progressive and sustained. The load-displacement behavior of sandwich panels is dictated by the critical state of the panel. The global buckling induces tensile and compressive failure in the skins and shear failure in the core, which results in decreasing the load carrying capacity rendering the sandwich system unstable.

In the third region, the sustained load curve for the sandwich panels is flat deboning between the skin and the core takes place without restraint. Wrinkling induces shear stresses along the skin-core interface, which triggers debonding between the skin and the core. The debond leads to stable crushing failure. The load falls to a level at which progressive deboning occurs and then it increases until the next corrugation. This process repeats itself. The reduction in pitch row spacing reduces the distance between the two peaks in the sustained load region. Finally completely crushed sandwich panels showing characteristics of skin folding between the corrugation lines. Greatest compression is always observed in the interface region, which results in the local loss of stability of the face sheet or the core. The debond buckling causes high inter-laminar stresses which, in turn, under increased compressive loading leads to the debond growth and final failure. The final failure occurs almost instantaneously upon initiation of debond buckling, or at loads considerably higher than the debond buckling load.
After the initial settlement, the behavior is linear until the first rupture occurs (usually in the skins). The initial failure of sandwich columns loaded quasi-statically in in-plane compression is related to global buckling, local buckling or face sheet fracture. At the initial stage of loading, the load is mainly carried by the face-sheets and hardly by the pyramidal truss core.

Subsequently, when the macro shear buckling occurs, the core begins to shear, and one-half of core trusses are compressed while the other half of core trusses are subjected to tension. Thus, the core trusses begin to carry loads, and the overall load capacity of the sandwich column will increase. In other words, the load–displacement curves will keep increase until the loads reach the peak load points, where node ruptures occur. Beyond the peak load points, the load–displacement curves drop suddenly and catastrophic fractures of nodes come into being. In theory the core could of course also fracture, but in most cases of practical interest the ultimate strain of the core exceeds that of the faces. The damaged structure shows a fast separation between skins and core due to further cracking of the extra-skins. The sandwich failure is never due to core subsiding.

Usually, the final failure is due to skins instability possesses corrugated core and skin possess different compression stiffness and consequently sustain different loading, the weakness of the interface between skins and corrugation induce an independent flexural behavior. Wrinkling phenomena are not present since the skin-core adhesion is not so strong to allow load transfer. Local buckling can take the form of localized buckling, dimpling and wrinkling. Localized buckling occurs in the vicinity of the load introductions, whereas dimpling is buckling of the face sheets into the cavities. Wrinkling can occur simultaneously all over the surface of the face sheets and is dependent on the material properties and geometry of the core and face sheets [15-16].

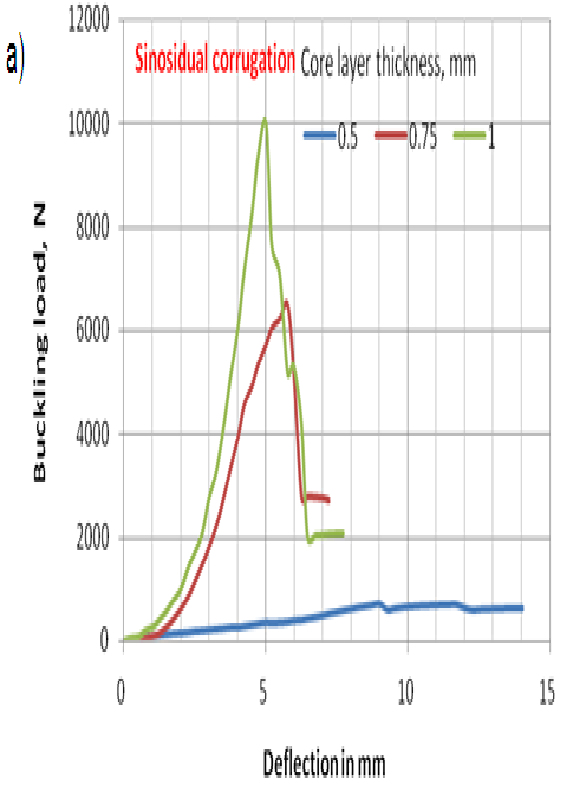

Fig 1(a) Edge wise compressive behavior of sinusoidal-corrugated core sandwich for 0.5, 0.75 and 1 mm corrugation thickness.

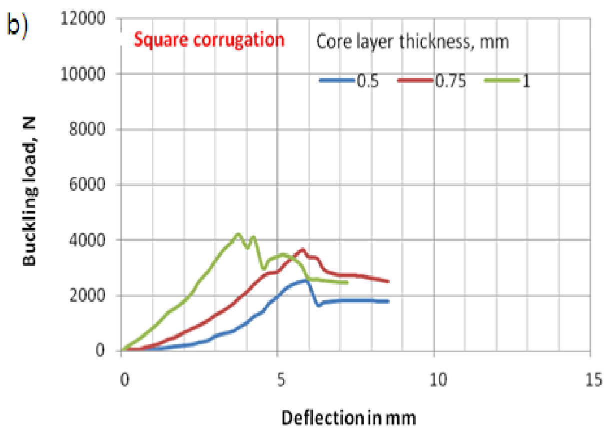

Fig 1(b) Edge wise compressive behavior of square -corrugated core sandwich for 0.5, 0.75 and 1 mm corrugation thickness.

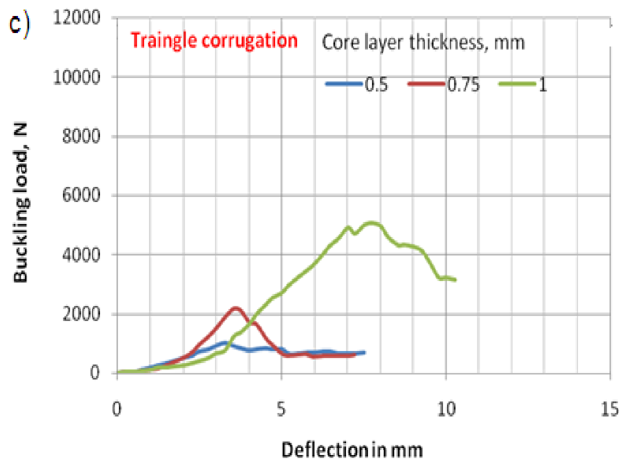

Fig 1(c) Edge wise compressive behavior of triangle -corrugated core sandwich for 0.5, 0.75 and 1 mm corrugation thickness.

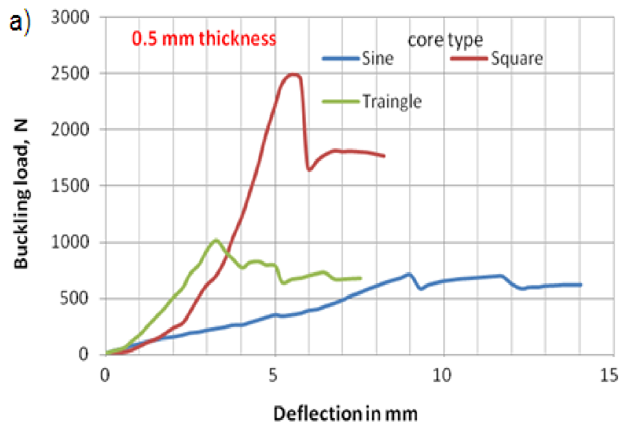

Fig 2(a) Edge wise compressive behavior of 0.5 mm core layer thickness for sinusoidal, square and triangle corrugated sandwich structure .

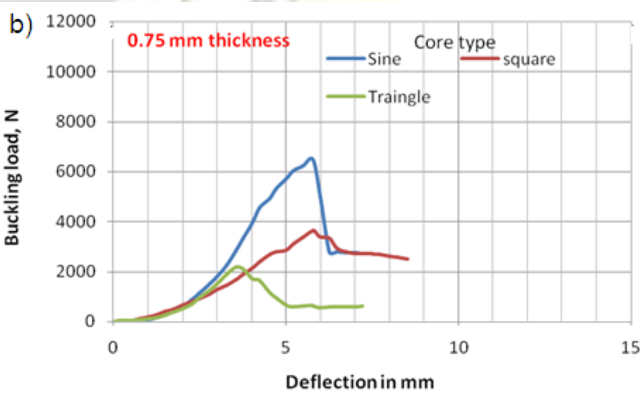

Fig 2(b) Edge wise compressive behavior of 0.75 mm core layer thickness for sinusoidal, square and triangle corrugated sandwich structure.

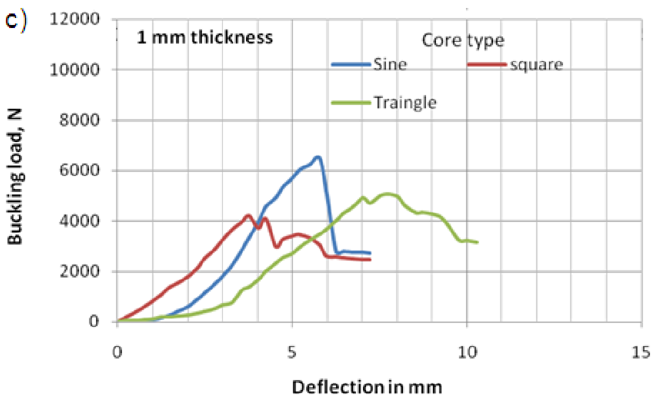

Fig 2(c) Edge wise compressive behavior of 1 mm core layer thickness for sinusoidal, square and triangle corrugated sandwich structure.

Damage mechanism

Fig 3 shows the failure of the sinusoidal specimen due to the edge wise compression. It can be seen in Fig 3(a) that initially the specimen is fixed between the two crossheads, as the load is applied the specimen starts to bend as seen in Fig 3(b).

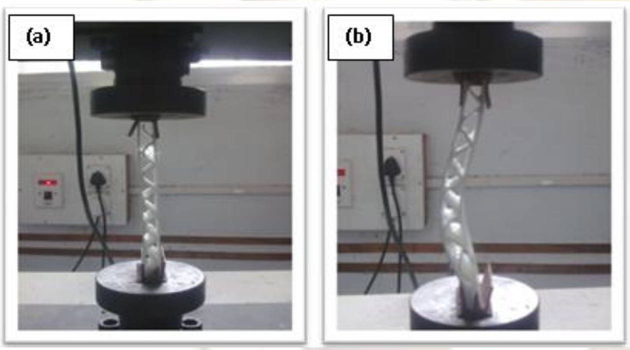

Fig 3 (a) initially the specimen is fixed between the two crossheads (b) Shows the collapse sequence of edge wise compression

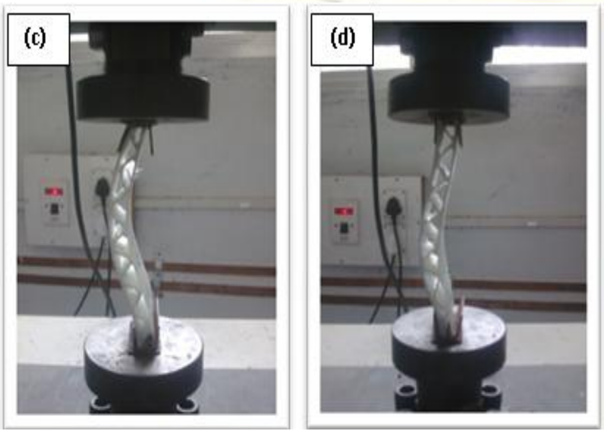

Fig 3(c) and (d) The bending of the specimen increases as the load is increased

The bending of the specimen increases as the load is further increased as seen in Fig 3(c) and 3(d). Finally, the specimen fails due to the separation of the corrugated core from the one of the face sheets as seen in Fig 3(e).

Fig 3(e) shows the collapse sequence of edge wise

In most specimens this type of failure was observed, Failure also occurred due to the wrinkling or buckling in the face sheet.

SEM provides evidence of the bonding in the epoxy /glass system for sinusoidal, square and triangle corrugated sandwich structures shown in Fig. 4(a), 4(b) and 4(c) respectively. Fiber slipping was the dominant failure mode in all three cases. Sinusoidal specimen shows (Fig. 4(a) strong adhesion between core and the skin. The interface bonding between the core and FRP skins is not strong in specimen with triangular corrugation as evident from 4(c).Even though the fiber slipping the dominant mode of failure in these specimens, due to the poor resin interaction between core and skin. Some area showed matrix cracking and fiber pull-out (Fig. 4(a)). The specimens of square corrugated specimens showed greater degree of fiber pull-out as presented in Fig. 4(b) than that of triangular corrugation sandwich structures.

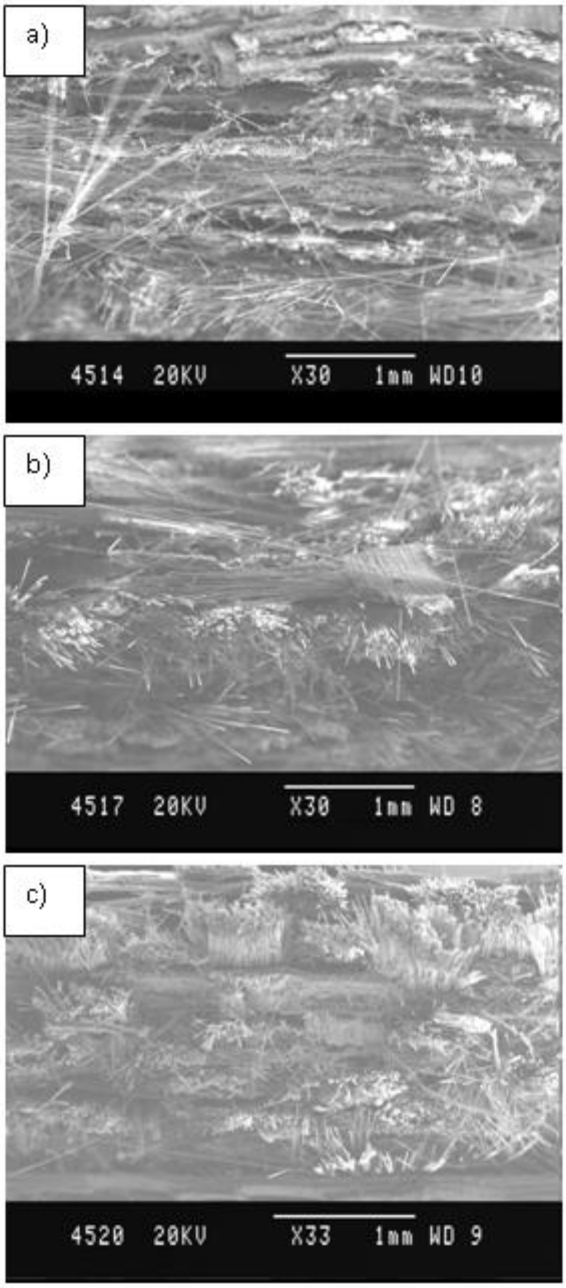

Fig. 4 SEM of interface between the corrugation and the skin after buckling for a) sinusoidal, b)square and c) triangle corrugation

IV. CONCLUSION

Different shaped core based corrugated sandwich structures were fabricated as per standards with different thicknesses and shapes The buckling response of corrugated core sandwich structures with sinusoidal, square and triangle profile having the thickness of 0.5mm 0.75mm and 1.0 mm has been evaluated. From the graphs it can be seen that the change in core thickness and the core profile there is a change in the peak load of the sandwich structure. For the sine profile core as thickness is increased there is a high increase in the peak load where as in case of square profile core slight increase in peak load with increase in the corrugation thickness is observed and the triangular profile core exhibits a increase in load carrying capacity when the thickness of the corrugation is increased, the mean peak load for 0.5mm thick triangle corrugation is 1178 N and for 1mm thickness it is to be 5350 N.

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