Compression Properties of X-Cor Sandwich

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1 General Introduction

Sandwich composites are ultra-light weight structural materials consisting of thin face sheets covering a low-density core. The sheets are comprised of stiff and strong fibre-reinforced laminate, and carry the bending loads of structure. The core is used with the most common being polymer foam, nomex and balsa, and supports transverse shear and through-thickness indentation load. Sandwich composites are used in a large number of structural applications because of their good bending properties and light-weight, including in aircraft, ships and rail carriages.

A major limitation of sandwich composites is their low through-thickness compression properties, which are dominated by the weak core, which has limited their application in structures which has to carry through-thickness compression loads. A new sandwich core material, X-Cor TM[1] (see Fig.1a,b) which consists of pultruded pins embedded in a foam carrier could solved this difficulty. The pultruded pins with high modulus, high strength transfer the loads from one face sheets to another face sheets directly, which resulted the high compression strength.

Fig. 1.a X-Cor sandwich

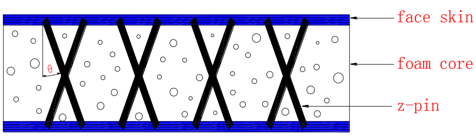

Fig. 1.b Schematic of X-Cor sandwich

The mechanical performance of X-Cor sandwich have been studied in recent years. Low velocity impact experiments on composite skin sandwich panels with foam cores reinforced by metallic pins indicate that these sandwich structure offer improved impact and delamination resistance[2-3].

M.C.Rice[4] studies on the collapse of pin-reinforced foam sandwich panel cores in three-points bending with simply surpported boundary conditions.

About compression properties of X-Cor sandwich, A.P.Mouritz[5] investigated compression properties of z-pinned sandwich composites with the parameters including z-pin diameter and z-pin volume fraction, established the through-thickness compression modulus with the mixture law and strength considering z-pin angle influence.

HAO Jijun[6] proposed an analytical fomula of equivalent out-of-plane compression modulus by investigating the three dimensional model of X-Cor unit cell and gave an analytical prediction rule with an Winkler elastic foundation. HAO also gained the conclusions which showed that the out-of-plane compression property was improved by increasing the angle between z-pin and face sheet, z-pin's volume fraction, diameter, restriction of their ends as well as foam property by experiment.

As a new material X-Cor sandwich has a strong characteristic with good flexibility design, but difficult in use due to too many design parameters. Althouh the mechanical performances of X-Cor sandwich could be studied through experimental testing , but it is enormous work because of many design parameters including of z-pin materials, z-pin diameters, z-pin angles, z-pin density, foam type, face sheet thickness etc. So the numerical analysis of X-Cor sandwich is an urgent demand. Previous research has revealed three-dimensional unit cell model to analyze shear properties of X-Cor sandwich [7][8], but the unit cell model cannot suit the requirement of practical engineering with too many design parameters.

2 Test

2.1 Test Materials

X-Cor sandwich consists of carbon-fiber sheets and polymer foam core is reinforced with fibrous composites pins. The sheets are laminate in a 1mm (laminate ply is [0/90/0/90]s or 2mm (laminate ply is [0/90/0/90/90/0/90/0]s)with GUANGWEI 12500 unidirectinal carbon/epoxy fiber lamina. The core is PMI foam (Rohacell 311G with density of 32kg/m^3) in 11.5mm reinforced with carbon fibre composite pins in 0.5 mm diameter, which is pultruded with Toray T300 carbon fibres and FW-125 epoxy resin. The arrangement of z-pin is 5×10mm, and there are three kinds of pin angles including 0° , 20° and 30° in this study. The independent contribution of the z-pins to the through-thickness compressive response was measured in this study. The method is that the foam core is removed manually by tweezers and leaving the z-pins to bridge faces of the sandwich panel. The serials number and geometry parameters are showed on Table 1. The composites are tested (see Fig.2) with 60mm × 60mm compression according to standard GB/T1453-2005 [9] at a loading rate of 0.5mm/min.

Fig. 2 Compress test fixture of X-Cor sandwich

2.2 Test Results

The compression response of the samples in this paper is shown in Fig.3a,b. The subjects of contrast test include restriction of z-pin ends of different sheet thickness, different z-pin angle and foam providing transervse support against z-pin buckling.

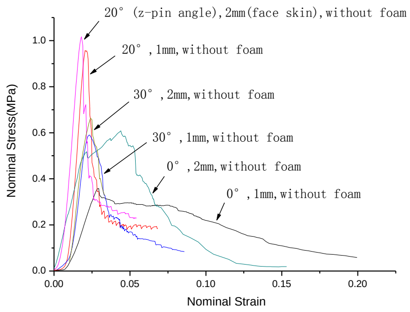

Fig.3.a Comparison of samples(without foam) compression stress-strain curves

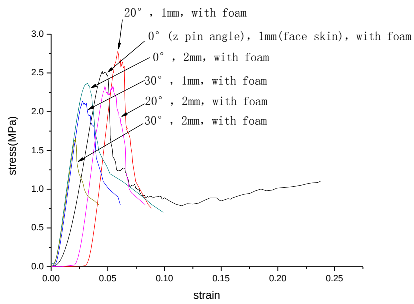

Fig.3.b Comparison of samples compression stress-strain curves

The typical compressive response comprises an initial elastic phase , followed by a peak strength and plastic collapse regime with falling stress-strain curve. In addition the compression response of the samples with foam presents with a rising ensued by condensation foam , see the total curve of samples (1mm face sheets , 0° pin angle).

Phenomenon in test as follows: when the stress reaches its maximum, the sample send out brittle sound suddenly ,after that the PI PA sound arise continuously, and the stress decreased sharply. By observing the PI PA sound was send out as a result of z-pin buckling and fracture.

The test result of the samples with and without foam see Fig.4a,b.

Fig.4a Test result of X-Cor sandwich without foam

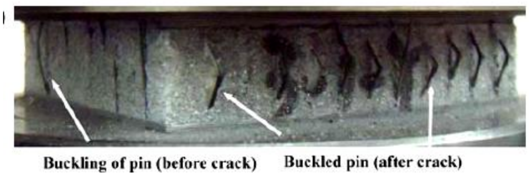

Fig. 4b Test result of X-Cor sandwich with foam

The peak strength of the samples without foam is all less than 1Mpa, and the peak strength of the sandwich with foam alone is rather low as we know. The peak strength of the samples with foam is more than 2Mpa(2mm face sheets ,30° pin angle except), compare Fig.3a, b. We conclude that a strong synergistic effect exists: the strength for the pin-reinforced foam core is more than the sum of the contributions from the foam and the pins respectively.

Now consider restriction of z-pin ends of face sheets see Fig.3a. With equivalent z-pin angle the strength of the samples with 2mm face sheets is higher than that of the samples with 1mm face sheets. So 2mm face sheets is stronger than 1mm on restriction of z-pin ends .

With same thickness face sheets the strength of the samples with 20° pin angle is higher than that of the samples with 30° pin angle, see Fig.3a, b. The strength of samples with 0° pin angle without foam is obvious low, and the strength of samples with 0° pin angle with foam is little low. The samples with 0° pin angle without foam first lose overall stability in test, then z-pins fracture. Defects are discovered on undone samples, z-pin angle offset about 2° on one direction(see Fig.5). The compression strength of X-Cor sandwich with 2° pin angle are greatly reduced when pin angle offset from the orthogonal direction, even at a shallow angle. In fact it was difficult to insert all the pins in the orthogonal direction even using embedding machine. The process of the sample lose overall stability and frature see Fig.5. The reason of phenomenon as follows: the state of X-Cor sandwich which pin angle is 0° and offset at a shallow angle on one direction belong to unstable equilibrium. X-Cor easily lose overall stability when carrying certain load. The state of X-Cor sandwich which z-pin angle is greater than 0° and staggered arrangemen don't belong to unstable equilibrium, and it don't lose overall stability.

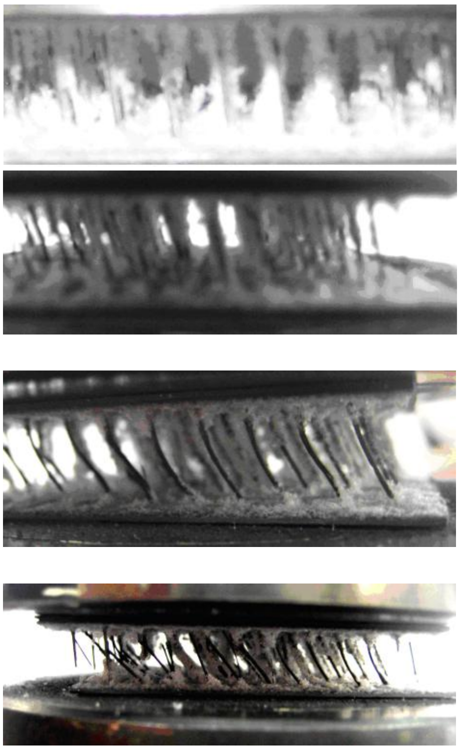

Fig.5 Failure modes of X-Cor sandwich (0° ,1mm thick ,without foam)

3 Discussion

It is argued below that the peak strength of the samples with and without foam is dictated by elastic buckling of the z-pins.

Z-pins is pultruded with high modulus, high strength material, z-pin's modulus is more higher than foam's, the out-of –plane load carrying capability of foam is almost neglected contrast to z-pins. So the peak strength of the samples with and without foam is dominated by that of the z-pins.

It is instructive to compare the predictions of the quasi-static strength with the measured strengths of the samples, as reported in Fig.3a,b. Assume that the z-pins are made from rigid-ideally elastic material of yield strength σ_y and that they are squashed by out-of-plane load. Then ,the compressive strength $\sigma_{\max}$ is given by[10]:

$$\sigma_{\max} = V_p \sigma_y \cos^2 \theta \quad (1)$$

Where V_p is the volume fraction of the z-pins, θ is z-pin angle. Upon taking σ_y =1100Mpa, V_p =0.38% and θ=20° for the samples with and without foam, we obtain $\sigma_{\max}$ =3.7Mpa,which is a factor of 3.7 greater than the measured strength of 1Mpa, and a factor of 1.7 greater than the measured strength of 2.7Mpa. It is concluded that the samples with and without foam undergo elastic buckling. So X-Cor sandwich buckling analysis is necessary on study compress properties.

4 The Finite Analysis

This paper unconsiders face sheets bending and affluent resin due to the z-pins embedding in face sheets. The out-of-plane load carrying capacity of foam and interaction betweem foam are unconsidered in model, and the transverse support against z-pin buckling by foam is considered.

The thickness comparison to the length and width of face sheets, the diameter comparison to the height of z-pin, three-dimensional analysis model which consist of solid elements will produce numerous calculations if the net of model is dense, or produce null result if the net of model is not enough dense[11].So solid elements are unconvenient in X-Cor sandwich analysis in practical structure.

The paper establishs composite structure finite element model which is composed of shell element simplified from face sheets, beam element simplified from z-pin, spring element imitating foam transverse support to z-pin. Document[12] points out the Winkle elastic foundations, assumes foam as elastic foundation, takes foam into innumerable independent, unrelated spring. During allowance range spring is compressed or pulled (see Fig.6). Foam in this paper is simplified several independent and unrelated spring element.

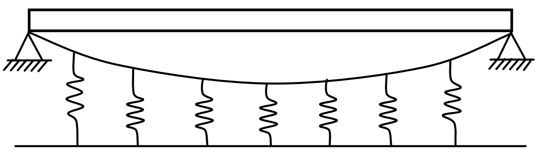

Fig.6 Calculation chart elasticity base beam

X-Cor sandwich finite element analysis uses of buckling package of Nastran. The geometry parameters and material properties in model agree with the samples. Load and constraints in model as follows: bring equal load on up sheet, namely there is 0.1N on every node of up sheet, buckling steps are ten.Freedom is zero on the Four angle nodes in down sheet, the rest are constrained Z direction. Rotation is constrained on nodes of up sheet.

The model which z-pin angle is 20 degree, sheet is 1mm thick, without foam model as example one, with foam as example two. There are 1300 nodes(nodes on load) on up sheet in example one, and there are 4865 nodes on up sheet in example two.

The calculated critical load of buckling analysis is buckling factor product the static load. The buckling factor of example one and example two respectively show Fig.7, Fig.8.

The first stage buckling of example one lose overall stability, but the failure in test don't appear, so buckling factor in the second stage buckling is used. The calculated critical load of example one is equal to$0.1\times1300\times25.69=3340$N

The calculated critical load of example two is equal to$0.1\times4865\times19.053=9269$N

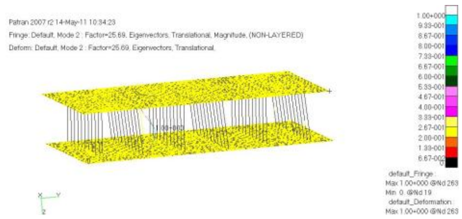

Fig..7 Second shape of example one

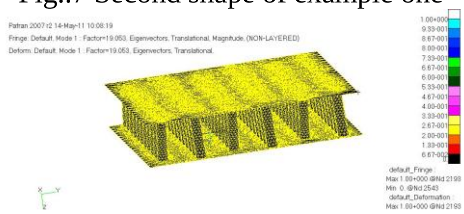

Fig..8 First shape of example two

4 Results

A strong synergistic effect exists in X-Cor sandwich between foam and z-pin, the peak strength is set by elastic buckling of the reinforcement z-pins ,with the foam core providing transverse support against buckling. The contrast betweem calculated critical load of model and measured maxium destroy load see Table 1.

From research in this paper, following conclusions are drawn:

1. When z-pin angle is 0°, the samples is strict with the embedding angle precision. In theory X-Cor sandwich with 0° pin angle is best in the out-of-plane load carrying capacity. But in test the samples with 0° pin angle without foam lose overall stabilty. The measured load data is obvious low. The samples with foam is little low on the measured maxium destroy load. The compressive strength of X-Cor sandwich with 0° pin angle is very sensitive to angle deviatio. Angle deviatio is always being in manufacture , so X-Cor sandwich with 0° pin angle is not priority considered.

2. Except that the measured data in test is low due to defects of the specimens, the rest data contrast to calculation, disagreement is less than percentage eight, the calculated results is agree with the measured. So the composite structure finite analysis model on this paper is reasonable. The calculated critical buckling load of model is little low than the the measured maximum destroy load in test, which is considered single z-pin buckling only in model analysis, the method is little conservative to the practial structure.

3. X-Cor sandwich will be studied more the compress properties of different design parameters in use of the model, which can be established basement in practical application as a new type material.

Table1 Compares the measured and calculated of specimens

Specimens numbers	Sheet thickness (mm)	Foam type	Z-pin angle (°)	The measured maxium destroy load (N)	The calculated critical load (N)	Note
SY1-11~15	1	null	0	1279±128	1253	Lose overall stability
SY1-21~25	1	311G	0	8648±519	10399	Little low of test
SY1-31~35	1	null	20	3596±360	3340	
SY1-41~45	1	311G	20	9480±758	9269	
SY1-51~55	1	null	30	2300±230	2365	
SY1-61~65	1	311G	30	7788±156	7505	
SY2-21~25	2	null	0	2052±205	1989	Lose overall stability
SY2-31~35	2	311G	0	9086±545	11083	Little low of test
SY2-41~45	2	null	20	3533±353	3660	
SY2-51~55	2	311G	20	8331±833	10248	Little low of test
SY2-61~65	2	null	30	2399±240	2683	
SY2-71~75	2	311G	30	5630±450	7940	Little low of test
Note：foam type null indicates without foam						

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