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EFFECT OF CORE THICKNESS AND INTERMEDIATE LAYERS ON MECHANICAL PROPERTIES OF POLYPROPYLENE HONEYCOMB MULTI-LAYER SANDWICH STRUCTURES

WPŁYW GRUBOŚCI RDZENIA I WARSTW POŚREDNICH NA WŁAŚCIWOŚCI MECHANICZNE WIELOWARSTWOWYCH STRUKTUR POLIPROPYLENU O STRUKTURZE PLASTRA MIODU

Sandwich structures are widely used in lightweight construction especially in aerospace industries because of their high specific strength and stiffness. This paper investigates the effect of core thickness and intermediate layers on the mechanical properties of a polypropylene honeycomb core/composite facing multilayer sandwich structure under three points bending. We developed a theoretical model which makes it possible to calculate the shear properties in multi-cores. The results obtained by this model are agreed with our experimental results, and the results obtained with bending test showed that the mechanical properties of the composite multilayer structures increase with core thickness and intermediate layers.

Keywords: Sandwich, multi-layer, bending, polypropylene honeycomb, thickness, intermediate layers

Struktury warstwowe są szeroko stosowane w lekkich konstrukcjach, szczególnie w przemyśle lotniczym, z powodu ich wysokiej wytrzymałości i sztywności. Zbadano wpływ grubości rdzenia i warstw pośrednich na właściwości mechaniczne polipropylenowego kompozytu o strukturze plastra miodu (rdzeń) i wielowarstwowej struktury w trakcie trójpunktowego zginania. Opracowano model teoretyczny, który umożliwia obliczenie właściwości ścinania w przypadku wielu rdzeni. Uzyskane wyniki modelowania są zgodne z naszymi wynikami eksperymentalnymi, a wyniki uzyskane w teście zginania wykazały, że właściwości mechaniczne kompozytowych struktur warstwowych rosną ze zwiększeniem grubości rdzenia i warstw pośrednich.

1. Introduction

Sandwich structured composites are a special class of composite materials which have become very popular due to high specific strength and bending stiffness. Low density of these materials makes them especially suitable for use in aeronautical, space and marine applications [1-2-3]. Sandwich panels are composite structural elements, consisting of two thin, stiff, strong faces separated by a relatively thick layer of low-density and stiff material. The faces are commonly made of steel, aluminium, composite and the core material may be foam, honeycomb and balsa wood. The faces and the core material are bonded together with an adhesive to facilitate the load transfer mechanisms between the components. This particular layered composition creates a structural element with both high bending stiffness - weight and bending strength – weight ratios.

In order to bring solutions to the industrialists, many developments and studies during these last years, were optimization of the mechanical performance /density ratio. Indeed, the general concept of optimisation sandwich structures has been investigated and developed by many researchers [4-6]. The structure of sandwich composites is shown in Fig. 1 (a). This study was undertaken with the same objective, but by having a strategy of optimization being focused more particularly on core material. Our step is to reconsider in its entirety core material and to propose a new concept of core complex (multi-layer cores) which rests on the material stacking of different nature according to a quite precise sequence. The structure of multilayer sandwich composites is shown in Fig. 1 (b). The various techniques used in the multilayer sandwich structures make it possible to adapt the mechanical properties according to various parameters such as the nature and skins thickness, the type and core material thickness and type and thickness intermediate layer. The structures used in the present work are formed by adhering two high-stiffness glass/polyester thin-face sheets with a low density polypropylene honeycomb core characterized by less strength and stiffness. The materials of this work are developed in the framework of a comparison with previously studied structures [7-8]. The purpose of this study is to determine the effects of core thickness and intermediate layers on the mechanical properties of polypropylene honeycomb core/ composite facing multilayer sandwich under three points bending.

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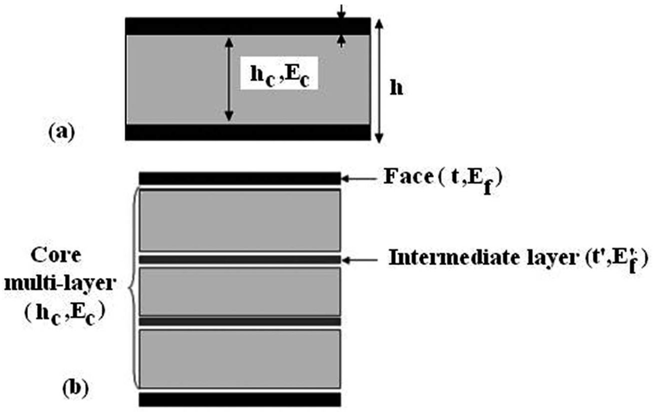


Fig. 1. The structure of a single (a) and multilayer (b) sandwich composite

2. Theoretical Analysis

2.1. Mechanical properties

In sandwich beam D is the sum of the flexural rigidities of the different parts, measured about the centroidal axis of the entire section, as shown in equation (1) [9]

$$D = b\left[\frac{E_f t^3}{6} + \frac{E_f t d^2}{2} + \frac{E_c h_c^3}{12}\right] = E_f \frac{b\left(h^3 - h_c^3\right)}{12} + E_c \frac{b h_c^3}{12} = 2D_f + D_0 + D_c \tag{1}$$

where b is the width of the beam, t_f and tc are the thicknesses of the face sheet and core, E_f and E_c are the Young's moduli of the face sheet and core, and $d = t + h_c$. D_f is the bending stiffness of a face sheet about its own neutral axis, D_0 is the stiffness of the face sheets associated with bending about the neutral axis of the entire sandwich, and D_c is the stiffness of the core [5].

Since the core is stiff in shear but soft generally, its Young's modulus is much smaller than that of the face sheet. By assuming $E_c << E_f$ and the face sheets are thin, then

$$D \approx E_f \frac{b\left(h^3 - h_c^3\right)}{12} \tag{2}$$

The shear stiffness Q is given by equation (3):

$$Q = G_c \frac{b(h-t)^2}{h_c} \tag{3}$$

The face stress is given by equation (4):

$$\sigma_f = C\frac{L}{btd}P \tag{4}$$

Where C is $^1/_4$ for 3 – points bending. In the core the shear stress is given by equation (5) [10]:

$$\tau_{c\max} = \frac{P_{\max}}{2bd} \tag{5}$$

The elastic deflection w_t of the indenters on the top face relative to those on the bottom face is the sum of the flexural and shear deflections [5],

$$w_t = w_1 + w_2 = \frac{PL^3}{48D} + \frac{PL}{4AG_c} \tag{6}$$

for a three-point bend (Fig. 2.).

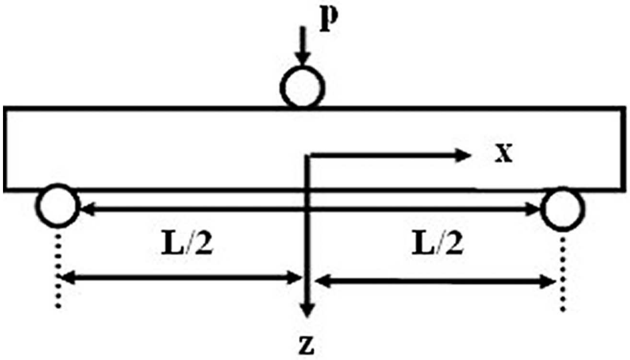


Fig. 2. Sandwich beam under three-point bending

3. Materials and experimental technique

3.1. Materials

We manufactured three series of the materials sandwichs multi-layers, with different thicknesses (10, 20, and 40 mm) within the Laboratoire de Physique des Milieux Denses (LMPD) by the hydraulic press process. The sandwich panels consisted of three main parts (Fig. 3.):

- The first, tow face sheet of composite glass fibres (T800/M300)/polyester resin. The nominal face thickness is 1 mm;
- The second part is a honeycomb polypropylene core;
- The third is the intermediate layers of specific composition of composite material. The nominal intermediate layers thickness is 0,05 mm.

Fig. 3. Honeycomb multi-layer sandwich

The mechanical properties of the basic materials are summarized in Tables 1 and 2.

TABLE 1
Mechanical properties of a polypropylene honeycomb core

Density [Kg/m^3]	80
Compressive strength [MPa]	1,3
Shear strength [MPa]	0,5
Elastic modulus [MPa]	15
Shear modulus [MPa]	8

TABLE 2
Mechanical properties of face sheet composite

Young's modulus [MPa]	9162
Tensile strength [MPa]	321
Shear modulus [MPa]	2101
Face thickness [mm]	1

3.2. Experimental technique

The samples are solicited in bending 3-points on a standard universal hydraulic INSTRON machine model 4302 (Fig. 4.). This test is performed with respect to the NFT54-606 norm. To check the results reproducibility, a minimum of 5 beams by composite type is tested. The crosshead displacement rate was 3 mm/min. The dimensions of the samples are: length = 440 mm, width = 35 mm.

Fig. 4. Three-points bending test

4. Results and discussion

4.1. Effect of core thickness

Fig. 5. Shows a typical load-bending curve for three core thicknesses sandwich structures. Each structure showed an initial linear elastic behaviour followed by a decrease in slope up to a maximum load magnitude. As the thickness of the sample with core and the flexural rigidity increased, the initial slope of the curve increased. Similarly, the magnitude of the maximum load increased with core thickness. The sample with the 40 mm thick had a significantly greater maximum load, as expected from the greater sample dimension of thickness and width (35 mm). When the core thickness decreases (20 and 10 mm), the curve load-bending reveals initially a linear behaviour of the beams until load rather high, then a nonlinear behaviour until a maximum loading. The load decrease then gradually when the bend increases. After sample failure, we observed the failure is induced in contact the face with the central support, and we also observed the failure core shear. These results show thus that after initiation and development of the first failure phenomena, the depression of the materials sandwich leads then local indentation, buckling and debonding of skin and core which occurs in the centre of the sample where the bending strain is exerted (Fig. 6).

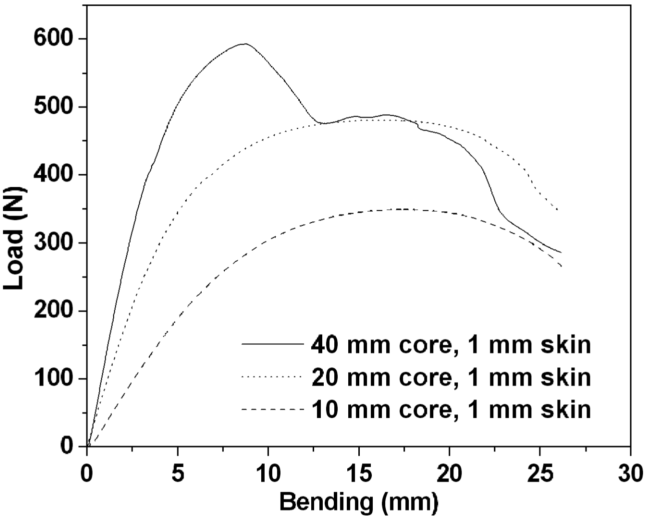


Fig. 5. Typical load-bending curve plot for each core thickness

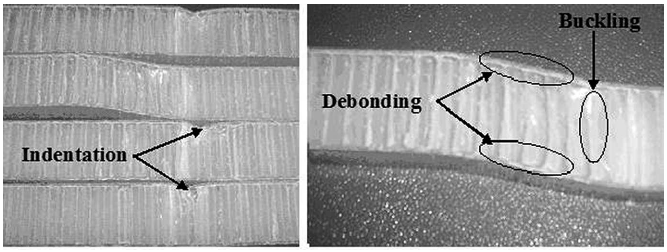


Fig. 6. Various types of skin and core failures

TABLE 3
Mechanical properties for each core thickness

Core thickness [mm]	10	20	40
Load [N]	350	480	594
Facing stress [MPa]	68,20	49	31
Core shear stress [MPa]	0,45	0,33	0,21
Bending stiffnes [N.mm^2]	213,75 10^5	527 10^5	855 10^5
Shear stiffness [N]	3388	6174	11767

The flexural properties calculated form the three point bend with L = 300 mm are given in Table 3. The core shear stress was found to decrease of about 53 percent as the core thickness increased from 10 to 40 mm. This may suggest that the test geometry is more influential on the applied shear stress. The facing stress experienced by the structures was found to decrease of about 54 percent with increasing core thickness from 10 to 40 mm. It is possible that this is related to the occurrence of core failure in the thicker samples. The bending and shear stiffness was found to increase of about respectively 75 and 71 percent as the core thickness increased from 10 to 40 mm.

4.2. Effect of intermediate layers

Fig. 7. Represents the load – displacement curve evolution for multi-layer honeycomb composite structures solicited in bending 3-points. Some is the type of composite structure tested, the bending behaviour is similar and can break up into three principal phases: A first phase each structure showed an initial linear elastic behaviour followed by a phase of nonlinear behaviour in which the maximum loading is reached. In a last phase, a reduction in the load applied is observed until the total rupture of the samples. The linear behaviour corresponds primarily to the work of the skins in traction and compression, whereas the nonlinear behaviour depends mainly on the core properties under the effect of the shear stress. This figure shows too the mechanical properties, "facing stress, core shear stress and bending stiffness increase of about respectively 25, 26 and 29 percent as the number of layer increased from single to quadruple layers. The measured mechanical properties of these composite sandwich multi-layers are listed in Table. 4.

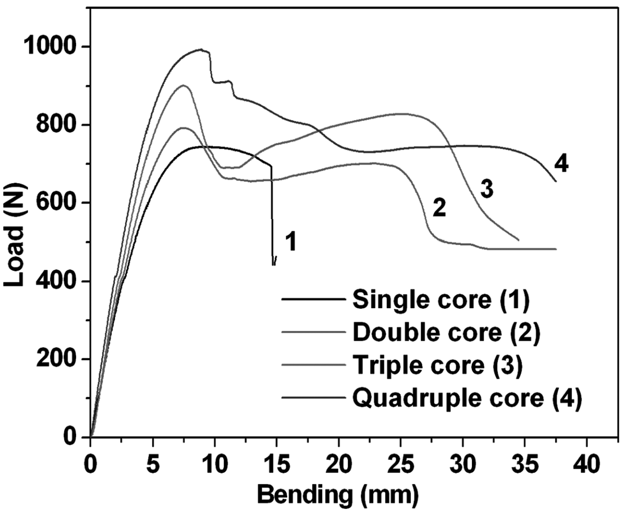


Fig. 7. Load-bending curve measured under static three-points bending with L = 300 mm of the multilayer sandwich (40 mm)

TABLE 4

Mechanical properties of the multilayer sandwich structures (40 mm)

Specimen	Load [N]	Facing stress [MPa]	Core shear stress [MPa]	Bending stiffness [N.mm^2]
Single core	740,67	38,71	0,25	$855\ 10^5$
Double core	792,68	41,43	0,28	$1058,38\ 10^5$
Triple core	903	47,20	0,31	$1054,68\ 10^5$
Quadruple core	1022	51,74	0,33	$1218,3110^5$

4.3. Shear properties of multi-layer core

To determine the shear properties of the multi-layer core, we have carried out a series of measurements while varying the distance L between the supports. This measurement technique enables us to determine an apparent shear modulus of the multi-layer core. Fig. 8 gives the results obtained with a single core with 40 mm thickness. The different curves of Fig. 8 make it possible to represent the evolution of δ/PL versus L^2 for a single core with thickness the 40 mm (Fig. 9). The experimental data are then fitted by a linear law describing the evolution of δ/PL versus L^2. Extrapolation to L = 0 gives the value of factor 1/4AG which is used to calculate the apparent shear modulus. A similar procedure is then applied to double, triple and quadruple cores. The values of the shear stiffness are presented in Table 5 (calculations using the experimental data).

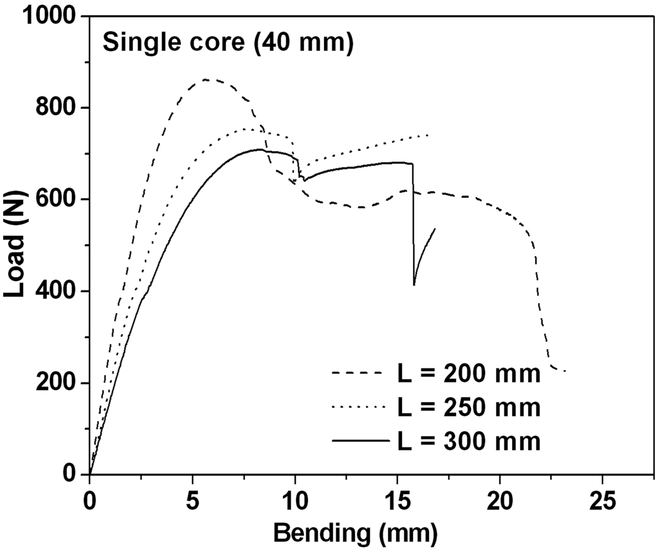


Fig. 8. Flexural test result for specimen single core (40 mm) versus support span

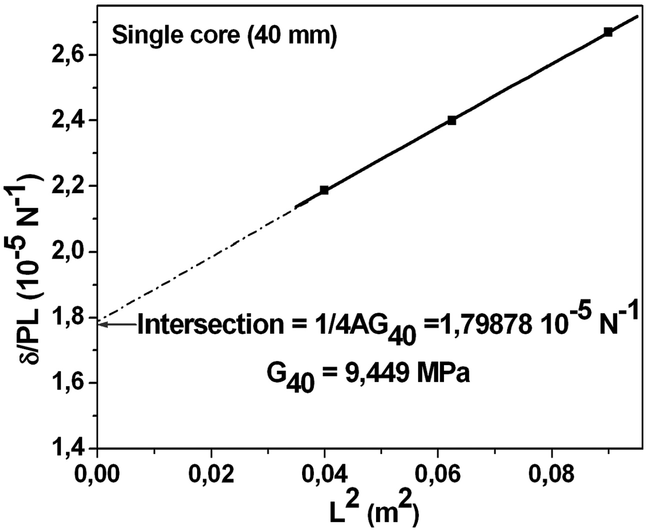


Fig. 9. Plot of δ/PL versus L^2 used to determine the shear modulus of the polypropylene single core

TABLE 5
Shear modulus and stiffness of the multilayer sandwich structures

Series (mm)	Sandwich multilayres	Shear modulus [MPa]	Shear stiffness [N]
10	Single sandwich	14.85	6289
	double sandwich	18.45	7845
20	Single sandwich	12.10	9338
	Double sandwich	16.20	12530
	Triple sandwich	18.5	14342
	Quadruple sandwich	21.5	15162
40	Single sandwich	9.44	13885
	Double sandwich	10.29	15153
	Triple sandwich	11.31	16675
	Quadruple sandwich	11.98	17683

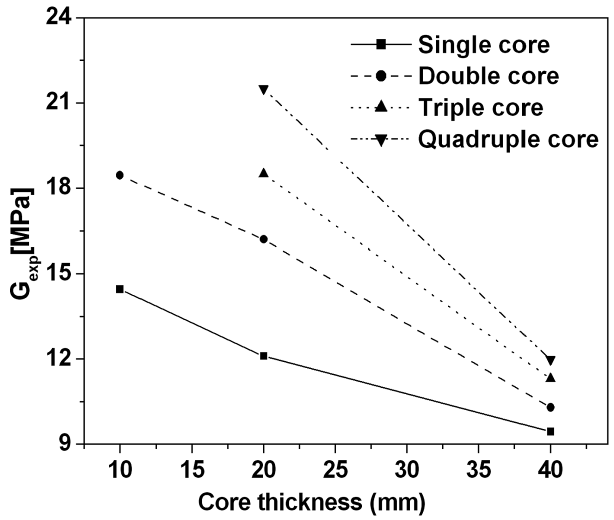


Fig. 10. Effect of core thickness on the shear modulus

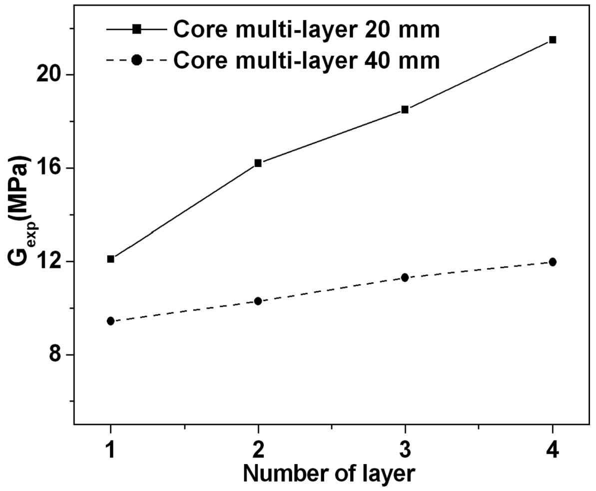


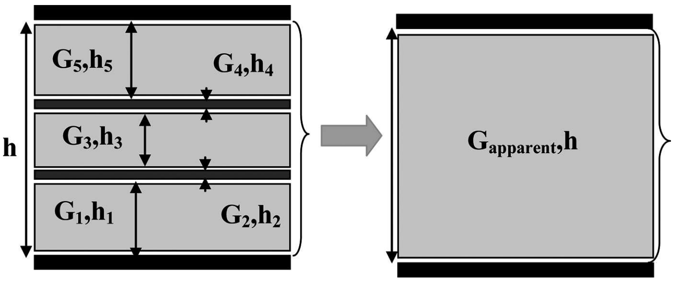
Fig. 11. Effect of intermediate layers on the shear modulus

The core shear modulus depends only on the type and thickness of foil used and core geometry, it would not be expected that the shear modulus would be affected by changes in core thickness and intermediate layers. However, the experimental data obtained suggest a marked decrease in shear modulus with increasing core thickness (Fig. 10) and marked increase with number of layer increasing (Fig. 11). Shear modulus decreased about 36 percent as core thickness increased from 10 to 40 mm, and increased about 43 and 21 percent as number of layers increased from single to quadruple layers with respectively series 20 and 40 mm.

5. Theoretical model

Theoretical model developed to calculate shear modulus apparent. This model take the shear modulus of the different materials constituting the sandwich multi-layer.

Assumption



With G_1, G_3, G_5, h_1, h_3 and h_5 are respectively the shear modulus and thicknesses of the core layers and G_2, G_4, h_2 and h_4 are respectively the shear modulus and the thicknesses of the intermediate layers. $G_{apparent}$ and h are respectively the shear modulus apparent and the total thickness of the sandwich structure.

$$G_{apparent} = \frac{1}{h}\sum_{i=1}^{N} G_i h_i \tag{7}$$

$G_1 = G_3 = G_5 = G_{nid\ d'abeille\ polypropylene} = 8$ MPa
and

$$G_2 = G_4 = \frac{E'_f}{2(1+\upsilon)} \tag{8}$$

The elastic modulus of the intermediate layer is deduced from the tensile test on the composite material- interface layer. $E'_f = 5500$ MPa and $G_2 = G_4 = 2115{,}4$ MPa

Table 6. Represents the comparison results obtained in shear evaluation of polypropylene honeycomb cores by experimental data, theoretical model and Berthelot [11]. The shear modulus obtained by Berthelot decreased about 27 percent with increasing the core thickness from 20 to 40 mm, and these results agreed with our experimental results. The shear modulus obtained by theoretical model decrease with increasing the core thickness from 10 to 40 mm and increase with increasing number of layer from single to double for serie the 10 and from single to quadruple for 20 and 40 series.

TABLE 6
Experimental, theoretical and Berthelot shear modulus

Series (mm)	Sandwich multilayres	Experimental shear modulus [MPa]	Theorical shear modulus [MPa]	Berthelot shear Modulus [MPa]
10	Single sandwich	14.85	8	
	double sandwich	18.45	18.5	
20	Single sandwich	12.10	8	12.8
	Double sandwich	16.20	13.3	
	Triple sandwich	18.5	18.5	
	Quadruple sandwich	21.5	23.7	
40	Single sandwich	9.44	8	9.4
	Double sandwich	10.29	10.6	
	Triple sandwich	11.31	13.3	
	Quadruple sandwich	11.98	15.9	

6. Conclusion

The effect of variations in core thickness from 10 to 40 mm and intermediate layers from single to quadruple on mechanical properties of a polypropylene honeycomb core was evaluated.

The results obtained by bending test showed that the mechanical properties increase with increasing core thickness and intermediate layers. Comparable results may be obtained in shear evaluation of polypropylene honeycomb multilayer cores by experimental test, Berthelot and theoretical model. This study is to be completed by a comparison with theoretical simulations of the bending behaviour.

Nomenclature

b – width of sandwich beam
h_c – thickness of core
t – thickness of face
t' – thickness of intermediate layer
h – thickness of sandwich ($=h_c + 2t$)
d – distance between the facing centroids
L – support span
E_f – face Young Modulus
E_c – core Young Modulus
E'_f – intermediate layer Young Modulus
G_c – core shear modulus
υ – poisson's ration
τ_c – shear stress core
σ_f – bending stress of facing skin for a sandwich beam
P – load
w_1 – bending or primary partial deflection
w_2 – shear or secondary partial deflection
w_t – total deflection
A – a geometrical parameter that depends on the thickness of the core and skin materials and the beam width
D – bending rigidity
Q – shear rigidity

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