World Applied Sciences Journal 9 (9): 1018-1027, 2010
ISSN 1818-4952

Optimization of a Sandwich Panel with a Kagome Truss Using the APDL Programming Language

[1]A. Fereidoon, [1]A. Abbasi, [2]M.G. Ahangari and [2]N. Kordani

[1]Department of Mechanical Engineering, Semnan Azad University, Iran
[2]Department of Mechanical Engineering, Semnan University, Semnan, Iran

Abstract: In this article, we apply design optimization using the APDL programming language to a sandwich panel including a Kagome core truss. The purpose of this optimization is to minimize the weight of a sandwich panel operating under tension and bending loads. The calculations consider constants such as $C_t = \frac{R}{L}$ (truss radius, R and sandwich panel height, L), $C_s = \frac{t}{L}$ (panel thickness, t), mL values (small truss length) and nL (large truss length in x-y plane). The optimization relations used for calculating the difference points of structures include the n and m variables and variations in their span. Later, Kagome trusses and similar trusses are compared.

Key words: Sandwich panel · Kagome truss · Core truss · Optimal design · ANSYS · Finite element method

INTRODUCTION

Sandwich panels with core trusses formed from direct links have distinct advantages compared with other structures, such as honeycomb structures. In addition to preferable allowances it creates because of its open architecture, sandwich panels with core trusses exhibit more endurance capacity than other competitive structures [1].

In this study, the weight of trussed sandwich panels is optimized under a crushing stress (tension). A desirable combination of width bending and shearing is associated with plastic and yield strength and these are then compared with results from other optimized panels. Many aspects of the optimization process can be studied with the basic model. The study concludes that a design relation based on pure moments and combination of moments, width shearing and the required accuracy for modeling of buckling behavior all must be considered in the design process.

Recently, super-light materials with high hardness and high strength have been considered for use in structures [2, 3]. Using the new materials in a vehicle, for example, allows for reduction of the weight as well as energy consumption. In general, a sandwich panel is made of two integrated sheets and one low-density core. Honeycomb structures and polymeric sponges are also made of this type of construction. Recently, truss matrix structures have been considered as a substitute since they not only have a similar strength as honeycomb cores, but it is also possible to use the interior of the cores for additional applications, such as cooling with high efficiency [4-7].

Recently, alternative metal matrix (net) materials with 0.1-10-mm pores have been created using new construction methods [8-10]. In 2001, the topology of net materials was studied by Krista, among others, using theoretical and empirical methods. These net (matrix) materials contain a sandwich structure that includes a three-dimensional matrix (network) made of solid triangle rods. They can be used in applications such as a structures designed for resistance against impact [11], as multi-application materials (simultaneously load-bearing and actively-cooling) [12, 13] and as substitutions for expensive and high-efficiency honeycomb materials.

Past research has focused on sandwich structures with truss cores using different standard cell topologies, such as the tetrahedral truss [14, 15], pyramidal truss [16] and octahedral truss [17]. Pyramid octahedral trussing has been studied for mechanical applications and the design has been optimized for special applications and manufacturing techniques.

Corresponding Auhtor: N. Kordani, Department of Mechanical Engineering, Semnan University, Semnan, Iran

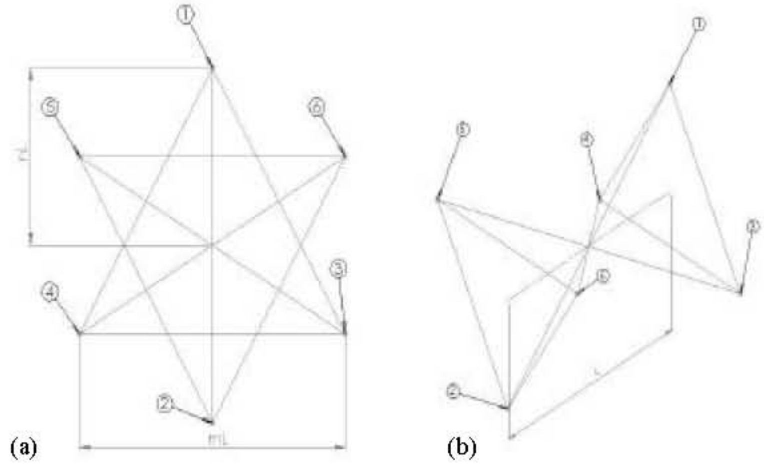

Fig. 1: Points of a Kagome truss

The Kagome truss is a type of trussing network structure that has similar mechanical properties to an octagonal truss [4]. Additionally, the Kagome truss has high strength against traction, which is the main fracture mechanism in truss network structures. However, there is also low anisotropy in its mechanical property. The elastic hardness of a Kagome truss is exactly similar to that of an octahedral truss in regard to its special relative density. The length of each pile in a Kagome truss is half that of each pile in an octahedral truss, resulting in strength against elastic traction (tension) that is four times the strength of an octahedral truss [18-21]. As a result, we aimed to study a sandwich panel with a Kagome core truss under tension and bending loads and to examine the influence of changes in the shell thickness and truss diameter. The approach chosen for simultaneous examination of both subjects is an optimization method that we performed using ANSYS software [22].

Modeling: First, an important task at the start of the modeling process is to find the points that can be used to model both the Kagome truss and the pseudo-Kagome truss. Figures 1a and 1b show the geometric relations between the components of the trusses and the truss points can be written as follows:

$$1.\begin{bmatrix} 0 \\ nL \\ 0 \end{bmatrix} \quad 2.\begin{bmatrix} 0 \\ -nL \\ L \end{bmatrix} \quad 3.\begin{bmatrix} x_3 \\ -\dfrac{nL}{2} \\ 0 \end{bmatrix} \quad 4.\begin{bmatrix} -x_3 \\ -\dfrac{nL}{2} \\ 0 \end{bmatrix} \quad 5.\begin{bmatrix} -x_3 \\ \dfrac{nL}{2} \\ L \end{bmatrix} \quad 6.\begin{bmatrix} x_3 \\ \dfrac{nL}{2} \\ L \end{bmatrix} \tag{1}$$

If the triangle formed by points 1, 3 and 4 is an isosceles triangle, then we have the following:

If the length of the 1-4, 3-1 sides is equal to mL, then

$$x_3 = \frac{L}{2}(4m^2 - 9n^2)^{\frac{1}{2}} \tag{2}$$

Then, to create a truss with these properties, we must use the following relation:

$$4m^2 - 9n^2 > 0 \Rightarrow \frac{m}{n} > \frac{3}{2} \tag{3}$$

Also note that if the length of the 4-3 side is equal to mL in the Kagome truss, then we must have the following relation:

$$\frac{L}{2}(4m^2 - 9n^2)^{\frac{1}{2}} = \pm\frac{mL}{2} \Rightarrow \frac{m}{n} = \sqrt{3} \tag{4}$$

Taking the previous calculation of the points of the truss, then by adding the 10, 9, 8 and 7 points with the following coordinates, we can describe the entire sandwich panel, where points 10, 9, 8 and 7 form the points of the shell:

$$7.\begin{bmatrix} -x_3 \\ -nL \\ L \end{bmatrix} \quad 8.\begin{bmatrix} -x_3 \\ -nL \\ L \end{bmatrix} \quad 9.\begin{bmatrix} x_3 \\ nL \\ 0 \end{bmatrix} \quad 10.\begin{bmatrix} -x_3 \\ nL \\ 0 \end{bmatrix} \tag{5}$$

Additionally, for truss construction in ANSYS software we use Link 8 elements and for shell construction we use Shell 63 elements.

Entering the Element Constants (Real Constants) into the Software: In entering the element constants (real constants), the Shell 63 elements and Link 8 elements are shell thickness and truss cross section, respectively and the software calculates values using the C_s, C_t parameters. Also note that these parameters can be entered manually in the program.

$$C_t = \frac{t}{L} \Rightarrow t = C_t L \quad (6)$$

$$C_s = \frac{R}{L} \Rightarrow R = C_s L \quad (7)$$

With the radius of the truss cross-section, we can calculate of each truss Area and by considering this point, the formative volume of one small member of the truss must be equal to one large member of the truss [2, 3]. Then if the cross-section is considered as a large number member A and a small number AA, then we have:

$$A(4n^2L^2 + L^2)^{\frac{1}{2}} = AA(mL) \quad (8)$$

$$AA = \frac{A(4n^2 + 1)^{\frac{1}{2}}}{m} \quad (9)$$

With this description, we can simply assemble the Kagome sandwich panel and pseudo– Kagome panel. The programming that performs this operation is given in the appendix.

The shape that is assembled by the ANSYS software is shown in Figure 3. In modeling all of the core truss points, low and high levels are shared. Clearly, all beginning and ending points of the trusses can move or rotate in three axes, as directed by this application. Properties of material are 200Gpa for Yang module, 0.3 for Poisson ratio, $7850\frac{Kg}{m^3}$ for Density and 355Mpa for yield stress.

Important Cases to Consider in Optimization:

- What variable (s) of this structure should be optimized (objective function)?
- What restrictions must be applied for this optimization?
- What is the minimum and maximum of these restrictions?
- How can we extract the values that are need for optimization using different programming/loading?
- How do we find the best method for solving the problem?

We answered all of these questions by consideration and determined that the best variable for optimization is the weight of the structure and all restrictions that apply simple in this problem. For choice of the most suitable restrictions, we use special articles. The results show that the restrictions can be expressed by the following:

$$1 - C_t = \frac{t}{L} \Rightarrow t = C_t L$$

$$2 - C_s = \frac{R}{L} \Rightarrow R = C_s L$$

Maximum Motion under Effect of Each Loading Safety Factor

Determination of the *n*, *m* Limitations Presented in this Article: The article that was used [4, 5, 22] for evaluation of the max and min restrictions is represented in a later part. For calculation of the max and min values that are needed for solution of the problem, we use matrix construction properties in the ANSYS software; this subject is clear in programming that is represented in the appendix. In the software, there are different solution methods that refer to the following:

First-Order Method: In this method, solution of the derivatives of the function is considered and applied in solving the problems such that the dependence variables change in the extended limit of the design area.

Sub-Problem Approximation: This is an approximate method for design variables using objective and position (mode) functions by curve-fitting. This method is a general and suitable method for solving the optimization problem in engineering fields.

Application of Bending Load to Structure and Reduction of the Weight of the Structure: By loading the structure in the y-direction (Figure 2), we consider optimization of the weight of the structure by applying restrictions because the truss is under high tension by loading in this direction and define the certainty coefficient (n2) for these restrictions. With this description, the restrictions are as follows:

$$0.01 \le C_t \le 0.03 \quad (10)$$

$$0.01 \le C_s \le 0.03 \quad (11)$$

$$0.5 \le m \le 1 \quad (12)$$

$$2 \le n_t \le 6 \quad (13)$$

$$md_y \le 1mm \quad (14)$$

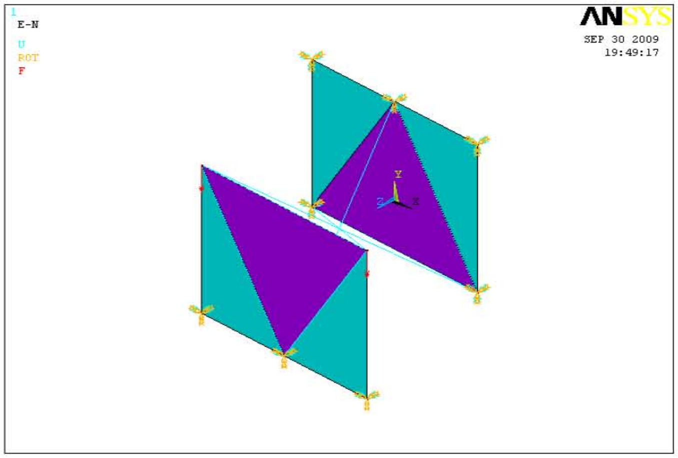

Fig. 2: loading in y axis direction

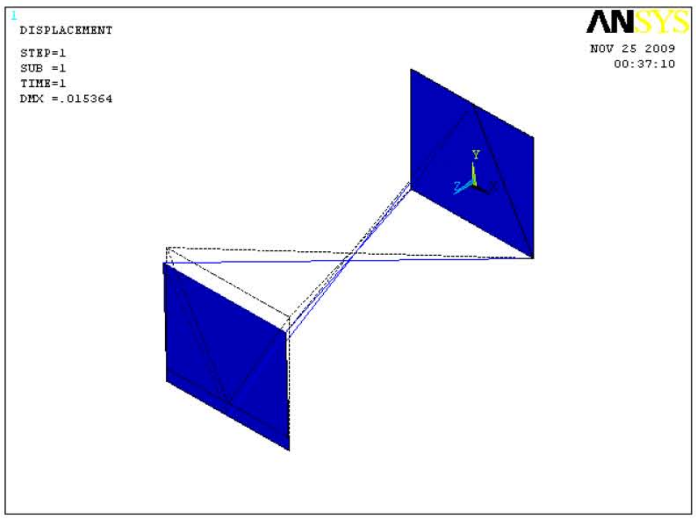

Fig. 3: Deformation, un deformation for y direction

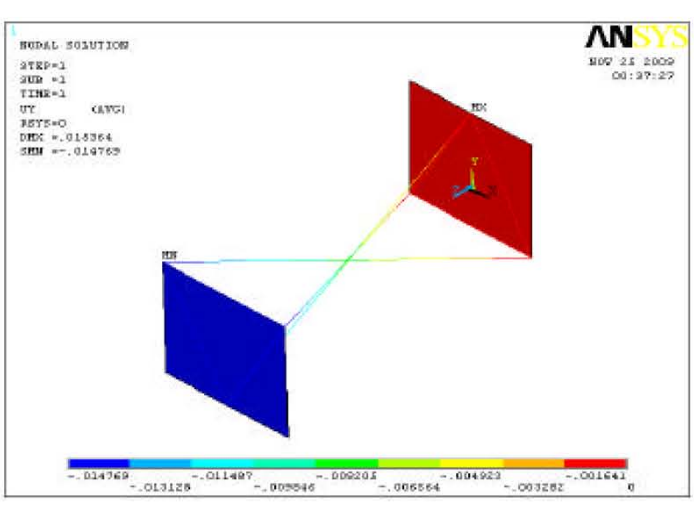

Fig. 4: Displacement for y direction and bending analysis

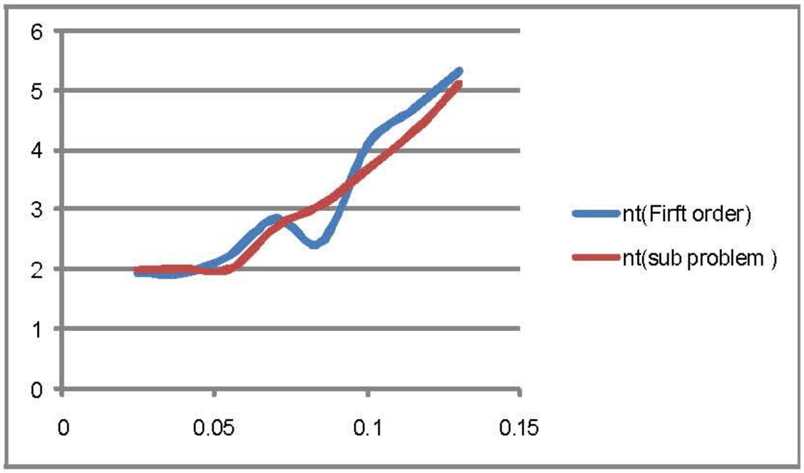

Fig. 5: Comparison of n_t value by both first order and sub problem method

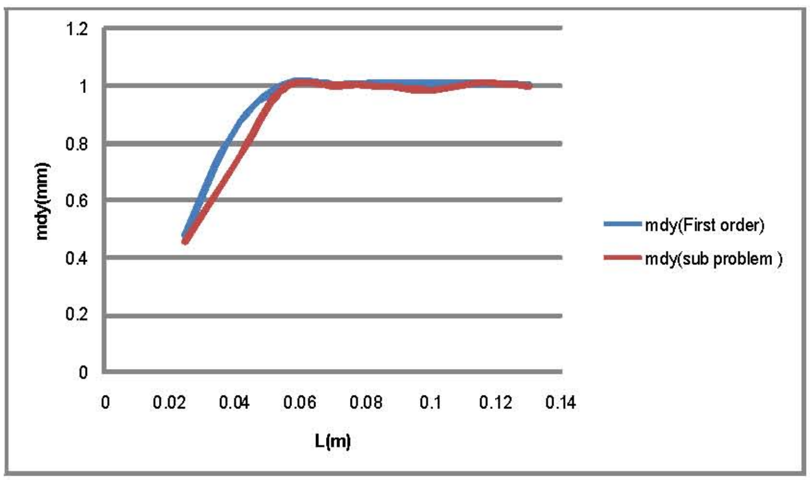

Fig. 6: Comparison Mdy values by first and sub problem method

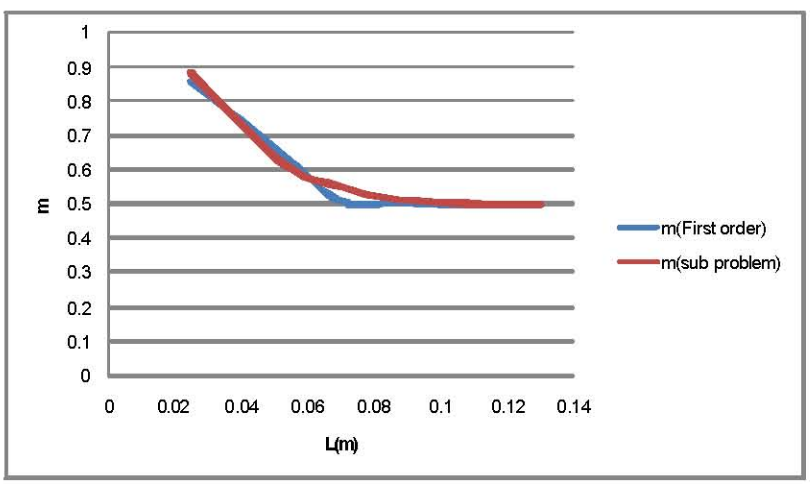

Fig. 7: Comparison m values by first and sub problem method

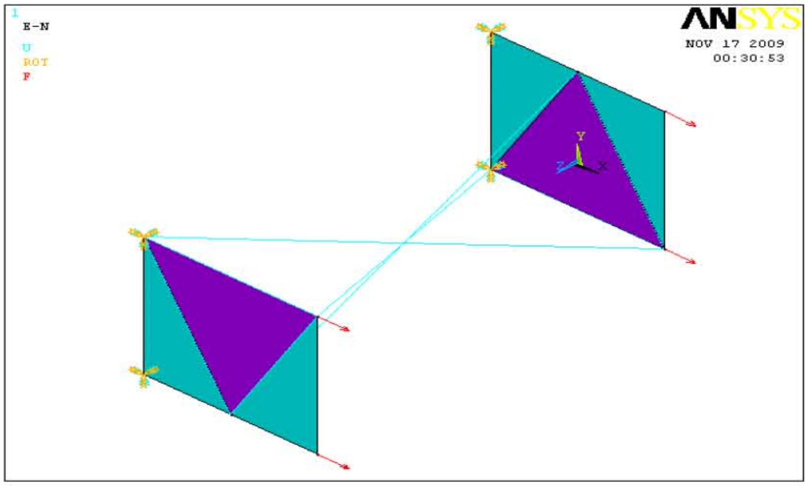

Fig. 8: Loading in the x axis direction tension load = 30 KN

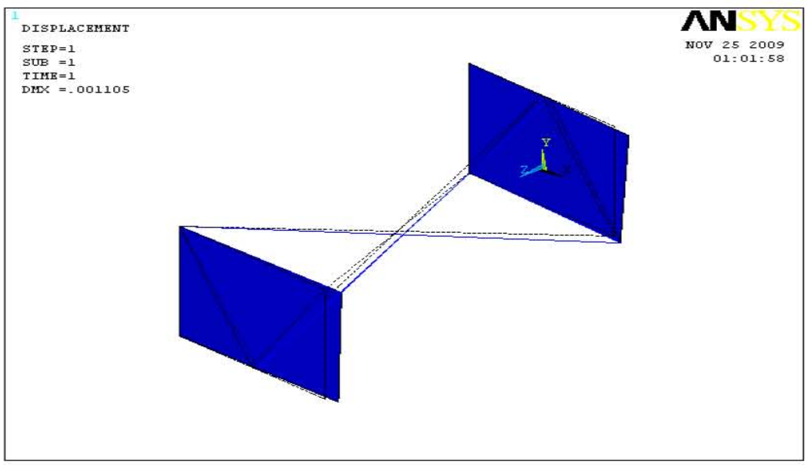

Fig. 9: Deformation / un-deformation in the x-direction

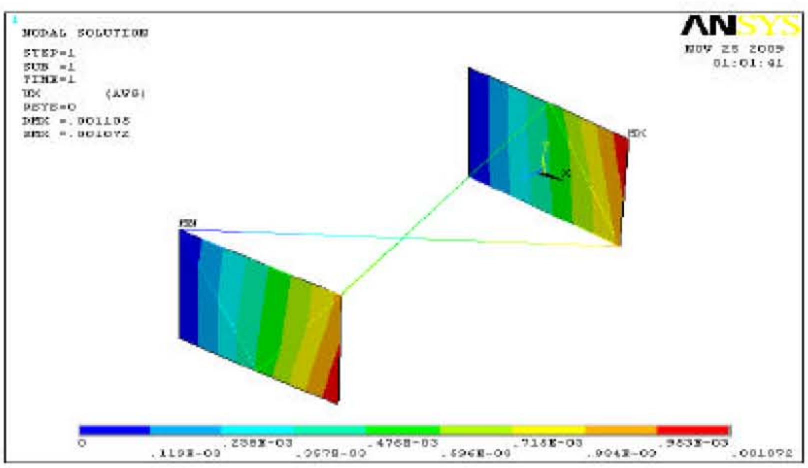

Fig. 10: Displacement in the x direction and tension analysis

Table 1: Optimized values for the *m,n*, *Mdy*, C_t, C_s variables under the influence of bending loading using a first-order method

L (m)	(m)	Nt	Mdy (mm)	Ct	Cs
0.025	0.88402	2.0049	0.45799	2.84E-02	1.01E-02
0.03	0.73368	2.0058	0.55087	2.49E-02	1.00E-02
0.035	0.73352	2.0106	0.63874	2.13E-02	1.00E-02
0.04	0.73314	2.0205	0.72425	1.87E-02	1.00E-02
0.045	0.73315	2.0124	0.81599	1.66E-02	1.00E-02
0.05	0.73823	2.0041	0.90755	1.49E-02	1.01E-02
0.055	0.73144	2.02	0.99033	1.36E-02	1.01E-02
0.06	0.6569	2.2734	0.98169	1.37E-02	1.01E-02
0.065	0.67275	2.4004	1.0005	1.29E-02	1.01E-02
0.07	0.56967	2.7245	1.0004	1.35E-02	1.01E-02
0.075	0.56888	2.9186	1.0008	1.30E-02	1.01E-02
0.08	0.72507	2.8821	1.0083	1.12E-02	1.00E-02
0.085	0.72416	3.0919	0.99851	1.09E-02	1.00E-02
0.09	0.71234	3.2913	0.99856	1.07E-02	1.00E-02
0.095	0.73848	3.4555	0.99469	1.03E-02	1.00E-02
0.1	0.74587	3.6655	0.98534	1.00E-02	1.00E-02
0.105	0.68159	3.8373	1.005	1.00E-02	1.00E-02
0.11	0.64766	4.0786	1.0035	1.00E-02	1.00E-02
0.115	0.61439	4.3072	1.0093	1.00E-02	1.00E-02
0.12	0.59526	4.5934	0.99814	1.00E-02	1.00E-02
0.125	0.56803	4.8242	1.0074	1.00E-02	1.00E-02
0.13	0.55243	5.1182	0.99868	1.00E-02	1.00E-02

Table 2: Optimized values for the *m,n*, *Mdy*, C_t, C_s variables under the influence of a bending load by the first-order method

L (m)	(m)	Nt	Mdy (mm)	Ct	Cs
0.025	0.85662	1.9605	0.4759	3E-02	1.01E-02
0.04	0.74351	1.9607	0.72425	2.09E-02	1.02E-02
0.055	0.6244	2.2535	0.99033	1.63E-02	1.01E-02
0.07	0.5067	2.862	1.0004	1.45E-02	1.01E-02
0.085	0.5017	2.4729	0.99851	1.31E-02	1.01E-02
0.1	0.5	4.0812	0.98534	1.21E-02	1.01E-02
0.115	0.5	4.6925	1.0093	1.13E-02	1.01E-02
0.13	0.5	5.3182	0.99868	1.06E-02	1.01E-02

Table 3: Optimized values for the *m*,n_s, Md_x, C_t, C_s, variables under influence of tension load by sub-problem

L (m)	(m)	Ns	Mdx (mm)	Ct	Cs
0.025	0.79098	2.0034	0.16244	1.01E-02	2.65E-01
0.03	0.79096	2.0032	0.19511	1.01E-02	1.84E-02
0.035	0.79092	1.9984	0.22826	1.01E-02	1.35E-02
0.04	0.77545	1.9944	0.25626	1.01E-02	1.05E-02
0.045	0.56199	2.0069	0.20731	1.00E-02	1.15E-02
0.05	0.51878	2.0072	0.21243	1.00E-02	1.01E-02
0.055	0.50237	2.3472	0.19346	1.00E-02	1.01E-02
0.06	0.50237	2.7905	0.17751	1.00E-02	1.01E-02
0.065	0.50237	3.2725	0.16399	1.00E-02	1.01E-02
0.07	0.50238	3.7932	0.15236	1.00E-02	1.01E-02
0.075	0.50229	4.3484	0.14236	1.01E-02	1.00E-02
0.08	0.50229	4.9475	0.13347	1.01E-02	1.00E-02

Table 4: Optimized values for the variables under tension load by the sub-problem method for a sandwich panel with a pseudo-Kagome core truss

L (m)	Nt	Mdy (mm)	Ct	Cs	(m)	(n)	M/n
0.025	2.0332	0.45307	2.73E-02	1.19E-02	0.97192	0.62996	1.542828
0.03	2.0501	0.52838	2.32E-02	1.21E-02	0.86994	0.58683	1.48244
0.035	2.1086	0.59144	2.06E-02	1.03E-02	0.80364	0.53339	1.506665
0.04	2.0317	0.71328	1.72E-02	1.00E-02	0.90573	0.60657	1.493199
0.045	1.9708	0.8402	1.49E-02	1.00E-02	0.98782	0.63691	1.550957
0.05	2.8054	0.63288	1.69E-02	1.35E-02	0.75261	0.50138	1.501077
0.055	2.0215	0.99174	1.24E-02	1.00E-02	0.94449	0.62939	1.500643
0.06	2.1716	0.99841	1.20E-02	1.01E-02	0.99897	0.56295	1.774527
0.065	2.6143	0.91285	1.18E-02	1.00E-02	0.96454	0.6458	1.493558
0.07	2.5156	0.99918	1.10E-02	2.70E-02	0.99887	0.56661	1.762888
0.075	5.3884	0.49791	1.55E-02	2.45E-02	0.92095	0.50502	1.823591
0.08	3.3195	0.86359	1.12E-02	1.02E-02	0.82368	0.56019	1.470358
0.085	3.0777	0.98315	1.04E-02	1.00E-02	0.77367	0.50426	1.534268
0.09	3.3727	0.95146	1.01E-02	1.33E-02	0.82217	0.54768	1.501187
0.095	5.9683	0.56555	1.28E-02	2.65E-02	0.78029	0.52008	1.500327
0.1	5.9797	0.59586	1.21E-02	1.01E-02	0.80593	0.53361	1.510335

Note that the *m* and *n* values are more impressive variables that determine the formative angle of the truss. Additionally, the *m*, *n* ratio specifies the truss type and therefore we can compare the *m.n* ratio between the Kagome core truss and pseudo-Kagome truss, as described in Figure 11.

Also note that this structure is under a 20*KN* bending load (Figure 3).

To obtain the complete bending load, we closed the end (terminate) points of the sandwich panel to rotation in the three directions and the displacement of x, y directions.

Solution of the Problem by the Sub-problem Approximation Method: After an iterative solution and changes in the conditions of the problem, the results show that the number of iterations was larger than 50. The results are shown in the following:

A Solution by the First-order Method: With consideration for the mentioned cases, the results show that the iteration number must be larger than 70 for best convergence. The results from this method with four different lengths of sandwich panel are follows:

Application of Tension Load to Structure and Reduction of the Weight to the Structure by Sub-problem: Loading in the x-axis direction creates a high tension in the panels (Figure 6) so that the ns certainty coefficient is considered for high and low levels (surfaces) and with regard to constraint for reduction of the structure weight.

Constraints Applied to the Problem Are as Follows:

$$0.01 \le C_t \le 0.03 \tag{15}$$

$$0.01 \le C_s \le 0.03 \tag{16}$$

$$0.5 \le m \le 1 \tag{17}$$

$$2 \le n_s \le 6 \tag{18}$$

$$md_x \le 1mm \tag{19}$$

A Solution by the Sub-problem Approximation: In this method, the conditions and convergence are similar to those of the bending load, but the difference is that the iteration number is reduced to 55. The results are shown in the following:

Optimization of a Sandwich Panel with a Pseudo-Kagome Core Truss under the Influence of a Tension Load and Comparison to a Sandwich Panel with a Kagome Core Truss: Previously, we observed that a Kagome sandwich with relations 1 and 2 can be made. In an attempt to optimize the weight of this sandwich type, with regard to the applied constraints this Kagome sandwich acts as a Kagome truss and relations 3 and 25 are added to the constraints. Because there is no equality relation between the *m* and *n* variables, relation 23 is added to the problem as a restriction. In general, all of the constraints applied in this problem are as follows:

The solution process and the amount of applied load are similar to that of the sandwich panel with the Kagome truss. The results of this analysis and optimization are shown here:

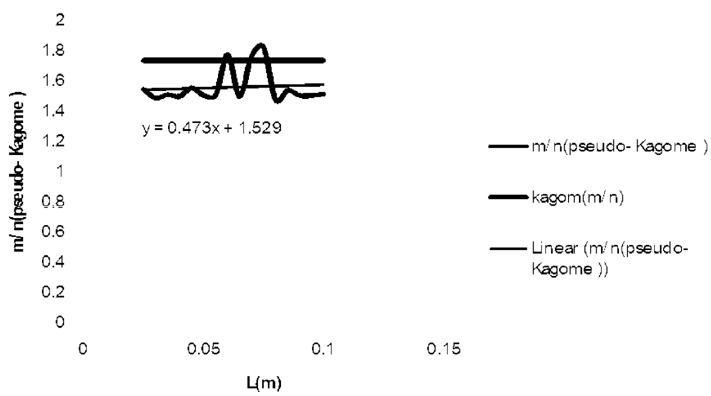

Fig. 11: Comparison of the *m, n* ratios between the sandwich panels with a Kagome truss and a pseudo-Kagome truss

RESULTS

- In comparing the effective variables and tension loading, we find that the Kagome truss causes the sandwich panel to stabilize. The pseudo-Kagome truss will have different issue.
- We observed that for many parameters, such as motion, there is no significant change resulting from increasing the length of the Kagome truss.
- A study of the C_s,C_t parameters shows that if the sandwich panel is under a bending load, to reduce the weight for different lengths of sandwich, it is better to change the truss diameter than the panel thickness. Note that this recommendation is reversed under a tension load.
- By considering Figure 11 for optimization of a sandwich panel with a pseudo-Kagome core truss, we find that all sandwich panels with pseudo-Kagome core trusses tend toward Kagome truss behavior in the optimization process. This means that the best situation occurs when we have $\frac{m}{n} = \sqrt{3}$.

Parameters Introduction

L Length of structure

E Yang module

PR Poisson ratio

dens Density

n_t Safety factor of truss

n_s Safety factor of shell

Md Displacement maximum

REFERENCES

1. Wicks, N. and J.W. Hutchinson, 2004. Performance of sandwich plates with truss cores, Mechanics of Materials, 36: 739-751.
2. Valizadeh, M., S. kiamahalleh, Abd S. Sata, Buniran and S.H. Sharif Zein, 2009. A Comparative Study on the Electrochemical Performance of Nickel Oxides and Manganese Oxides Filled in Multiwalled Carbon Nanotubes, World Appl. Sci. J., 6: 711-718.
3. Bahari, A. and G. Sadati, 2009. Magneto-Transport in the Single Walled Carbon Nanotube (SWNT), World Appl. Sci. J., 7: 8-11.
4. Wicks, N. and J.W. Hutchinson, 0000. Sandwich Plates Actuated by a Kagome Planar Truss, Division of Engineering and Applied Sciences, Harvard University Cambridge, MA 02138.
5. Dirk Mohr, 2005. Mechanism –based multi-surface plasticity model for ideal truss lattice materials, International J. Solid and Structural, 42: 3235-3260.
6. Liu, T., Z.C. Deng and T.J. Lu, 2006. Design optimization of truss-cored sandwiches with homogenization, International J. Solid and Structural, 43: 7891-7894.
7. Rabczuk, J., Y. Kim, E. Samaniego and T. Belytschko, 2004. Homogenization of sandwich structures, International journal for numerical methods in engineering, 1009-1027.
8. Gustafsson, R.N.G., 2000. Ultralight stainless steel sandwich materials-HSSA. In: H.R. Meyer-Piening and D. Zenkert, 5: 169-176.
9. Evan, A.G., J.W. Hutchinson, N.A. Fleck, M.F. Ashby and H.N.G. Wadley, 2001. The topological design of multifunctional cellular metals, Progress in Materials Science, 46: 309-327.

10. Wadley, H.N.G., N.A. Fleck and A.G. Evans, 2003. Fabrication and structural performance of periodic cellular metal sandwich structures, J. Computer Science and Technol., 63: 2331-2343.
11. Hutchinson, J.W. and Z. Xue, 2005. Metal sandwich plates optimized for pressure impulses, International J. Mechanical Sci., 47: 545-569.
12. Kim, T., C.Y. Zhao, T.J. Lu and H.P. Hudson, 2004. Convective heat dissipation with lattice-frame materials, Mechanics of Materials, 36: 1011-1020.
13. Tian, J., T. Kim, T.J. Lu, H.P. Hudoson, D.J. Sypeck and H.N.G. Wadley, 2004. The effect of topology upon fluid-flow and heat-transfer within cellular copper structures, International J. Heat and Mass Transfer, 47: 3171-3186.
14. Wicks, N. and J.W. Hutchinson, 2001. Optimal truss plates, International J. Solids and Structures, 38: 5165-5183.
15. Deshpande, V.S. and N.A. Fleck, 2001. Collapse of truss-core sandwich beams in 3-point bending, International J. Solids and Structures, 38: 6275-6305.
16. Wallach, J.C. and L.G. Gibson, 2001. Mechanical behavior of a three-dimensional truss material, International J. Solids and Structures, 38: 5165-5183.
17. Deshpande, V.S., N.A. Fleck and M.F. Ashby, 2001. Effective properties of octet-truss lattice material, J. the Mechanics and Physics of Solids, 49: 1747-1796.
18. Allen, H.G., 1969. Analysis and Design of structural Sandwich panels .Pergamon, Oxford.
19. Hutchinson, R.G., N. Wicks, A.G. Evans, N.A. Fleck and J.W. Hutchinson, 2003. Kagome plate structures for actuation, International J. Solid and Structural, 40: 6969-6980.
20. Wang, J., A.G. Evans, K. Dharmasena and H.N.G. Wadley, 2003. On the performance of truss panels with Kagome cores, International J. Solid and Structural, 40: 6981-6988.
21. David, J. Sypeck and Haydn N.G. Wadley, XXXX Cellular Metal truss Core Sandwich, Advanced Engineering Materials, 759-761.
22. ANSYS11, Inc., ANSYS User's Manual.