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AN AUTOMATED LIGHT WEIGHT DESIGN OF COMPOSITE LAMINATED BEAM

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المخلص العربى :

تم تقديم تصميم آلي بسيط وفعال لايجاد الوزن الخفيف للحزمة الرقائقية المركبة في هذا البحث. يعتمد التصميم الآلي على طريقة العناصر المحدودة في هذا البحث. تم استخدام برنامج لإجراء تحليل آلي لسلوك الحزمة لعدة سيناريوهات للتصميمات والوصول إلى الوزن الأكثر ملاءمة للحزمة المركبة التي تم تحليلها. في مشكلة التصميم ، يكون الهدف هو تقليل الوزن الإجمالي للحزمة ، ويتم اختيار سماكة الطبقات وزوايا اتجاه الألياف كمتغيرات تصميم. بالنسبة لشعاع مركب مصفح والتحقق من صحتها. أجريت عملية التصميم على مجموعة FEللأحمال الثابتة ، تم تطوير نماذج من تسلسلات التراص المحددة مسبقًا والتي شكلت عدة سيناريوهات للتصميمات ووصلت إلى الوزن الخفيف بالنسبة لها. تشمل القيود أقصى انحراف. يتم تنفيذ مثال لحزمة ناتئ ثابتة. تكشف النتائج التي تم الحصول عليها أن النهج المقترح فعال ويقدم حلولاً أفضل مقارنة بالوقت الذي يستغرقه الجهد الحسابي.

Abstract:

A simple and efficient automated design for the lightweight of the composite laminated beam is presented in this paper. The automated design is based on the finite element method (FEM). In the present research, FE software (ANSYS) is used to perform an automated analysis of the behavior of the beam for several scenarios of designs and reach the most suitable weight for the analyzed composite laminated beam. In the design problem, the objective aims to minimize the overall weight of the beam, and the thicknesses and fiber orientation angles of the layers are selected as design variables. For static loads, FE models of a laminated composite beam are developed and validated. The design process was conducted on a set of pre-defined stacking sequences that formed several scenarios of designs and reached a light weight for them. The constraints include the maximum deflection. A numerical example of a fixed cantilever beam is executed. The obtained results reveal that the proposed approach is efficient and provides better solutions compared to the time taken for computational effort.

KEYWORDS

Laminated Composite beams, light weight design, FEA, ANSYS.

1. INTRODUCTION

Owing to various remarkable mechanical properties like high stiffness-to-weight ratio, high strength-to-weight ratio, high corrosion resistance, great fatigue properties, and tractability in design, composite materials have been broadly employed in many engineering applications such as automotive industries, civil infrastructures, and aerospace structures, especially in civil engineering where structural components are required to be light and highly durable. The ability to locally adjust the material system to the mechanical environment makes it a challenge to develop optimal laminated composite structures. Laminated composite materials consist of ply lay-ups stacked, each ply made of fiber polymeric material oriented in a specific direction. Figure (1) shows a schematic of a laminated composite material. Laminated composites give the designer the ability to tailor the material according to the loading conditions.

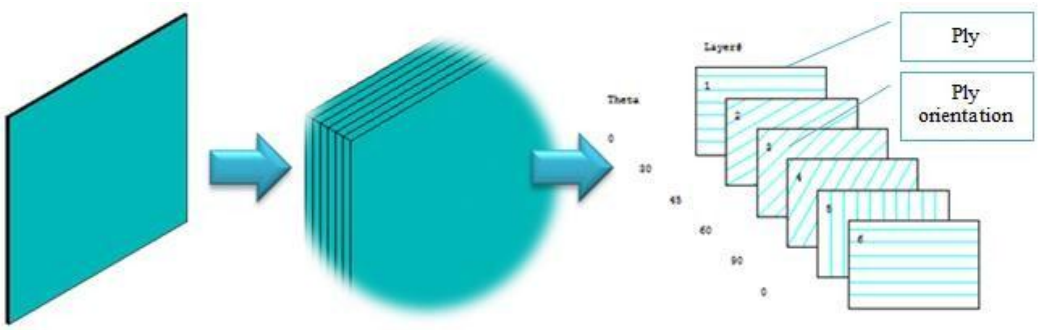

Figure (1): Laminated composite material

Although possessing various exceptional properties and flexibility in design, it is not easy to design a composite structure that can totally exploit these advantages because of its complex mechanical behaviors. Therefore, setting up and solving design problems of composite structures to find an optimal solution for different applications is really necessary and important. However, because of complicated mechanical behaviors, the optimal design procedures of laminated composite structures are usually more challenging than those associated with isotropic material structures. Recently, Finite Element Method (FEM) approaches for composite structures have recently gained popularity in the civil engineering sector. This is because commercial finite element analysis (FEA) tools are widely used and have the ability to accurately represent composite structures. The FEA software ANSYS provides significant capabilities for the structural analysis of composite structures. Lightweight design can be achieved through the application of FE-based optimization approaches.

In recent years, many works have been published for the analysis of the laminated composite structures and finding the optimal design. For example, the optimum design of laminated composite plates for maximizing the first natural frequency can be found in Refs. (Apalak et al., 2014, Sadr and Ghashochi Bargh 2012, Topal 2012, Apalak *et al*. 2013, Hwang *et al*. 2014), or those for maximizing the buckling load factor in Refs (Hajmohammad et al., 2013, Jing *et al*. 2015, Ho-Huu *et al*. 2016), or those for minimizing the weight in Refs. (Cho 2013, Liu et al., 2013, Fan *et al*. 2016, VoDuy *et al*. 2017b), and or those for maximizing strain energy in Ref. (Le-Anh *et al*. 2015).

The optimal design of laminated composite beams to minimize the free vibration frequency was found in Refs. (Roque *et al*. 2016, Tsiatas and Charalampakis 2017), or those to minimize the weight in Refs. (Liu 2015, 2016), or those to maximize the buckling load and minimize the weight at the same time in Ref. (Reguera and Cortínez 2016). So far, the literature review shows that most of the studies focus on the objectives of the fundamental frequency and buckling load factor; and the design variables are often only the fiber orientations that aim to enhance the stiffness of the structure. Nevertheless, the objective of minimizing the structural weight with design variables of thickness and fiber orientations at the same time to save material cost and apply to light structures is still somewhat limited.

2. MATERIALS AND METHODS

2.1. Problem definition

The problem is formulated with a minimum weight as the objective function, ply-up with various orientation angles and a different number of plies is used as design variables, and deflection values are used as response constraints. In Figure (2), a cantilever beam is used as an example to reach the minimum weight. The beam is constructed of graphite and epoxy and subjected to an axial load of 50 t, a length of L of 2 m, and cross-sectional dimensions of 15 x 30 cm. The mechanical properties of graphite and epoxy are given in Table (1). An FE model of the laminated beam is created and verified with the results of the composite beam in Ref. (H.A. Elghazaly et al., 2014). Figure (3) shows the deflection plot for the beam with laminate layup [0] 4s for the web and [15,-15] 4s for the flange in ANSYS software.

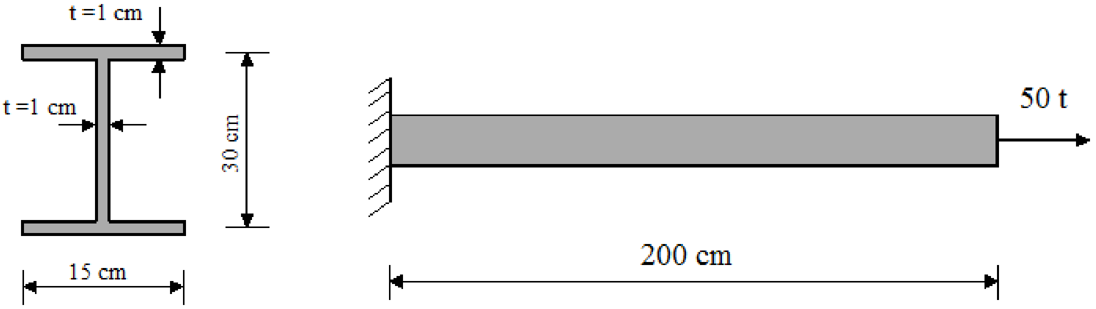

Figure (2): Structure geometry, boundary conditions and case loading.(H.A.Elghazaly et al., 2014)

Table (1): Orthotropic Properties of Unidirectional Graphite/Epoxy

Material	**E1 (GPa)**	**E2 (GPa)**	**G 12 (GPa)**	**Poisson ratio**
Graphite/Epoxy	1560	130	70	0.23

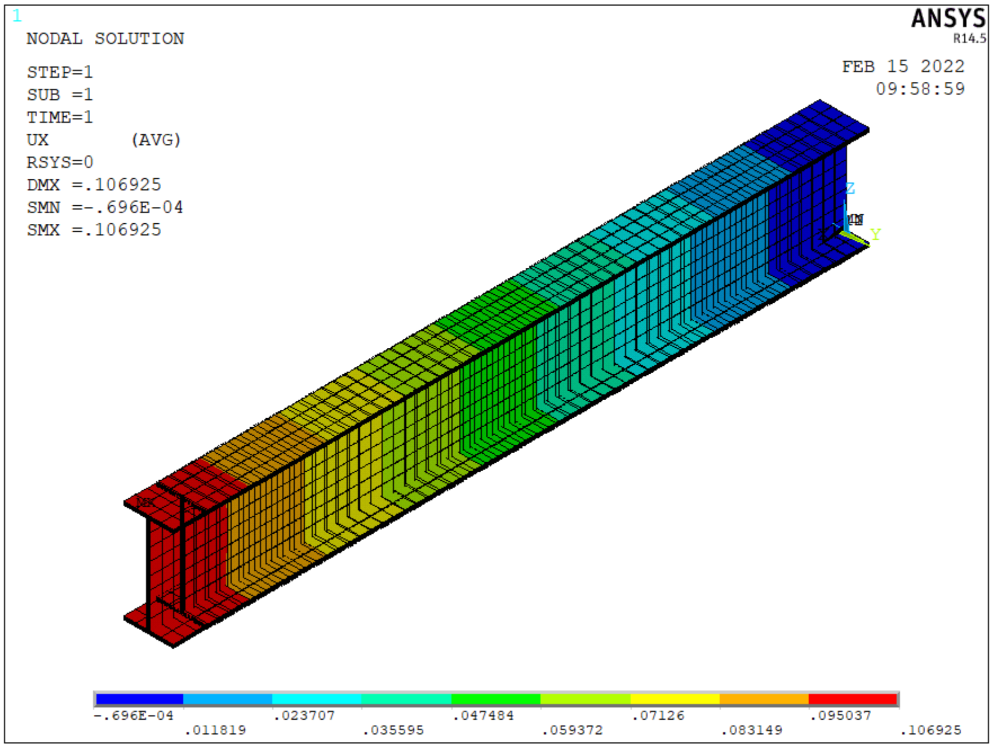

Figure (3): Deflection of Composite Beam with I-section and Laminate Sequence [0]4s for web and [15/−15]4s for flange.

3. RESULTS AND DISCUSSION

Finally, the trial-and-error design method proposed in this paper highlights a good solution regarding the minimizing of the weight of the composite laminated beam for all design scenarios and solves it using ANSYS before evaluating the weights for all scenarios. In this approach, most of the possible design scenarios are prepared with the limits of the values of the design variables, and then an ANSYS model is created for all these scenarios to be run in the ANSYS software to find the maximum deflection of them to check the safety of the designs. Then the weights of all accepted designs are calculated and arranged to find the minimum weight. The process of creating and inserting ANSYS txt files for all these designs (FEA preprocessing steps) in ANSYS is time-consuming, requires manual intervention, and is often error-prone. So, an automatic design code has been set up without user interaction. This code creates ANSYS txt files for all possible designs and then inserts them into the ANSYS program to analyze them.

Table (2): All succeed designs weights by try and error method

Design no	**weight (Kg)**	**Number of layers for flange**	**corresponding optimal lay-up of flange**	**Number of layers for web**	**corresponding optimal lay-up of web**	**Width of flange**	**Height of web**
1	**5.97**	4	[15/-15/15/-15]	4	[45/-45/-45/45]	12	24
..	..	..	..	..	..	..	..
171	6.09	4	[0/0/0/0]	4	[45/-45/-45/45]	12	24
..	..	…	..	..	..	..	..
340	**6.22**	4	[-45/45/45/-45]	4	[30/-30/-30/30]	13	24
678	**6.35**	4	[-45/45/45/-45]	4	[15/-15/-15/15]	13	25
116256	**13.61**	7	[15/-15/15/0/15/-15/15]	8	[30/-30/30/-30/-30/30/-30/30]	15	29
..	**..**	..	…	…	..	…	…
116425	**13.64**	8	[45/-45/45/-45/-45/5 -45/45]	7	[0/0/0/0/0/0/0]	15	29
..	**13.64**	..	..	..	..	..	..
116929	**13.75**	8	[0/0/0/0/0/0/0/0]	8	[-15/15/-15/15/15/-	14	28

					15/15/-15]		
..	**13.75**	..	..	..	..	..	..
117267	**13.87**	8	[-15/15/-15/15/15/ -15/15/-15]	7	[-15,/15/-15/0/-15/15/ -15]	15	30
..	**…**	..	…	..	…	..	..
117603	**14.01**	8	[-30/30/-30/30/30/ -30/30/-30]	8	[-15/15/-15/15/15/ -15/15/-15]	15	27
..	**..**	..	..	..	…	..	..
117939	**14.26**	8	[15/-15/15/-15 /-15/15/15/15]	8	[0/0/0/0/0/0/ 0/0]	14	30
..	**…**	..	…	..	…	…	..
118107	**14.51**	8	[-15/15/-15/15/15/ -15/15/-15]	8	[-30/30/-30/30/30/-30 /30/-30]	15	29
…	**..**	…	…	..	…	..	..
118275	**14.76**	8	[-60/60/-60/60/60/ -60/60/-60]	8	[15/-15/15/-15/-15/15/ -15/15]	15	30

After the total possible designs are automated analyzed in ANSYS software and checked on the deflection and the stresses, the succeed designs are listed in the table above. With the help of the weight function, all the weights of the successful designs are calculated and sorted from minimum to maximum weights. Such a way achieved high accuracy and saved a lot of computational time. In the above table, every value for the weight is achieved by a number of designs that contain different configurations of fiber angles for the flange and web and also have different section dimensions. The table (3) showed the different combinations of the variables that achieved the minimum weight.

Table (3): All succeed configurations for the optimal weight

Optimal design no	**weight**	**Number of layers for flange**	**corresponding optimal lay-up of flange**	**Number of layers for web**	**corresponding optimal lay-up of flange**	**Width of flange**	**Height of web**
1	**5.97**	**4**	**[0/0/0/0]**	**4**	**[0/0/0/0]**	**12**	**24**
2	**5.97**	**4**	**[-30/30/30/ -30]**	**4**	**[75/-75/-75/75]**	**12**	**24**
3	**5.97**	**4**	**[45/-45/-45/45]**	**4**	**[-30/30/30/-30]**	**12**	**24**
4	**5.97**	**4**	**[15/-15/-15/15]**	**4**	**[60/-60/-60/60]**	**12**	**24**
5	**5.97**	**4**	**[75/-75/-75/75]**	**4**	**[75/-75/-75/75]**	**12**	**24**
6	**5.97**	**4**	**[30/-30/-30/30]**	**4**	**[90/-90/-90/90]**	**12**	**24**
7	**5.97**	**4**	**[45/-45/-45/45]**	**4**	**[45/-45/-45/45]**	**12**	**24**
….	**5.97**	**….**	**…..**	**….**	**….**	**….**	**….**
170	**5.97**	**4**	**[-90/90/90/-90]**		**[-90/90/90/-90]**	**12**	**24**

4. CONCLUSIONS

The main conclusions of the current study are:

- A developed automated design for the laminated composite beam is carried out in an easy way.
- The devised procedure has resulted in many proposed values for the optimal weights. It also cuts the response time in half while avoiding manual errors. This procedure not only saves time but also overcomes the limitations of FE software for the analysis of composite materials.
- This approach provides good functionality and easy and simple steps with no or minimum experience.

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