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A MULTI-CRITERIA ANALYSIS OF LIGHT-WEIGHT SANDWICH STRUCTURE TECHNOLOGY

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Abstract: *The purpose of this paper is to analyse the main existing technologies for the manufacturing of light-weight sandwich structures and to evaluate their strengths and weaknesses using a multi-criteria analysis. Each of the existing technologies are presented and a series of relevant criteria are defined in order to evaluate which technology is better suited for the manufacture of a sandwich panel with low relative density, a low cost and in a short time. The study results into the conclusion that the research for new and more performing technologies should continue, in order to enhance the use of sandwich structures at the level of the advantages they may offer.*

Key words: *sandwich structure, periodic cellular cores, multi-criteria analysis.*

1. Introduction

Strong and lightweight materials and structures are a continuous quest for engineers in various fields. As in many applications, inspiration came from the natural world, where structures such as the bones of flying birds prove that light and strong structures can be created. Over many years of research, numerous methods have been developed that can create synthetic light-weight structures suited for industrial applications, of a wide variety of materials and geometries.

However, there are still limitations in using the sandwich structures, mainly due to the high cost of the current technologies [3]. As the ever need for balance between cost and performance grows continuously, more and more research is focused on improving the existing technology, or creating new means of developing advanced structures.

In order to develop new technologies and structures, one should analyse the strengths and weaknesses of existing ones, and find areas where significant improvement can be made.

2. Technologies for the Creation of Light-Weight Sandwich Structures

The technology used for the construction of periodic cellular structures varies according to the purpose of the structure that needs to be created. This is done by either changing the geometry of the cell structure, or the material used in its creation [2]. The main technologies used today for creating metallic sandwich structures, together with their advantages and disadvantages, are discussed further.

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2.1. Honey-comb cellular structures

a) Mechanical expansion

The procedure is based on the use of flat metal sheets glued between each other longitudinally and then mechanically expanded to form the honeycomb structure. The advantage of this technology is that it creates light-weight core structures with a relatively high bending stiffness. The technology also poses a series of disadvantages: the maximum thickness of the metal sheets that can be used is limited to around 0.03-0.05 mm, which reduces the core's resistance to compression and impact [4]. Also, the process is not continuous and is relatively time consuming (Figure 1).

b) Corrugation

This method begins with the use of metal sheets which pass through a press made out of a pair of corrugated rolls. The rolls have the same pattern as the desired shape of the cell. The corrugated metal sheets are then welded or glued together to form the honey-comb core, which is then cut at the desired length.

The technology has the same advantages as mechanical expansion, but at a higher cost, due to a longer time required to complete the process [4].

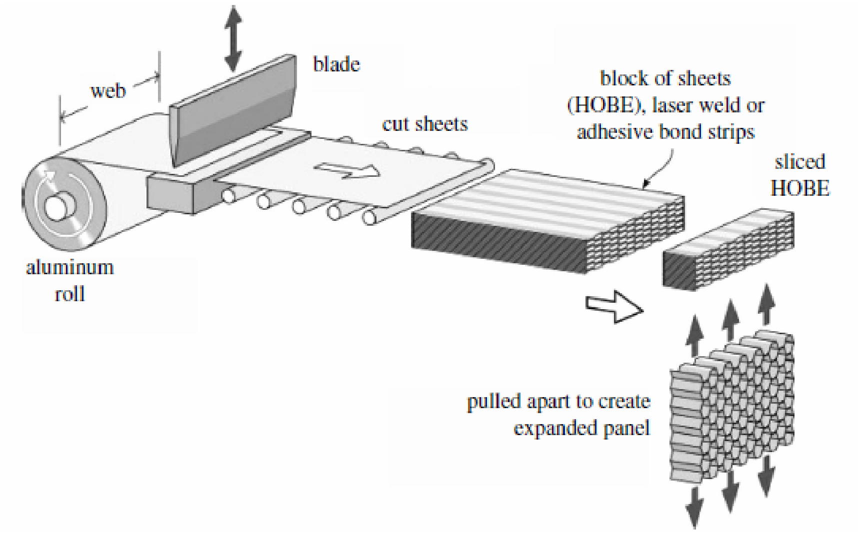


Fig. 1. *Manufacturing honey-comb structures through mechanical expansion* [6]

2.2. Prismatic Structures

a) Metal extrusion

The technology consists in a molten metal which is poured into a complex die and then extruded into the desired shape of the sandwich core.

This procedure, however, requires the use of complex tools, it has low energy efficiency, and the process takes a long time to finish [5], [6].

b) Corrugation

Similar to the use of corrugation in the manufacturing of honey-comb structures (Figure 2), corrugation can be used to obtain prismatic structures from metal sheets (Figure 3). This procedure is fast and simple, and can create corrugations with different shapes. The end product has a relatively low density. Prismatic structures obtained through corrugation have relatively lower compression stiffness, though [4].

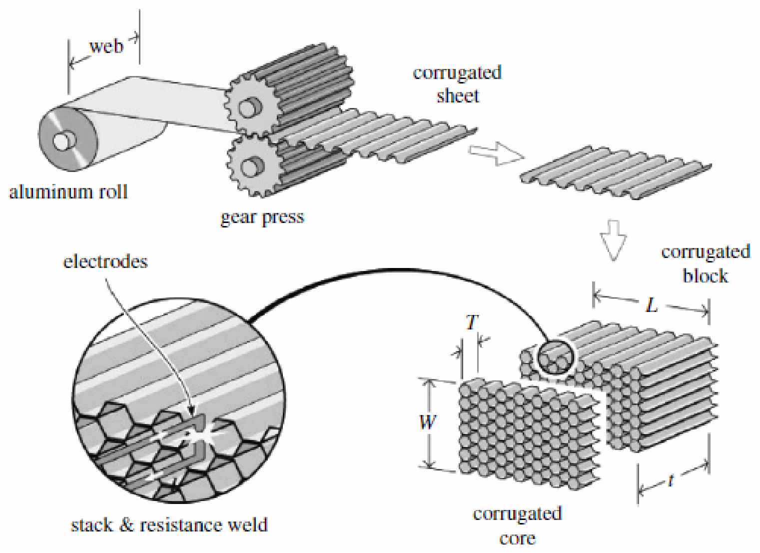
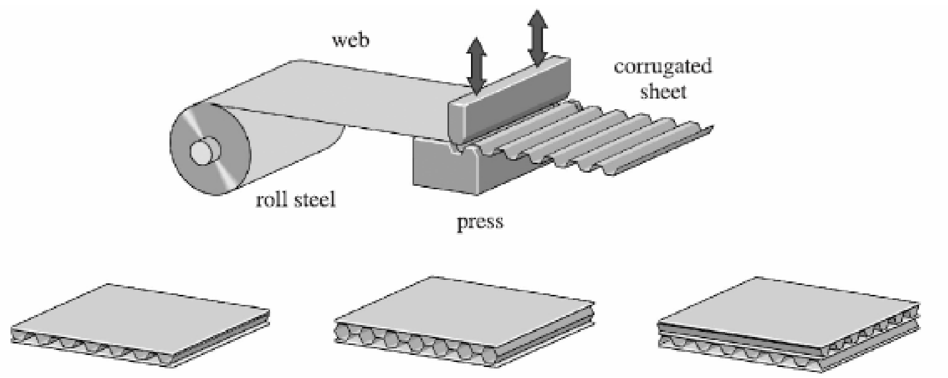


Fig. 2. *Manufacturing honey-comb structures through corrugation* [6]



a) single layer corrugation b) double layer corrugation c) cross-ply double layer corrugation

Fig. 3. *Manufacturing process of prismatic cellular structures through corrugation* [6]

2.3. Lattice Truss structures

a) Perforated metal sheet forming

The method uses metal sheets as input into process. First, the metal sheet is cut into the desired geometry, either by laser cutting or perforation. Then, the perforated sheet is bended in a die, resulting in the lattice core structure (Figure 4). This procedure creates a low-weight cellular structure, with relatively low density. The main disadvantage, however, is the large quantity of waste material, which increases the cost, and the relative complexity of the process [4].

b) Slitting and expanding

In this case, a metal sheet is slit and then expanded into a matrix with the required geometry. It is then further flattened using a rolling mill and then folded at a specific angle using a press [6]. The method creates little to no waste; therefore it assures a much better efficiency in the material usage.

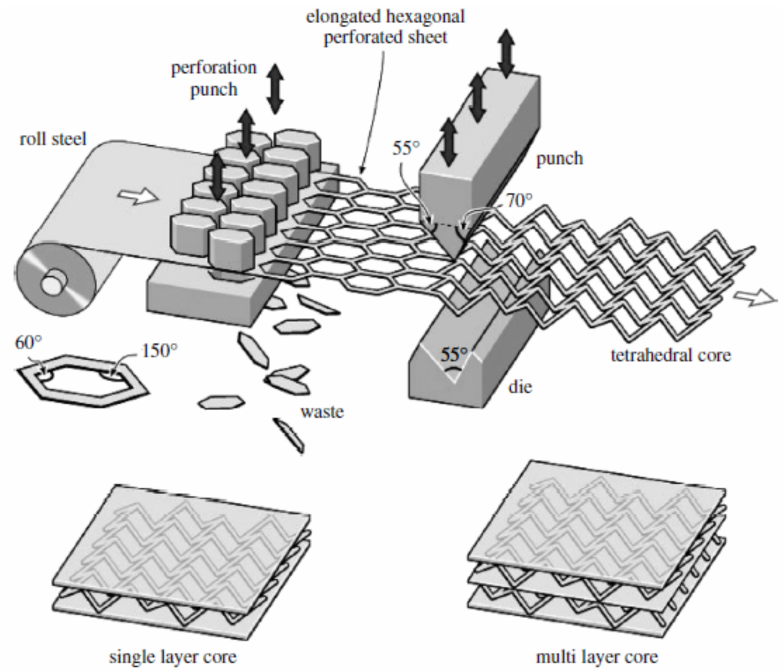


Fig. 4. *Perforation and bending metal sheets for the manufacture of lattice truss structures* [6]

3. Multi-criteria Analysis

A multi-criteria analysis is an objective way of comparing various items or processes based on a number of pre-defined criteria. The FRISCO method was used for this multi-criteria analysis. It requires the selection of criteria that are relevant to the objective of the analysis, ordering the criteria based on their importance in the analysis, and then giving each item or process a grade based on how well it fulfils each criteria. In the end, a formula is applied to compile all the data and sort the items [1].

3.1. Defining the criteria

The objective of the paper is to compare the main existing light-weight sandwich structures technologies and to try to identify which one of them is the most suited for the quick and low-cost manufacturing of low-weight, high-resistance sandwich panels. As such, the following criteria were considered to be relevant for obtaining this goal:

- simplicity of the process (criterion A);
- the cost of the process (criterion B);
- duration of the process (criterion C);
- low relative density of the sandwich structure obtained (criterion D).

3.2. Ordering the criteria

All criteria are compared to each other in order to establish the order of their importance. In Table 1, a number was given at each intersection of two criteria: 1 means the criteria on the horizontal is more important; ½ means they are equally important and 0 means the criteria on the vertical column is more important.

After the criteria are sorted, a weight coefficient is computed, using Eq. (1):

$$\gamma_i = \frac{p + \Delta p + m + 0.5}{-\Delta p' + \frac{N_{crt}}{2}}, \tag{1}$$

Ordering the criteria Table 1

	A	B	C	D	Points	Rank	γ_i
A	½	0	1	0	1.5	3	1
B	1	½	½	½	2.5	2	2.6
C	0	½	½	0	1	4	0.375
D	1	½	1	½	3	1	4.25

where: p - is the total number of points obtained by an element on a line; Δp - is the difference between the number of points of an element and the number of points of the element with the lowest number of points; m - is the number of elements with lower number of points than a given element; N_{crt} - is the total number of criteria; $\Delta p'$ - is the difference between the number of points of an element and the number of points of the element with the highest number of points.

3.3. Grading the technologies

Considering the advantages and disadvantages of each technology, and the way in which each one fulfils the selected criteria, grades (N_i) were awarded for each of the technologies, Table 2. Grades are given from 1 to 10, where 10 means the technology perfectly fulfils that criterion.

Grades awarded to each technology Table 2

	Tec.1	**Tec.2**	**Tec.3**	**Tec.4**	**Tec.5**	**Tec.6**
Criteria	N_i	N_i	N_i	N_i	N_i	N_i
A	7	6	4	8	6	6
B	8	5	4	9	5	7
C	5	4	4	8	7	6
D	6	6	7	7	9	9

where:

Tec.1 = mechanical expansion for honey-comb structures;

Tec.2 = corrugation for honey-comb structures;

Tec.3 = metal extrusion for prismatic structures;

Tec.4 = corrugation for prismatic structures;

Tec.5 = perforated metal sheet forming for lattice truss structures;

Tec.6 = slitting and expansion for lattice truss structures.

3.4. The final classification of technologies

In order to obtain a final classification of the analysed technologies, the coefficients obtained at step 3.2 are multiplied to the grades given at step 3.3. This gives the results presented in Table 3.

Final classification of technologies Table 3

		Tec.1	**Tec.2**	**Tec.3**	**Tec.4**	**Tec.5**	**Tec.6**
Criteria	γ_i	$N_i \times \gamma_i$	$N_i \times \gamma_i$	$N_i \times \gamma_i$	$N_i \times \gamma_i$	$N_i \times \gamma_i$	$N_i \times \gamma_i$
A	1	7	6	4	8	6	6
B	2.6	20.8	13	10.4	23.4	13	18.2
C	0.375	1.875	1.5	1.5	3	2.625	2.25
D	4.25	25.5	25.5	29.75	29.75	38.25	38.25
Total		**55.175**	**46**	**45.65**	**64.15**	**59.875**	**64.7**

4. Results and Conclusions

The results of the multi-criteria analysis are presented in Table 3 as coefficients obtained by multiplying the grades of each technology with the ranking coefficient (Table 1) of each criterion. A higher number indicates a technology that is better suited for fulfilling the selected set of criteria. No technology obtained a maximum coefficient.

According to the multi-criteria analysis, the technologies that are best suited for the manufacturing of light-weight sandwich structures seem to be the slitting and expansion of lattice truss structures and the corrugation of prismatic structures. However, they also have their strengths and weaknesses. While the corrugation of metal sheets is quick, simple and efficient, the creation of lattice truss structures through slitting and expansion creates structures with a lower relative density.

Therefore, the search for even better technologies that are faster, cheaper and deliver better results should continue. One possible direction is the analysis and development of new technologies, focusing on improving the mechanical characteristics of end products through the way they are manufactured. As physical and mechanical properties of cellular cores are highly dependent on material characteristics and cell geometry, consideration of these aspects should be the key focus in developing new technologies, together with the criteria already discussed in this paper.

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