Honeycomb Core Materials: New Concepts for Continuous Production

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CONTINUOUSLY PRODUCED HONEYCOMB CORES

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ABSTRACT

Today mechanical requirements and weight targets demand a lightweight sandwich design in many non-aerospace application areas. The large production cost of honeycomb core materials often prevents their use in low cost sandwich constructions. Other sandwich core materials however provide lower mechanical properties. The currently employed concepts for the production of honeycomb cores are reviewed to evaluate their potential for a fully automated production with high productivity.

Two new cost efficient honeycomb materials and their continuous production processes, developed at the K.U.Leuven, are presented. These materials and production methods enable an automated in-line production of paper (TorHex) and thermoplastic film (ThermHex) based honeycombs. The continuous in-line lamination and further processing to sandwich parts with fiber reinforced thermoplastic skins shows large potential for cost sensitive applications.

KEY WORDS: Core Materials, Manufacturing/Fabrication/Processing, Cost/Economics

1. INTRODUCTION

Two groups of sandwich core materials can be distinguished, the homogeneous and the structured cores. Figure 1 shows the core materials grouped by the type of skin support.

![Figure 1: Homogeneous and structured core materials](image-url)
Homogeneous core materials, especially polyurethane (PU) foams, are widely used in low cost applications (e.g. in building and automotive industry). Recently, polypropylene foams (EPP) have become a better recyclable alternative to PU foams. However, they are more expensive and have lower mechanical properties than PU foams.

From the structured core material types, the corrugated core in cardboard is well known for its packaging applications, but it has also been used in automotive headliners and, made from metal sheets, in building applications.

Honeycomb core materials are used in aerospace since many decades as the preferred core material for buckling and bending sensitive sandwich panels and structures. They provide very high mechanical properties at a low density. Unlike corrugated core types, which have cell openings in the in-plane direction, honeycomb core types have only openings in the out-of-plane direction and provide a bi-directional support for the skins (figure 1). Honeycomb sandwich materials can offer weight and cost savings thanks to their excellent performance per weight, but those savings are threatened by the high costs of the honeycomb core production today. The demands for low costs and high production capacities require automated and continuous processes.

2. HONEYCOMB CORE PRODUCTION TODAY

2.1. Paper honeycomb production today  The main reason for the high costs of traditional expanded honeycomb cores is the batch like production process. Honeycomb core production today is most often labor intensive, discontinuous and not in-line. Most honeycombs are adhesive bonded expanded cores [1]. Low cost paper honeycombs can be produced by the traditional expansion process, shown in figure 2. First, glue lines are printed on flat sheets. Second, a stack of many sheets is made and the glue is cured. In the third step, slices are cut from this block. Finally, the sheets are pulled apart, thus expanding the stack into a hexagonal honeycomb core. The residual stresses in paper honeycombs have to be relaxed after expansion by controlled application of moisture and heat. For low cost applications, the degree of automation has exceeded the level reached in aerospace honeycomb production. However, cell size and core height of these honeycombs made out of unimpregnated low cost papers are usually above 10 mm, because the conventional honeycomb production becomes more time consuming at lower cell sizes. Those low cost paper honeycombs are mainly used for door filling and inner packaging protection elements. In the automotive industry they have been used as side impact energy absorption elements in doors.

A second production process for conventional honeycombs is the corrugation process. This process is not so often used since it is more expensive. This is due to the required handling operations (stacking and bonding of the corrugated sheets) and the more difficult cutting from the block. However, if inexpensive corrugated cardboard sheets are used, a somewhat heavier but more cost efficient honeycomb core can be produced by this process. With standard corrugated cardboard sheets cell sizes of 5 mm and below can be realized. The cell size is
important for the surface quality, because a large cell size results, even with rather thick skins, frequently in a print through of the honeycomb pattern. Thus, nowadays paper honeycombs for automotive applications are commonly produced by this manual process via a block of stacked corrugated cardboard sheets, shown in figure 3. Sandwich panels with this paper honeycomb core and glass fiber or natural fiber mat reinforced skins are used for sun roof panels, hard tops, parcel shelves, spare wheel covers and luggage floor assemblies [2].

![Figure 3: Manual production of honeycomb cores from corrugated cardboard](image)

The low amount of raw material required for the production of honeycomb cores can result in a very cost efficient sandwich material for automotive parts if a suitable raw material type (i.e. paper or polypropylene films) and an efficient production method are combined. However, the rather high costs of the production processes limit the use of honeycombs for many applications in the automotive and furniture industry.

2.2. Thermoplastic honeycomb production today

Nowadays, thermoplastic honeycomb cores are produced via several processes. Thermoplastic honeycomb cores have also found recently an increasing market in low cost applications. One of the most common processes is the production via a block of extruded tubes, shown in figure 4. After the tubes are extruded, they are subsequently stacked and welded together. Next to the standard polypropylene (PP), polycarbonate (PC) and polyetherimide (PEI) versions are also available [3]. The tubular honeycomb was one of the first commercial thermoplastic honeycombs. Most applications have been non-structural. Nevertheless, tubular honeycomb cores as well as other out-of-plane extruded honeycombs have been used in a variety of structural applications. The mechanical properties depend largely on the core density and the tube diameter.

![Figure 4: Tubular extruded honeycombs (e.g. from polypropylene)](image)

The companies Tubus Bauer, Plascore, Induplast and Newcourt are producers of tubular honeycombs. Recently these cores have been used as core material in automotive spare wheel covers in combination with glass fiber reinforced polypropylene skins.

A second type of out-of-plane extruded cores are the hexagonal honeycombs. Figure 5 shows the scheme of the out-of-plane extrusion process used by the companies Induplast/Nidacore and the resulting core [4]. The extruded blocks are long, but the in-plane dimensions of the core are only 150 mm x 150 mm. Therefore, multiple blocks are welded together.
Subsequently the cores are cut to the appropriate thickness by a saw or by a hot steel wire.

**Figure 5: Out-of-plane extruded hexagonal honeycomb from polypropylene**

Both out-of-plane extrusion processes require the production of blocks followed by the cutting from blocks, leading to a rather low degree of automation and relatively high costs. Development activities aimed to reduce the production costs especially of thermoplastic honeycombs have been intensified during the last five years. The company Hexcel developed a complex process for the production of polypropylene and polyethylene terephthalate (PET) honeycombs, the so-called Cecore [1]. Each honeycomb cell was created separately by contact welding with moving tools, as can be seen in figure 6 [5]. Based on this development, Hexcel has introduced a thermoplastic honeycomb from non-woven fabrics, called HexWeb EM, on the market in 2001.

**Figure 6: Continuously corrugated thermoplastic honeycombs**

Machinery for the automation and adaptation of the traditional expansion process for thermoplastic material has been built, recently by Versacore [6]. Figure 7 shows the expansion of a stack of welded strips to a honeycomb core. The Versacore/Thermostack machinery has been introduced on the market in 2002.

**Figure 7: Continuously expanded thermoplastic honeycombs**

Both processes enable the continuous automated production of thermoplastic core and should thus lead to lower cost. Although, when producing honeycombs with a small cell size, the production speed is limited, since the node bond between the strips has to be made by the welding tools step by step. Besides those developments several patents on new core production process concepts have been filed during the last years. Recently, the company Sodesa developed a process to continuously extrude honeycomb cores in-plane.
A sophisticated mechanism directs the melt, which has the form of many narrow extruded rectangular strips, into a wavy pattern so that the cells are formed. Figure 8 shows a drawing of the production process and the resulting product, called Hexacore [7].

![Figure 8: In-plane extruded honeycombs from polypropylene](image)

An elegant technique to produce a thermoplastic honeycomb in a continuous film “weaving” process has recently been developed by the company Wacotech. This process and the product, which has been introduced under the tradename Wavecore by Tubus Bauer is shown in figure 9. It is a honeycomb that is “woven” from a large number of films. Oscillating tools are used to move the films sideways every second row. Hence square cells are created by three walls of one film and by a fourth wall from the film beside it. The walls are welded together at small overlaps in the corners. The production speed is limited by the motion of the tool which needs to be moved out of the cells vertically [8].

![Figure 9: Woven film honeycombs (e.g. from polypropylene)](image)

The core materials depicted in figure 8 and 9 allow a more automated production, but the production speeds do not yet permit the widespread introduction into packaging markets. Moreover these materials have a less optimal internal structure.

### 2.3. Continuous production processes from packaging industry

The packaging industry has a very high demand on the cost effectiveness of production processes. The efficient production technology of the corrugated cardboard packaging industry leads to very low costs. However, the corrugated core leads to rather low mechanical properties.

![Figure 10: Continuous in-line production of corrugated panels](image)
Figure 10 shows, apart from a single flute corrugated cardboard an aluminium panel that is produced by the company Metawell with a similar process.

The packaging industry employs besides corrugated cardboard also thermoplastic sandwich materials, e.g. extruded twin sheet panels [9] or sandwich panels with a thermoformed cup-shaped core layer [10], both from polypropylene. Those materials are produced by continuous in-line processes, but have generally lower mechanical properties compared to a sandwich material having a hexagonal honeycomb core. However, due to their low price they are also used in several automotive applications.

For the production of the thermoplastic cup-shaped panels the air bubble film production concept from the packaging industry has been employed (figure 11). Those sandwich panels consist of three sheets. The middle sheet is rotationally vacuum thermoformed to a cup shape. Two outer layers are subsequently welded on these cups. This core type is commercialised in Japan by the company Plapearl and in Europe by the company Conpearl, mainly for reusable packaging boxes.

![Continuous in-line production of cup-shaped panels](image)

**Figure 11: Continuous in-line production of cup-shaped panels**

Similar to the corrugated cardboard process, a sandwich core is produced at very low costs from a single material sheet by successive in-line operations. However, those thermoplastic panels are not symmetrical and thus vulnerable to thermal warping. Moreover, the overall mechanical properties are rather modest, because the wall thickness is drastically reduced due to the elongation at the cup tops and, like in corrugated cores, the core layer is not vertical.

### 3. FOLDED HONEYCOMB SANDWICH CORES

The increasing demand for low cost sandwich core materials and their advantageous mechanical properties have stimulated research activities at the K.U.Leuven to reduce the production costs of honeycomb cores, produced from paper as well as from thermoplastic films. In the framework of the EUREKA research projects ThermHex and TorHex, cost efficient honeycomb materials and their continuous production processes have been developed. For the production of those patented, so called “folded” honeycombs, production technology and processes of the packaging industry are used [11, 12]. The feasibility of two core versions has been proven: the ThermHex thermoplastic honeycomb and the TorHex paper honeycomb. These folded honeycombs are produced from one thermoplastic sheet or one corrugated cardboard sheet respectively, by successive in-line operations. The development of cost efficient production machinery was driven by the request for large production capacities for packaging applications like reusable thermoplastic boxes and recyclable cardboard boxes and lead to very cost efficient core materials for automotive and other applications.
3.1 TorHex  The TorHex paper honeycomb process uses the corrugated cardboard production technology to a maximum extent. The principal production concept is shown in figure 12. After the production of a single flute corrugated cardboard, the TorHex honeycomb process requires a lengthwise slitting step and a folding/turning step. Sheets of corrugated cardboard can hereby be processed to honeycomb core sheets at a very low cost.

![Figure 12: The TorHex paper honeycomb process](Image)

Figure 13 shows a schematic view of a TorHex panel production line, which has been realized in lab-scale.

![Figure 13: Production line for TorHex honeycomb panels](Image)

It is expected that this process will not be much more expensive than the additional corrugation and gluing steps for a double flute corrugated cardboard. A large potential market in the packaging industry enables to develop efficient production equipment. A possible production speed of more than 100 m/min will lead to a high productivity and minimal costs.

3.2 ThermHex  The ThermHex core, the thermoplastic folded honeycomb, has hexagonal cells and closed skin strips, which allow a fast and reliable bonding of the skins onto the core without additional glue. The ThermHex core material can be produced continuously in one production line. All the production steps can be done successively by rotational operations, which should make high production speeds possible. Starting from one endless thermoplastic film, the production steps are:

1. Forming of half-hexagonal shapes by deep drawing or by vacuum thermoforming
2. Folding of the half-hexagonal web to build the honeycomb core
3. Internal bonding of the honeycomb core by thermal fusion
4. Lamination of thermoplastic skins onto the honeycomb core

This concept has proven feasibility for different types of thermoplastic materials. Thermoplastic folded honeycomb samples have been produced from different films (mainly from PP and PET).

![Figure 14: The ThermHex thermoplastic honeycomb process](image)

Figure 14 shows a schematic view of a production line with rotational vacuum thermoforming. The possibility to thermoform the shape with vacuum enables to use a rotational process. This rotational thermoforming process is meant to be applied for low cost thermoplastic honeycombs from one PP film, and for production in large quantities. A similar rotational thermoforming process, with speeds up to 50 m/min, is used for the production of air bubble film. The folding operation is performed by pushing the half-hexagonal rows into a channel. The web folds easily due to the alternating upper and lower position of the skin strip connections.

![Figure 15: Production line for ThermHex honeycomb panels](image)

The internal bonding of the core by thermal fusion in a laminator can be enhanced by the use of a lower melting coating on the thermoplastic film. To produce a sandwich panel, skins can be laminated additionally in-line onto the core.

4. POTENTIAL APPLICATIONS

The main difference between the TorHex and the ThermHex production process is the direction of take up during the folding operation. In the TorHex process, a larger core height
requires a larger cell size or a contraction of the production width. Thus, an optimal efficiency of the TorHex process is anticipated at core heights below 6 to 8 mm, while for the ThermHex process the most efficient and competitive core heights are expected to be between 6 mm and about 14 mm. Although height variations are possible, a cost efficient continuous production is in general optimal with a limitation of the height variety. The advantage of a PP honeycomb is clearly the moisture resistance, which allows also application in body panels or aerodynamic underbody panels. Paper honeycombs, on the other hand, have a higher thermal resistance. Automotive applications are, besides packaging applications, the most promising market for continuously produced low cost honeycomb sandwich materials, because the market is very price sensitive. In figure 16 some examples of suitable material combinations for ThermHex and TorHex honeycomb panels are shown.

![Some possible ThermHex and TorHex material combinations](image)

**Figure 16: Some possible ThermHex and TorHex material combinations**

For the production of thermoplastic sandwich parts, two main concepts can be distinguished. The core and the skin materials can be batch wise assembled in the mould or continuously in-line with the core production. Sandwich parts with TorHex or ThermHex honeycomb cores can be produced with this process. However, continuously produced honeycombs permit further cost reductions by an in-line pre-assembly by lamination of the skins onto the core. During the forming process the skins slip on the core layer or the core can be compressed locally to allow a complex curved part. In particular the high thermal stability of the TorHex core allows the pre-heating of the complete sandwich after an in-line pre-assembly of the flat panel.

5. CONCLUSION

The basic reason to use honeycomb sandwich construction is that it provides the highest strength to weight and stiffness to weight ratios. However, the automotive industry requests additionally to a performance per weight also a performance per cost advantage. The production of environment friendly paper and polypropylene honeycomb cores has been gradually optimised towards automated processes in the last decade. The potential in many application areas, driven by to the increasing emphasis on weight reduction, is mainly determined by the production cost. The folded honeycomb materials and production concepts offer a cost efficient automated in-line production of polypropylene and paper based honeycombs. They have the potential to reduce the production costs for honeycomb core sandwich parts, so that the raw material weight savings translate directly into cost savings. Those new cost efficient and recyclable materials aim at the reduction of production costs and at the exploitation of the economical advantages of sandwich constructions. Additional research is necessary on the further processing of thermoplastic and paper based honeycomb sandwich materials to complex and low cost parts. Furthermore, design guidelines for the development of optimal honeycomb
cores and parts which fulfill the mechanical performance and cost requirements need to be established.

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REFERENCES

3. Court, C., Castorina, L., Continuous process for forming structure suitable for use as a core member, Newcourt Inc., WO 99/41061 International patent publication, 1999
5. Fell, B., Continuous process for the preparation of honeycomb structural material and apparatus suitable for use therein, Hexcel Corporation, WO 97/16304 International patent publication, 1997
6. Hering, G.K., Method and device for joining sections of a thermoplastic continuous web material, Versacore Ind. Corp., WO 01/51273 International patent publication, 2001
10. Con-Pearl, Con-Pearl friedola Gebr. Holzapfel GmbH, Product information, Geismar Thüringen, 2000