FOLDED HONEYCOMBS
Fast and continuous production of the core and a reliable core-skin bond

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SUMMARY: This paper presents a new honeycomb material production concept developed and patented by the K.U.Leuven. The folded honeycombs join the excellent honeycomb properties with the very efficient production technology of corrugated cardboard. Inner structure, shear and flat-wise compression properties of folded honeycombs are similar to conventional expanded honeycombs. However, their production concept is derived from the corrugated cardboard production. The production from a single continuous sheet allows for a continuous process, resulting in high speed and low cost production of this new sandwich core material for packaging and structural applications. Furthermore, the new honeycomb core exhibits a different concept for the critical core-skin bond. The bonding of the skins can be fast and inexpensive due to a larger contact area with the skins, resulting in a more reliable bond, improved peel strength and enhanced after impact performance.

KEYWORDS: honeycomb, folded honeycomb, continuous production, core-skin bond, debonding, sandwich core

INTRODUCTION

The interest in sandwich materials is permanently growing and expanding to additional industries. Traditionally mainly two production principles have been used to manufacture honeycomb sandwich core materials. Both, the expansion process and the corrugation process are usually labour intensive batch processes. Large industrial sectors like aeronautical and automotive industries and civil construction stimulated various research activities to reduce the production costs of core materials and panels. Several more automated versions of the main production principles have been developed during the last years, especially for thermoplastic honeycombs [1,2] but also for aluminium honeycombs [3,4]. Furthermore, new sandwich material concepts like in-situ foamed panels and woven sandwich fabrics [5] have been developed. However, they have generally lower mechanical properties than the aerospace honeycomb sandwich cores and are still too expensive for many applications. In spite of increasing effort, current production of conventional honeycombs is usually a labour intensive batch production process. Due to the expensive core and sandwich production process, honeycomb cores are still used to more than 50% in aerospace applications.
On the other hand, low cost paper honeycombs are widely used in the packaging industry for inner packaging and protection elements. These honeycombs are produced by machines using the conventional expansion process. The degree of automation in the production of paper

honeycombs for packaging applications has exceeded the level reached in the aluminium or Nomex® honeycomb production, since larger production quantities allows a bigger investment in machinery. However, the produced cell sizes are usually above 10 mm and the thickness tolerances, as well as the quality of the cell geometry do not meet the high demands for structural honeycombs. The expansion process of honeycomb production becomes more and more difficult to automate for smaller cell sizes. Furthermore, the difficult core-skin bond has retained the corrugated cardboard producers from recognising the honeycomb structure as a possible alternative to the corrugated core.

THE FOLDED HONEYCOMB CONCEPT

The folded honeycomb material and its production concept has been developed and patented by the K.U.Leuven. In Fig. 1 the folded honeycomb concept is presented as the synthesis of the honeycomb structure and the corrugated cardboard production principle. The inner structure of folded honeycombs is similar to conventional expanded honeycombs thus yielding excellent shear and flat-wise compression properties. Nevertheless, their production concept and their core-skin bonding concept are derived from the very efficient mass sandwich production technology of corrugated cardboard.

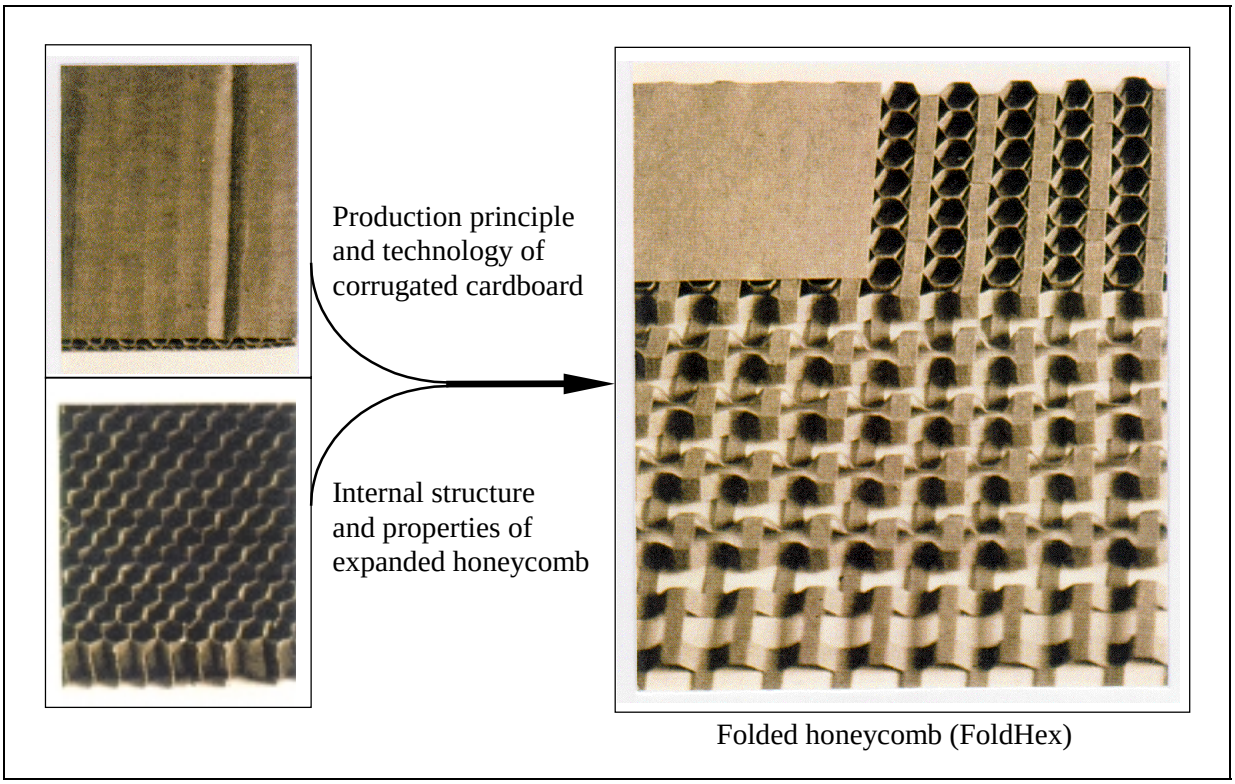

Fig. 1: The folded honeycomb concept.

A variety of core structures, including partially closed honeycombs and honeycombs with completely closed cells can be obtained from one single sheet [6].

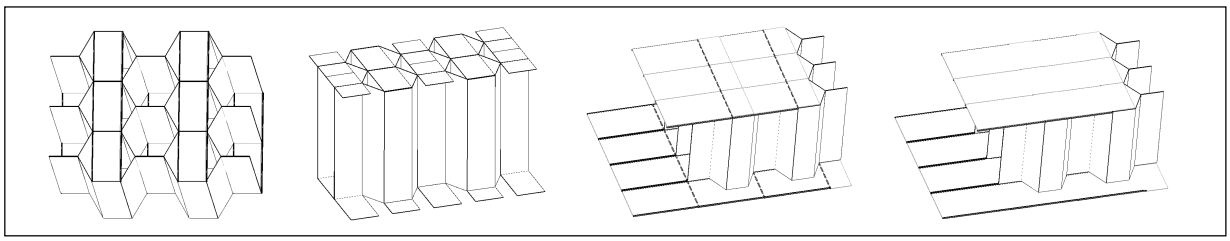

Fig. 2: Partially closed and completely closed folded honeycombs.

All folded honeycombs versions of Fig. 2 are produced, without an expansion process step, by corrugation prior to folding of the half cell webs to a honeycomb.

CONTINUOUS CORE PRODUCTION

The new honeycomb core material is produced from a single continuous sheet by successive in-line cutting, folding and glueing, as shown in Fig. 3. This allows for a continuous production process, resulting in high speed and low cost production of the core. Furthermore, this honeycomb production line can be extended to a continuous sandwich material production by adding a skin bonding process step.

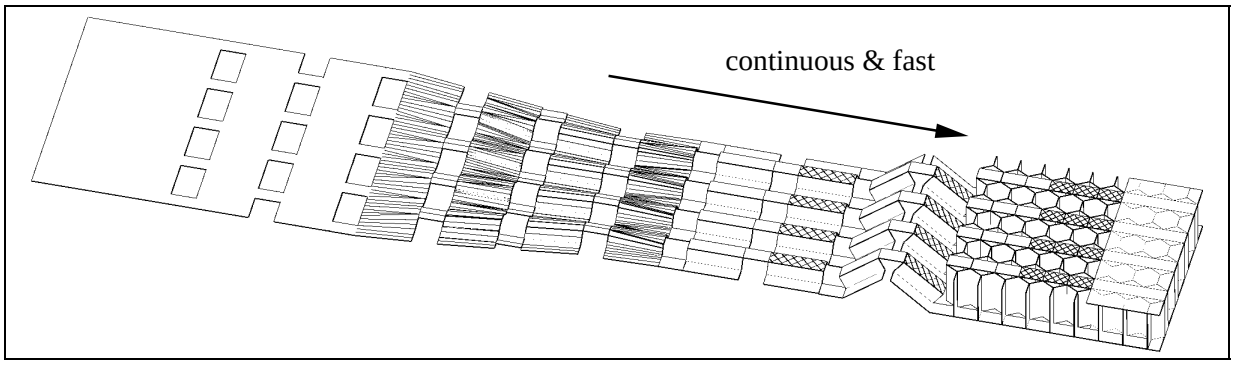

Fig. 3: Continuous length wise production process.

The in-line production from a single continuous sheet reduces the alignment and handling effort prior bonding of the cell walls. The folding together of the half cell webs by rotation towards each other may be done in a crosswise production process alternatively, see Fig. 4. The cross-wise corrugation is easier to perform, but the height of the honeycomb cells is then formed from the width of the sheet and thus limited. Corrugated cardboard is produced with a similar process, allowing speeds up to 400 m/min and a production width of 2.5 m. However, for structural folded honeycombs the length wise production process is preferable.

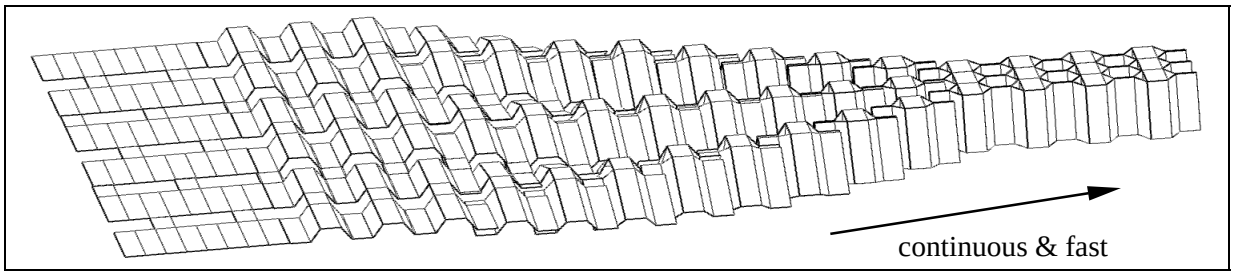

Fig. 4: Alternative cross wise production process.

Two length wise production concepts for fully closed folded honeycombs are shown in Fig. 5.

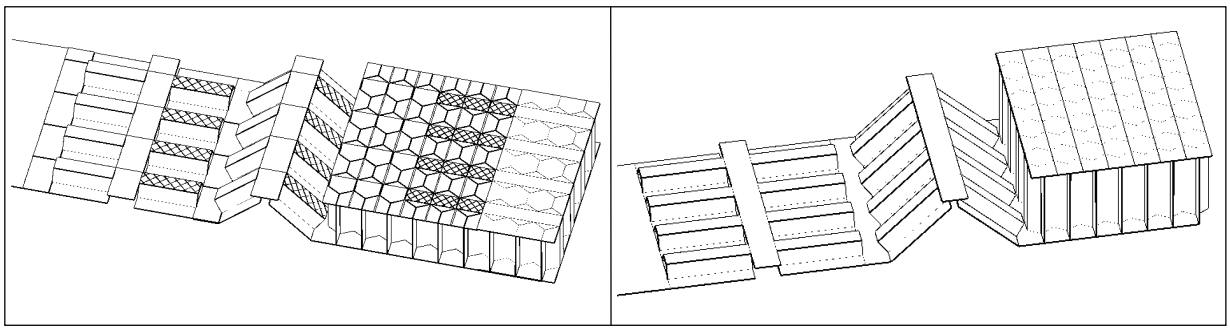

Fig. 5: Continuous production processes for fully closed folded honeycombs.

Fully closed folded honeycomb versions have the advantage that no material is cut out. In general, cutting of a honeycomb block to the desired core thickness is not required and material can be saved, since folded honeycombs are directly produced with the final thickness. A folded honeycomb with closed skin strips from a thermoplastic sheet, as shown at the right side in Fig. 5, could be used without any additional skins after welding together the skin strips.

CORE-SKIN BOND

The production of conventional honeycomb sandwich panels requires bonding of the skins onto the thin cell walls of the core. To achieve optimal bonding, an accurate control of the glue resin viscosity is necessary. Thus, the bonding of the skins to the core is a critical and expensive process step, resulting in a bond which is still debonding sensitive. Often rather thick and heavy resin layers are used to ensure a good resin fillet formation. Fig. 6 shows resin fillets in two conventional aluminium honeycomb panels with different resin layer weights.

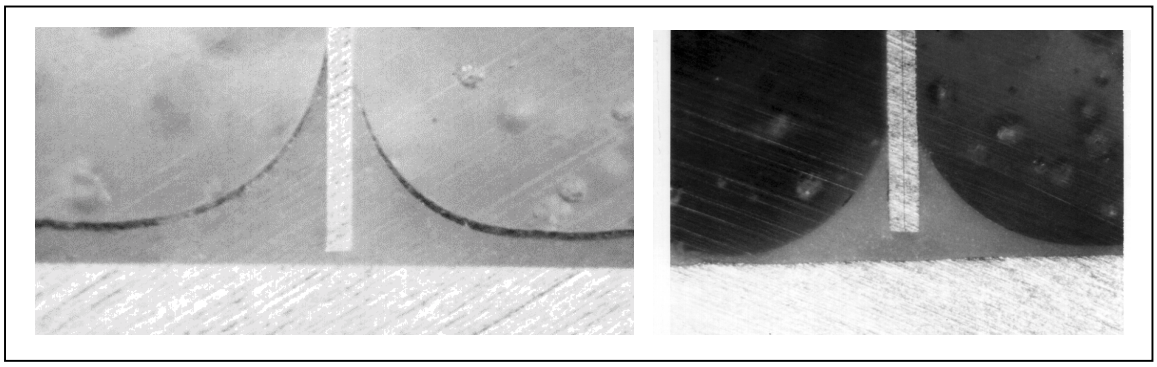

Fig. 6: Core-skin bond in conventional aluminium honeycombs panels.

Several techniques to reduce the required amount of resin and to enable a more reliable bond have been developed earlier [7]. Fig. 7 shows a technique with resin drops applied onto the cell walls prior the bonding, as well as the resulting resin fillet.

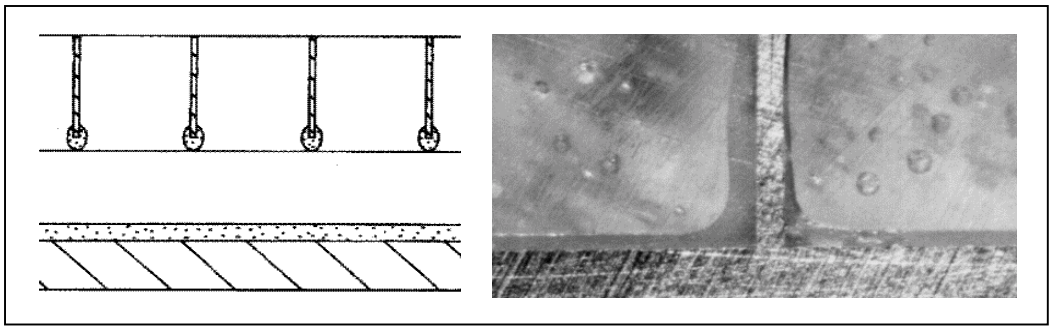

Fig. 7: Core-skin bond in conventional honeycomb panels with adhesive drops.

In welded steel honeycomb panels larger areas on the cell wall have been used to allow an easier core-skin bonding [8] as shown in Fig. 8.

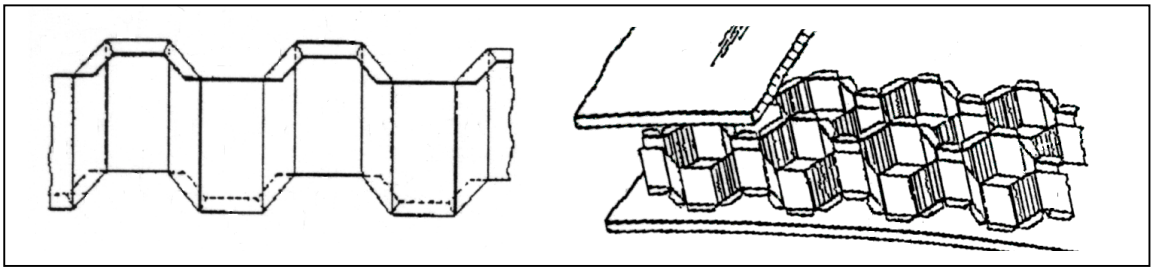

Fig. 8: Additional core-skin bond areas in corrugated honeycomb panels.

For thermoplastic honeycombs different techniques are used. Frequently a non woven thermoplastic layer is welded to the cell wall tops of the core to ensure that the panel manufacturer produces a reliable core-skin bond. Still, usually with conventional honeycombs the quality control effort for a reliable core-skin bond has to be made by each panel producer.

The folded honeycomb core exhibits a different concept for the critical core-skin bond. The special folding pattern of the new honeycomb provides a larger contact area with the skins. Fig. 9 shows a unit cell and a top section view just below the skins with the different resin distribution in the core-skin bond [9].

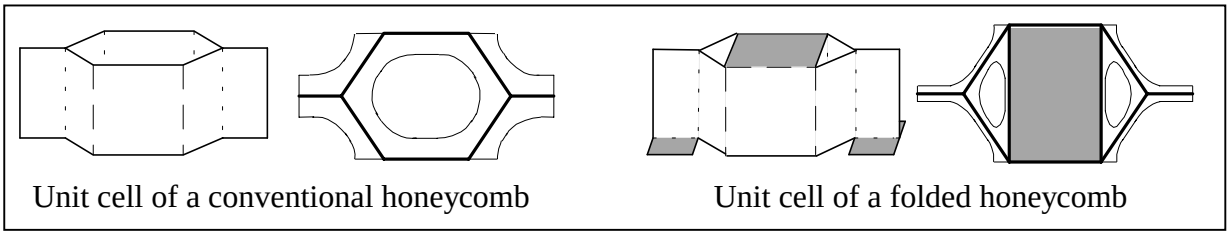

Fig. 9: Resin distribution in a conventional and a folded honeycomb panel

In the following Fig. 10 the density increase due to the additional areas is compared with the density increase due to bonding resin layers with different weight.

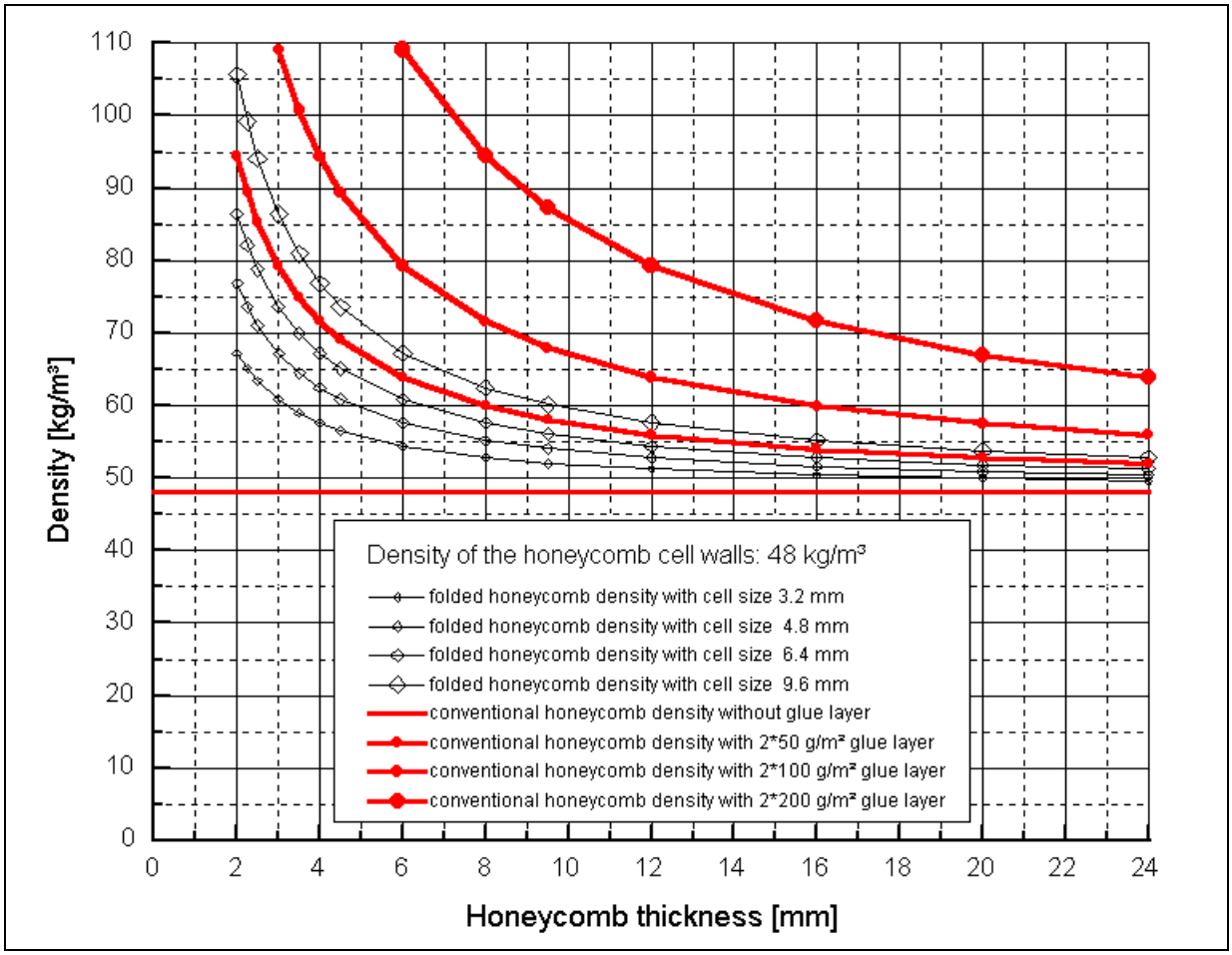

Fig. 10: Density comparison of conventional and folded honeycombs.

This comparison shows that the additional weight of the skin connection areas is equal to a glue resin layer of about 50 g/m² between the core and each skin. Today, often resin layers of more than 100 g/m² are used to bond conventional honeycombs.

In folded honeycombs the bond at the additional skin connection areas will ensure a reliable and tough bond under less controlled production conditions, as well as under impact and peel loads. Thus, much less resin is required for the fillet core-skin bond to transfer shear loads to all cell walls. The saving of more than 50 g/m² per resin layer might be possible, resulting still in a more reliable bond which can be produced faster and with smaller quality control effort.

The development of a production line for low cost honeycombs both for packaging and structural applications in the EUREKA project "FoldHex" will enable to develop efficient large scale production technology [10]. In the first two years of this project a feasibility study will lead to a lab-scale line and a detailed evaluation of the mechanical properties, especially peel strength and after impact performance. In the second project phase a demonstration line and prototype applications will be developed.

CONCLUSION

The new folded honeycomb sandwich core material offers an unique option for a very cost efficient production of the core and the core-skin bond. It has the potential to bring aerospace honeycombs into our daily life.

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