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Structural Performance Rectangular Honeycomb Core Sandwich Panels

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Abstract-The focus has then been shifted to describing the experimental methodology adopted in this research. A variety of tests were performed to establish the structural capacity of RHCSP under the isolated effect of shear, out-of-plane compression and two-way flexural behavior under centered patch loads. These tests were essential for the development and validation of analytical expressions for predicting the capacity of the panels to several failure modes, whichare introduced in Chapter 5 and form the basis of a design method for RHCSP. More importantly, the next chapter focuses on the validation of detailed numerical models against these experimental results, so as to achieve a reliable and computationally efficient methodology for assessing the structural behavior of RHCSP under different loading and support conditions.

1. Introduction

The cellular and prismatic corrugated cores demonstrated the most attractive combination of performance, fabrication viability and manufacturing at a mass production level. Considering the application as two- way sandwich panels for offshore topside deck systems, a final set of candidate systems has been established, including the hexagonal honeycomb core and the square honeycomb core sandwich panels. A thorough investigation follows to establish the most suitable topology from within this set of candidate sandwich panels.

The hexagonal honeycomb core is among the more efficient core configurations for sandwich panels to achieve fully effective two-way spanning action. It consists of hexagonal cells orientated in 3 different directions, which give rise to this type of sandwich panel configuration is commonly employed in aerospace engineering [1][2], due to its high specific strength-to-weight and stiffness-to-weight ratios. Out of all cellular arrangements, the hexagonal honeycomb shape provides the core with the smallest density, minimising the final weight of the product.

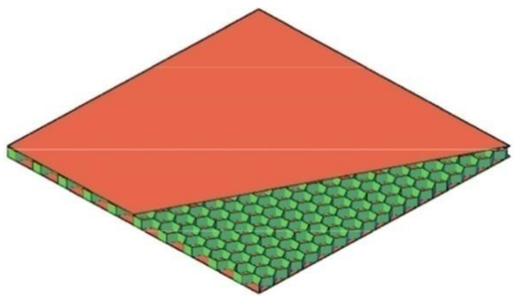


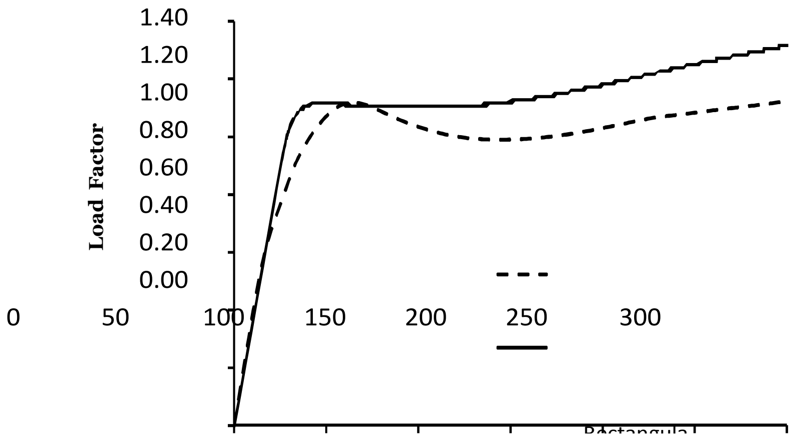
Figure 1: Square honeycomb core sandwich panel

The weight saving potential of the two candidate core systems has been assessed via mathematical expressions to calculate the density of the cores varying each geometric characteristic. When compared to the conventional deck system, both candidate systems display potential to save weight and material, but they are characterised by different structural performance and mass production feasibility as discussed henceforth.

2.Structural Performance

The detailed modeling approach employed in the numerical simulations is described in Chapters 4 and 5 for the case of RHCSP, while detailed information on the strategy used to represent sandwich panels with hexagonal honeycomb core can be found in [3][8]. For both types, the analysed panel is 3×3 m^2 large and it is vertically supported along its 4 edges. Moreover, an effective height of 100 mm and 3 mm thick top and bottom plates have been considered, ensuring equal contribution from the top and bottom plates to the flexural stiffness and capacity. Furthermore, the dimensions of the core have been calculated to guarantee that the weights of the two sandwich panels are identical, set to 101 kg/m^2. This has led to a hexagonal honeycomb core with regular hexagonal cells with 60 mmlong and 3 mm thick plates, and to a square honeycomb core with 100×100 mm^2 cell dimensions and 3 mm thick plates.

The nonlinear responses under uniformly distributed load (UDL) of both configurations are shown in Figure 2.

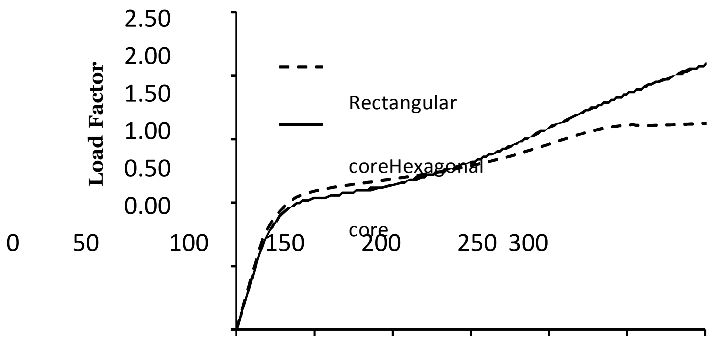


Central displacement [mm]

Figure 2: Nonlinear structural response of alternative sandwich panels under imposed UDL

Offshore topside deck systems are mainly intended to support heavy equipment, usually supported on rectangular pads, leading to highly concentrated patch loads. Thus, nonlinear simulations under patch loading have been also carried out to investigate the performance of the two alternative solutions. The load was applied over an area of 250×250 mm^2 at the centre of the panel obtaining again similar nonlinear responses asdisplayed in Figure 3.

The responses under distributed and patch loading indicates similar performance characteristics and weight saving potentials. Thus, it is expected that either candidate system,with appropriate design, could achieve significant weight savings while providing an adequate structural capacity to resist the loads of an offshore topside.



Central displacement [mm]

Figure 3: Nonlinear structural response of alternative sandwich panel under imposed patch loading

3.Fabrication Process and Challenges

The establishment of an efficient mass production method requires careful consideration of the costs associated with the core fabrication and the welding between the top and bottom plates and the core. This includes the costs of bending, spot welding and laser welding, which increase with the complexity of the welding pattern. With regards to the welding process between the top and bottom plates and the core, POSCO has established that laser welding is viable for the typical dimensions envisaged. Most importantly, POSCO also established that the minimum thickness for the core plate to be welded through laser stake welding is 3 mm, which is in agreement with previous experimental research, as discussed.

To fabricate a hexagonal honeycomb core, continuously stacking corrugated sheets is the best option

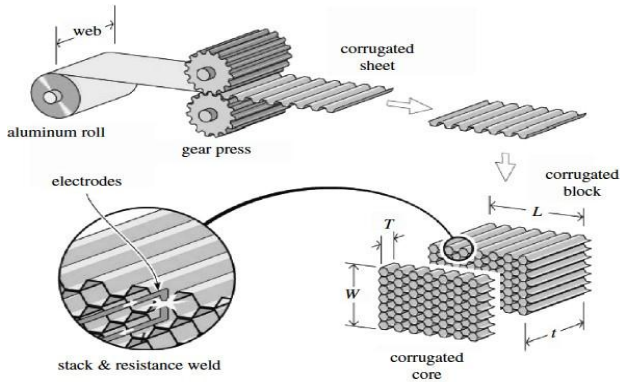


Figure 4: Hexagonal honeycomb cores from corrugated sheets[4]

since extrusion of structural steel is more problematic. This manufacturing process requires cutting and bending a continuous plate by 60 degrees until the desired length of corrugations is achieved. A diagram of such a process is schematically illustrated in Figure 4 [4]. As shown in the figure, after cutting the plates, these are connected to each other by laser welding or resistance spot welding. This manufacturing process has a drawback associated with significant waste of material and unnecessary additional weight due to the doubled plate thickness at the joints between each sheet.

The most suitable manufacturing process for square honeycomb cores requires cutting the strips up to half the core height and then slotting them together [5], as illustrated in Figure 5. The mass production of these panels can be vastly simplified by using this strategy, particularly if it is not necessary to weld the slotted strips.

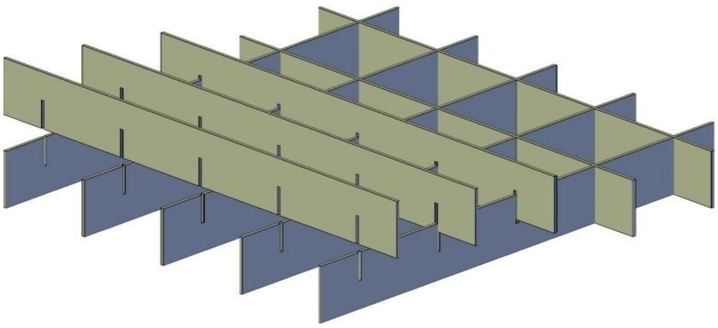


Figure 5: Square honeycomb core from slotted strips

Compared to the hexagonal core, the square shape can facilitate the pattern for laser stake welding the top and bottom plates. Considering the mass production requirement, the fabrication strategy with square honeycomb core assembled by slotted strips, without welding along the slotted web, represents the most convenient option among all the fabrication solutions presented before. Furthermore, current mass production of I-core sandwich panels, i.e., one-way spanning sandwich components with core strips running along one principal direction in shipyards [6] renders the establishment of a mass production process for the proposed solution a highly realistic prospect.

3.1.Geometric characteristics

The process that led to the selection of square honeycomb core sandwich panels has been briefly described. Nonetheless, there is significant potential for achieving further performance enhancement from the aforementioned configuration through practical and viable product development. Various alternatives and schemes have been proposed, mainly involving alterations in the core configuration, which governs the weight and the structural performance of the sandwich component.

Firstly, the potential for achieving further weight reduction through the implementation of perforations in the core strips has been investigated. Laser-cut perforated strips can be fabricated through an automated process, involving the cutting of openings in circular or other geometrical shapes, which can be performed at the same time as the slots are cut. Circular openings were preferred since this shape leads to reduced local stress concentrations. Based onthese considerations, the configuration with circular perforations in the core, as depicted in Figure 6, has been selected and analysed in detail via physical testing.

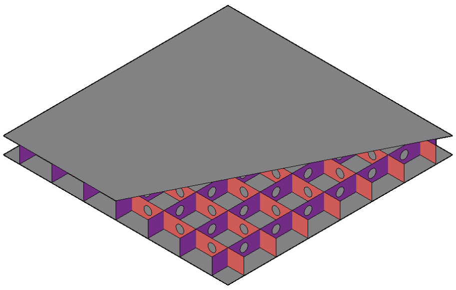


Figure 6: Square honeycomb core with hollowed strips

Another alternative for enhancing the performance of the panel is the use of aspect ratios different from 1.0 for the core cells. As previously mentioned, the application of sandwich panels in offshore decks requires the use of components capable of adapting to a wide range of spans with different aspect ratios as well as loading conditions. To ensure versatility of the product, an adaptation from the square honeycomb core configuration has been proposed, based on cutting the slots and assembling the strips with different spacing and different thickness in the two orthogonal planar directions as shown in Figure 7. In this manner, an anisotropic response with a priori specified characteristics can be established, achieving the required performance in each bending direction.

Figure 7: Rectangular honeycomb core sandwich panel with an anisotropic response

Additionally, no extra complexity arises for the fabrication of this structural configuration, and it is therefore considered a highly viable alternative for further performance and flexibilityenhancements of the sandwich panel system which can be achieved by cutting the slots and assembling the core strips with different spacing in the two orthogonal directions.

For the concepts discussed throughout this thesis to be clearly stated, a consistent nomenclature is required for every geometrical aspect influencing the structural performance of RHCSP. These variables, illustrated in Figure 8, are as follows:

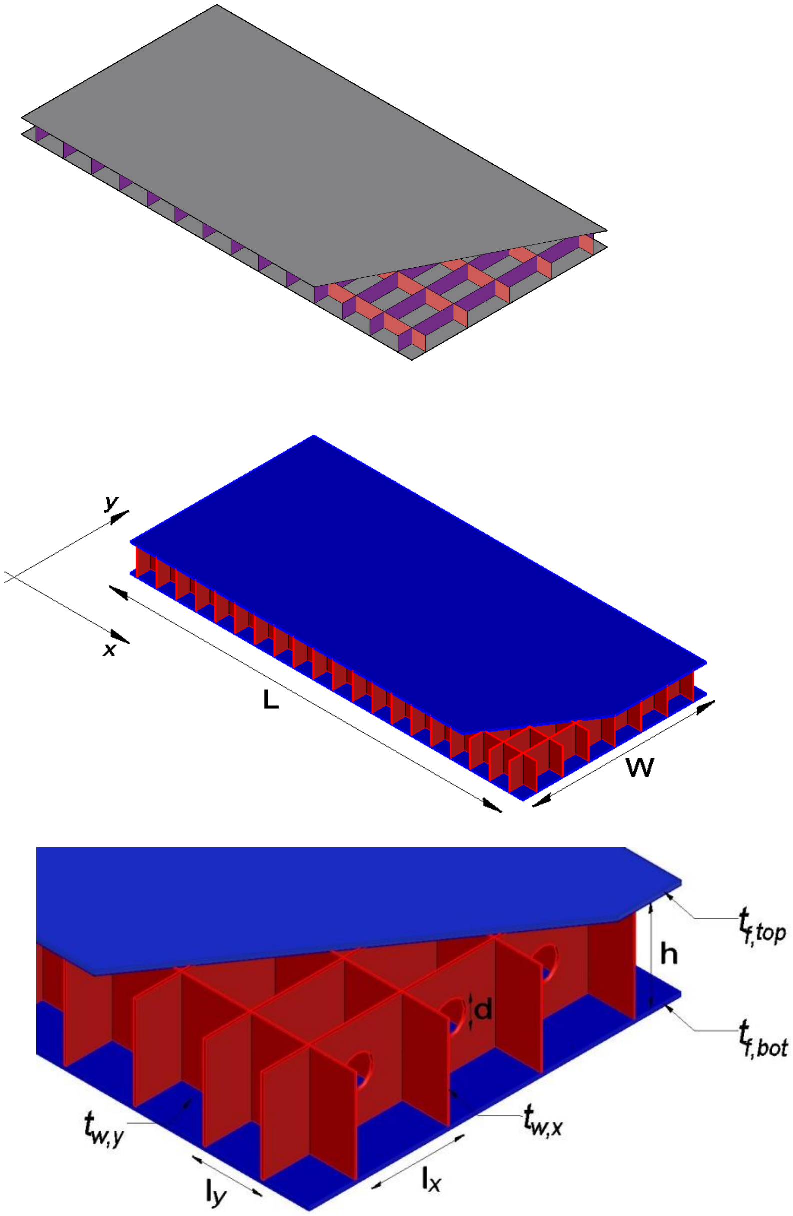


Figure 8: Geometric characteristics

Following the selection of the most optimal candidate system to fulfill the objectives of the project, an experimental programme was carried out to investigate the structural performanceof RHCSP.

4. Result Analysis

The result was mostly undertaken at POSCO's Global R&D Centre in Incheon, South Korea. The result was devoted to the investigation of the sandwich panel production method and its potential impact on structural performance. It involved small-scale testing to analyze the panel behavior under shear and transverse compressive loads, and large-scale tests to assess the two-way response under patch loading.An overview of the proposed result is provided in Table 1 below, wherethe scope of each type of test is concisely explained.

Table 1: Experimental programme overview

Test	Test scope
Shear test	Test shear response of the panel core
Flatwise compressive test	Test compressive response of the panel core
Panel test	Assess two-way response and resistance to equipment loads

Due to budgeting constraints, two specimens were tested in each scheme, even though, ultimately, the number of specimens should be determined based upon the attainment of successful validation and adequate statistical correlation for all types of tests. In the tests where this correlation cannot be attained, more testing is required in the context of future work. RHCSP, beyond the conventional configuration with a solid core, the experimental programme considered also the effect of perforations in the core to the shear response of the panel, as illustrated in Figure 3-7.

A summary of the tests of the result is given in Table 2.

Table 2: Summary of physical tests

Test	Specimen size [mm]	Number of tests	Specimens per test
Shear test	600×300×100	2	2
Flatwise compressive test	600×600×100	2	2
Large panel test	1500×1500×70	2	1

The testing equipment employed in the result includes a 1000 kN universal testing machine, with a distance between supporting columns of 1500 mm, and a 3000 kN universal testing machine, with a distance between supporting columns of 1000 mm. The manufacturing of the test specimens involved the cutting of steel sheets with a thickness tolerance of 1% by using a laser cutting machine with a tolerance of 0.05 mm. The laser welding process was completed by a 12 kilowatts 'fast axial flow' laser welding machine (Figure 3-10) capable of performing laser stake welds up to a total of 15 mm thickness, including both the plate and the core thicknesses.

5. Conclusion

The selection process that led to the definition of the sandwich panel topology investigated in this research has been presented in this paper. In the process, the advantages provided by different solutions presented in the literature were examined in terms of weight saving potential, manufacturability and adequate structural performance. The overall success of the result is deemed to be satisfactory. On one hand, the tests were successful and provided novel information on the structural response of RHCSP.

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