

Redesign of ZIGZAG Chair by fiber reinforced plastics: fusing product design and engineering

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Abstract

This study is the application of new design method for integrating the product design (styling and functional design) and the engineering design (strength design of structure), which can make the best use of the composite materials' characteristics obtained by the experiment and the analysis. Among them, the carbon fiber reinforced composite plastics (CFRP) have excellent high strength and lightness. Here, using these materials' characteristics, ZIGZAG Chair made from wood, which had the refined style, was redesigned by CFRP. In this redesign process, the engineering point of view was used as a new proposed design method. The designed ZIGZAG Chair was manufactured by hand lay-up molding of CFRP according to analytical results, and its styling and strength were evaluated. The analytical results, that is, strength and displacement, were in good agreement with the pilot model's one.

Keywords: composite material, strength analysis, product design, design process, ZIGZAG chair.

1 Introduction

Development and the practical use of high strength composite materials in recent years are remarkable, and those materials are applied to various products. As the



example of using the product, which uses a high strength composite materials, the titanium alloy, the aluminum base alloy and the carbon fiber reinforced plastics are used in the car exterior and aircraft structural members. Among them, the use of the carbon fiber reinforced plastics is remarkable. The use ratio of composite materials such as the carbon fiber reinforced plastics accounts for about 50% or more of the whole in the aircraft Boeing 787 developed recently [1]. This carbon fiber reinforced plastics materials, which has high strength, greatly contributes to lightening and the strength improvement of the product. Moreover, as the integral molding technique can use as this product manufacturing, the shape that has not been made an embodiment so far can be made. Product design is a field where the sensibility and engineering to invent the product united. The product design which makes the best use of the characteristic of a high strength composite materials enough is difficult, because there was no deep verification in a past design process for the material in product design field. Here, a new product design technique to make the product which made the best use of the characteristic of a high strength composite materials enough was examined, and verified from engineering points of view.

2 Design method

The purpose of this research is to verify the proposed design method [2, 3] by applying ZIGZAG Chair [4]. It concisely explains the proposed design method for high strength composite materials as follows. In current product design, the designer makes the planning concept and the investigation analysis for the design object, and after these processes, the design element are extracted and the concrete product shape are produced. This process corresponds to the upperstream process in the design, and after the idea development, the product design by the engineer is done in the downstream process shown in fig. 1.

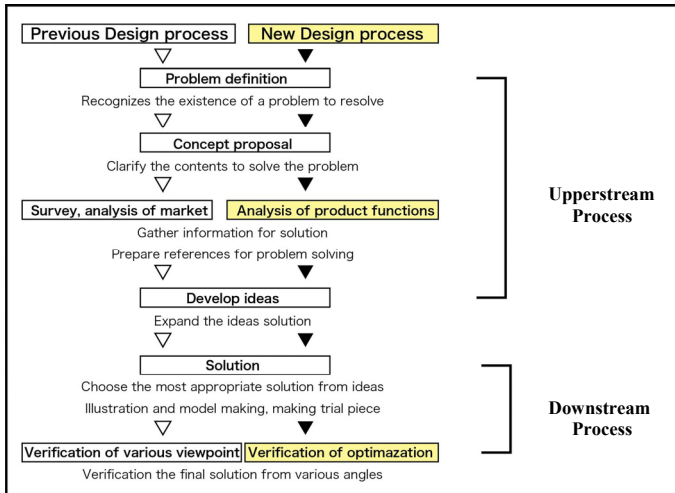


Figure 1: Design process [5].

The new design process proposed by this research shifts the optimization design stage in the downstream process to the analysis of the investigation of the upstream process. The idea progresses by extracting a concrete element that makes the best use of the strength characteristic of high strength composite materials [6].

The product with very light and strong strength can be made by the strength optimization required to the designed object. The material characteristic evaluation to achieve the function and strength of the product is included in the upstream design process shown at the right of fig. 1.

3 Design target

In this study, ZIGZAG Chair (fig. 2) that Rietvelt (Gerrit Thomas Reitveld) had designed in 1934 is chosen as research target. This wooden chair is that its shape has the structure and the function, and this is best suitable for the verification with the trial of a new design method.

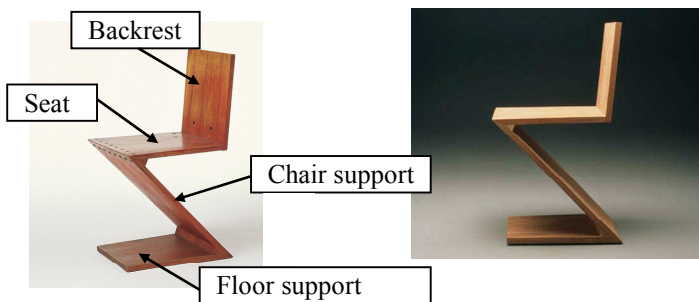


Figure 2: ZIGZAG Chair Produced by Gerrit Thomas Reitveld made of wood in 1934.

3.1 Overview of original ZIGZAG Chair

Zigzag Chair is shown in fig. 2. This chair was original designed by Gerrit Thomas Rietvelt, who was a Dutch architect and cabinet manufacturer. This chair is formed by four straight-line wood panels which consist of backrest, seat, chair support and floor support. They are supported by small corner block (reinforcing member). This chair has enough strength despite its appearance, and its design quality also has been assessed highly. However the original wooden structure is too heavy to move easily.

3.2 Redesigning structure of ZIGZAG Chair

Here, the redesigning ZIGZAG Chair using typical composite material, Carbon Fiber Reinforced Plastics (CFRP) is carried out. The proposed design method is verified in this design and production and new structure's ZIGZAG Chair which has high design quality with lightness and strength is manufactured. As for the

structure of ZIGZAG Chair which has enough strength which uses CFRP, there are three kinds of structures; 1) Rib structure model, 2) Hollow structure model, 3) Fold structure model, shown in figs. 3, 4 and 5, respectively. In this study, authors focused on the fold structure in consideration of mass production, aesthetic externals of the product, and lightness in weight.



Figure 3: Original model. Figure 4: Rib model. Figure 5: Fold model.

4 Design

4.1 Fold structure

This is the model, which is consisted of fold CFRP plate members shown in fig. 5. This structure is designed as thin as possible from the point of side view. By having folds to each surface, it can increase rigidity of surfaces. For these reasons, the fold structure can have both high design quality and rigidity.

The fold structure strength was evaluated by the analysis. The analytical model is shown in fig. 6. The model combined the monotony of CFRP. The displacement and the rigidity variations were calculated and the effect of folding angle θ_f of two plates on the rigidity was evaluated. Fig. 7 shows an analytical result of displacement to the angle of the fold.

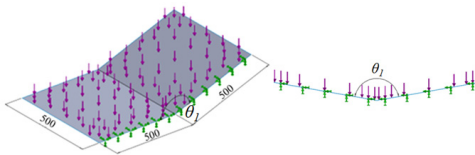


Figure 6: Folding element model.

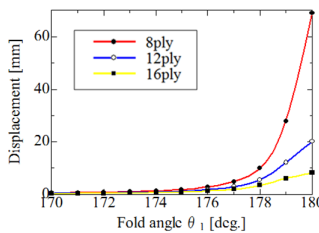


Figure 7: Relation between displacement and folding angles.

The angle (folding angle θ_i) between two boards under one side fixed edge is changed and the opposite edge displacement of the fixed side was calculated in increasing load. The vertical distributed load on the plate was subjected. As for the decrease in the plate angle θ_i , the rigidity increases rapidly. The rigidity in range of 177° is more than ten times in comparison with that of 170° . In the range of less than 177° , the rigidity gradually increase. The value of bend rigidity D increases by a factor of eight when the plate thickness is double, and as a result, the value of displacement becomes 1/8. However, in the case of folding structure, the displacement decreasing ratio becomes small with decreasing folding angle, because of increasing the distance from neutral axis.

4.2 Styling design

It was clarified that the rigidity of fold structure greatly increased from FEM analysis. The product design was carried out based on this analytical result. In redesign of ZIGZAG Chair, it is required the design which makes the best use of designer's sensitivity for engineering. A series of ZIGZAG Chair that progresses the idea is shown in fig. 8 by thinking about the structure and the balance of beauty confirming the change in shape with the fold. In this idea development, it gave priority to looking to thinness and not becoming of shape monotony. The depth of the fold was designed not to exceed the thickness 20mm of original wooden ZIGZAG Chair. Figure 9 shows the final proposed design.

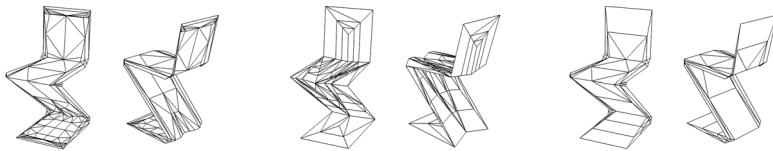


Figure 8: First idea of ZIGZAG Chair.

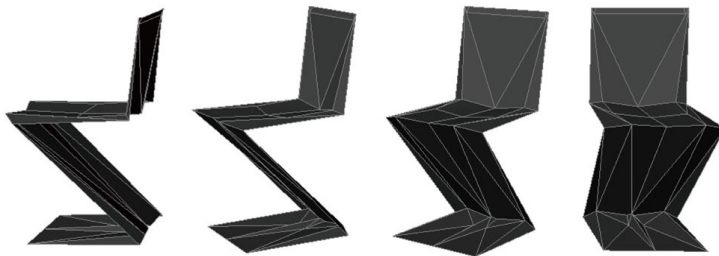


Figure 9: Final proposed design.

5 Verification

5.1 Production of verification model

The outline of ZIGZAG Chair manufacturing process shows in fig. 10. The wooden pattern was produced with 3D-CAD data of final prototype conceived from a new design method, and the chair made of CFRP was molded as a prototype in the hand lay-up method.

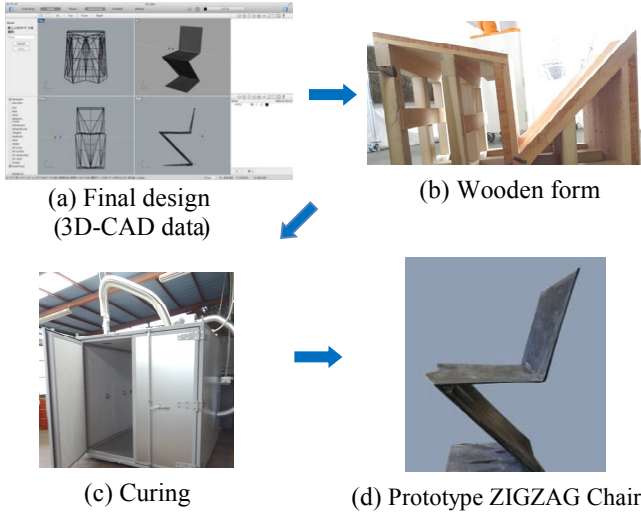


Figure 10: Outline of ZIGZAG Chair manufacturing process.

The body of ZIGZAG Chair is formed by the carbon fiber clothes which impregnated vinyl ester resin. In the forming, the stress analysis of the prototype model was performed and the stress concentration parts were laminated by 24ply and other parts were laminated by 12ply in the hand lay-up molding as shown in fig. 11. The formed ZIGZAG Chair was cured for two hours at 120°C by using the oven shown in fig. 10(c). The prototype model molded in this process is shown in fig. 12.

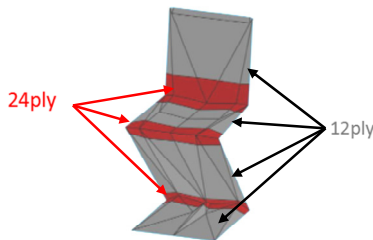


Figure 11: Laminating condition.

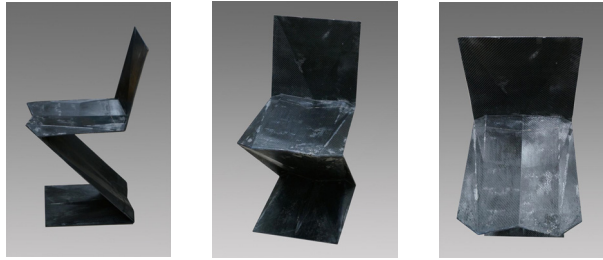


Figure 12: Prototype ZIGZAG Chair.

5.2 Analytical verification

Fig. 13 shows an analytical results to the final molding prototype model. Boundary conditions are shown in fig. 13(a); Backrest load is 100N, Seat load is 580N and floor support is fixed.

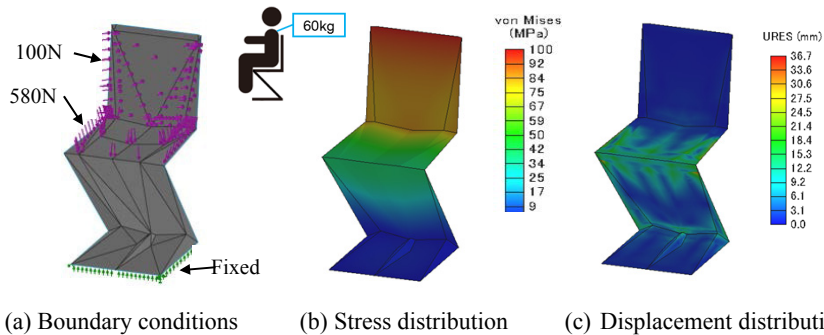


Figure 13: Analytical results.

The comparison between analytical results and experimental results to final prototype model are shown in table 1.

Table 1: Analytical and experimental results.

	Displacement	Weight
Analysis	29.2mm	3.52kg
Experiment	28.8mm	3.5kg

Analytical results correspond well to experimental ones. An effective optimization design becomes possible by combining partial reinforcement by a laminating number increase in a high strength composite materials with the FEM analysis.

6 Summary

By introducing the engineering aspect to analyze strength in upstream design process (product design process), a new design element concept can be extracted. As new design method example, the redesign ZIGZAG Chair was carried out by the best use of the characteristics of carbon fiber reinforced plastics and the designer's sensitivity. In this research, the affectivity of a new design method was proven by produce and verifying an actual model.

References

- [1] <http://www.carbonfiber.gr.jp/field/carft.html>, Japan Carbon Fiber Manufacturing Association, 2014.
- [2] Iida H., Sakamoto H. & Ohbuchi Y., Development and application of new design method by high-strength composite material, *Applied Mechanics and Materials*, **372**, pp. 17–20, 2013.
- [3] Iida H., Sakamoto H., Ohbuchi Y. & Fujishima T., Application of new design method by high-strength composite material, *Applied Mechanics and Materials*, **607**, pp. 915-919, 2014.
- [4] Zigzag chair, available from <http://www.cassina-ixc.jp/shop/g/gzig-zag>, (accessed on 20 March, 2013) (in Japanese).
- [5] Matsuoka Yoshiyuki, & Satoshi Miyamoto, *The concept of optimal design* Kyoritsu Shuppan Co., Ltd. (in Japanese), 2008.
- [6] W. Strunk Jr., E.B. White, *The Elements of Style*, third ed., Macmillan, New York, 1979.

