MULTIFUNCTIONAL COMPOSITE WITH REINFOCEMENT FIBERS AND FUNCTIONAL FIBERS OPTIMALLY PLACED

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Keywords: *multifunctional composite, tailored fiber placement, shape memory alloy, optimization, embroidery machine*

Introduction

Mechanical properties of fiber reinforced plastic (FRP) laminate are significantly affected by the fiber orientation. Accordingly, if the fibers can be placed along a desired path for some purpose, which are curved in general, FRP structure can be designed more lightly and more sophisticatedly. To this end a tailored fiber placement (TFP) method using an embroidery machine has been studied [1, 2].

Oka et al. [1] proposed a design method for the embroidery-based TFP and verified its availability for a bending-torsion problem. It was also found that the effects of embroidery, such as holes made by a needle and thickness variation due to the fiber orientation, played important roles on prediction of the mechanical properties of the composite laminates. Then Nishida et al. [2] proposed a design method considering such effects to predict the mechanical properties more precisely. Using this method eigen-frequencies of a CFRP cantilever plate were controlled and the error between calculation and experiment was evaluated.

In the previous studies anisotropic properties can be distributed spatially. To develop this method and to create more sophisticated structures, a method to design multifunctional composites varying properties temporally is proposed by placing functional elements as well as reinforcement fibers simultaneously optimally. In this paper, shape memory alloy (SMA) fibers are used as a functional element, and the reinforcement fiber path and SMA fiber path are examined so as to minimize the deflection under uniformly distributed load and maximize displacement at a certain point when SMA is activated.

Embroidery-based TFP

The embroidery machine considered here is shown in Fig. 1 (Tajima, TCWM-101). When a desired path of a reinforcement fiber bundle is input to the embroidery machine, the machine places the fiber bundle on the desired path on a substrate and processes a dry preform. The substrate was assumed to be comprised of plain woven carbon fabrics with a stacking sequence of $[45°/0°]$. Then the preform was assumed to be impregnated with resin by using the vacuum assisted resin transfer molding method (VaRTM).

Example problem

The following example was considered: Find simultaneously optimal paths of SMA fibers and carbon fibers so that (Objective 1) a displacement at a point near a corner (the point in Fig. 2) of a cantilever plate with a size of 150mm×100mm was maximized when the SMA fibers were activated and (Objective 2) an averaged deflection of the plate was minimized when uniform pressure difference acted on the plate. The TFP layer was divided into 15 elements to determine the reinforcement carbon fiber path and the SMA fiber path was assumed to be U-shaped along a trigonometric function

$$y = a\cos(bx) + c\sin(dx) + e \tag{1}$$

as shown with a white curve in Fig. 2. The fiber angle was limited within $\pm 60°$ and the difference in fiber angle between the neighboring elements was limited within $\pm 30°$.

Result

A multi-objective genetic algorithm (MOGA) was applied for searching the optimal solutions. In MOGA, infinite number of solutions existed for satisfying two objectives. A set of optimal paths of carbon fibers and SMA fibers are shown with black curves and the white curve respectively in Fig. 2. The objective 1 was weighted more in this solution. The principal stress direction when the concentrated force acted at the point near the corner is shown in Fig. 3. The optimal SMA fiber path was nearly along the direction of the principal stress and the carbon fiber path was nearly perpendicular to the SMA fiber path. To suppress the displacement against the uniform pressure, the fiber angle became about 0 degree near the root. The displacement distribution when the SMA fibers were activated is shown in Fig. 4.

Conclusion

To develop TFP method using an embroidery machine, a multifunctional smart composite was designed. The composite plate included SMA fibers as well as reinforcement carbon fibers which were placed along curved optimal paths so that a displacement at a point was maximized when the SMA fibers were activated and an averaged displacement of the plate was minimized under uniform pressure. The paths seemed reasonable for the objectives. As the next step, it is necessary to make the composite and compare the value of the analysis with the experiment.

Acknowledgements

A part of this study was supported by JSPS KAKENHI Grant Number 26420811.

References

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Figure 1: *Embroidery machine.*

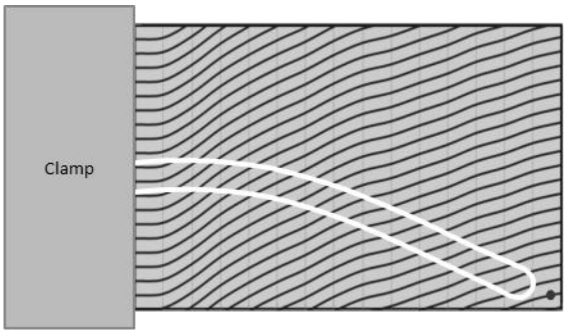

Figure 2: *Optimal carbon fibers and SMA fibers paths. Black curve: carbon fiber path, white curve: SMA fiber path.*

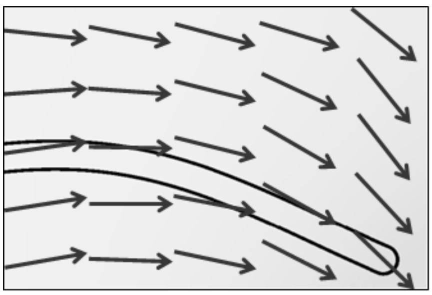

Figure 3: *Optimal SMA fiber path and direction of the principal stress.*

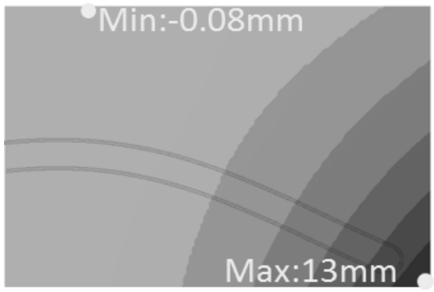

Figure 4: *Displacement distribution when SMA fibers are activated.*