博士論文（要約）

Statistical Research on Stochastic Elastic Properties of Carbon Fiber Tape Reinforced Thermoplastics

（炭素繊維テープ強化熱可塑性プラスチックの確率的弾性特性に関する統計的研究）

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論文の内容の要旨

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This thesis investigates the stochastic elastic properties of carbon fiber tape reinforced thermoplastics (CTT), which are developed for mass production automotive application.

In chapter 1, aiming for energy consumption reduction of passenger vehicle, several types of carbon fiber reinforced thermoplastics (CFRTP) are introduced, among which CTT has high mechanical properties, good formability and short cycle time, and is a promising candidate for automotive prime structural material. However, the variation of its elastic properties depends strongly on the structure size, and the mismatch of laboratory scale and automotive scale becomes a problem. Consequently the goal of this study is to clarify factors and how the stochastic elastic properties are influenced, and propose a solution for obtaining results close to large scale in a laboratory scale.

In chapter 2, a literature review is given on studies concerning random orientated composites, of which CTT is also a member. The modelling methods of stochastic characteristic of composites are sorted and introduced as well. The statistical analysis can provide two way functional relationship between inputs and outputs, but the underlying data is difficult to guarantee. An analytical model is highly abstracted, hence very productive but can only handle simple shapes. A finite element method can represent structures with good precision, however is computational expensive. At last, a solution to the study goal is proposed as a combination of analytical model and statistical analysis.

In chapter 3, an analytical model for predicting tensile modulus of CTT is

established. Tapes are represented by equivalent square plies with the same thickness and area as well as orientation to avoid overlap. The square plies are then "laminated" into a cell. Cells array along transverse direction of form a row, and at last rows array along longitudinal direction to form a tensile specimen. Basic composite theories such as classical laminate theory and rule of mixture are used hence the reliability of the analytical model can be trusted.

In chapter 4, Monte Carlo simulation is performed to obtain statistical properties of effective tensile modulus from the analytical model. The tentative simulation shows that CTT tensile modulus has a normal distribution. The acceptable number of trials is also discuss an n=1000 is determined. Tensile tests are also conducted on two kinds of CTT with different matrix, tape size, and specimen size. The results are examined with statistical hypothesis testing in consideration of different sample size n. Both mean and variance match very well, hence the model is validated.

In chapter 5, statistical analysis is performed to results from a series of Monte Carlo simulation. The influences of tape properties, tape size and specimen size on distribution type, mean and variance of E_{cell}, E_{row} and E_{spec} are investigated respectively. It is clarified that mean of E_{cell} has a linear relationship with t/T, where t and T are thickness of tape and specimen. Otherwise variance of E_{cell} has a quadratic relationship with t/T. Further investigation is conducted on relationships among distribution parameters of E_{cell}, E_{row} and E_{spec}. Finally, conclusions about CTT tensile modulus can be summarized as below.

- The distribution can be considered as normal distribution when $\frac{t\sqrt{tw}}{TW}$ is larger than a certain value determined by tape properties.
- Mean of tensile modulus

$$\mu_{spec} = -\frac{A}{p} + B$$

- Variance of tensile modulus can be described with a precise form

$$\sigma_{spec}^2 = \left(-\frac{C}{p^2} + \frac{D}{p}\right)\left(\frac{1}{q} - \frac{d_q - d_q^2}{q^2}\right)\left(\frac{1}{r} - \frac{d_r - d_r^2}{r^2}\right)$$

or with a simple form

$$\sigma_{spec}^2 = \left(-\frac{C}{p} + D\right)/\mathrm{pqr}$$

- Regression coefficients A, B, C and D are related to tape property, while A, C and D have positive correlation with anisotropy of tape.

Basing on the functional relationships above, a procedure to determine the size of CTT specimen is established.

In chapter 6, a modified analytical model for three point bending test is established. Validation of the flexural model is performed. However the results from experiment and simulation agree with each other in variance but not in mean. Since three point bending test of CFRTP can be influenced by G_{13}, an indirect measurement for G_{13} by changing the span length and linear fitting is conducted, and the bending modulus is corrected by removing the influence of G_{13}. The result is better but still not enough, hence the accuracy of G_{13} still need to be improved.