博 士 論 文 の 内 容 の 要 旨

氏名	HUANG CANYI
学位名	博士（　工学　）
学位授与年月日	2021 年 9 月 30 日
論文題目	Study on static and dynamic mechanical behavior of woven fabric (織物の静・動的力学挙動に関する研究)

（博士論文の内容の要旨）

Woven fabric is one of the most widely used materials in textile composites and structural applications. Some woven fabrics especially high-performance fabrics are viscoelastic in nature which exhibit a combination of both elastic and viscous behavior. Therefore, the characteristic of mechanical behavior of fabric material should include both static mechanical properties like tensile behavior and dynamic mechanical properties like impact behavior.

Nevertheless, there are still problems refer to the mechanism performance and behavior of woven fabric that have not been explored at present and they still require further study. For instance, there are few literature reports on the mechanism of the effect of crimp or inter-yarn friction on woven fabric's tensile properties, and research on low-velocity impacts on woven fabrics is almost nonexistent. It is crucial for engineering to develop woven fabrics especially high-performance fabrics with improved all-round being well understood performance. As a result, this research carries out static and dynamic mechanical study by combing experimental and numerical methods to investigate in tensile and impact mechanical behavior of high-performance Twaron® woven fabric which have never been solved by other researchers up to present, and aiming to provide valuable application reference for body armer and composite materials industry.

In the present research, a physical-geometric-feature of continuous yarn in a plain-woven fabric is created and its FE model is analyzed by considering the two key issues of woven fabric, the crimp and inter-yarn friction. The basic parameters of Young's modulus of single yarn and the inter-yarn friction coefficient are investigated for practical fabrics in tensile and pull-out tests. FE analysis indicated that the stress-strain curves of the FE model are effective in evaluating the equivalent modulus of a woven fabric by comparing with a tensile experiment on Twaron CT ® Plain Woven Fabric. In addition, a simplified three-dimensional model of the unit cell of plain-woven fabric (UCPW) is employed to quantitively investigate two important fabric characteristics – the crimp rate of the yarn and inter-yarn friction to determine their influence on the mechanical properties of the fabrics. Furthermore, we use FE analysis to evaluate how the crimp rate and inter-yarn friction affect the mechanical properties by determining the equivalent modulus of single yarn and UCPW in both uniaxial and biaxial tensile loading. The stresses at representative nodal points and the mechanical interaction between yarns are also investigated from a microscopic perspective, and their deformation mechanisms are also analyzed and discussed. After the tensile research, low-velocity drop weight impact experiments of plain-woven Twaron CT® at an impact energy of 15, 20, 30 J are carried out on a 9250HV drop weight impact tester. Specially treated specimens are designed and used to deal with boundary conditions because the fabric is too flexible and cannot be fixed precisely. Experimental results reaffirm that Twaron® is an impact-rate-sensitive material and that a greater initial impact energy resulted in a larger breaking load, greater failure strain, larger energy absorption and shorter contact duration to the fabric in the impact process. Numerical impact model is created and the dynamic mechanical parameters of Twaron® is analyzed and applied to FE model to describe the rate-sensitive mechanical properties through a three-element spring-dashpot model. Standard earth gravity is applied to the impact model to reflect the impact process realistically as well. The results indicate that a remarkably close agreement is obtained between the simulation and experimental results in various impact scenarios. Thus, the energy absorption mechanisms and stress distributions during the impact process are clarified. The influence of specimen shape and size are also analyzed systemically. These results indicate that the present experimental set-up

and the developed fabric geometry model are effective at investigating many additional mechanical problems in textile fabrics and/or flexible material structures.

Finally, as well known to all, defects, such as holes, appear in fabrics after long-term use or damage. Holes can weaken the mechanical properties of fabric-based soft body armor and fabric-reinforced composites to a certain degree. Hence, prediction the effect of hole defect in the mechanical properties of fabric is of great importance for material designers. In the present study, the impact model is created and validated by drop weight impact experiment. Moreover, models of single- and multilayer panels of plain weave as well as different weaving architectures are designed and created with and without holes to compare impact properties. The influence of the size and location of hole defect on the impact behavior of single-layer Twaron® fabric are investigated, the degree of influence of hole defects with different sizes on the impact behavior and the influence level by different location of the hole defects are well understood. In addition, the effect of hole defects on the impact behavior of multi-layer armor panel are also studied. Hole defects become less influential in terms of impact contact force and have less severe constraining effect on front layer of the panel when the number of multi-layer armor panels increased. Furthermore, the effect of hole defects on the impact behavior of different weaving architectures (i.e., plain, twill, basket, and satin weave) are analyzed. Plain weave fabric has the highest energy absorption capability in impact scenarios with and without holes among all the woven architectures. Plain weave fabric is the most affected and twill weave is the least affected by hole defects in terms of transverse wave velocity; the satin weave is the most affected and the twill weave is the least affected by hole defects in terms of energy absorption. These findings will provide guidance for engineering of soft body amour and composite materials.