博　士　論　文　の　内　容　の　要　旨
Abstract of Doctoral Dissertation

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論文題目 Dissertation Title	Study on analysis of puncture resistance mechanism and influencing factors of aramid composite materials （アラミド複合材料における突き刺しメカニズムと影響因子の解析に関する研究。）

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Personal safety and protection have never been more relevant to society. Therefore, it is of great practical significance to prepare light- weight and convenient protective materials with excellent anti-stab performance. In this dissertation, we focus on analysis of puncture resistance mechanism and influencing factors of aramid composite materials. The study finds that the addition of the radial properties of the yarn and the optimization of the contact part of the yarn will greatly improve the accuracy of the simulation results. After obtaining accurate simulations, we conduct an in-depth analysis of the stab-proof mechanism and the factors affecting the stab-proof performance.

In order to better achieve the goal of this experiment, we carefully designed the material structure of the experiment. After studying the influence of fabric interweaving structure on this experiment, we design a composite with a mesh structure for puncture analysis, using Kevlar/epoxy to prepare mesh composites with the mesh spacing of 1 mm. Using the prepared new material structure, the puncture resistance of the material is tested by the puncture machine developed by our laboratory. The puncture failure morphology is analyzed with the help of a high-speed camera, and the puncture energy is analyzed using the force-displacement curve. The results of this analysis will serve as a benchmark against which to simulate the experimental results.

The influence of the anisotropy of the yarn on the accurate value of the simulation results mainly studied. On the above experiments, we conduct stab-proof simulation experiments. Firstly, a 1:1 simulation model of mesh composite material is established by CAD software. Then, a simulated puncture experiment is carried out according to the actual experimental conditions and material parameters. When setting the material parameters, the problem of yarn anisotropy is mainly considered. The tensile properties of the yarn in the axial direction

are tested, and then the compressive properties of the yarn in the radial direction are tested by the method developed by Professor KAWAMURA after optimization. The test finds that the radial modulus of the yarn is much smaller than the axial modulus of the yarn. Using the measured data, the model parameters are set according to the material anisotropy. After accounting for the yarn anisotropy, the results of the stab-resistance simulation are closer to the actual results. The simulation results without considering the yarn anisotropy are quite different from the actual results. Therefore, the anisotropy of the yarn has a great influence on the accuracy of the simulation results.

The influence of the contact between the yarns on the precise value of the simulation results is mainly studied. In order to ensure the accuracy of the interface optimization in the model, we have carried out a detailed analysis of the real object. The interface is then observed by electron microscope, and the damage morphology of the interface failure is analyzed by SEM. Comparing the types of subsequent destruction of the classic interface, the most accurate optimization solution is finally confirmed. In the model, a resin layer is added to the part where the yarn is in contact with the yarn, and the contact between the yarns is optimized by setting the contact surface of the resin layer and the setting of the failure criterion. By optimizing the contact conditions between the yarns, the details of the stab-resistant simulation results are more in line with the actual results. It is found that after considering the anisotropy of the yarn and the contact between the yarns, the accurate value of the simulation results is greatly improved, and it is closer to the actual experimental results. That is, it is meaningful to consider the yarn anisotropy and the yarn-to-yarn contact in the simulation experiments.

Using the optimized model, we deeply analyze the puncture mechanism of this material and the influencing factors of its puncture resistance. The simulation results show that the main failure modes of the mesh material are resin fracture and flexural deformation of the yarns at the splices, while the surrounding area of the material is hardly affected. Based on this optimized model, by adjusting the parameters of the material, the influencing factors of the stab resistance of the material are studied. The influencing factors include the ratio of the axial and radial elastic moduli of the yarn (E_L/E_T), the ratio of the tensile strength of the yarn to the shear strength of the resin (σ_F/σ_R), and the diameter of the yarn (R). Experiments show that as the E_L/E_T ratio increases, the stab resistance of the material decreases. The stab resistance performance of the material improves with increasing E_L or yarn diameter but deteriorates with increasing σ_F/σ_R ratio.