

CHAPTER

5

FILAMENT-WOUND COMPOSITE STRUCTURE AND DESIGN FACTORS

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5.1 CONFIGURATION OF COMPOSITE MATERIALS

Composite material is defined as material that has two or more distinct constituents. In our surroundings, composite materials can be seen anywhere. Nature itself is full of examples of composite material. Wood, for example, consists of three constituents called cellulose, lignin and hemicellulose. While its leaf has a primary vein that becomes the core of the leaf and secondary veins that spread from the primary vein and hold the leaf blade, which is called the lamina. Then looking at the bone in our body, it is constructed by layers of collagen fibres and ground substances that act as a matrix, which is hardened by the binding of inorganic mineral salt. If we look closer at the design structure in those examples, each constituent is in an arrangement that acts as the reinforcement for the whole structure, and this makes it strong. Indeed, nature is wonderful and inspires most man-made inventions. And this is also how composite materials were designed. The concepts from nature were engineered to meet the requirements of inventions that exist in our world.

The growth of material advancement nowadays has remarkably increased, especially in applications that require lightweight but high-strength materials. Composite material is one of the best options to serve

the need for a high strength-to-weight ratio required by numerous advanced applications. Industries such as aerospace, automobile, sports equipment and electronics are synonymous with the use of composite materials, especially the fibre reinforced plastics (FRP).

FRP composites especially carbon fibre reinforced polymer (CFRP), offer significant advantages for industrial applications for their exceptional strength-to-weight ratio, widespread availability, and cost-effectiveness in today's advanced manufacturing landscape. CFRP is the composite material that is symbolically known to have the strength of steel with the weight of paper. This is the reason why CFRP is the most popular material to suit the advanced application material requirements.

Since a few decades ago, numerous efforts have been performed to improve the performance of CFRP. These efforts focused not only on improving its material properties but also on improvements in terms of manufacturing, lifespan, maintenance and environmental reliability. Even though a lot of research and development has been performed, there are still room for improvement and new discoveries required to fulfil the industry's requirements and serve the future of advanced applications. Nowadays, the advancement of composite materials is still evolving. The world always needs better material. Emerging technologies in telecommunication, electronic devices, aerospace and renewable energy sectors are among the technologies that constantly seek better material. Thus, numerous efforts were continuously made to contribute to material advancement, including nanomaterial, self-healing material, smart material, shape-memory material and many more. Though currently available composite materials also still need improvement to be well suited to technology demands.

One of the aspects that contributes to the material properties of CFRP materials is the ply orientation (Lei et al., 2024). As CFRP is constructed with several layers of carbon plies with different angles of orientation to produce so-called multidirectional CFRP laminate, the orientation of the carbon ply will have significant effects on the performance of CFRP laminate. The importance of ply orientation to fracture toughness has been a hot topic discussed and explored by

academics, researchers and industries (Rodríguez-Luján et al., 2025). Some areas of studies that have been discussed recently are regarding the behaviour of multidirectional and unidirectional laminates (Silva et al., 2020), the fracture toughness of asymmetrical laminates (Blondeau et al., 2019) and simulation studies of composite delamination (Almeida et al., 2017). From these literatures, each of these topics indicates a lot of aspects that need to be considered in designing composite materials, including angle of ply orientation, stacking sequence, and simulation method. Thus, a study that focuses on a combination of those aspects is required to understand its effects on the fracture toughness of CFRP materials.

Therefore, this chapter focuses on key considerations in the design of CFRP laminates, with particular emphasis on the influence of ply orientation achieved through stacking sequence and fibre angle configuration. It also explores how statistical methods can be applied to assess the impact of different stacking sequences on various structural profiles, aiming to identify the optimal laminate configuration under compressive loading. To illustrate this, the chapter presents a case study utilising the Design of Experiments (DoE) approach, specifically a 2^3 factorial design, to determine the significant factors affecting CFRP configuration through static structural analysis using ANSYS software.

5.2 CARBON FIBRE REINFORCED POLYMER STACKING SEQUENCE AND FIBRE ORIENTATION

Carbon fibre reinforced polymer (CFRP) composites are a composite material that uses carbon fibre as its fibre constituent. Compared to other fibres in composite materials, carbon fibre has four times higher elastic modulus than glass fibres and two times higher compared to aramid fibres. Other properties such as light weight, high durability, high temperature resistance and the ability to mass produce make CFRP composites one of the best composite materials to suit most advanced applications. This can be seen in a lot of structures that were made from CFRP composites, including bicycle frames, car bodies, wind turbine blades, boats, aeroplanes and space exploration.