Preface

Work on long continuous fiber polymer matrix composites has been ongoing for more than 70 years. There are more and more applications of these materials in making many engineering structures such as aircraft, automobiles, wind turbines, and sports equipment. The manufacturing of these structures has been mostly by hand. Recent advances in automated manufacturing technologies have introduced the use of automated tape laying (ATL) and automated fiber placement (AFP). The manufacturing of structures using composite materials is basically an additive manufacturing process, where layers of the materials are deposited over previous layers. This is the case whether the manufacturing is done by hand (hand lay-up) or by machine (ATL or AFP). Recently, the surge of 3D printing has brought more focus on the method of additive manufacturing. However, 3D printing normally refers to the use of powder, paste, or liquid forms of materials such as plastics or metals. For products made by 3D printing using plastics, the materials usually do not have high strength and modulus. There have been attempts to incorporate long continuous fibers into the process using regular 3D printing machines. However, the amount of fibers that can be incorporated is usually low (less than 10% by volume). On the other hand, ATL or AFP machines handle composite prepregs, where the fiber volume fraction is on the order of 60%. It is along the line of these ATL and AFP machines that the concept of 4D printing of composites (4DPC) was formed.

Over the past few years, there has also been rapid development of materials for 4D printing. This process is an extension of 3D printing. In this process, materials of different properties are deposited onto a flat mold (or molds of simple geometry). During the material deposition process, different materials are deposited at different locations onto the flat mold. These flat layers (or stacks of layers) of the material are then subjected to some external stimuli. The different materials react differently to external stimuli such as the absorption of water (or other liquids), heat, or light. The configuration of the spatial variation in material properties needs to be designed such that upon excitation from the external stimuli, the flat material structure would curl up to make some curved structure. Using this technique, structures of complex geometries can be made without the use of molds with complex geometry. This method usually uses materials that have low modulus and strength.

The concept of 4DPCs extends the concept of 4D printing but uses long continuous fiber composites that have been used for many years in industries. As such, stiff and strong structures with complex geometries can be made using molds of simple geometries such as flat plates. These structures can be classified into three categories: U-structures, C-structures, and A-structures. U-structures are unconstrained structures. These are the curved pieces resulting from the shape transformation from the flat stack of layers. These structures have free edges. If the edges are constrained by bonding, they become C-structures. While the U-structures may change shape due to variations in ambient conditions such as temperature and moisture, C-structures do not.

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One particular type of C-structure is the A-structure ("A" stands for almost). This refers to structures like the A-cylinder or the A-cone. They have the same shape as the cylinder or cone and may have mechanical properties that are similar to the perfect cylinder or cone, except that the edges of the A-cylinder or A-cone are bonded.

There are many applications of structures made by 4DPC. One application for a U-structure can be in the area of effective packaging. In this case, flat shapes are shipped to remote locations. Upon arrival, thermal activation can be used to change the flat structure into a curved structure. This is particularly useful for sending shelters to refugee camps or for sending supplies to outer space. Another application for the U-structures can be a cover for space instrumentation. During the evening, when the sun is not shining, the composite structure closes to protect the instrumentation. During the day, it opens up to expose the instrumentation to sunlight. One application for the C-structures is the corrugated core for a flexible wing. The corrugated composite core is made by 4DPC. Subsequently, it is bonded to the upper skin and lower skin to enable the manufacturing of a flexible wing. One application for the A-structures is the A-cone. The 4DPC process allows the composite cone to be made without the need for a mold of conical shape. It was demonstrated that this A-cone has the same buckling strength as a cone of similar weight made using the process of filament winding.

This book presents the development of 4DPCs since the inception of the concept in November 2016.

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