Patrick Madden/pam289

Process Optimization for Compression Molding of Carbon Fiber–Reinforced Thermosetting Polymer

Xie, Jiuming & Wang, Shiyu & Cui, Zhongbao & Wu, Jin. (2019). Process Optimization for Compression Molding of Carbon Fiber–Reinforced Thermosetting Polymer. Materials. 12. 2430. 10.3390/ma12152430. https://www.researchgate.net/publication/334777119_Process_Optimization_for_Compression_Molding_of_Carbon_Fiber-Reinforced_Thermosetting_Polymer

In our project, our objective is to perform compression molding on a state-of-the-art carbon matrix composite (CMC) and then perform mechanical testing on the manufactured CMC pieces. This article describes the optimization of compression molding on a carbon fiber-reinforced thermosetting polymer, which our CMC can be categorized as. Within the article, they test several different compression molding criterion to improve the mechanical performance of their composites, and this information can be pivotal in determining our own parameters for when we do our compression molding. This information can help us improve our own mechanical performance, and as such this article is very useful.

Carbon-fiber reinforced thermosetting polymer (CFRTP), owing to its high specific strength, specific modulus, fatigue resistance, corrosion resistance, and damage safety, is a dominant material when it comes to choosing a lightweight but extremely strong part. This material is heavily used in aerospace applications thanks to these fantastic properties, and the market for this material continues to grow due to its simple fabrication and processing. There are several different methods for molding CFRTPs, such as compression molding, autoclaving, winding, or pultrusion. Compression molding is a cost-effective way to safely and consistently manufacture CFRTPs. However, the final product's properties can be directly affected by preheating temperature, molding temperature, molding pressure, pressure holding time, cooling rate, exhaust pressure, exhaust times, and blank holder force. To optimize these parameters for improved mechanical performance, five process parameters were selected to characterize this process, specifically compression temperature, compression pressure, pressure holding time, cooling rate, and mold-opening temperature. By use of orthogonal tests and single-factor tests the tensile strength, bending strength, and interlaminar shear strength (ILSS) of the compression molded test pieces were analyzed. Through these tests, processing parameters when performing compression molding can be optimized for improved mechanical performance.

In this experiment, continuous carbon fiber (CCF300)-reinforced polyacrylonitrile (PAN) resin composite was used, and it was compression molded in a custom made 2000kN test machine. The tests were carried out on a universal material testing machine by MTS Systems Corporation, used for analysis of tensile and compressive properties of materials. To create samples for this experiment, prepreg was vacuum dried, interlaced at 90 degrees within a flat mold, preheated, heated, pressurized, pressure held, cooled, and unloaded. After this, each sample was cut into 20 test samples by water jet, after which the tensile strength, bending strength, and ILSS tests were performed, and the results averaged for each parameter tested.

From the orthogonal tests, the five earlier compression molding parameters were ranked in terms of their impact on mechanical properties. Tensile strength and ILSS were most impacted by compression temperature, followed closely by pressure-holding time. Bending strength was most impacted by pressure-holding time, followed by compression temperature. For the three mechanical properties, mold-opening temperature showed small affect.

Single-factor tests were then performed based on which compression molding parameters most affected mechanical performance. During this process only one criterion is changed while the rest remain unchanged. Through this method, a relationship between the parameters and mechanical properties can be established and mapped. However, since ILSS is not greatly affected by compression molding process parameters, only tensile and bending strength were tested.

A single-factor test was performed on compression temperature, keeping pressure-holding at 20 minutes, compression pressure of 50 MPa, cooling rate at 3.5 degrees C/min, and mold-opening temperature of 80 degrees C. From these tests, both tensile and bending strength are at their maximum at 150 degrees C, with a quick drop as temperatures increase. This is because if the heating temperature is too low, the resin within the compression mold cannot fully melt or flow, leading to high flow viscosity and insufficient impregnation. If the temperature is too high, the fibers can ablate and the resin degrade, reducing performance.

A single-factor test was also performed on pressure-holding time, with the same parameters as the previous test but with a compression temperature of 150 degrees C. The test showed that as time increased, so too did the mechanical properties, until a point. The mechanical performance remained constant after this threshold because both resin flow and impregnation improve with more pressure-holding time. However, once a threshold time is reached, resin flow ceases as full impregnation occurs. 20 minutes was determined to be the optimal time for the best mechanical properties.

Compression pressure was also tested across 40-55 MPa at 5 MPa intervals, with the same compression molding parameters as before. Mechanical properties increased as pressure increased, and a sweet spot of 50 MPa yielded the greatest mechanical properties, while 55 MPa resulted in decreased performance. A possible explanation for this is that growing pressure provides a greater driver for resin flow, causing increased impregnation rate and resin permeability. This causes the PAN matrix and carbon fibers to be bonded tighter than previously, increasing performance. However, if the pressure is too high, the molten resin may overflow and damage the resin structure.

Finally, a single-factor test was performed on cooling-rate, with the same parameters as the previous tests. From the results, a cooling rate of 3.5 degrees C/min gave the best mechanical properties, but as cooling rate increased, mechanical properties began to degrade. Theoretically, increased cooling rate causes greater residual stress within the samples, but in this test, an “increased” cooling rate showed better mechanical properties.