SHEET MOLDING COMPOUNDS (SMS) COMPOSITES MADE USING POST-INDUSTRIAL CARBON FIBER PREPREG WASTE

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Abstract
This study provides a fundamental understanding of the interplay between the process parameters and the resin characteristics of carbon fiber (CF) prepregs in composites manufactured by sheet molding compounding (SMC) and subsequent compression molding. The desired resin characteristics and appropriate processing conditions necessary to utilize post-industrial, pre-consumer CF prepregs are identified. First, the CF prepregs are converted to SMC and then to composite plates through compression molding. The tensile properties, impact strength, the density and void content of the composites are determined as a function of the width of the CF prepreg tapes used in SMC and of the out-time of the CF prepreg tapes and as a function of the pressure applied during compression molding. It is observed that the distribution of the CF prepreg chips within the SMC is not totally random which leads to in-plane anisotropy. It was concluded that in plane anisotropy masks any effect of the CF prepreg tape characteristics such as tape width and out-time. The produced CF SMC composites significantly outperform the current state of the art SMC composites i.e., 60 wt% 25.4mm long GF/epoxy.

1. Introduction

There is high-demand for carbon fiber reinforced polymers (CFRP) mainly due to the superior mechanical properties and low density of carbon fibers. CFRP are commonly used in aerospace where the overall demand of CF prepregs has increased significantly lately [1]. As a consenquence the prepreg trim waste produced from the aerospace industries has also Currently the prepreg trim waste ends up in landfills usually after it has been cured to avoid leaching of chemicals to the envinrment. In addition to the environmental effect, the high cost of these high performance materials dictate the need for a sustainable solution that is the conversion of the prepreg trim waste from the aerospace industry into high value products such as composites for automotive applications where currently the use of carbon fibers is cost prohibitive.

Sheet molding compounds (SMC), that consist of thin sheets of uncured thermoset resin i.e., epoxies or polyesters, reinforced usually with chopped glass fibers (GF) up to 50-60 wt% are commonly used for automotive applications. The parts are made by compression molding of the SMC because it is a cost effective and reliable manufacturing method that can be easily automated for high volume production. The key advantages of SMC are their high strength to weight ratio, inherited design flexibility and improved damage resistance among others [2]. For these reasons, the SMC technology is selected in this study in order to convert the CF prepreg trim waste into composites. The trim waste is available in many forms including continuous tapes. The incoming materials from Boeing usually varies in terms of the tape width and the out-time of the prepreg trim waste. This creates the need to understand the effect of these two material characteristics on the properties of the composties. Short CF reinforced polymer composites, not aerospace grade CFRP but better than traditional SMC composites were first introduced to the aerospace community by Halpin and Pagano [3-5]. Boeing 787 has already used this material for window frames [3-6].

In this study, the effect of the CF prepreg tape width and outtime of the tapes on the mechanical properties of the composites made by first converting the tapes into SMC and them compression molding the SMC is determined.

2. Experimental Section

2.1. Materials

Prepreg trim waste was supplied by Boeing in the form of tapes consisting of ~ 60 wt% unidirectional (UD) CF reinforced epoxy manufactured by Toray Composite Materials (America), Inc.,. These tapes without using extra resin were used to make the SMC sheets. The aspect ratio of the tapes (length/width) was a variable that was investigated. The prepreg tapes were cut in the SMC line at a length of either 25.4 or 50.8 mm. Another variable that was investigated was the outime of the tapes, and thus fresh tapes where the resin was still tacky were stored in the freezer until they were used, and they were compared to aged or dry prepreg tapes that were stored at ambient temperature for various time periods prior to their use in the SMC line.

2.2. Manufacturing of Composites

The prepreg tapes were converted to SMC using an SMC production line by Finn and Fram Inc.The only difference between this SMC line and the heavy duty industrial lines is the width of the produced SMC, which is 0.3 m versus 0.9-1.5 m width of the industrial lines. As a consequence, the obtained results are highly relevant to industry. The prepreg trim waste tapes in form of spools, were fed through the guide to the cutting head of the SMC line. The tapes were cut in chips of predetermined length and were thrown randomly on the carrier film on the conveyor belt.

The major difference between the “fresh” and “aged” prepreg tapes in terms of processing was that the “fresh” can be converted to continuous sheets but the “aged” tapes cannot. The pressure applied during the compation zone of the SMC line on the “fresh” chip squeezes out the resin which acts as adhesive among the chips. The chips of the “aged” tapes were not sticking to each other and were collected at the end of the SMC line as individual chips that were manually placed in the mold for compression molding. Five spools of prepreg tape were used and the feeding guides were spaced equally along the width of the SMC line. The distance between the plate guide for throwing the prepreg chips on the conveyor belt was kept constant. The set values for the process parameters that were used are reported in Table 1. The resulted SMC was ~ 4 mm thick and 280 mm wide.

A closed mold was used to fabricate the composite plates using either the CF prepreg SMC or the individual CF prepreg chips in a Wabash V-50-1818-2TMX hotpress under vacuum. Once the mold was filled it was closed and placed in the press. The temperature was increased to 195 ºC and then a pressure and vacuum was applied for 15 minutes.

Table 1. Set values of processing parameters in the SMC production line.

Processing Parameters	Set Value
Feed pressure	200 KPa
Cutting pressure	275 KPa
Upper belt tension	415 KPa
Lower belt tension	480 KPa
Speed of cutting	1500 RPM
Conveyor setting	15 (range 0-60)
Winder tension	480 KPa
Number of spools	5
Distance between neighboring feeding guides	57.15 mm

2.3 Characterization Techniques

The degree of cure (DOC) of the SMC composites was measured using a DSC Q2000 (TA Instruments). The ~6 mg samples were heated from 25 °C to 300 °C at 10 °C/min. Each data point is an average of at least three measurements. DOC is the ratio of (total -residual) enthalpy of cured resin to the enthalpy of curing the prepreg resin. The composite plates with dimensions of 280 mm X 280 mm X 5 mm were kept at ambient temperature for 24 hours prior to cutting and testing to prevent any potential plastic deformation during handling/testing. The thickness profile for each plate along 3 different cross sections was measured using a Mitutoyo micrometer 118-129. The test coupons were cut out from the plates using a waterjet (MAXIEM 1515). The density and the void content of the composites were determined using the water displacement technique and polymer digestion using acids respectively. Specifically, Mettler Toledo AG245 was used following ASTM D792 to obtain the density. Each date point reported is an average of three measurements. The sample was weighed in air and water at ambient temperature to calculate density per Archimedes' principle. The void content, was determined according to ASTM D 3171. Each sample of ~ 2 grams was immersed in nitric acid and heated at 80 ^{o} C for 2 hours followed by rinsing the fiber with distilled water to remove any resin residue. The fiber was then heated for 5 hours at 115 ^{o}C and cooled overnight before it was weighed.

The tensile properties of the SMC prepreg composites were determined per ASTM D638 using an Instron 33R 4466 equipped with 10 kN load cell for dog bone samples with a gauge length of 57 mm, width of 13.1mm and thickness of 4 to 5mm. An extensometer, Instron 2630-106, with a gauge length of 25 mm was used to record the axial strain. The modulus was calculated between the axial strain values of 0.05% and 0.2%. The impact energy was measured using Charpy with no notch tests with an Instron SI series pendulum impact tester with a maximum impact head of 406.7 J (300 ft-lbf) according to ISO179 with a support span of 43 mm for 12.7 mm wide and ~5 mm thick rectangular samples. Each data point reported is an average of at least seven tests.

A Phenom G2 Pro (Phenom-World BV) scanning electron microscope (SEM) at an acceleration of 5 kV was used to study the fracture surfaces of the SMC composites. A plasma sputter (Ted Pella Inc.) was used to apply gold coating on the surface of the samples prior to SEM imaging to minimize charging. Through thickness microstructure, prior to fracture, has been observed as well. A sample cross-section of 9 mm X 5 mm was set in an epoxy mold and polished in an Allied Hightech Metprep 3 polisher. Then a Leica DM 2500P optical microscopy was used to take images.

3. Results and Discussion

In order to understand the effect of the pressure during the compression molding stage plates using the same type of CF prepreg tapes (same chip length and same age of the prepreg) were used. The plates made and the corresponding compression molding pressure used for each are shown in Table 2. The impact strength of these plates is presented in Figure 1. One would expect that higher pressure will lead to composite plates with fewer voids and more in-plane alignment of the CF prepreg chips. However, as shown the variation in the strength among testing coupons from the same plate is so high due to the inherited in-plane anisotropy that it masks any effect of the pressure.

A similar conclusion was reached in case of the tensile properties. Also it was determined that the void content is similar for all composites and is not affected by the pressure applied.

Table 1. ID of composite plates and the corresponding pressure during compression molding for each plate (more than one plate using the same pressure was made to determine variability).

Plate ID	Pressure during compression molding (MPa)
P6.1	1
P6.2	1
P6.3	1
P7.1	2
P7.2	2
P8.1	4.7

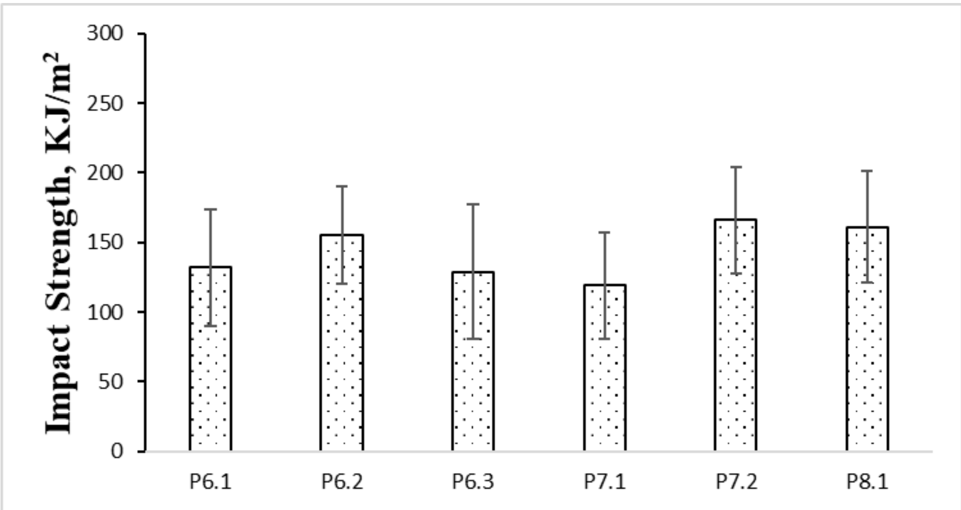

Figure 1. Impact strength as a function of the pressure during compression molding (the P6 plates were made using 1 MPa, the P7 plates using 2 MPa and the P8 plate using 4.7 MPa)

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3. Conclusions

CF prepreg trim waste, available in form of tapes, was successfully converted in composite using SMC production line and compression molding. It was found that the out-time of the prepreg tapes is affecting the ability to convert the tapes into SMC but once the composites are made, there is no effect of the prepreg age on the properties of the resulted composites. Also there is no effect of the pressure used during compression molding.

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