Novel Methods for Composites Recycling via Pyrolysis

Andy George | Manufacturing Engineering Technology

Project Purpose

The purpose of this research is to further the field of composites processing through a characterization of reclaimed carbon fibers under conditions of pyrolysis.

Project Importance

Vast quantities of carbon fiber are scrapped and sent to landfills each year. The American Composites Manufacturer's Association estimates that in 2017, the automotive industry alone used over four billion pounds of composite materials[1]. Without an industry-standard practice of salvaging at least some of this material at the end of its usable life, billions more will go to waste. Use of recycled carbon fibers has the potential to save large amounts of money that otherwise would be spent on virgin carbon fibers when the recycled carbon fiber is perfectly usable in many applications. Money would be saved by reducing redundant purchasing and lowering raw materials costs.

There are many challenges with recycling carbon fiber that this research hopes to assist in overcoming. Here are two brief examples:

First are the challenges associated with the process of pyrolysis. Pyrolysis is emerging as the industry preferred method of recycling composites. Pyrolysis is essentially off-gassing the resin at temperatures in excess of 800 degrees Fahrenheit in a deoxygenated environment. One of the challenges, however, is that this also removes any of the sizing and coupling agents which protect the fibers during manufacturing and improve the adhesion of the fibers to the matrix for improved mechanical properties. What remains are discontinuous fibers that are fluffy, hard to control and disperse into a matrix due to a lower surface energy (without the coupling agent). In industry, pyrolysis is done in a deoxygenated environment by flooding the chamber or oven with nitrogen, an inert gas. Removing the oxygen prevents the resin matrix from combusting, which has been shown to leave behind a charred substance on the surface of the fibers.

Secondly, to recycle composite parts, the parts are typically shredded into a discontinuous fiber state after pyrolysis. Discontinuous and randomly oriented fiber composites do not exhibit the same high performance characteristics as continuous fiber composites due to their truncated fiber lengths. Discontinuous fiber composites can have more voids and may not achieve as high of a fiber-to-resin ratio because their fibers aren't as easily nested together, as opposed to longer continuous fibers. In turn, this reduces the specific strength achievable by these

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[1] ACMA, https://acmanet.org/composites-industry-overview/

materials. Discontinuous fibers can be realigned in order to improve part performance. However, at this time there has been little work done to achieve a uniform fiber direction. Fibers that are discontinuous also increases the complexity of reapplying a sizing agent.

Project Overview

The project will encompass (1) a literature review of the current state of the art of composites recycling, and (2) an experiment that will evaluate retention of properties after the pyrolysis process and utility of the application of a sizing agent in post-processing.

As a part of the body of the work, the strengths and stiffness being achieved with reclaimed carbon fibers in thermoplastics by leading researchers and producers will be reported, with a discussion of the technologies/processes being used to achieve these values. In addition to the strengths that can be achieved, there is definitely a marketing advantage that a business could gain from incorporating recycled fibers into their product, as BMW has done with the roof panel of their i8 supercar[2].

Potential uses for recycled composites will be discussed, as well as their limitations once reclaimed. Because they are now discontinuous they are likely no longer eligible for high-performance applications, such as in heavily loaded structures, so appropriate new fields must be identified to be able to reuse the fibers.

Technologies and processes such as those outlined in current literature reviews[3] demonstrate that there are few established standards for composites recycling in industry practice, and accordingly, this need will be addressed as well.

For the experimental phase of the research, a roll of unprocessed carbon fiber material will be selected for producing 4 test groups:

(1) Virgin-sized carbon fibers, no pyrolysis
(2) Processed (3mm fibers), no pyrolysis
(3) Fibers reclaimed with pyrolysis, oxygen-free environment
(4) Fibers reclaimed with pyrolysis, ambient air environment

Fiber samples will then be processed into 3mm length fibers. Fibers will then be introduced to the matrix at a predetermined percent fiber volume content. Following this, samples will be

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[2] Can We Make Recycled Carbon Fiber Sexy?, Dale Brosius
https://www.compositesworld.com/articles/can-we-make-recycled-carbon-fiber-sexy

[3] Current Status of Recycling of Fibre Reinforced Polymers: Review of Technologies, Reuse and Resulting Properties, Géraldine Oliveux, Luke O.Dandy, Gary A.Leeke
https://www.sciencedirect.com/science/article/pii/S0079642515000316?via=ihub

molded by an injection molding process to produce samples for tensile testing. Samples will then be tensile tested and analyzed at fracture point.

Industry use for injection molded CFRP samples can also be benchmarked in this effort, both for processing and for mechanical properties.

Response variables involved include:
- Oxygen vs deoxygenated atmosphere (during pyrolysis)
- Bath vs spray vs no application (method of sizing)

Control variables include:
- Fiber & Sizing
- Fiber resin ratio
- Fiber Length
- Pyrolysis Time & Temperature

These factors could be tested using a mixed level design of experiments. One 2 level factor and one 3 level factor would require a minimum of 6 runs, but should have at least 3 replicates.

Figuring out the best method of dispersing fibers into matrix seems like it may prove difficult. However, this could be remedied by simply mixing the fibers into a matrix in small batches and extruding pellets with the extruder in the lab, followed by a run through the injection molder to get uniform dog bone samples.

Although uncertainties exist in the viability of sizing application and surface treatment for composites recycling, building upon previous work in pyrolysis and utilizing the unique resources available at BYU (composites lab, ready access to aerospace-grade fibers, industry standard processing equipment, scanning electron microscopes, etc.), the work's importance and potential for contributions to the field are clear.

Qualifications of Thesis Committee

Faculty Advisor - Andy George

Dr. Andy George is an Associate Professor of Manufacturing Engineering. Professor George holds a Ph.D. in Composites Process Engineering from the University of Stuttgart's Institute for Aircraft Design, which he completed within a European research network fellowship. Previously he received a B.S. in Chemical Engineering (with a focus on biomaterials) and an M.S. in Manufacturing Engineering (focusing on non-destructive measurement of weathering damage in plastics), both at Brigham Young University. He has worked for the Swedish Institute of Composites (Swerea SICOMP), where he consulted the European aerospace industry on composites processing. Professor George currently teaches undergraduate and graduate courses on composites and plastics materials and processing. His research deals with modeling and simulation of resin infusion composites processing, studying flow and other phenomena through porous media, permeability measurement, fabric compressibility, thermosetting resin cure kinetics, capillary flow, void formation and movement, and void mechanical effects. Professor George currently serves as the chair of the SAMPE Utah chapter.

Faculty Reader – Yuri Hovanski
Dr. Yuri Hovanski is an Associate Professor of Manufacturing Engineering Technology. He earned a B.S. Degree in Mechanical Engineering at Brigham Young University, and then completed his M.S. and Ph.D. degrees in Mechanical Engineering at Washington State University. Working as a senior research engineer at Pacific Northwest National Laboratory, he has actively participated as a member of AWS, ASM, TMS, and SAE, including various committees and in organizational leadership roles. Professor Hovanski has focused on the development of low-cost solutions to facilitate industrial application of friction stir welding, introducing cost-efficient solutions for thermal telemetry, new tool materials and production techniques for friction stir spot welding tooling, high-speed friction stir welding for production of aluminum welded blanks, and friction stir scribe technology for joining very dissimilar materials. As the inventor of friction stir scribe technology, he has led the effort in to demonstrate effective means of joining aluminum to steel, magnesium to steel, aluminum to titanium, and polymer composites to aluminum. He actively reviews literature related to joining technologies for more than a dozen publications, and he has authored or co-authored more than 50 publications documenting his work. Professor Hovanski teaches courses on automation, the internet of things, and smart factories. His research focuses on automation in manufacturing environments, as well as novel joining technologies.

Honors Coordinator – Mike Miles
Dr. Michael Miles is a professor of Manufacturing Engineering. He earned a B.S. in Metallurgical Engineering in 1989 from University of Idaho, an M.S. degree in Metallurgical Engineering in 1991 from The Ohio State University, and a Ph.D. in Materials Science and Engineering in 1995 from Ecole des Mines de Paris. He worked as a project engineer, engineering manager, and assistant plant manager for American National Can/Pechiney and Rexam from 1995 to 2001. Professor Miles' teaching interests include welding and joining, casting, metal forming, manufacturing systems, and lean manufacturing. His research efforts focus on novel solid state joining processes, microstructure/formability relationships in sheet metal alloys, and the simulation of forming and joining processes. Professor Miles has been supported by grants from the National Science Foundation (6), the Department of Energy (3), the Auto/Steel Partnership (2), DARPA (1), NASA (1), South Korea RE-EV Program (1), and the Society of Manufacturing Engineers (1), for a total of $2.8 MM.

Project Timeline
27 September 2019 - Thesis Proposal submitted
14 December 2019 – Literature Review Complete
1 February 2019 – Experimental Results Complete
21 February 2020 - Thesis Defense Information Form submitted
11 March 2020 – Thesis Defense occurs by this date
20 March 2020 – Final Thesis PDF submitted

IRB or IACUC Approvals

None required for this project.

Funding

For this project, $1000 of funding is requested from the Honors Program. Analysis from the Scanning Electron Microscope will cost $15 per half hour. Approximately six hours of analysis will be sufficient. Additionally, a tube furnace that feeds nitrogen gas into the oven will need to be constructed, at approximately $300 cost. Other funds will enable the researcher to cover misc. expenses, and other costs incurred from the use of the lab and materials. Lastly, these funds will allow the researcher to help write, print, and publish the materials.

$180 300 $480 ?

Other sources include ORCA/experiential learning funding, as well as other sources from within the college of engineering.

Culminating Experience

It is anticipated that after the completed paper will be published, a poster session local to BYU will be attended with a presentation of the final work. Additionally, a few other conferences have been identified that would be a good fit for this work, with opportunities to find an industry connection. Dr. George and Dr. Hovanski have provided a few ideas to me in this regard. These opportunities are (but are not limited to):

- Utah Conference for Undergraduate Research (UCUR), February 2020
- CAMX 2020, Florida, March 2020
- Annual Conference on Engineering and Information Technology (ACEAIT), Osaka Japan, Mar 2020
- SAMPE Spring Conference, Seattle WA, May 2020