THROUGH-THICKNESS REINFORCEMENT FOR WOVEN LAMINATES

ALEJANDRA G. CASTELLANOS

Master's Program in Mechanical Engineering

APPROVED:

Pavana Prabhakar, Ph.D., Chair

Yirong Lin, Ph.D.

David A. Roberson, Ph.D.

Charles Ambler, Ph.D.
Dean of the Graduate School

to my

Family and Friends

with unconditional love

THROUGH-THICKNESS REINFORCEMENT FOR WOVEN LAMINATES

by

ALEJANDRA G. CASTELLANOS

THESIS

Presented to the Faculty of the Graduate School of

The University of Texas at El Paso

in Partial Fulfillment

of the Requirements

for the Degree of

MASTER OF SCIENCE

Department of Mechanical Engineering

THE UNIVERSITY OF TEXAS AT EL PASO

May 2016

Acknowledgements

I would like to express my deep-felt gratitude to my advisor, Dr. Pavana Prabhakar from the Mechanical Engineering Department at The University of Texas at El Paso, for her advice, encouragement, enduring patience and constant support through my master.

I also wish to thank the other members of my committee, Dr. Yirong Lin from the Mechanical Engineering Department and Dr. David Roberson from the Metallurgical, Materials and Biomedical Engineering Department, both from The University of Texas at El Paso for their guidance and expertise I needed in order to complete this work.

I want also to thank Shuvo, Jerry, Jose and Emilio for the ZnO nanowires. I want to thank Andy for his inconditional love and support during my master. Andy, thanks to you I am here. Additionally, I want to thank all my friends who have been in every step of my educational process and who have give me all kind of support (not in specific order): Luis Chavez, Diego Delfin , Luis Varela, Luz Bugarin, Raudel Avila, Luis Delfin, Daniela Aguilar, Juan Gomez, Alan Esparza, Jesus Ortega, Ricardo Martinez, Armando Delgado, Sergio Guerrero, Jerry Rodriguez, Sergio Quevedo, Jaime Cruz, Jose Romero and Marco Avalos. Thank you guys for all your support and never letting me quit, without you it would not be the same. I love every one of you.

Abstract

Fiber reinforced polymer composites have gained popularity in aerospace and naval applications due to their tailorable mechanical properties and high strength-to-weight. Despite these advantages, between the layers of fabric (laminas), there is a resin-rich region known as interlaminar region, with no reinforcement which is very susceptible to damage. Different types of reinforcements have been tested for the interlaminar region. However, all of these methods have proved to decrease the in-plane properties due to damage to the fibers. In this thesis, a new reinforcement technique with ZnO nanowires is proposed to increase the damage resistance. This thesis describes the design, manufacturing and testing of woven composites with ZnO nanowire reinforcement. Damage resistance and durability of these composites are evaluated under quasi-static loading (Mode-I and Mode-II) and under dynamic loading (impact). Nanowire reinforcements appear to increase the damage resistance of a composite without reducing the in-plane properties of the composite. For quasi-static loading, the improvement of the interlaminar fracture toughness for Mode-I and Mode-II was approximately 74% and 28%, respectively. For dynamic loading, the damage degree was reduced by approximately 18%. This improvement is attributed to the resistance of nanowire reinforcement towards creating new surfaces.

Table of Contents

List of Tables

List of Figures

Chapter 1

Introduction

Technology is improving every day; as a result, human beings have become more demanding. They want the lightest cell phones, the car with the best fuel efficiency and the fastest computer. Most of these innovations have been possible due to advancements in the field of materials. Although technology is evolving, materials are not at the same rate. To overcome this problem, materials like polymers, composites, and ceramics have become a very attractive option to replace conventional materials such as steel and aluminum. Composite materials are not an invention of human kind, as they exist in nature. A perfect example is wood, which is made by cellulose fibers that are held together in a substance known as lignin [2]. Cotton is also made by cellulose fibers, but the combination of cellulose fibers with lignin, which is weaker than cellulose fibers, is what makes wood stronger than cotton. Composite materials are not a new technology as they were used thousands of years ago. The first register of humankind using composites was from ancient Egypt. Egyptians used chopped straw to reinforce mud bricks and laminated wood veneer reinforcing with glue for sarcophagi. Later, metals started to dominate the world. First bronze in 1500 BC, then iron, and steel in 1850 [3]. Composite materials then began to gain popularity again in 1980 due to their excellent mechanical properties [4]. Composite materials are a combination of two or more constituent materials with different mechanical properties. This combination results in a ”super” material that exhibits the best properties of the constituent materials plus added properties that the individual materials do not exhibit alone [5]. There are two general phases of constituent material: matrix phase and reinforcing phase (Fig. 1.1).