ผลของน้ำมันแก๊สโซฮอล์ต่อสารประกอบแต่งพอลิไวนิลคลอไรด์ เสริมแรงด้วยเส้นใยแก้ว

นางสาวกังสดาล เอกเจริญ

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิศวกรรมศาสตรมหาบัณฑิต
สาขาวิชาวิศวกรรมเคมี ภาควิชาวิศวกรรมเคมี
คณะวิศวกรรมศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย
ปีการศึกษา 2552

EFFECTS OF GASOHOLS ON GLASS FIBER REINFORCED POLYVINYL CHLORIDE COMPOSITE

Miss Kangsadan Ekcharoen

A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Engineering Program in Chemical Engineer
Department of Chemical Engineering
Faculty of Engineering
Chulalongkorn University
Academic Year 2009

Thesis Title	EFFECTS OF GASOHOLS ON GLASS FIBER REINFORCED POLYVINYL CHLORIDE COMPOSITE
By	Miss Kangsadan Ekcharoen
Field of Study	Chemical Engineering
Thesis Advisor	Varun Taepaisitphongse, Ph.D.

Accepted by the Faculty of Engineering, Chulalongkorn University in Partial Fulfillment of the Requirements for the Master's Degree

.... Dean of the Faculty of Engineering
(Associate Professor Boonsom Lerdhirunwong, Dr.Ing.)

THESIS COMMITTEE

A Soottitantawat
.... Chairman
(Apinan Soottitantawat, Ph.D.)

.... Thesis Advisor
(Varun Taepaisitphongse, Ph.D.)

.... Examiner
(Assistant Professor Anongnat Somwangthanaroj, Ph.D.)

.... External Examiner
(Associate Professor Somsak Woramongkolchai, D.Eng.)

กังสดาล เอกเจริญ : ผลของน้ำมันแก๊สโซฮอล์ต่อสารประกอบแต่งพอลิไวนิลคลอไรด์เสริมแรงด้วยเส้นใยแก้ว. (EFFECTS OF GASOHOLS ON GLASS FIBER REINFORCED POLYVINYL CHLORIDE COMPOSITE) อ. ที่ปรึกษาวิทยานิพนธ์หลัก: อ. ดร. วรัญ แต้ไพสิฐพงษ์, 159 หน้า.

งานวิจัยนี้มีจุดมุ่งหมายเพื่อศึกษาผลกระทบของปริมาณเส้นใยแก้วและความเข้มข้นของเอทานอลในน้ำมันแก๊สโซฮอล์ที่มีต่อสมบัติเชิงกายภาพและสมบัติเชิงกลของสารประกอบแต่งพอลิไวนิลคลอไรด์เสริมแรงด้วยเส้นใยแก้ว ที่ถูกเตรียมจากพีวีซีเรซินที่มีค่า K เท่ากับ 58 (และสารเติมแต่งอื่น ๆ) ผสมกับเส้นใยแก้วชนิด E-glass แบบสั้นที่มีขนาดความยาวเฉลี่ย 3 มิลลิเมตร โดยใช้ปริมาณเส้นใยแก้วตั้งแต่ 0, 15 และ 25 เปอร์เซ็นโดยน้ำหนัก ส่วนผสมทั้งหมดจะถูกผสมในเครื่องผสม (Mixer) และนำมารีดเป็นแผ่นโดยใช้เครื่องผสมชนิดสองลูกกลิ้ง (Two- roll milling) แล้วอัดขึ้นรูปเป็นแผ่นด้วยเครื่องอัด (Compression Molder) ตัดเป็นรูปชิ้นงานแบบดัมเบลล์ (Dumbbell shape) แท่ง (Bar shape) สี่เหลี่ยมจัตุรัส (Block shape) และแบบวงกลม (Disk shape) ชิ้นงานที่ได้ถูกแช่ในน้ำมันทดสอบ 4 แบบตามมาตรฐาน SAE J1681 คือ $C(E0)_A$, $C(E20)_A$, $C(E85)_A$ และ $C(E100)_A$ ในโหลแก้วที่อุณหภูมิห้องเป็นระยะเวลา 16 อาทิตย์

ผลการทดลองพบว่าเส้นใยแก้วมีการกระจายอยู่ทั่วเนื้อเรซิน มีการยึดเกาะที่ดี ทำให้สมบัติเชิงกลของสารประกอบแต่งพอลิไวนิลคลอไรด์เสริมแรงด้วยเส้นใยแก้วเพิ่มมากตามปริมาณเส้นใยแก้วที่เพิ่มขึ้น มวลและปริมาตรของสารประกอบแต่งเพิ่มขึ้นเนื่องจากการดูดซับไอโซออกเทนและโทลูอีนเข้าไปในพีวีซีเมตริกซ์ น้ำมันทดสอบที่มีส่วนผสมของแอลกอฮอล์น้อย ได้แก่ $C(E0)_A$ และ $C(E20)_A$ ทำให้สมบัติการทนแรงดึง ค่ายังมอดูลัส (Young's modulus) ค่าทนแรงดัดงอ และค่าทนแรงกดอัดของสารประกอบแต่งพอลิไวนิลคลอไรด์เสริมแรงด้วยเส้นใยแก้วลดลงมากกว่า แต่ทำให้ค่าทนแรงกระแทกเพิ่มขึ้นมากกว่าน้ำมันทดสอบที่มีส่วนผสมของแอลกอฮอล์มาก ได้แก่ $C(E85)_A$ และ $C(E100)_A$ เนื่องจากการลดลงของสมบัติเชิงกลของพีวีซีเมตริกซ์เองจากการดูดซับไอโซออกเทนและโทลูอีนเข้าไปในพีวีซีเมตริกซ์ ดังนั้นสารประกอบแต่งพอลิไวนิลคลอไรด์เสริมแรงด้วยเส้นใยแก้วมีความไม่เหมาะสมที่จะใช้งานร่วมกับน้ำมันที่มีส่วนผสมของแอลกอฮอล์น้อย (≤ 20% โดยปริมาตร)

ภาควิชา วิศวกรรมเคมี ลายมือชื่อนิสิต
สาขาวิชา วิศวกรรมเคมี ลายมือชื่อ อ.ที่ปรึกษาวิทยานิพนธ์หลัก
ปีการศึกษา 2552

5070213221 : MAJOR CHEMICAL ENGINEERING

KEYWORDS : POLYVINYL CHLORIDE / GLASS FIBER / GASOHOLS / GLASS FIBER REINFORCED POLYVINYL CHLORIDE COMPOSITE

KANGSADAN EKCHAROEN: EFFECTS OF GASOHOLS ON GLASS FIBER REINFORCED POLYVINYL CHLORIDE COMPOSITE. THESIS ADVISOR: VARUN TAEPAISITPHONGSE, Ph.D., 159 pp.

In this work the effects of glass fiber content and ethanol concentration in gasohols on the physical and mechanical properties of PVC/GF composites were studied. PVC resins with K-value of 58 (and other additives) were mixed with chopped E-glass fiber of 3 mm length at 0, 15, and 25 wt% using two-roll mill, then compressed into sheet, and cut into dumbbell shape, bar shape, block shape and disk shape specimens. The specimens were immersed into 4 different test fuels, namely $C(E0)_A$, $C(E20)_A$, $C(E85)_A$, and $C(E100)_A$, prepared according to SAE J1681, in glass jars at room temperature for 16 weeks.

The experimental results revealed relatively good dispersion of the glass fiber in the composites. The mechanical properties of PVC/GF composites increased with increasing glass fiber content. The mass and volume of PVC/GF composites increased due to absorption of iso-octane and toluene into PVC matrix. Test fuels with low ethanol content, namely, $C(E0)_A$ and $CE(20)_A$, caused the tensile strength, Young's modulus, flexural strength and compressive strength of PVC/GF composites to decrease more but the impact strength to increase more than test fuels with high ethanol content, namely, $C(E85)_A$ and $CE(100)_A$, due to the reduction of mechanical properties of PVC matrix itself from absorption of iso-octane and toluene into PVC matrix. PVC/GF composites were not compatible with fuels with low ethanol content ($\leq$ 20 vol%).

Department: CHEMICAL ENGINEERING Student's Signature
Field of Study: CHEMICAL ENGINEERING Advisor's Signature
Academic Year : 2009

ACKNOWLEDGEMENTS

The author would like to express sincere gratitude and deep appreciation to my advisor, Dr. Varun Taepaisitphongse, for his vision, intelligence, guidance and kindness throughout the course of this research. Furthermore, I would like to thank the committee of this thesis, Dr. Aphinan Soottitantawat, Asst. Prof. Dr. Anongnat Somwangthanaroj, and Assoc. Prof. Dr. Somsak Woramongkolchai, for the kind advices and good comments.

PVC resin, mixer, two-roll mill, and compression mold supported by Vinythai Public Company Limited is gratefully acknowledged. Partial financial support from the Research Assistant Grant, Faculty of Engineering, Chulalongkorn University, Bangkok, is greatly appreciated.

Additionally, thanks to all my friends and everyone in the Polymer Engineering Laboratory, Chulalongkorn University, for their discussion and friendly encouragement.

Finally, I would like to thank, from the bottom of my heart, my parents who always give their unfailing love, understanding, and generous encouragement throughout my entire study.

CONTENTS

PAGE

PAGE

LIST OF TABLES

LIST OF FIGURES

PAGE

PAGE

PAGE

PAGE

PAGE

PAGE

PAGE

PAGE

PAGE

CHAPTER I

INTRODUCTION

1.1 General Introduction

Presently, the rate of gasoline consumption has been increasing dramatically along with the price increase around the world. In order to lower the gasoline consumption, an alternative energy source from crop product is developed. The one of alternative energy becoming well known is gasohol. Gasohol is a mixture of gasoline and ethyl alcohol. It is widely used as an alternative fuels for gasoline. Commercially, E0 (or normal gasoline), E20, E85, and E100 (or pure ethanol) refer to gasohols with 0, 20, 85, and 100 vol% ethyl alcohol, respectively. In Thailand, the trend of gasohol consumption rate is rising rapidly. This results in reduction of imported crude oil and domestic crop price enhancement. Gasohols with higher content of ethanol are more corrosive to materials than gasohols with lower ethanol content. And can damage some equipment such as fuel pipe, fuel pump, fuel spray, fuel container and also including all of the rubber seal inside the fuel system. Hence, there is a need to develop material that is more compatible with gasohols [1].

Lately, plastic is becoming widely used as an alternative material for gasohol fuel system, due to the corrosive resistance, flexibility, transparency and easily molding. There are many types of plastic in these days and polyvinyl chloride (PVC) is generally considered as a possible candidate. Obviously, PVC has remarkable properties such as environmental endurance and chemical endurance.

In engineering, the material trend is becoming lighter with high toughness and high corrosive resistance. Normally, the plastic with lower modulus is tougher than the higher one. To increase the plastic toughness, the reinforcing substance such as glass fiber is added. The glass fiber is a high-tensile fiber with high modulus and high humidity and corrosive resistance. Moreover, the glass fiber also has very stable structure and cheaper price compared with other fiber material. The application of glass fiber to the PVC should give better mechanical properties of PVC. This can be developed into suitable fuel system parts for automobile using gasohol.

In this work, the effects of glass fiber content and ethanol concentration in gasohols on the physical and mechanical properties of PVC/GF composites were studied. The compatibility between PVC/GF composites and gasohol was studied the effects of ethanol concentration in gasohol on physical and mechanical properties of PVC and PVC/GF composites. Four different concentrations of gasohol will be used.

1.2 Objectives

1. To study the effects of glass fiber content on the physical and mechanical properties of PVC/GF composites.
2. To evaluate the effects of ethanol concentration in gasohol on physical and mechanical properties of PVC and PVC/GF composites.
3. To study the compatibility between PVC/GF composites and gasohol.

1.3 Scopes of the Study

- Polyvinyl chloride, trade name as SIAMVIC 258RB, is supplied by Vinythai Public Company Limited.
- E-Chopped strand glass fiber (ECS-401AD Chopped strand) with aspect ratio 272.73 is purchased from Jushi Group Co., Ltd.
- PVC dry blend designated “$\text{PVC}_{\text{stock}}$” is mixed with the appropriate additives per formulation shown in Table 4.1.
- $\text{PVC}_{\text{stock}}$/GF composites at these weight ratios of $\text{PVC}_{\text{stock}}$: GF at 100:0, 85:15 and 75:25 are prepared.
- Four test fuels $C(E0)_A$, $C(E20)_A$, $C(E85)_A$ and $C(E100)_A$ are prepared from Fuel C and aggressive alcohol according to SAE (Standard J1681).

  Note: ASTM Test Fuel C

  - Test Fuel C is composed of 50% toluene and 50% iso-octane

Aggressive ethanol

- Synthetic ethanol 816.0 g, de-ionized water 8.103 g, sodium chloride 0.004 g, sulfuric acid 0.021 g and glacial acetic acid 0.061 g (SAE J1681)

- These physical properties of the polymeric composite will be determined:
  - Mass change
  - Volume change
  - Water absorption
- These mechanical properties of the polymeric composite will be determined:
  - Tensile properties (ASTM D638)
  - Flexural properties (ASTM D790)
  - Compressive properties (ASTM D695)
  - Impact properties (ASTM D256)
- The scanning electron microscope (SEM) of the polymeric composite

CHAPTER II

THEORY

2.1 Polyvinyl chloride (PVC)

PVC is a polymer which composes of large-sized molecules comprising of carbon (C), hydrogen (H) and chlorine (Cl) atoms. PVC is a thermoplastic which softens, melts or flows when heated and hardens as it cools. So, it can be reformed into another product many times under various processes, without its original structures and properties destroyed. PVC is popular because it is a multi-function plastic with unique properties comparing with other types of plastic i.e. lightweight, durable, easy to clean, free of rust, more resistant to acids and other common chemical substances and being a good insulator [2]. It is made from natural products, which are common salts at 57 weight percent and petroleum or natural gas at 43 weight percent. The PVC production process is made by the electrolysis of salt. When salt water is chemically decomposed by an electric current being passed through it, chlorine is produced (along with caustic soda or sodium hydroxide (NaOH) and hydrogen). Refining crude oil yields naphtha and after various purification and other processes produces ethylene which is a molecule made up of carbon and hydrogen. Chlorine and ethylene are both gases and when chemically combined form another gas called vinyl chloride monomer (VCM) as shown in Figure 2.1. Through another chemical process called polymerization, the VCM molecules become bound together so as to form a chain, a giant molecule composed of thousands of monomers, called polyvinyl chloride polymers (PVC) as shown in Figure 2.2 [3-5]. Where n= 700-1500 hold a unique position among the polymers produced today. It is relatively inexpensive and is used in such a wide range of applications that its versatility is almost unlimited.

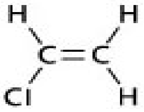


Figure 2.1 Vinyl Chloride Monomer (VCM) [6]

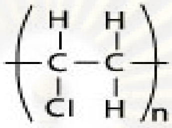


Figure 2.2 Polyvinyl Chloride Polymers (PVC) [6]

Due to poor properties of PVC such as stiff, hard, tough and poor heat stability, PVC is never used alone. It is always mixed with heat stabilizers, lubricants, plasticizers, fillers, and other additives to make processing possible, all of which can influence its physical and mechanical properties [6]. Typical Physical and mechanical properties of rigid PVC are shown in Table 2.1 [7].

Table 2.1: Typical Physical and Mechanical Properties of Rigid PVC [7]

ASTM or UL test	Property	PVC (Rigid)
Physical		
D792	Specific volume (g/cm³)	0.778-1.47
D570	Water Absorption, 24 hrs (%)	0.032-4
Mechanical		
D638	Tensile Strength (MPa)	37.6-54.3
D638	Tensile Modulus (MPa)	2,210-3,705
D638	Tensile Elongation at Break (%)	2.6-190
D790	Flexural Strength (MPa)	12,800
D695	Compressive strength (MPa)	74.50
D790	Flexural Modulus (MPa)	80-90
D256	IZOD Notched Impact (J/m)	16-1,070

PVC has an excellent resistance (no attack) to dilute and concentrated acids, alcohols, bases, aliphatic hydrocarbons and mineral oils. It has good resistance (minor attack) to vegetable oils and oxidizing agents. It has limited resistance (moderate attack and suitable for short term use only) to aldehydes. But it has poor resistance (not recommended for use) with aldehydes, esters, aromatic and halogenated hydrocarbons, and ketones [8].

2.2 Glass fiber

Glass fiber (or fiberglass) refers to individual filaments made by attenuating molten glass in special fiber-forming furnace. A continuous filament is a glass fiber of great or indefinite length; a staple fiber is a glass fiber of relatively short length [9].

Five glass fiber formulations are made. The most common is E-glass. This glass resists moisture and results in products with excellent electrical properties. C-glass is designed for use where optimum chemical resistance is required. D-glass (a high-boron-content glass) has very good electrical properties, particularly the dielectric constant, and is used in electronic applications. S-glass is used for high strength and stiffness, whereas R-glass is a high strength glass fiber used mainly for aerospace glass-reinforced composite application and a lower-cost fiber than S-glass [9].

Glass filaments are made in a variety of diameters. The filament is formed into a strand with 200, 400, 800, 1000, 2000, 3000, or 4000 filaments to a strand. A sizing agent is applied to the filaments to bond them into the strand and to give them environmental and abrasive protection. Subsequently, coupling agents are added to the finished products to enhance adhesion of the resin matrix to the glass fiber. Silanes, chrome complexes, and polymers are used as coupling agents.

The strands are then used to manufacture the various types of glass reinforcements. Glass fabrics, glass mat, and chopped strands are the most common reinforcements in reinforced plastics, but there are also many others.

In the form of short (1/4-1/2 in.) fiber, glass fiber leads to good impact strength, electrical properties, and temperature resistance in many thermosetting compositions. This use is not to be confused with its function as long fibers or woven fabric to reinforce resin matrix composites [9].

2.3 Composites

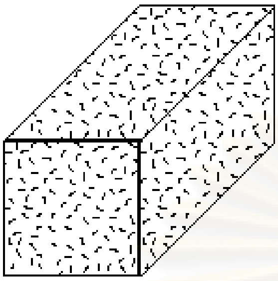
A composite is a homogenous material created by the synthetic assembly of two or more materials (a selected filler or reinforcing element and compatible matrix binder) to obtain specific characteristics and properties. Modern structural composites, frequently referred to as advanced composites, are a blend of two or more components, one of which is made up of long fiber and other, for polymeric composites, a resinous binder or matrix that holds the fibers in place.

The fibers are strong and stiff relative to the matrix (perhaps several times more than the matrix material) and are generally orthotropic (having different properties in two difference directions). The fiber for advanced structural composite is long, with length-to-diameter ratios of over 100. When the fiber and the matrix are joined to form a composite, they both retain their individual identities and both directly influence the final properties of composite. The resulting composite is composed of layers (laminate) of the fibers and matrix stacked in one or more directions to achieve the desired properties [9].

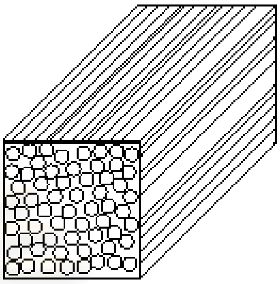
Common Categories of Composite Materials

Generally, a composite material is composed of reinforcement (fibers, particles, flakes, and/or fillers) embedded in a matrix (polymers, metals, or ceramics). The matrix holds the reinforcement to form the desired shape while the reinforcement improves the overall mechanical properties of the matrix. When designed properly, the new combined material exhibits better strength than would each individual material. Based on the form of reinforcement, common composite materials can be classified as follows [10]:

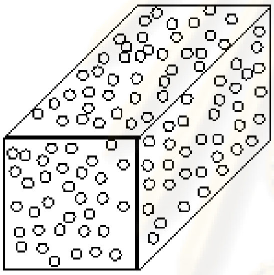
1. Fibers as the reinforcement (Fibrous Composites):



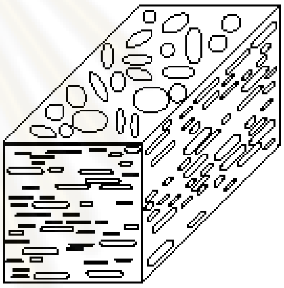
a. Random fiber (short fiber) reinforced composites



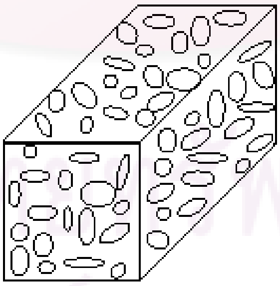
b. Continuous fiber (long fiber) reinforced composites



2. Particles as the reinforcement (Particulate composites)



3. Flat flakes as the reinforcement (Flake composites)



4. Fillers as the reinforcement (Filler composites)

2.4 Glass-reinforced plastic

Glass-reinforced plastic (GRP) is a composite material or fiber-reinforced plastic made of a plastic reinforced by fine glass fibers. Like graphite-reinforced plastic, the composite material is commonly referred to by the name of its reinforcing fibers (fiberglass). Thermosetting plastics are normally used for GRP production- most often polyester (using butanone as a catalyst), but vinyl ester or epoxy are also used. The glass can be in the form of a chopped strand mat (CSM) or a woven fabric.

As with many other composite materials (such as reinforced concrete), the two materials act together, each overcoming the deficits of the other. Whereas the plastic resins are strong in compressive loading and relatively weak in tensile strength, the glass fibers are very strong in tension but have no strength against compression. By combining the two materials, GRP becomes a material that resists both compressive and tensile forces well. The two materials may be used uniformly or the glass may be specifically placed in those portions of the structure that will experience tensile loads [11].

2.5 Gasohol

Gasohol is a blending of unleaded gasoline and 99.5 % ethanol, mixed at different ratio. In the gasohol, the ethyl alcohol serves as an additive to enhance oxygenates value and octane number of gasoline which normally rendered by Methyl-Tertiary-Butyl-Ether (MTBE) [12]. Because of this make gasohol has higher octane, or antiknock, properties than gasoline and burns more slowly, coolly, and completely [13]. The ethanol is usually obtained by fermentation, followed by distillation, using crops, such as maize, wheat, potatoes, rice, corn, tapioca or sugar cane [14]. Combustion of gasohol produces lower levels of hydrocarbons, carbon monoxide and carbon dioxide than general 95 octane gasoline, and helps to reduce black smoke, aromatic hydrocarbon, benzene, and dust emission from exhaust pipes [15].

Background

The use of ethanol (alcohol) in motor vehicles is neither a new technology nor a new concept. There is extensive literature on the subject dating back into the 20's and alcohol has a often been used in both war and peace.

Alternate energy sources must meet certain criteria to be competitive with conversional fuels. Some of special requirements [16] these energy supplies will have to meet are as follows:

1. Fuels must be capable of being stored over extended time periods,
2. Storage, transportation and distribution of fuels used should be economical,
3. Handling of alternate fuels should not involve additional hazards such as fire, explosion, etc., in comparison to conventional fuels,
4. Alternate fuels should not impose major engineering changes to processes and/or systems using them.

Mixing alcohol with gasoline produces gasohol. Advantages of fuel blends are that alcohol tends to increase the octane rating, which is particularly important in unleaded fuel, and reduce carbon monoxide (CO) emissions from the engine. The primary disadvantage of mixing methyl and ethyl alcohol with gasoline is that under certain conditions these alcohols may separate from the gasoline. An engine adjusted to burn gasoline efficiently will produce less power from alcohol should it separate from the gasoline. Separation is caused by the polar nature of the alcohol molecules and their tendency to absorb water, also a polar substance. Methyl alcohol is the most likely to separate, butyl alcohol the least likely. The tendency for separation increases as the temperature decreases, the quantity of water absorbed increases, and the quality of the gasoline decreases [17].

The proportion of ethanol used in Gasohol is generally 10 percent across the world, including Thailand because this proportion of mixture can be used in vehicles without engines modification. However, many countries are now trying to promote the use of ethanol by mixing it at a higher proportion with gasoline. Brazil is one such country, which embraces ethanol blend from 20 percent (E20) up to pure ethanol (E100). Besides Gasohol E5 or E10, the United States, Canada and Sweden also use Gasohol 85, which has only 15 percent of gasoline in its mixture. The gasoline content is kept in this formula because it helps engines to start easily during the cold weather. Gasohol with 85 percent concentration of ethanol has as high an octane rating as 105, which can boost the vehicle engine's performances [12].

E10

E10, sometimes called gasohol, is a fuel mixture of 10 vol% ethanol and 90vol% gasoline that can be used in the internal combustion engines of most modern automobiles. According the Philippine Department of Energy E10 is not harmful to cars' fuel systems. However, it is not allowed to be used in aircraft [18].

E15

E15 contains 15 vol% ethanol and 85 vol% gasoline. This is generally the greatest ratio of ethanol to gas that is recommended by auto manufacturers that sell vehicles in the United States, though it is possible that many vehicles can handle higher mixtures without trouble. Flexible-fuel vehicles (FFV) are designed to take higher concentrations, up to 96% v/v ethanol (and no gasoline) [18].

E20

E20 contains 20 vol% ethanol and 80 vol% gasoline. Since February 2006, this is the standard ethanol-gasoline mixture sold in Brazil, where concerns with the alcohol supply resulted in a drop in the ethanol percentage, previously at 25 vol%. Brazilian flexible-fuel cars are set up to run with gasoline in such concentration range and few will work properly with lower concentrations of ethanol. U.S. FFV can run below 20 vol%

ethanol, but up to E85. This fuel is not yet widely used in Australia or the United States. It will be mandated by the U.S. state of Minnesota by 2013. Available also in Thailand with tax reductions for “E20” engine cars [18].

E85

E85 is a mixture of 85 vol% ethanol and 15 vol% gasoline, and is generally the highest ethanol fuel mixture found in the United States. It is common in Sweden, and there are more than 1000 public E85 fuel pumps in the U.S. as of 2006, mostly concentrated in the Midwest, with over half of those in Minnesota. This mixture has an octane rating of about 105. This is down significantly from pure ethanol but still much higher than normal gasoline 87 octane. The addition of a small amount of gasoline helps a conventional engine start when using this fuel under cold conditions. E85 does not always contain exactly 85 vol% ethanol. In winter, especially in colder climates, additional gasoline is added (to facilitate cold start). E85 contains approximately 27% less energy per gallon than conventional gasoline, although ethanol typically burns more efficiently. These results in a fuel economy loss of less than the energy content would imply [18].

E95

E95 designates a blend of 95 vol% ethanol and 5 vol% ignition improver and is used in some diesel engines where high compression is used to ignite the fuel, as opposed to the operation of gasoline engines where spark plugs are used. Because of the high ignition temperatures of pure ethanol, the addition of ignition improver is necessary for successful diesel engine operation. This fuel has been used with success in many Swedish busses since the 1980's [18].

E100

E100 is ethanol with up to 4 vol% water, which is most widely used in Brazil and Argentina. Operation in ambient temperatures below 15 °C (59 °F) causes problems with pure or so-called neat, ethanol for starting engines. The most common cold weather solution is to add an additional small gasoline reservoir to increase the gasoline content momentarily to permit starting the engine. Once started, the engine is then switched back to neat ethanol. Ethanol used as a fuel in Brazil is the azeotrope (the highest concentration of ethanol that can be achieved via distillation) and contains 4 vol% of water [18].

Fuel property change with ethanol addition

The addition of ethanol to gasoline results in changes to the properties of the fuel. When fuel properties change they can affect engine performance in many ways. This includes exhaust and evaporative emissions, fuel economy, operability, full load performance (power) and durability. The extent to which changes in fuel composition affects these engine performance qualities are very dependent on the engine itself, including engine design, fuel system and control system, as well as emissions control equipment.

Table 2.2 summaries the some of the major properties of gasoline, ethanol, and mixtures of 10% and 20% (by volume) ethanol with gasoline. This is assuming splash blending of the components with no special blend stock for the gasoline component.

Table 2.2 Properties of Gasoline, Ethanol and Gasoline/Ethanol Blends; except for [1] and [2] from calculation) [19].

Property	Gasoline	Ethanol	10% Ethanol / Gasoline Blend	20% Ethanol / Gasoline Blend[2]
Specific Gravity @ 15.5 °C	0.72-0.75	0.79	0.73-0.76	0.735-0.765
Heating Value (MJ/kg) (BTU/lb)	 43.5 18,700	 27 11,600	 41.9 18,000	 40 17,200
Heating Value (MJ/litre) (BTU/gal)	 32 117,000	 21.3 76,000	 30.9 112,900	 29.9 109,000
Approx Reid Vapour Pressure @ 37.8ºC (kPa)[1]	59.5	17	64	63.4
Stoichiometric Air/Fuel Ratio	14.6	9	14	13.5
Oxygen Content (% by weight)	0	35	3.5	7

Volatility

Fuel volatility can be described by vapour pressure, each of which is important in understanding what is required from the fuel in terms of satisfying engine operability requirements. When small amounts of ethanol are added to gasoline, the vapour pressure of the mixture is greater than the vapour pressure of either the gasoline or alcohol alone. The molecules of pure alcohol are strongly hydrogen-bonded, but with small amounts of alcohol in a non-polar material (i.e. gasoline) the hydrogen bonding is much less extensive and the alcohol molecules behave in a manner more in keeping with their low molecular weight. Thus the alcohol becomes more volatile [20].

Reid Vapour Pressure

Guibet states that increases in the Reid Vapour Pressure (RVP) of 6 – 8 kPa can be expected with ethanol additions of only 3% to base gasoline with normal volatility. This increase in RVP. The RVP is a measure of the vapour pressure of a liquid as measured by the ASTM D 323 procedure and is commonly applied to automotive fuels. For automotive fuels, the Reid Vapour Pressure (RVP) measured at 37.8 deg C is used to define the fuel volatility [21]. Figure 2.3 shows RVP of the fuel for different ethanol blend content. The RVP only drops consistently below the gasoline RVP with blends of ethanol greater than 30%.

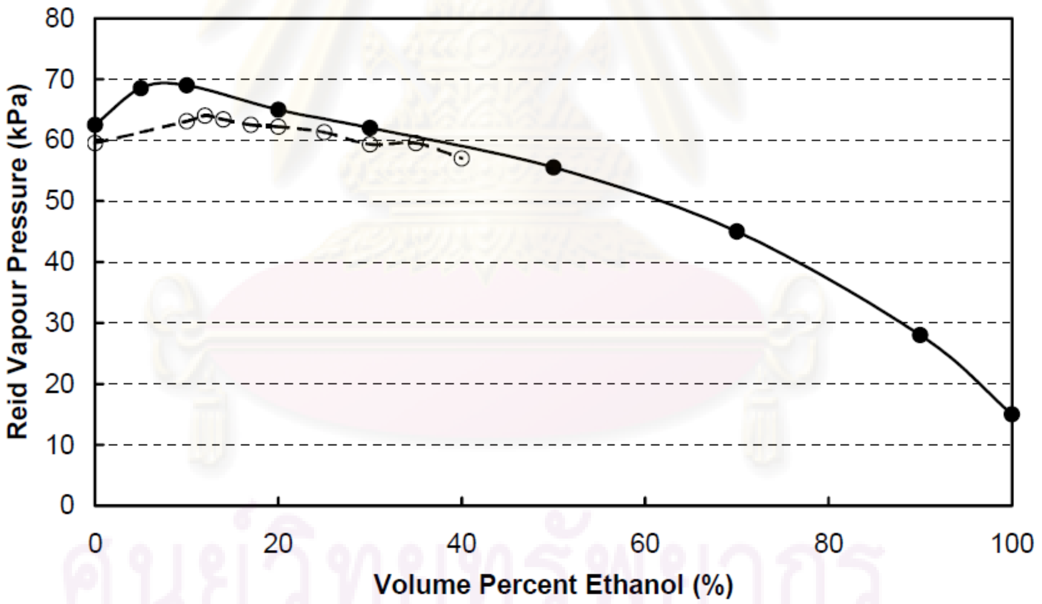


Figure 2.3 Reid Vapour Pressure with High Blend Ethanol [21];

solid line ——, dashed line – –

Table 2.3 shows the change effect of an addition of 10% and 20% ethanol on the RVP of the base gasoline fuel.

Table 2.3 Increase in RVP with ethanol addition

Volume % Ethanol added	RVP (kPa)
0	62
10	67.3
20	69

Gasohol vs. Gasoline

Many studies have been carried out to compare gasohol and gasoline as automotive fuels. In almost all studies gasohol has shown itself to be comparable in performance, but to have major environmental advantages. Some of these are as follows:

(a) 10% alcohol boosts the octane of lead free gasolines. This is particularly important when octane enhancers, such as MMT (methyl cyclo pentadienyl manganese tricarbonyl) and lead are under restrictions.

(b) Gasohol has been shown by studies in Purdue School of Technology to produce more horsepower for each lb. of fuel burned.

(c) The exhaust pollution from gasohol is reduced 50-60% compared to regular gasoline (measured as unburned hydrocarbons)

(d) The carbon monoxide emitted when using gasohol is often so low it cannot be measured.

(e) Carbon build-up is reduced.

More and more oil companies are using alcohol to boost octane “super unleaded gasoline” without any reference to gasohol [22].

Ethanol as an automotive fuel

Tables 2.4 compare some of properties of ethanol to those of isooctane.

Table 2.4 Comparison between the properties of isooctane and ethanol [16]

Property	Isooctane (C_8H_{18})	Ethanol (C_2H_5OH)
Molecular Weight	114.224	46.07
C:H weight ratio	5.25	4.0
Boiling Point, °C at 1 atm	99.24	78.3
Vapor Pressure, psi at 37.8 °C	1.708	2.5
Surface Tension, dynes/cm at 20 °C 1 atm	18.77	23
Viscosity, cp at 20 °C 1 atm	0.503	1.17
Specific Heat of Liquid, Btu/lb-F at 77 °F and 1 atm	0.5	0.6
Heat of Vaporization, Btu/lb at 25 °C and 1 atm	132	395
Heat of Combustion, Btu/lb at 25 °C		
-Higher heating value	20,556	12,780
-Liquid fuel-gaseous H2O	19,065	11,550
Stoichiometric Mixture, lb/air/lb	15.13	9.0
Autoignition Temperature, °C	417.8	362.8
Octane Number	100	106

Ethanol has Btu content significantly higher than that of methanol (approximately 12,780 Btu/lb vs. 9,500 Btu/lb for methanol). However, ethanol's Btu value is still significantly lower than gasoline's. A gallon of ethanol contains about 0.7 the Btu capacity of gasoline. The addition of ethanol to gasoline causes the Btu capacity to drop. In addition, there is much concern and controversy as to the mpg efficiency between ethanol-gasoline blends and gasoline.

Ethanol also has a relatively high octane rating-106-107.5 RON (Research Octane Number) and 85-100 MON (Motor Octane Number). The addition of ethanol to nonleaded gasoline causes the octane rating to increase along with the antiknock capacity of the fuel [16].

2.6 Polymer Solubility

Liquid environments can have positive and negative effects on the properties of polymeric materials. Some chemical or solvents can have detrimental effects on a polymer component. Figure 2.4 shows results of creep rupture tests done on PVC tubes as a function of the hoop stress. It can be seen that the lifespan of the tubes in contact with iso-octane and isopropanol has been significantly reduced as compared to the tube in contact with water.

The measured data for the pipes exposed to iso-octane clearly show a slope reduction with a visible endurance limit, making it possible to do long-life predictions. On the other hand, the samples exposed to isopropanol do not exhibit such a slope reduction, suggesting that isopropanol is a harmful environment with acts as a solving agent and leads to gradual degradation on the PVC surface.

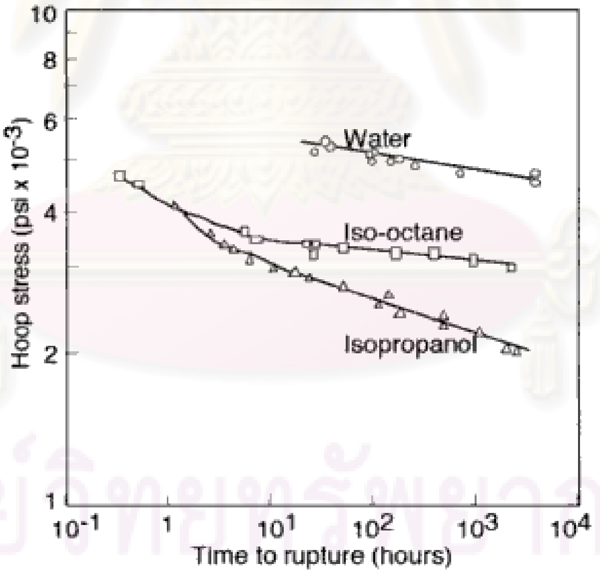


Figure 2.4 Effect of different environments on the stress ruptures life of PVC pipe at 23ºC [23]

The question of whether a chemical is harmful to a specific polymeric material needs to be addressed if the polymer component is to be placed in a possibly threatening environment. Similar to polymer solutions, a chemical reaction between a polymer and another substance is governed by Gibbs free energy equation. If the change in enthalpy, ΔH, is negative, a chemical reaction will occur between the polymer and the solvent [23].

1. The Solution Process

Dissolving a polymer is a slow process that occurs in two stages. First, solvent molecules slowly diffuse into the polymer to produce a swollen gel. This may be all that happens-if, for example, the polymer-polymer intermolecular forces are high because of cross linking, crystallinity, or strong hydrogen bonding. But if these forces can be overcome by the introduction of strong polymer-solvent interactions, the second stage of solution can take place. Here the gel gradually disintegrates into a true solution. Only this stage can be materially speeded by agitation. Even so, the solution process can be quite slow (days or a weeks) for materials of very high molecular weight.

2. Polymer Texture and Solubility

From what has already been said, it is clear that the topology of the polymer is highly important in determining its solubility. Cross linked polymers do not dissolve, but only swell if indeed they interact with the solvent at all. In part, at least, the degree of this interaction is determined by the extent of cross linking: Lightly cross linked rubbers swell extensively in solvents in which the unvulcanized material would dissolve, but hard rubbers, like many thermosetting resins, may not swell appreciably in contact with any solvent.

The absorbance of solubility does not imply cross linking, however. Other features may give rise to sufficiently high intermolecular forces to prevent solubility. The presence of crystallinity is the common example. Many crystalline polymers, particularly nonpolar ones, do not dissolve except at temperatures near their crystalline melting points. Because crystallinity decreases as the melting point is approached and the melting point is itself depressed by the presence of the solvent, solubility can often be achieved at temperatures significantly below the melting point. Thus linear polyethylene, with crystalline melting point T_m = 135 °C, is soluble in many liquids at temperature above 100 °C, while even polytetrafluoroethylene, T_m = 325 °C, is soluble in some of the few liquids that exist above 300 °C. More polar crystalline polymers, such as nylon-66, T_m = 265 °C, can dissolve at room temperature in solvent that interact strongly with them (for example, to form hydrogen bonds).

There is little quantitative information about the influence of branching on solubility; in general, branched species appear to be more readily soluble than their linear counterparts of the same chemical type and molecular weight.

Of all these systems, the theory of the solubility, based on the thermodynamics of polymer solutions, is highly developed only for linear polymers in the absence of crystallinity. Here the chemical nature of the polymer is by far the most important determinant of solubility, as is elucidated in the remainder of this section. The influence of molecular weight (within the polymer range) is far less, but it is of great importance to fractionation processes, which yield information about the distribution of molecular weights in polymer samples.

3. Solubility Parameters

Solubility occurs when the free energy of mixing is negative. It was long thought that

$$\Delta G = \Delta H - T\Delta S$$

The entropy of mixing ΔS was always positive, and therefore the sign of ΔG was determined by the sign and magnitude of the heat of mixing ΔH. For reasonably nonpolar molecules and in the absence of hydrogen bonding, ΔH is positive and was assumed to be the same as that derived for the mixing of small molecules. For this case, the heat of mixing per unit volume can be approximated (Hildebrand 1950) as

$$\Delta H = \nu_1 \nu_2 (\delta_1 - \delta_2)^2$$

Where ν is volume fraction and subscripts 1 and 2 refer to solvent and polymer, respectively. The quantitative δ^2 is the cohesive energy density or, for small molecules, the energy of vaporization per unit volume. The quantitative δ is known as the *solubility parameter*. (This expression for the heat of mixing is one of several alternatives used in theories of the thermodynamics of polymer solutions)

The value of the solubility-parameter approach is that δ can be calculated for interactions such as hydrogen bonding, solubility can be excepted if δ_1-δ_2 is less than 3.5-4.0, but not if it is appreciably larger.

This approach to polymer solubility, pioneered by Burrell (1955). Has been extensively used, particularly in the paint industry. A few typical values of δ_1 and δ_2 are given in Table 2.5; for polymers. Extensive tabulations has been published. Perhaps the easiest way to determine δ_2 for a polymer of known structure is by the molar-attraction constants *E* of Table 2.6,

$$\delta_2 = \rho \sum E/M$$

where values of *E* are summed over the structural configuration of the repeating unit in the polymer chain, with repeat molecular weight *M* and density ρ.

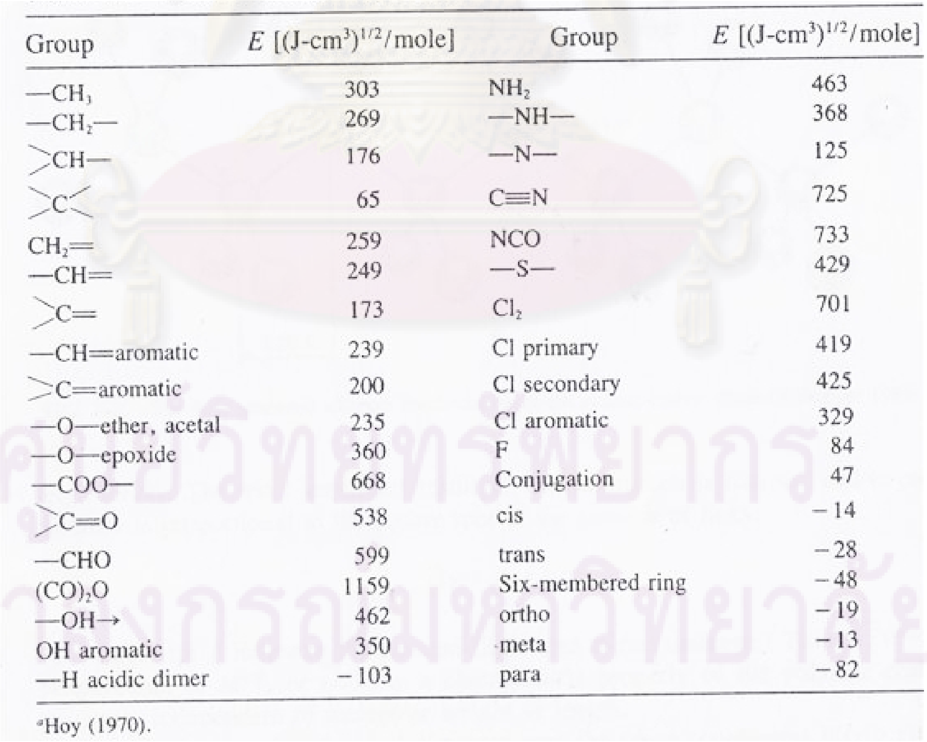
The original solubility-parameter approach was developed for nonpolar systems. Modifications to include polarity and hydrogen bonding have led to three-dimensional solubility-parameter schemes, which lack the simplicity of the single-parameter method but are more widely applicable. Despite its shortcomings, the concept is nevertheless still extremely useful and should not be abandoned without test.

In contrast to the above considerations of the thermodynamics of dissolution of polymers, the rate of this step depends primarily on how rapidly the polymer and the solvent diffuse into one another. Solvents that promote rapid solubility are usually small, compact molecules, but these kinetically good solvents need not be thermodynamically good as well. Mixtures of a kinetically good and liquid are often very powerful and rapid polymer solvents.

Table 2.5 Typical values of the solubility parameter δ for some common polymers and solvents [24]

Solvent	δ_1 [(J/cm^3)$^{1/2}$]	Polymer	δ_2 [(J/cm^3)$^{1/2}$]
n-Hexane	14.8	Polyethylene	16.2
Toluene	18.3	Polypropylene	16.6
Benzene	18.7	Nylon-66	27.8
Acetone	19.9	Poly(vinyl chloride)	19.4
Methanol	29.7	Polystyrene	17.6
Water	47.9	Polyacrylonitrile	31.5

Table 2.6 Molar attraction constants *E* [24]



Group	*E* [(J-cm^3)$^{1/2}$/mole]	Group	*E* [(J-cm^3)$^{1/2}$/mole]
—CH_3	303	NH_2	463
—CH_2—	269	—NH—	368
$>$CH—	176	—N—	125
$>C<$	65	C≡N	725
CH_2=	259	NCO	733
—CH=	249	—S—	429
$>$C=	173	Cl_2	701
—CH=aromatic	239	Cl primary	419
$>$C=aromatic	200	Cl secondary	425
—O—ether, acetal	235	Cl aromatic	329
—O—epoxide	360	F	84
—COO—	668	Conjugation	47
$>$C=O	538	cis	−14
—CHO	599	trans	−28
$(CO)_2O$	1159	Six-membered ring	−48
—OH→	462	ortho	−19
OH aromatic	350	meta	−13
—H acidic dimer	−103	para	−82

[a]Hoy (1970).

2.7 Chemical Resistance

The ability of some polymers to resist strong acids, alkalis, and solvent is notable. The primary factors affecting the ability of a polymer to retain original physical properties after exposure to a reactive chemical are the exact chemical and morphological nature of the polymeric compound, type and concentration of the chemical, time and temperature of exposure, part thickness, and the mechanical stresses that are simultaneously acting on the sample. In general, chemical resistance tests, as conducted by resin suppliers and compounders, involve exposure of thin, molded plaques to a representative range of chemicals, one chemical at a time, over a limited range of temperatures, and without mechanical stress. Immediately after exposure the samples are tested for weight gain, volume swell, hardness and tensile properties, all at room temperature.

The commonly used chemical resistance tests are briefly described as follows: in immersion tests with liquid chemicals, molded or machined tensile test samples (dumbbells) are completely immersed in the test liquid, which should be in a temperature controlled bath. Samples are withdrawn periodically and subjected to standard tensile stress strain tests, weight, thickness, and hardness measurements at room temperature immediately afterward. ISO 175 (ASTM D543) describes procedure in detail and gives a list of about 50 different reagents to cover the span of potentially damaging chemicals. Test data is relative, but with experience in particular product applications, results of a minor compound change to a new polymer, can be fairly reliable when combined with other data and understanding of the chemical nature of polymers. The main flaw is that the samples are under zero mechanical load during immersion. To correct this flaw, some simple tests are in use that combines mechanical stress with chemical attack over time.

In an immersion test in which the polymer does not actually breakdown because of chemical reactions with the reagent, excessive volumetric swelling will be a limiting criterion. There two stages in the process of chemical swelling by liquids. First, liquid solvent is dissolved into or absorbed on the surface of the polymer solute. Second, solvent diffuses through the free volume of the polymer. The first step occurs because solvent-solvent bonds, polymer-polymer bonds, and polymer-solvent chemical bonds for certain combinations are sufficiently similar thermodynamically that little thermal energy is needed to form solvent-polymer bonds. For convenience, imagine that the polymer is a liquid also, and that the cohesive interaction between molecules of this liquid can be measured by thermodynamic method. This interaction is measured by a property of the polymer called the *cohesive energy* density (CED), and values have been measured and published for many polymers and solvents. If the polymer CED is sufficiently similar to the solvent CED, the two materials will be compatible and the polymer will rapidly absorb the chemical solvent. Rate of diffusion of the chemical into the polymer then depends on viscosity and size of the chemical molecule, free volume of the polymer, temperature, and similar purely physical factors. As the chemical diffuses into the polymer, the polymer increases in volume or swells, and the weak interactions between macromolecules become even weaker. If the polymer is under mechanical stress, it will fail at a lower load than if it had not been chemically attacked. If a swollen polymer is not stressed, it may completely recover its original properties when the solvent is allowed time to diffuse back to the surface and evaporate. If it does recover completely, the reversibility is an indication that uptake of the chemical did not lead to chemical reactions with the polymer. Another indication of reversibility is that there is a maximum degree of swelling; that is, if weight change is plotted against time of exposure there will be an asymptote or maximum value [25]

CHAPTER III

LITERATURE REVIEWS

B. Jones et al. in 2008 [26] studied tested eight different plastics to determine if they performed significantly different when immersed in Fuel C (Fuel C was a mixture of 50 vol% toluene and 50 vol% iso-octane), C (E10)$_A$ (Fuel consisting of 90 vol% ASTM test Fuel C and 10 vol% aggressive ethanol) and C (E20)$_A$ (Fuel consisting of 80 vol% ASTM test Fuel C and 20 vol% aggressive ethanol). Aggressive ethanol composed of Synthetic ethanol 816.00 g, de-ionized water 8.103 g, sodium chloride 0.004 g, sulfuric acid 0.021 g, and glacial acetic acid 0.061 g (SAE J1681). The study found that four of the materials, polyamide 6 (PA 6), polyamide 66 (PA 66), polyethylene terephthalate (PET) and polyetherimide 1010 moldable (PEI) were compatible with the three fuels. The other four materials, acrylonitrile butadiene styrene (ABS), polyurethane 55D-90 Adurameter hardness (PUR), polyvinyl chloride flexible version (PVC) and polybutylene terephthalate (PBT) were affected by all three fuels to varying degrees. The ABS specimens failed after less than one week of immersion in all three fuels. The specimens turned to a jelly-like mass in the bottom of the jars. This material was not compatible with any of the fuels. It was noted that, no automotive or small engine fuel system applications of ABS could be located, quite possibly due to its incompatibility with fuel. PVC (flexible version) demonstrated significant changes in mass and volume in all three fuels but to a higher degree in ethanol fuels. The PBT data also showed significant changes in impact resistance in all three fuels but to a greater extent in the ethanol blends as shown in Figure 3.1. PUR was deemed incompatible with both E10 and E20 due to cracking and changes in mass, volume, tensile strength as shown in Figure 3.2. In each case with PVC, PUR, and PBT both E10 and E20 caused large enough changes to raise a concern. Because of this, these materials would be a poor choice for use with either E10 or E20. Finally, no fuel system components made of either PUR or PVC could be located.

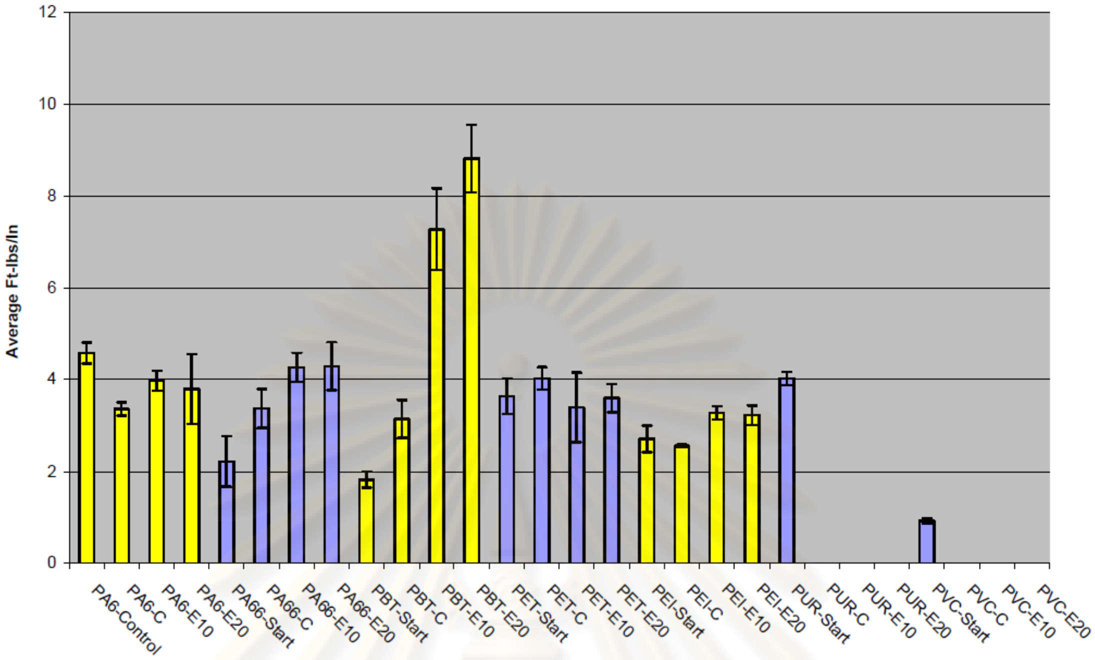


Figure 3.1 Graph comparing the non-immersion and immersion impact results [26]

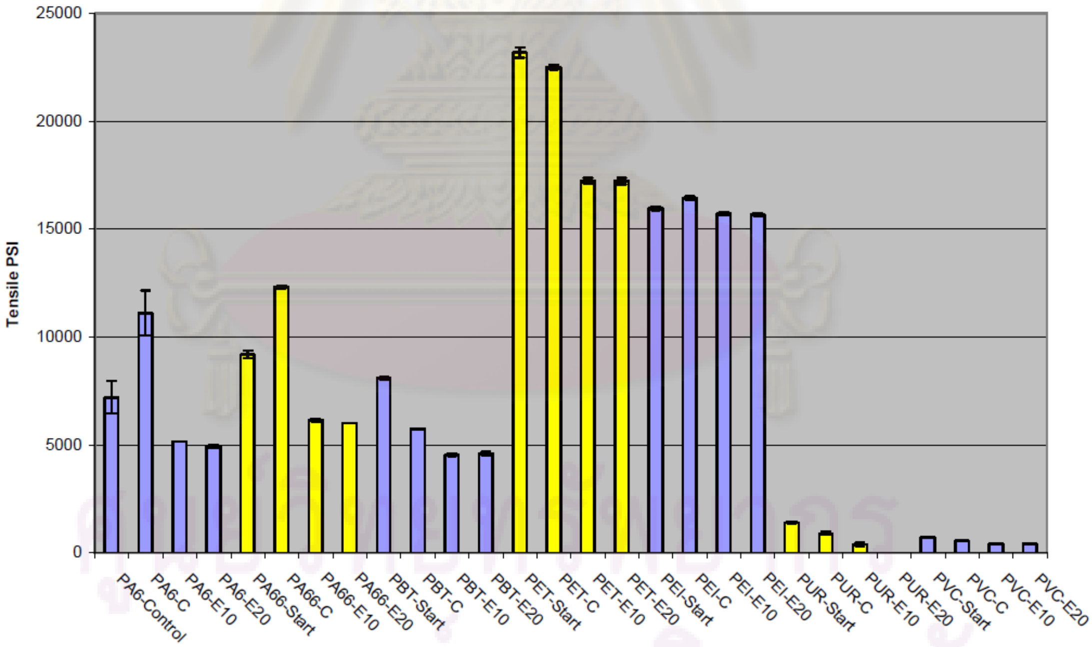


Figure 3.2 Graph comparing the non-immersion and immersion tensile strengths [26]

S. Tungjitpornkull et al. in 2008 [27] studied the effects of E-chopped strand glass fibers with different initial fiber lengths and contents when introduced into wood-polyvinyl chloride (WPVC) composites having the wood content of 50 parts per hundred resin (phr). The initial fiber lengths and glass fiber contents were varied from 3, 6, and 12 mm, and 10, 20, and 30 phr, respectively, and the mechanical and morphological properties of the wood/polyvinyl chloride (WPVC) composites were monitored. The results suggested that ECS glass fibers with different initial fiber length and contents could be used to improve the mechanical properties of the WPVC composites. It was found that the stiffness and strength of the WPVC composites increased with increasing glass fiber contents. The tensile and flexural moduli and strengths of the WPVC composites increased with increasing glass fiber contents as shown in Figures 3.3-3.4. The tensile and flexural moduli and strengths of the WPVC composites at 10–20 phr glass fiber loadings were more dependent on carbonyl (C=O) content on the fiber surface as shown in Figure 3.5 and Table 3.1, but those at 30 phr glass fiber loadings were influenced by the average final length of glass fibers as shown in Figure 3.6.

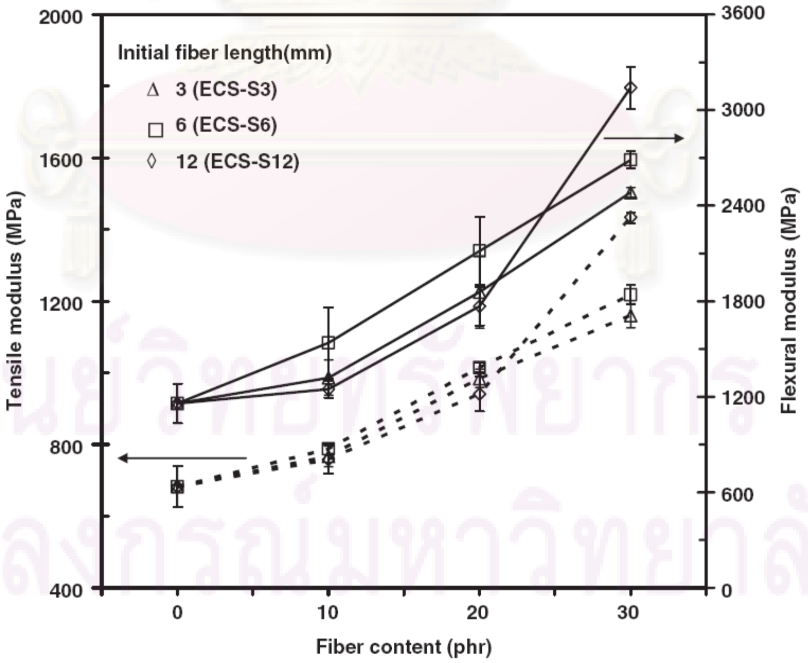


Figure 3.3 Effect of initial fiber length and content of glass fiber on tensile and flexural moduli of WPVC composites [27]

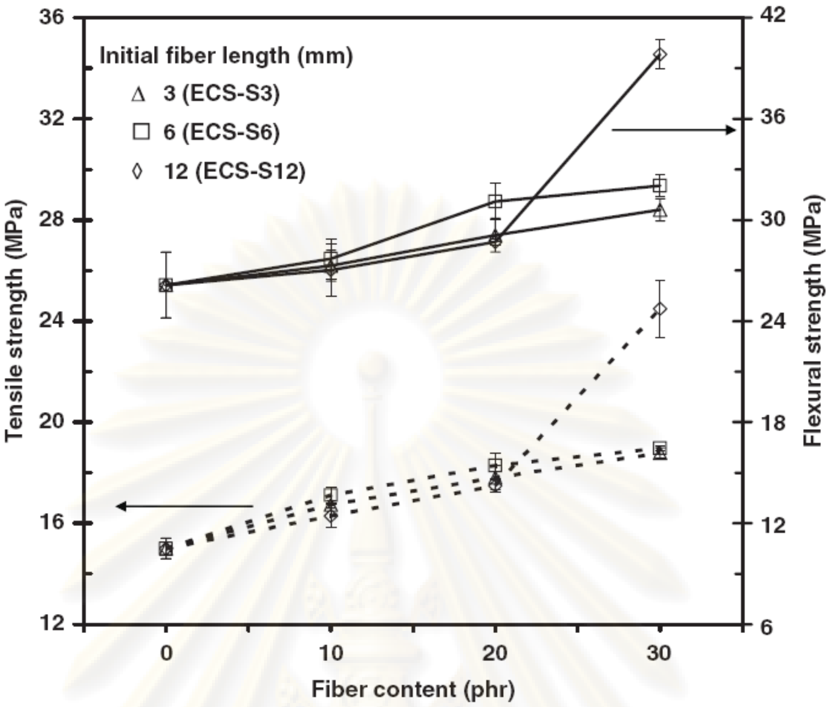


Figure 3.4 Effect of initial fiber length and content of glass fiber on tensile and flexural strengths of WPVC composites [27]

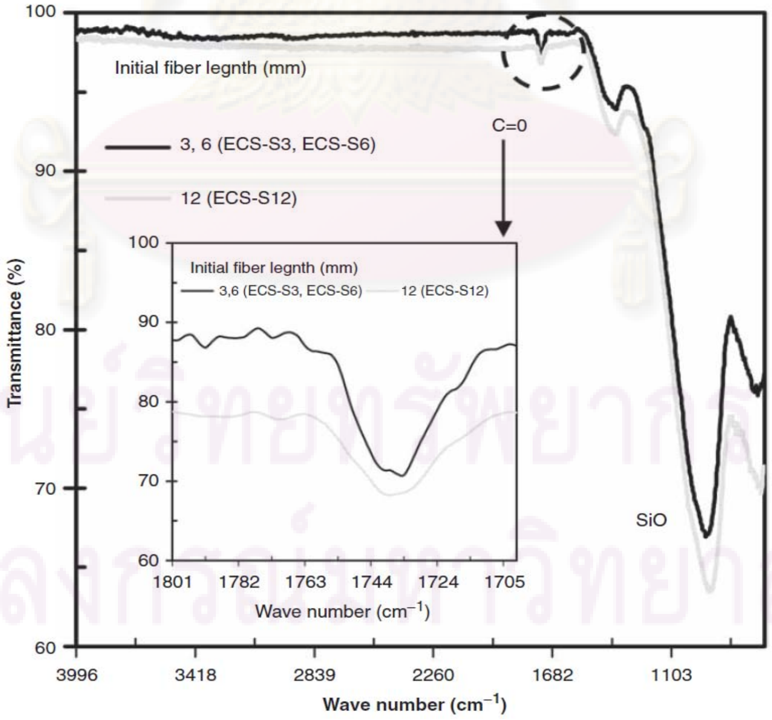


Figure 3.5 FTIR spectra of ECS-S3, ECS-S6 and ECS-S12 glass fibers [27]

Table 3.1 Carbonyl content on fiber surface from FTIR spectra [27]

Trade code	Initial fiber length (mm)	W0ave number (cm^{-1})	Selected functional groups	C=O content
ECS-S3	3	1737	C=O	0.30
ECS-S6	6	1737	C=O	0.30
ECS-S12	12	1738	C=O	0.24

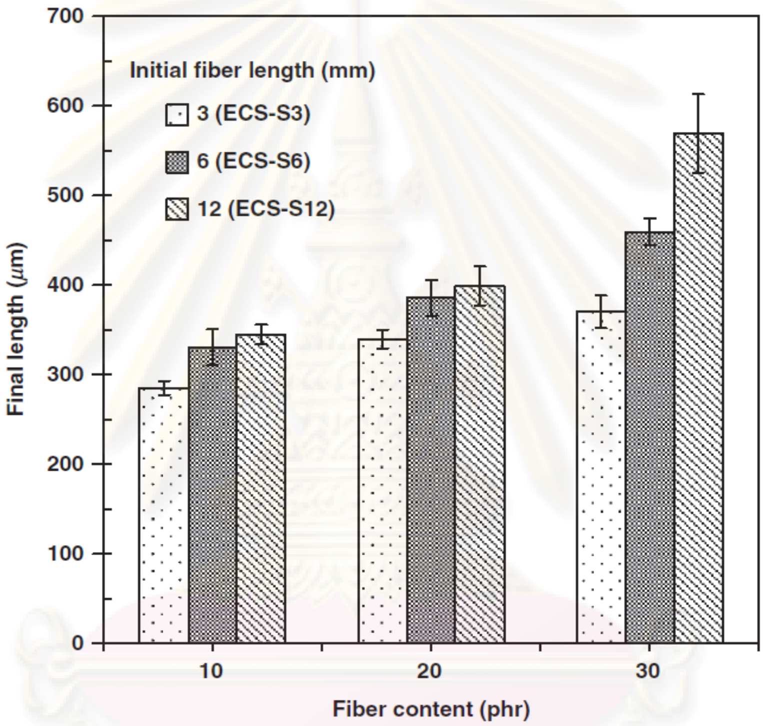


Figure 3.6 Influence of glass fiber content on final length of glass fiber after extrusion process [27]

S. Tungjitpornkull and N. Sombatsompop in 2008 [28] studied the effect of E-glass fibers (GF) with different fiber forms, loadings and orientation angles on the properties of wood/polyvinyl chloride (WPVC) composites. The WPVC composed of GF reinforced WPVC composites were manufactured either by compression molding or by twin-screw extrusion process and the mechanical properties of the composites from these two processes were then compared as shown in Figures 3.7-3.8. The experimental results showed that the GF/WPVC composites produced from compression molding process had better mechanical properties as a result of lower shearing stress during manufacture, which resulted in less thermal degradation of PVC and lower breakage of glass fiber as shown in Figure 3.9. The tensile properties of GF/WPVC composites (made by compression molding) were more affected by the fiber orientation angle than the flexural properties as shown in Figure 3.10. The GF/WPVC composites with fiber orientation angle of 0° were found to give the maximum mechanical properties, the reasons being associated with a continuity of fiber length to bearing the applied load and minimum fiber-end defects. By compression molding technique, the glass fiber reinforced WPVC composites gave the overall mechanical properties of 30–50% higher than the non-reinforced WPVC composites.

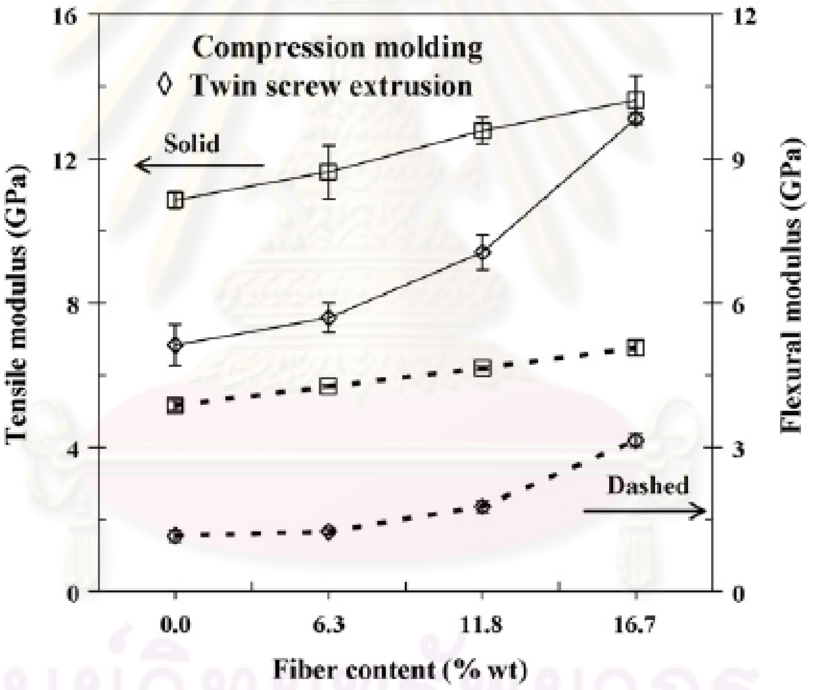


Figure 3.7 Effect of glass fiber content on tensile and flexural moduli of GF/ WPVC composites by compression and twin-screw extrusion processes [28]

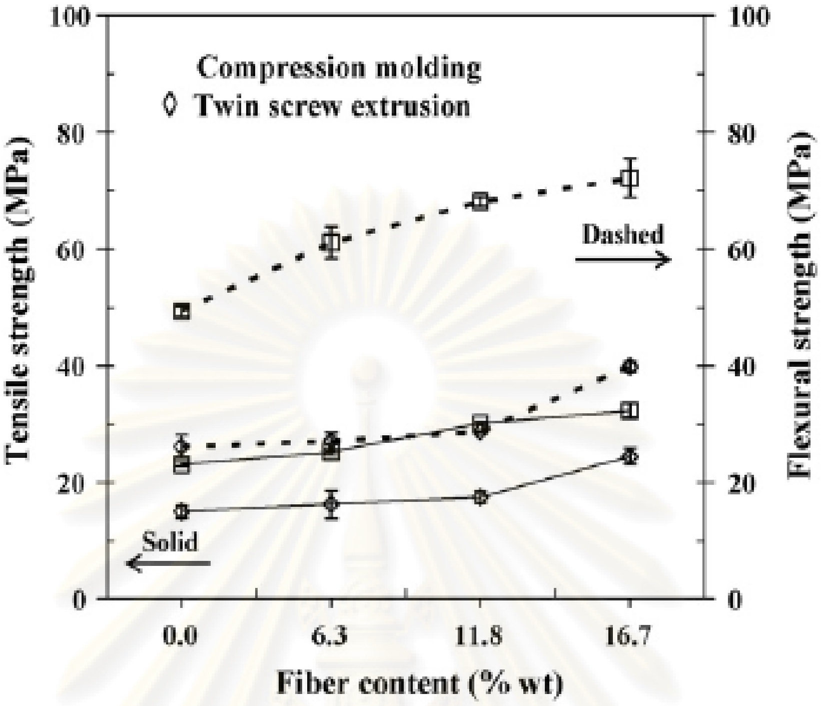


Figure 3.8 Tensile and flexural strengths of glass fiber reinforced WPVC composites by compression and twin-screw extrusion processes [28]

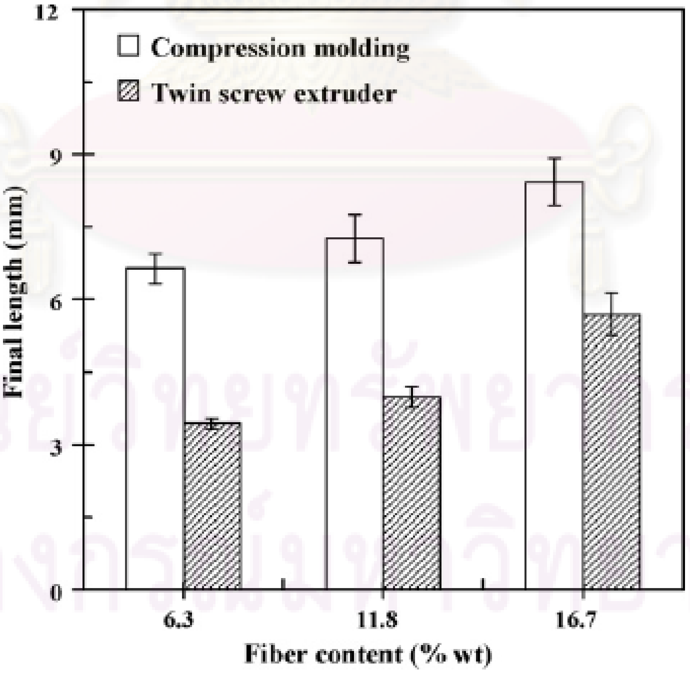


Figure 3.9 Final length of E-chopped strand (ECS-S12) fibers after compression and twin-screw extrusion processes [28]

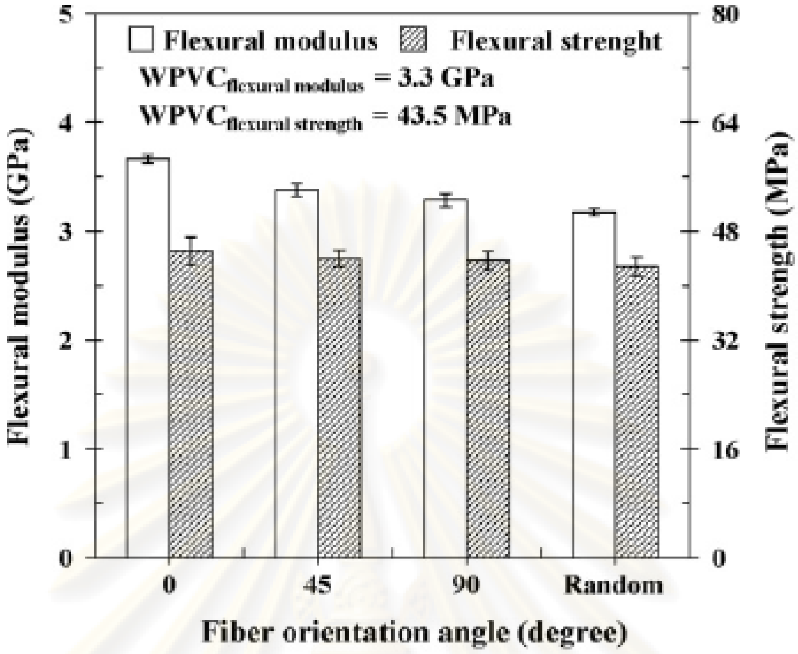


Figure 3.10 Effect of fiber orientation angle on flexural properties of glass fiber reinforced WPVC composites. (Fiber content at 11.8 wt% by compression molding) [21]

A. Ranney and V. Parker in 1997 [29] Previous research has shown that the most commonly used well casing materials stainless steel, polyvinyl chloride (PVC), and polytetra fluoroethylene (PTFE) are not stuited for all monitoring environment and application. This study is part of a series of experiments that were conducted to determine the suitability of four other polymeric well casing materials acrylonitrile butadiene styrene (ABS), fluorinated ethylene propylene (FRP) for use in ground water monitoring wells. In these studies, these four materials were compared with two other commonly used polymeric well casings, PVC and PTFE. Part I of these studies examines the resistance of these materials to degradation by chemicals. Future reports will consider sorption and leaching of organic and metal contaminants.

In this study, the six materials were exposed to 28 neat organic compounds (including one acid) and to extremely acidic and alkaline aqueous solution for up to 112 days. This was done to simulate the most aggressive environments to which monitoring well casings may be exposed. The casings were observed for changes in weight and signs of physical degradation (swelling, softening, deterioration, or dissolution)

The two-fluorinated polymers (FEP and PTFE) were not degraded by any of the test chemicals. Among the nonfluorinated products tested, FRE was the most inert. Three organic chemicals caused the glass fibers to separate and two organic solvents caused weight gains exceeding 10 percent. ABS was the most readily degraded material tested. By the end of the study, only the acid and alkaline solution had little effect on ABS. FRP was more severely degraded by the organic chemicals than FRE but was less affected than PVC, FRP and FRE lost weight when exposed to highly acidic condition.

CHAPTER IV

EXPERIMENTAL

4.1 Raw Materials

4.1.1 PVC Resin

Suspension PVC with the trade name of SIAMVIC 258RB is supplied by Vinythai Public Company Limited in the form of powder having a *K*-value of 58. This PVC is a low K-value resin suitable for rigid PVC processing. It has good thermal stability and can be easily processed even at low temperature.

4.1.2 Filler

E-Chopped strand (ECS) glass fiber length and diameter 3 mm., glass fiber diameter 11 µm. and aspect ratio 272.73. Fiber and treated with silane under the trade name of ECS-401AD Chopped strand is purchased by Jushi Group Co., Ltd.

4.2 Preparation of the PVC $_{\text{stock}}$ and PVC $_{\text{stock}}$ /Glass fiber Composites

4.2.1 Preparation of PVC $_{\text{stock}}$ Dry Blend

PVC dry blend, designated "PVC $_{\text{stock}}$" was prepared from the formula given in Table 4.1 Suspension PVC resin (Siamvic 258RB, K value 58) and other additives were supplied by Vinythai Public Company Limited.

Table 4.1 Formula for PVC $_{stock}$ Dry Blend

Ingredient	Concentration (phr*)
PVC (Siamvic 258 RB)	100
Stabilizer (SAK-WP-08-NP)	4
Processing aid (Kane Ace PA20)	6
External lubricant (Loxiol P1141)	2
Internal lubricant (Calcium stearate)	0.5

(*phr = part per hundred parts of PVC resin)

PVC (35 kg) was blended with the above additives in a hot and cold mixer as followed.

Hot Mixing Steps

- Adding PVC resin and solid additives to the mixer.
- Mixing at low speed (400 rpm) for 3 min.
- Mixing at high speed (1200 rpm) for 15 min.
- Adding Loxiol P1141, mixing until temp reaches up to 120 °C.
- Discharging to a cold mixer.

Cold Mixing Steps

- Mixing until the temperature is decreased to 30 °C.
- Discharging to a container.

The obtained PVC $_{stock}$ dry blend was further mixed with glass fiber composite as described below.

Preparation of PVC $_{stock}$ sheet for reference properties measurement

The PVC $_{stock}$ (300g) was mixed in two-roll mill with 0.3 mm gap at 175 °C for 5 min. The resulted PVC $_{stock}$ compound is rather white as shown in Figure 4.1. The compound was compression-molded in a hot-press machine at the temperature of 170 °C and the pressure of about 150 psi for 4 min into a sheet form. As shown in Figure 4.2, the dimension of the compression molded specimen was 200×200×4 mm^3 (W×L×D).

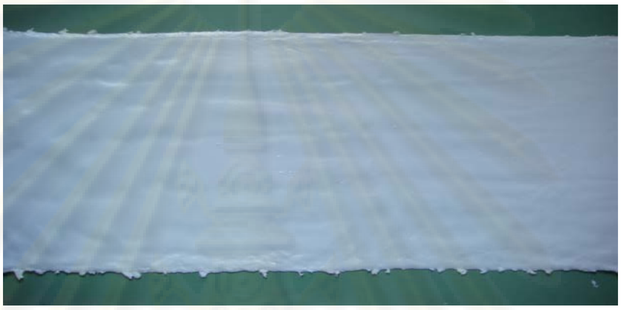


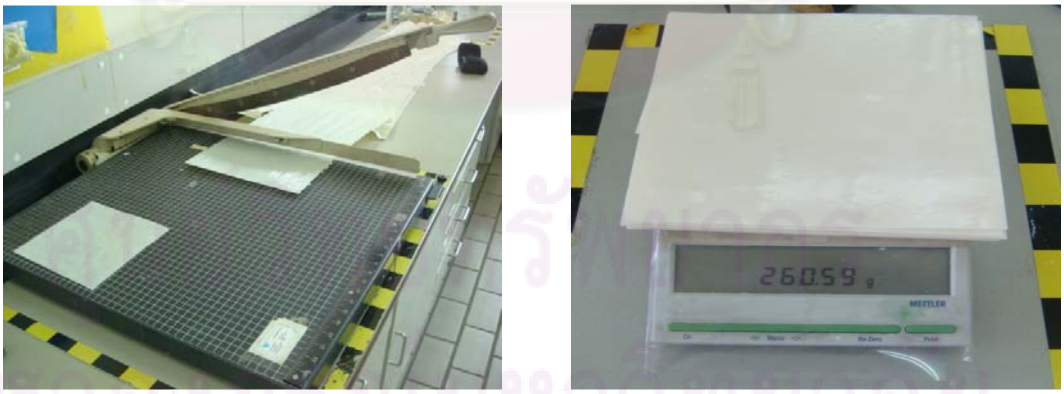
Figure 4.1 PVC $_{stock}$ Compound from a Two-roll Mills

Figure 4.2 Compression-molded PVC $_{stock}$ Sheet

4.2.2 Preparation of PVC$_{stock}$ /Glass fiber composites

The appropriate amounts of PVC stock and glass fiber were blended together (i.e. PVC$_{stock}$: GF: 300g: 0 g, 255 g: 45 g and 225 g: 75 g) to get the contents of GF in composites at 0, 15 and 25 wt%, respectively. The obtained mixture was then mixed in two-roll mill with 0.5 mm gap at 175 °C for 5 min. The obtained compound was shown in Figure 4.3. The compound was compression-molded at the temperature of 170 °C and the pressure of about 150 psi for 4 min. The dimension of compression molded sheet is 200×200×4 mm^3 (W×L×D) as presented in Figure 4.4.

Figure 4.3 PVC$_{stock}$/ glass fiber compound from a Two-roll Mills



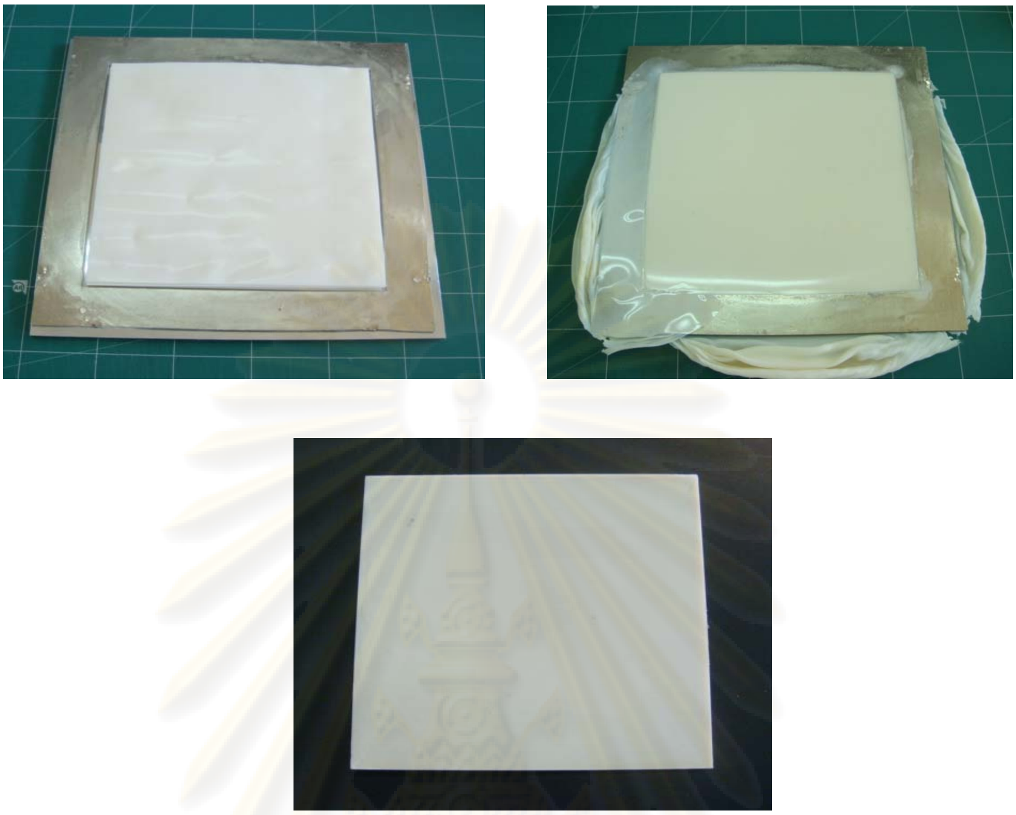


Figure 4.4 Compression-molded PVC $_{stock}$/ glass fiber composite Sheet

The composite was then cut into test pieces (dog-bone shape, bar shape and circle shape) for further mechanical property evaluations (tensile, Izod impact properties and weight loss). It was noted that the hot and cold mixing steps, the compounding step, and the compression molding step were carried out at Vinythai plant in Rayong province, Thailand.

4.3 Measurement of PVC $_{stock}$ / glass fiber composites Properties

4.3.1 Physical Properties Evaluations

The evaluation of water absorption and physical change were carried out at the Polymer Engineering Laboratory, Chulalongkorn University, Bangkok.

Change in Weight, Dimension, and Appearance

This test covers the evaluation of plastic materials for resistance to chemical reagents, simulating performance in potential end use environments. Chemical reagents can include lubricants, cleaning agents or anything else that the test material may be expected to come in contact with. The test includes provisions for reporting changes in weight, dimensions, appearance and strain condition (ASTM D543).

Test procedure:

Five test specimens can be weighed and measured prior to contact with the test fuels. To simulate end use stress in the test samples are used. Depending upon the type of contact anticipated for the test sample. The test samples are then sealed in a container, and either left at room temperature. After the agreed upon period of time, the specimens are removed and evaluated for desired properties such as change in weight, appearance.

Specimen size:

50.8 mm diameter x 3.2 mm disk for molded plastics. The thickness shall be measured to the nearest 0.025 mm as shown in Figure 4.5.

Data:

Reports often include visual evidence of decomposition, swelling, clouding, crazing, cracking, and/or change in physical properties.

Figure 4.5 Specimen (disk) for Change in Weight, Dimension, and Appearance

Water Absorption

Water absorption is used to determine the amount of water absorbed under specified conditions. Factors affecting water absorption include: type of plastic, additives used, temperature and length of exposure. The data sheds light on the performance of the materials in water or humid environment.

While all polymers absorb water to some degree, some are sufficiently hydrophilic that they absorb large enough quantities of water to significantly affect their performance. Water will case the polymer to swell and serves as a plasticizer, consequently lowering its performance, such as in electrical and mechanical behavior [23].

Test procedure:

Five test specimens are dried in an oven for a specified time and temperature and then placed in desiccators to cool. Immediately upon cooling, the specimens are weighed. The material is then submerged in water at room temperature for 56 day or until equilibrium. Specimens are removed, patted dry with a lint free cloth, and weighed.

Specimen size:

50.8 mm diameter x 3.2 mm disk for molded plastics. The thickness shall be measured to the nearest 0.025 mm as shown in Figure 4.6.

Data:

Water absorption is expressed as increase in weight percent.

Percent water absorption = [(Wet weight – Dry weight)/ Dry weight] × 100%

The density of a solid is determined with the aid of a liquid whose density ρ_o is know (water or ethanol are usually used as auxiliary liquids). The solid is weighed in air (A) and then in the auxiliary liquid (B). The density ρ can be calculated from the weighing as follows

$$\rho = \frac{A}{A-B} \times \rho_0$$

Figure 4.6 Specimen (disk) for Water Absorption evaluation

4.3.2 Mechanical Properties Evaluations

The evaluation of tensile, flexural, compressive properties and Izod impact strengths were carried out at the Polymer Engineering Laboratory, Chulalongkorn University, Bangkok.

Tensile Strength

The tensile test is performed to characterize stress-strain behavior of material. However, standardized tests such as DIN 53457 and ASTM D638 are available to evaluate the stress-strain behavior of polymeric materials [23]. The ASTM D638 test also uses one rate of deformation per material to measure the modulus; a slow speed for brittle materials and fast speed for ductile ones. The relationship between the applied force, or load, and the elongation the specimen exhibits is linear. In this linear region, the line obeys the relationship defined as "Hooke's Law" where the ratio of stress to strain is a constant, or

$$E = \frac{\sigma}{\varepsilon}$$

E is the slope of the line in this region where stress (σ) is proportional to strain (ε) and is called the "Modulus of Elasticity" or "Young's Modulus" [23]. By its basic definition the uniaxial stress is given by:

$$\sigma = \frac{F}{A}$$

where F = Load applied [N], A = Area [m^2]

Tensile Modulus is the ratio of tensile stress to tensile strain of a material in the elastic region of a stress-strain curve. A "Tangent" tensile modulus value is the slope of the elastic region of the stress-strain curve and is also known as Young's Modulus, or the Modulus of Elasticity. A "Secant" tensile modulus value is the slope of a line connecting the point of zero strain to a point on the stress-strain curve at a specified strain. This is used for materials that exhibit little or no linear behavior in Figure 4.7.

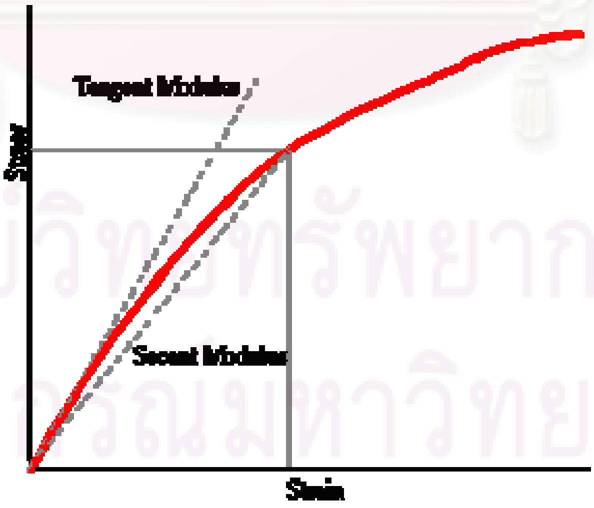


Figure 4.7 Illustrations of Tangent and Secant Tensile Modulus [30]

The general factors, affecting the toughness of a material are: temperature, strain rate, relationship between the strength and ductility of the material and presence of stress concentration (notch) on the specimen surface. Fracture toughness is indicated by the area below the curve on strain-stress diagram (see the figure 4.8):

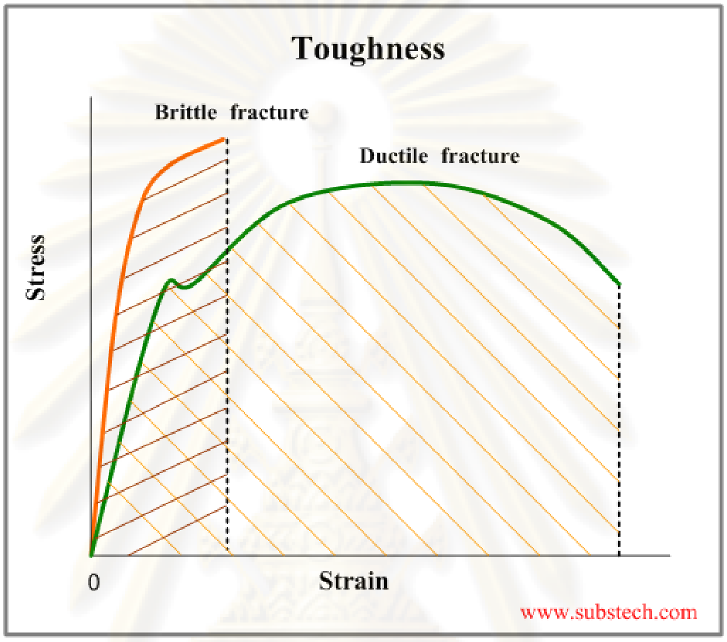


Figure 4.8 Toughness of the Ductile and Brittle of Materials [31]

Test procedure:

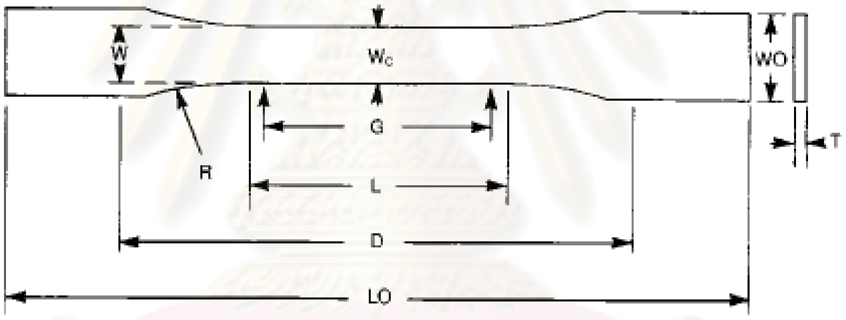
Five test specimens shall be prepared by machining operation or die cutting the materials in sheet. Specimens can also be prepared by compression molding the material to be tested. The crosshead speed was 50 mm/min. Modulus testing may be conducted at the same speed as the other tensile properties provided that recorder response and resolution are adequate [23].

Specimen size:

The dog-bone shape specimens are prepared for tensile testing following ASTM D638 (or ISO 527). The appearance and the dimension of sample are shown in Figure

4.9 and 4.10, respectively. At five measurements are taken using Instron universal testing machine in Figure 4.11. An average value and a standard deviation are statistically calculated.

Figure 4.9 Dog-bone Shape Specimen for tensile strength evaluation



W: Width of narrow parallel portion	10 ± 0.5 mm.
L: Length of narrow parallel portion	60 ± 0.5 mm.
WO: Width at ends	20 ± 0.5 mm.
LO: Length overall, minimum	160 mm.
G: Distance between reference line	50 ± 0.5 mm.
D: Initial distance between grips	115 ± 5 mm.
R: Radius of fillet	60 mm.

Figure 4.10 Dimension of Dog-bone shape Specimen (ASTM D638 or ISO 527)

Figure 4.11 Universal Testing Machines (Instron Model 5567)

<u>Flexural Strength</u>

The flexure test according to ASTM D790 serves determining strength and form change properties under bending loading. The 3-point flexure test is the most common for polymers shown in Figure 4.12. Results are plotted in a stress-strain diagram. Flexural strength is defined as the maximum stress in the outermost fiber. This is calculated at the surface of the specimen on the convex or tension side. Flexural modulus is calculated from the slope of the stress vs. deflection curve. If the curve has no linear region, a secant line is fitted to the curve to determine slope [32].

Figure 4.12 Universal Testing Machines (Instron Model T609-109) for Flexural Test [33]

Three-Point Bend Test

In the three-point bend test, maximum flexural stress at break σ_f is calculated from fracture load F: [34]

$$\sigma_f = \frac{6M}{Bd^2} = \frac{3FL}{2Bd^2}$$

M: maximum bending moment	*F*: the load (force) at the fracture point
L: the lengths of the support span	*B:* width of specimen
D: thickness of specimen	

Test Procedure:

The specimen lies on a support span and the load is applied to the center by the loading nose producing three points bending at a specified rate. A support span-to-dept ratio shall be of 16:1 (Figure 4.13). The specimen is deflected until rupture occurs in the outer surface of the test specimen or until a maximum strain of 5.0% is reached, whichever occurs first. Procedure employs a strain rate of 0.01 mm/mm/min.

Specimen size:

A variety of specimen shapes can be used for this test, but the most commonly used specimen size is 12.7 x 64 x 3.2 mm^3 (W×L×D) for ASTM (Figure 4.14).

Data:

Flexural strength, flexural stress at specified strain levels, and flexural modulus can be calculated.

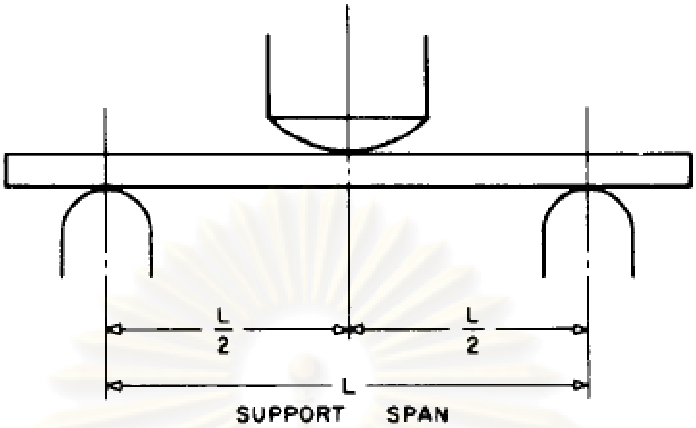


Figure 4.13 Maximum radius support span = 16 times of specimen depth;

Maximum radius loading nose = 4 times of specimen depth.

Figure 4.14 Bar shape specimen of PVC $_{stock}$ / glass fiber composite

Compressive Properties

A compression test determines behavior of materials under crushing loads. The specimen is compressed and deformation at various loads is recorded. Compressive stress and strain are calculated and plotted as a stress-strain diagram [23]. A large number of relatively complex loading direction and specimen configurations were developed to measure the compression strength of composite materials [34]. The compressive strength of the material would correspond to the stress at the red point shown on the curve in Figure 4.15.

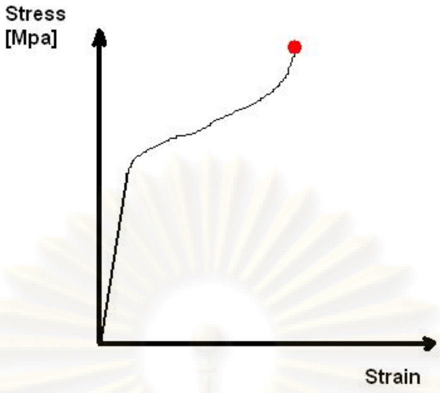


Figure 4.15 Illustration of compressive strength of the material [34]

Even in a compression test, there is a linear region where the material follows Hooke's Law. Hence for this region [33]:

$$E = \frac{\sigma}{\varepsilon}$$

where this time E refers to the Young's Modulus for compression. There is a difference between the engineering stress and the true stress. By its basic definition the uniaxial stress is given by:

$$\sigma = \frac{F}{A}$$

where F = Load applied [N], A = Area [m^2]

Test Procedure:

The specimen is placed between compressive plates parallel to the surface. The specimen is then compressed at a uniform rate. The maximum load is recorded along with stress-strain data. An extensometer attached to the front of the fixture is used to determine modulus.

Specimen size:

Specimens are blocks shape for ASTM D695, the typical blocks are 12.7 x 25.4 x 12.7 mm^3 (W×L×D). For ISO, the preferred specimens are 50 x 10 x 4 mm^3 (W×L×D) for modulus, 10 x 10 x 4 mm^3 (W×L×D) for strength as shown in Figure 4.16.

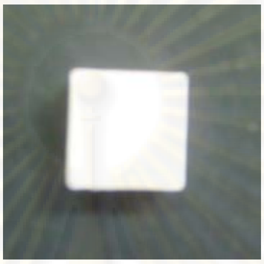


Figure 4.16 Specimen (blocks) for Compressive Properties evaluation

Data:

Compressive strength and modulus are two useful calculations.
Compressive strength = (maximum compressive load / minimum cross-sectional area)
Compressive modulus = (change in stress / change in strain)

Izod Impact Strength

Notched Izod Impact is a single point test that measures the resistance of material to impact from a swinging pendulum as shown in Figure 4.17. Izod impact is defined as the kinetic energy needed to initiate fracture and continue the fracture until the specimen is broken. Izod specimens are notched to prevent deformation of the specimen upon impact. This test can be used as a quick and easy quality control check to determine if a material meets specific impact properties or to compare materials for general toughness [23].

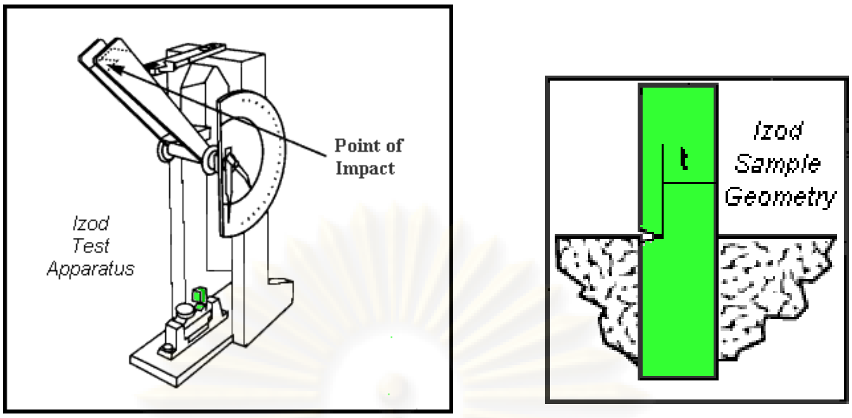


Figure 4.17 A pendulum swings on its track and strikes a notched, cantilevered plastic sample [35]

Test procedure:

The specimen is clamped into the pendulum impact test fixture with the notched side facing the striking edge of the pendulum. The pendulum is released and allowed to strike through the specimen. If breakage does not occur, a heavier hammer is used until failure occurs. ASTM impact energy is expressed in J/m or ft-lb/in. Impact strength is calculated by dividing impact energy in J (or ft-lb) by the thickness of the specimen. The test result is typically the average of 10 specimen. Specimens shall be prepared from sheets specimens [23].

Specimen size:

The bar shape specimens are prepared for Izod impact strength testing following ASTM D256 (or ISO 180) as shown in Figure 4.18 . The standard specimen for ASTM is 12.7 x 64 x 3.2 mm^3 (W×L×D) as shown in Figure 4.19. The depth under the notch of the specimen is 10.16 mm. The impact tester (Yasuda) is shown in Figure 4.20.

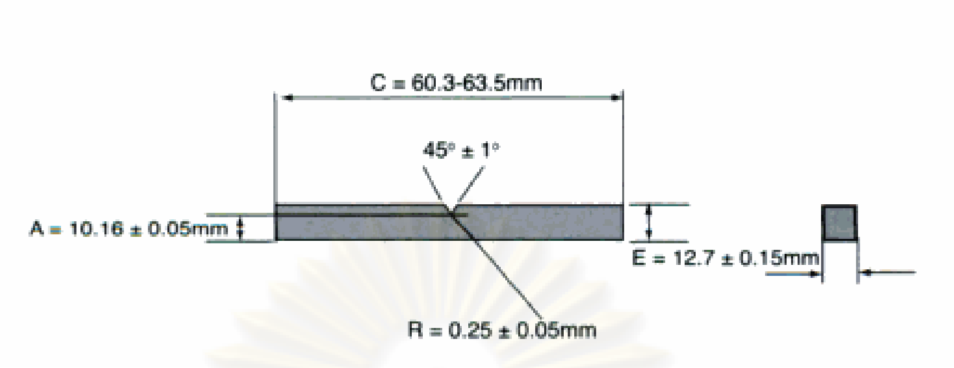


Figure 4.18 Dimension of impact test specimen ASTM D256 [23]

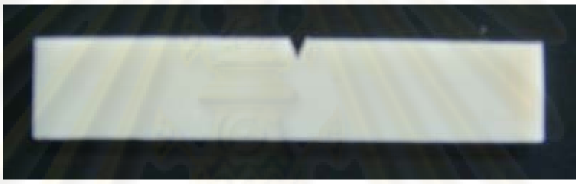


Figure 4.19 Bar shape Specimen for Izod Impact strength evaluation

Figure 4.20The impact tester (Yasuda)

4.3.3 Scanning Electron Microscope (SEM)

The morphology of the composites were examined by Scanning Electron Microscope (SEM). SEM is a type of electron microscope that images the sample surface by scanning it with a high-energy beam of electrons in a raster scan pattern. The electrons interact with the atoms that make up the sample producing signals that contain information about the sample's surface topography, composition and other properties such as electrical conductivity.The composite samples were broken in liquid nitrogen and then coated with gold palladium alloy under vacuum [36].

<u>Test procedure:</u>

Test specimens are sputter coated with gold, then placed in a vacuum chamber for viewing on the computer monitor at up to 200 and 2,000 x magnifications in the Hitachi JEOL JSM-5200 is shown in Figure 4.21

<u>Specimen size:</u>

All samples must also be of an appropriate size to fit in the specimen chamber and are mounted rigidly on a specimen holder called a specimen stub. Several models of SEM can examine any part of a 6-inch (15 cm) semiconductor wafer, and some can tilt an object of that size to 45 degrees.

Figure 4.21 Scanning electron microscope (SEM).

4.4 Preparation of Testing Fuels

The procedures for testing the effect of gasohol on physical and mechanical properties of the PVC $_{stock}$ / glass fiber composites were adapted from standards of Society of Automotive Engineers (SAE) and American Society for Testing and Materials (ASTM). After the samples are prepared, the weights and dimensions are measured to provide a baseline for comparison. The molded sheets were then cut into dumbbell shape, bar shape, block shape and disk shape specimens. The specimens were immersed into 4 different test fuels, namely $C(E0)_A$, $C(E20)_A$, $C(E85)_A$, and $C(E100)_A$, prepared according to SAE J1681, in glass jars at room temperature for 0,4,10 and 16 weeks before testing. The following properties were measured before and after immersion: volume, weight, appearance, tensile, flexural, compressive properties, Izod impact strengths and water absorption.

The compatibility test PVC $_{stock}$ / glass fiber composites with test fuels required four different shaped test specimens. The first was a 50.8 mm. diameter by 3.175 mm. thick disk. This specimen shape was used for volume, weight, appearance change and water absorption measurements. It will be referred to as the appearance specimen. Five appearance specimens of each material were immersed in each test fuel. The second specimen shape prepared and immersed was a Type 1 tensile dumbbell as specified by ASTM D638 (2003) (see Fig. 4.7). These samples were used for tensile strength and elongation measurements. They will be referred to as the tensile specimens. Five tensile specimens of each material were prepared and immersed in each test fuel. The third specimens used were Izod-type specimens as specified by ASTM D256 (2006) (see Fig. 4.12). They were used for impact testing. Ten samples were placed in each of the test fuels. The fourth specimens used were block specimens (10x10x4 mm.). They were used for compression testing. Five samples were placed in each of the test fuels.

Once the physical data was recorded, the specimens were immersed in glass jars containing the appropriate test fuels: $C(E0)_A$, $C(E20)_A$, $C(E85)_A$ and $C(E100)_A$ prepared according to SAE J1681, at room temperature for 0,4,10 and 16 weeks. The test fluid was changed twice a month. After the immersion time each specimen was dimensionally measured and weighed. The immersed tensile specimens were tested in accordance to standards to measure tensile strength and young's modulus. Then block specimens were tested to measure compressive properties. Finally, impact testing was conducted on all test samples to determine impact resistance.

Terminology

E0 - Fuel consisting of 100 vol% gasoline and 0 vol% ethanol

E20 - Fuel consisting of 80 vol% gasoline and 20 vol% ethanol

E85 - Fuel consisting of 15 vol% gasoline and 85 vol% ethanol

E100 - Fuel consisting of 0 vol% gasoline and 100 vol% ethanol

ASTM Test Fuel C - Test Fuel C is composed of 50 vol% toluene and 50 vol% iso-octane

Aggressive ethanol - Synthetic ethanol 816.00 g, de-ionized water 8.103sodium chloride 0.004 g, sulfuric acid 0.021 g, and glacial acetic acid 0.061 g (SAE J1681)

C $(E0)_A$ - Fuel consisting of 100 vol% ASTM test Fuel C and 0 vol% aggressive ethanol

C $(E20)_A$ - Fuel consisting of 80 vol% ASTM test Fuel C and 20 vol% aggressive ethanol

C $(E85)_A$ - Fuel consisting of 15 vol% ASTM test Fuel C and 85 vol% aggressive ethanol

C $(E100)_A$ - Fuel consisting of 0 vol% ASTM test Fuel C and 100 vol% aggressive ethanol

CHAPTER V

RESULTS AND DISCUSSION

The effects of glass fiber content and ethanol concentration in gasohols on the physical, mechanical, water absorption, and morphological properties of PVC/GF composites were studied. PVC resins with K-value of 58 (and other additives) were mixed with chopped E-glass fiber of 3 mm length at 0, 15, and 25 wt% using two-roll mill, then compressed into sheet, and cut into dumbbell shape, bar shape, block shape and disk shape specimens. The specimens were immersed into 4 different test fuels, namely $C(E0)_A$, $C(E20)_A$, $C(E85)_A$, and $C(E100)_A$, prepared according to SAE J1681, in glass jars at room temperature for 16 weeks. The tensile strength, Young's modulus, flexural strength and compressive strength were tested by Universal testing machine and their impact property was tested by impact tester. In addition, the microstructure of PVC/GF composites was observed by scanning electron microscope (SEM).

5.1 Physical properties evaluation

5.1.1 Mass change

Fig. 5.1-5.6 showed clearly that the mass of PVC/GF (0-25 wt%) composites immersed in $C(E0)_A$ and $C(E20)_A$ test fuels increased with immersion time with plateau level of around 12-20% and be stable in 4-16 week (B.Jones et al.)[26]. But the mass of specimens immersed in $C(E85)_A$ and $C(E100)_A$ test fuels hardly changed with immersion time. These could be because the mass increase was due to the solubility parameter of the toluene is near that of PVC and PVC has low polar as $C(E0)_A$ and $C(E20)_A$ cause absorption of iso-octane and toluene into PVC matrix (Fred W. Billmeyer et al.) [24]. PVC has higher solubility in hydrocarbons than alcohols (A. Ranney et al.) [29]. And $C(E0)_A$ and $C(E20)_A$ test fuels have more iso-octane and toluene than $C(E85)_A$ and $C(E100)_A$ test fuels. Similar results were obtained for other composites.

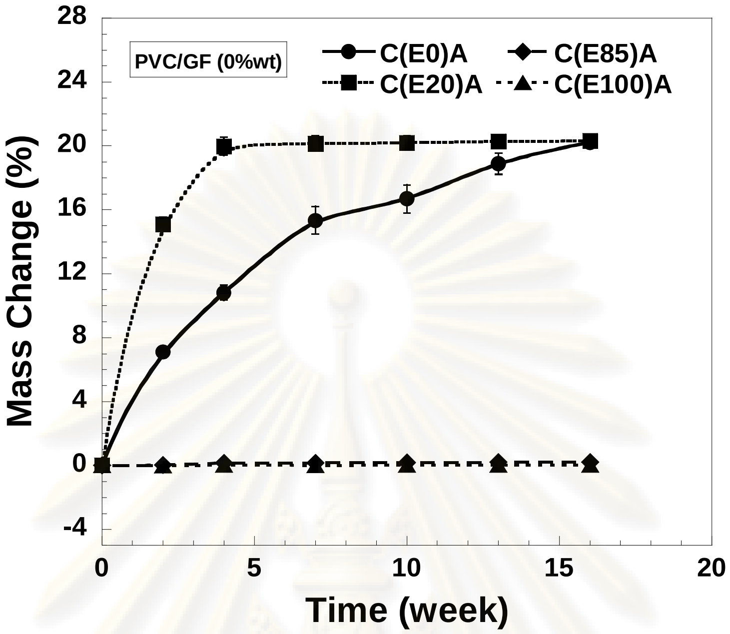


Figure 5.1 Effect of percent of ethanol in test fuel and immersion time on mass change of PVC/GF (0 wt%) composites

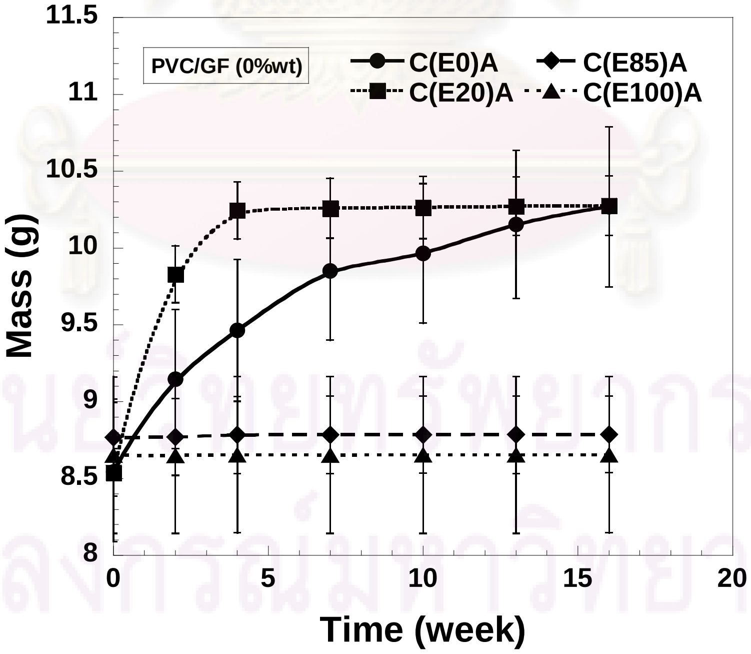


Figure 5.2 Effect of percent of ethanol in test fuel and immersion time on mass of PVC/GF (0 wt%) composites

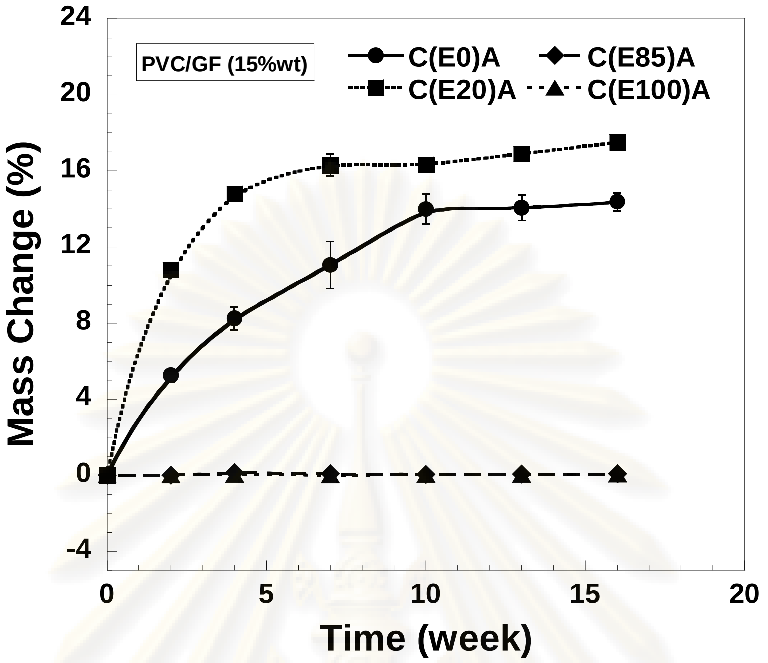


Figure 5.3 Effect of percent of ethanol in test fuel and immersion time on mass change of PVC/GF (15 wt%) composites

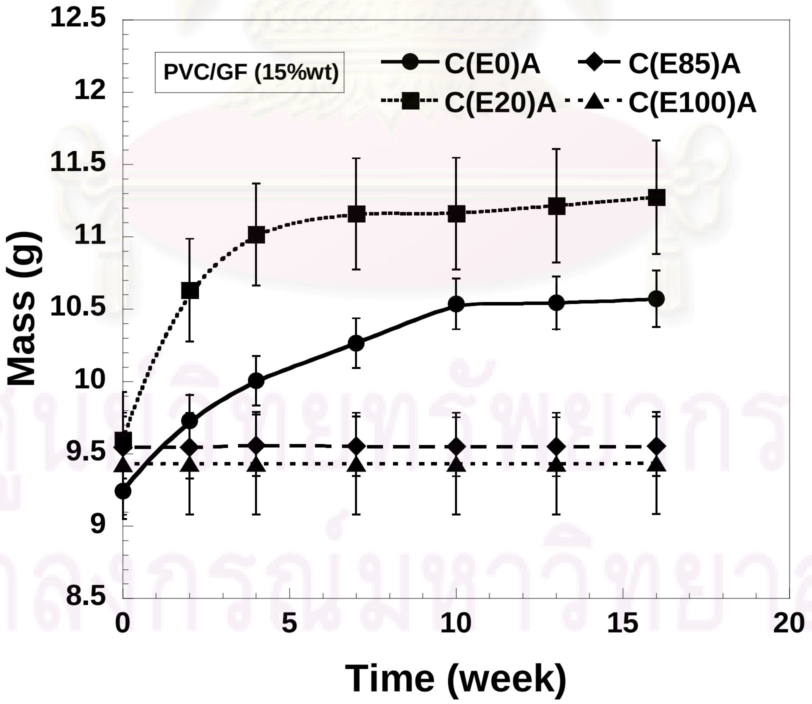


Figure 5.4 Effect of percent of ethanol in test fuel and immersion time on mass of PVC/GF (15 wt%) composites

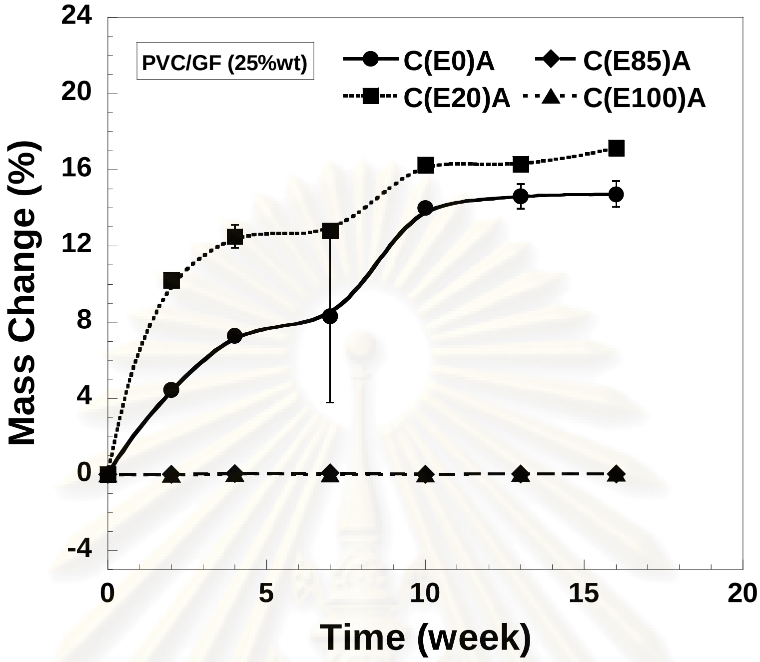


Figure 5.5 Effect of percent of ethanol in test fuel and immersion time on mass change of PVC/GF (25 wt%) composites

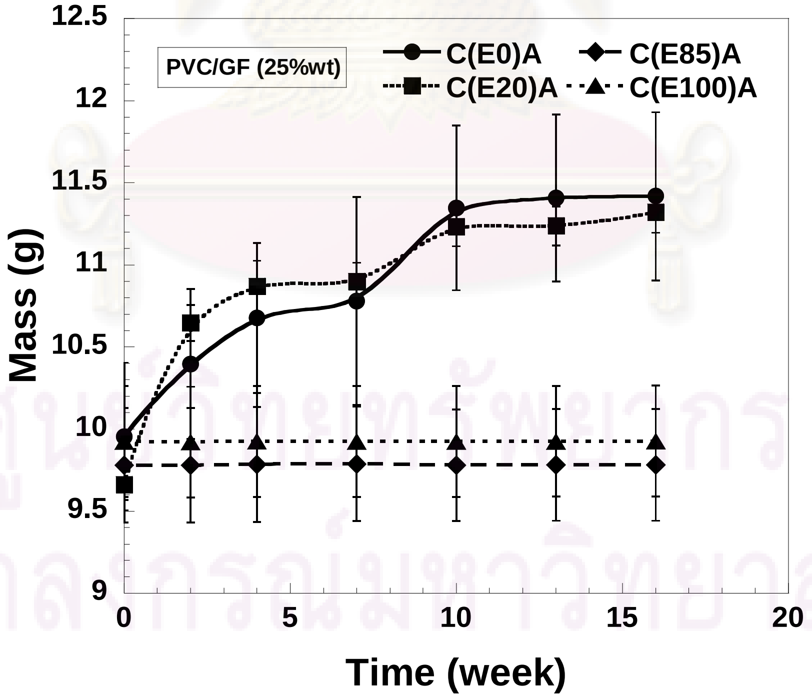


Figure 5.6 Effect of percent of ethanol in test fuel and immersion time on mass of PVC/GF (25 wt%) composites

Fig. 5.7-5.14 showed that the mass of composites with higher content of GF increased less than the mass of composites with lower content of GF. This was clearly due to less mass of PVC matrix in composites with higher GF content.

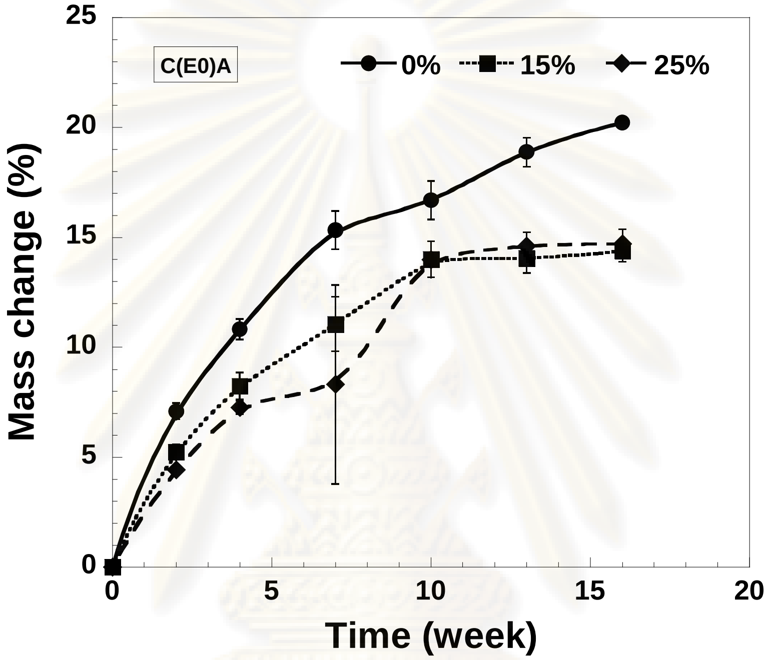


Figure 5.7 Effect of percent of GF in composites and immersion time on mass change of PVC/GF composites immersed in $C(E0)_A$ test fuel

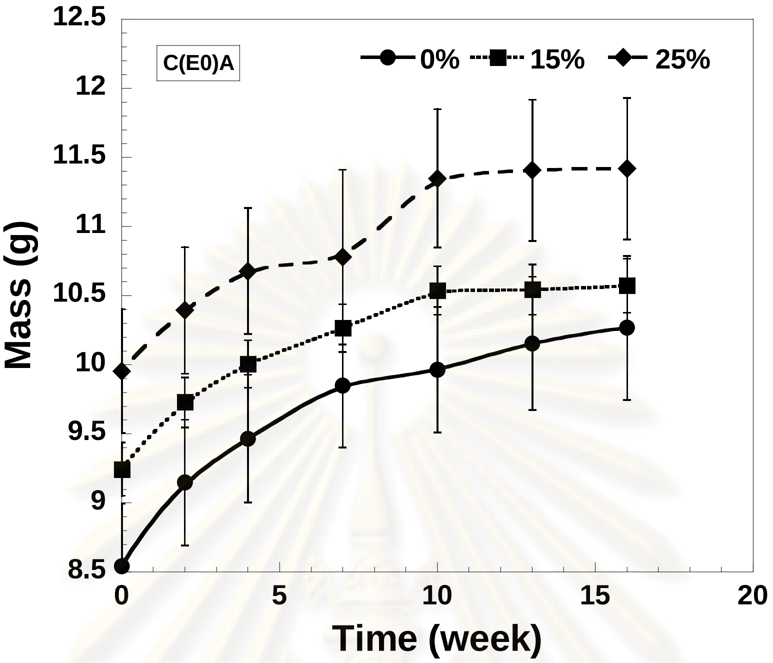


Figure 5.8 Effect of percent of GF in composites and immersion time on mass of PVC/GF composites immersed in C(E0)$_A$ test fuel

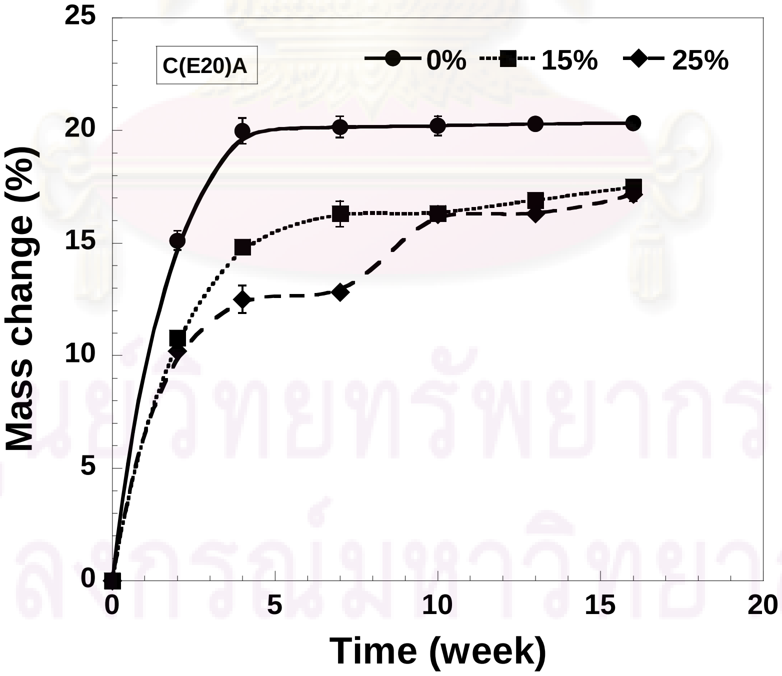


Figure 5.9 Effect of percent of GF in composites and immersion time on mass change of PVC/GF composites immersed in C(E20)$_A$ test fuel

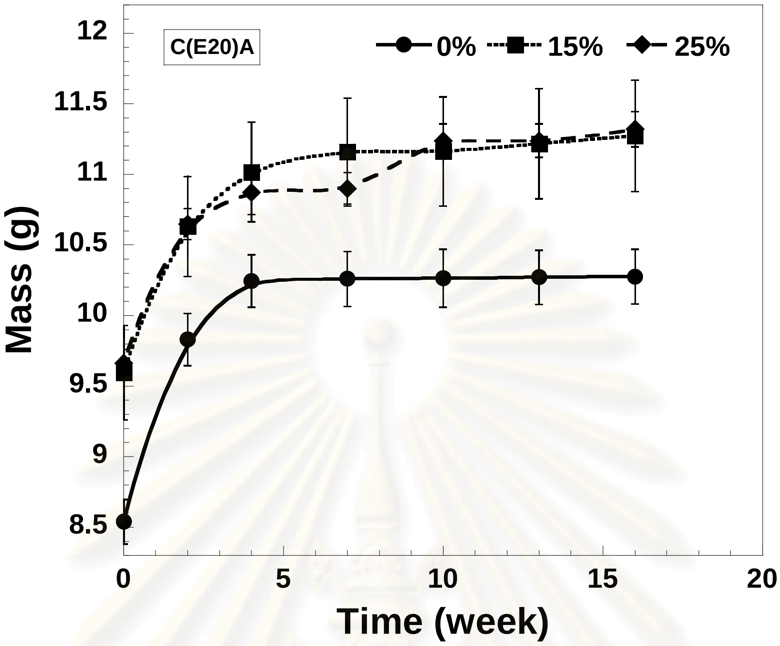


Figure 5.10 Effect of percent of GF in composites and immersion time on mass of PVC/GF composites immersed in C(E20)$_A$ test fuel

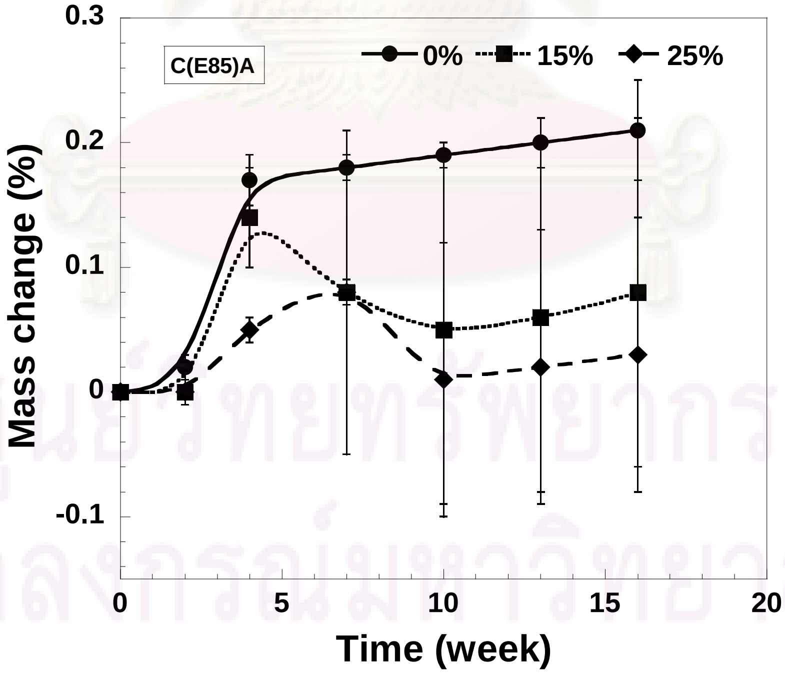


Figure 5.11 Effect of percent of GF in composites and immersion time on mass change of PVC/GF composites immersed in C(E85)$_A$ test fuel

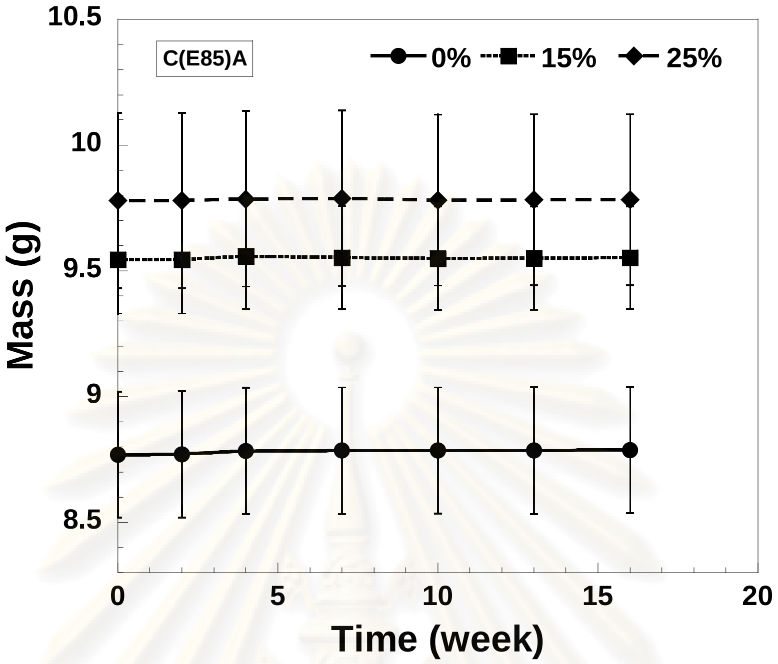


Figure 5.12 Effect of percent of GF in composites and immersion time on mass of PVC/GF composites immersed in C(E85)$_A$ test fuel

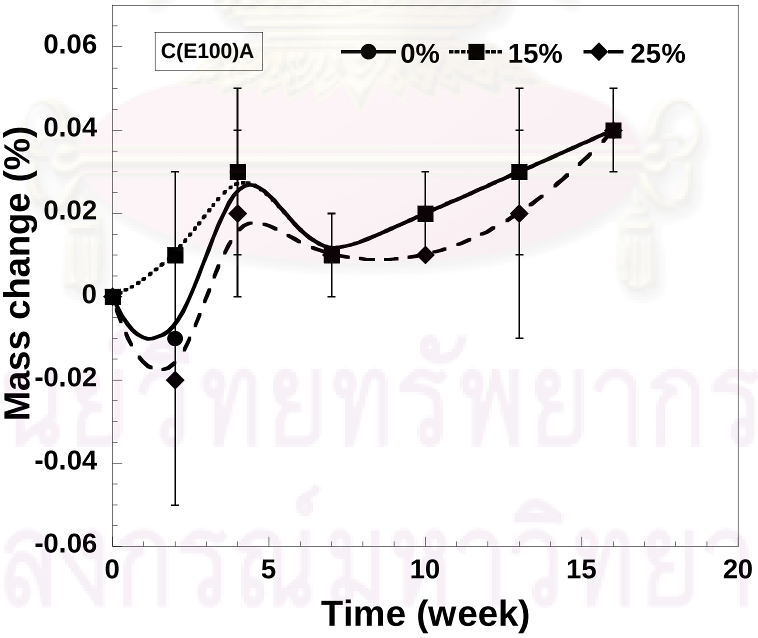


Figure 5.13 Effect of percent of GF in composites and immersion time on mass change of PVC/GF composites immersed in C(E100)$_A$ test fuel

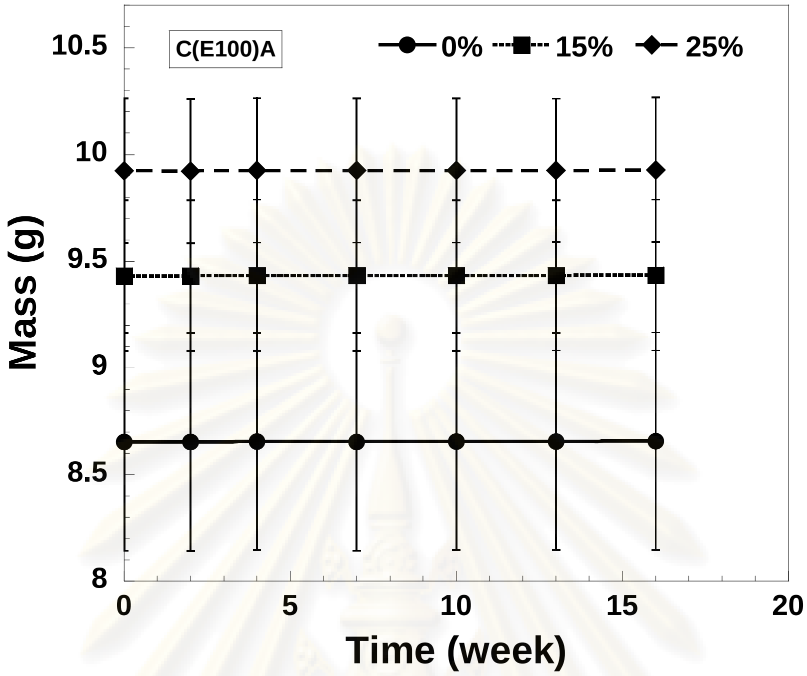


Figure 5.14 Effect of percent of GF in composites and immersion time on mass of PVC/GF composites immersed in $C(E100)_A$ test fuel

5.1.2 Volume change

Fig. 5.15-5.20 showed clearly that the volume of PVC/GF (0-25 wt%) composites immersed in $C(E0)_A$ and $C(E20)_A$ test fuels increased with immersion time with plateau level of around 15-35% and be constant in 4-16 week (B.Jones et al.)[26]. But the volume of specimens immersed in $C(E85)_A$ and $C(E100)_A$ test fuels hardly changed with immersion time. These could be because the volume increase was due to the solubility parameter of the toluene is near that of PVC and PVC has low polar as $C(E0)_A$ and $C(E20)_A$ cause absorption of iso-octane and toluene into PVC matrix (Fred W. Billmeyer et al.) [24]. PVC has higher solubility in hydrocarbons than alcohols (A. Ranney et al.) [29]. And $C(E0)_A$ and $C(E20)_A$ test fuels have more iso-octane and toluene than $C(E85)_A$ and $C(E100)_A$ test fuels. Similar results were obtained for other composites.

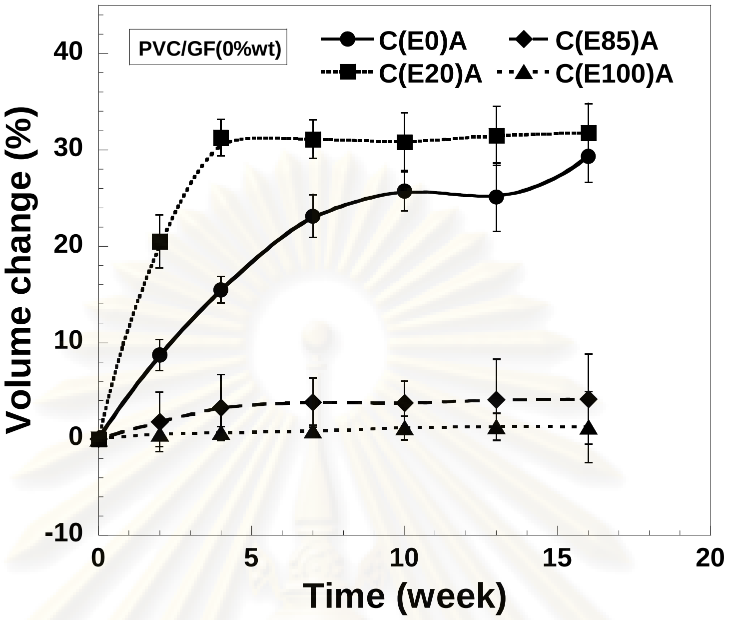


Figure 5.15 Effect of percent of ethanol in test fuel and immersion time on volume change of PVC/GF (0 wt%) composites

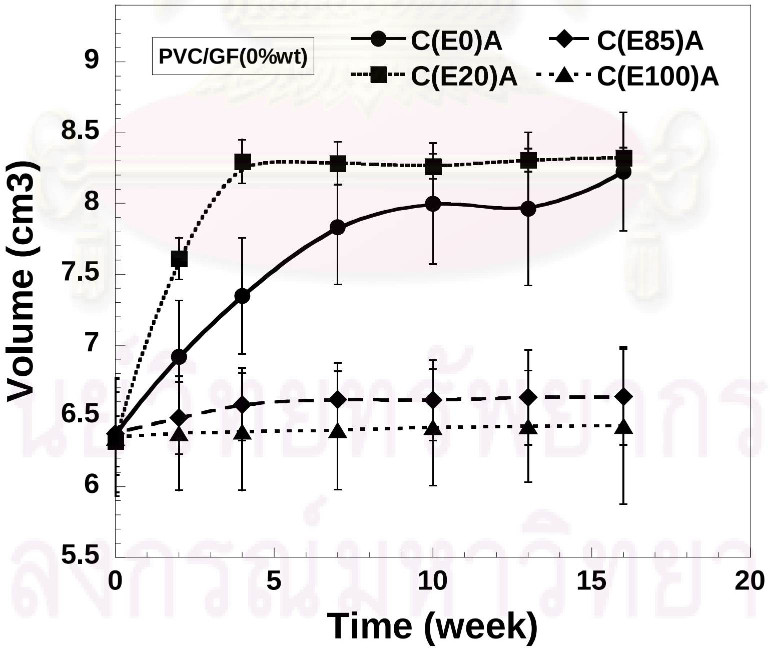


Figure 5.16 Effect of percent of ethanol in test fuel and immersion time on volume of PVC/GF (0 wt%) composites

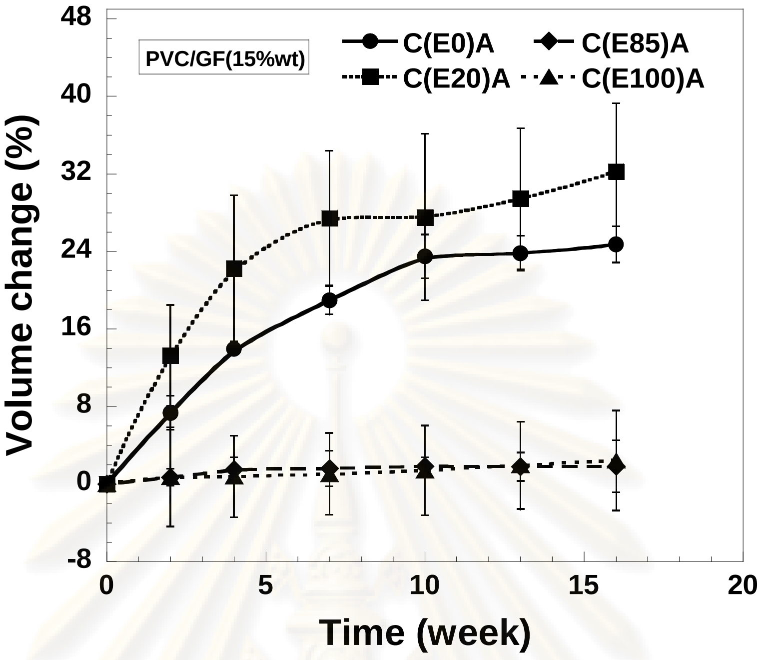


Figure 5.17 Effect of percent of ethanol in test fuel and immersion time on volume change of PVC/GF (15 wt%) composites

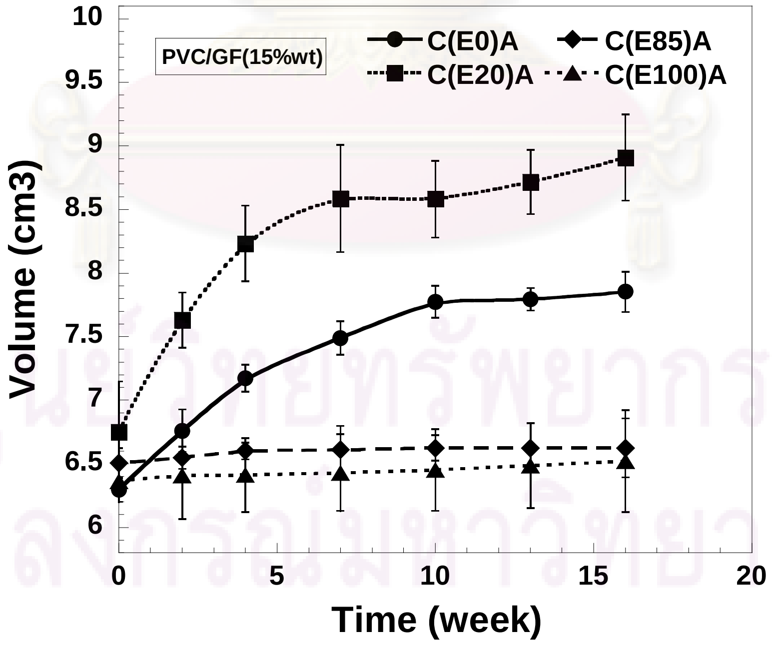


Figure 5.18 Effect of percent of ethanol in test fuel and immersion time on volume of PVC/GF (15 wt%) composites

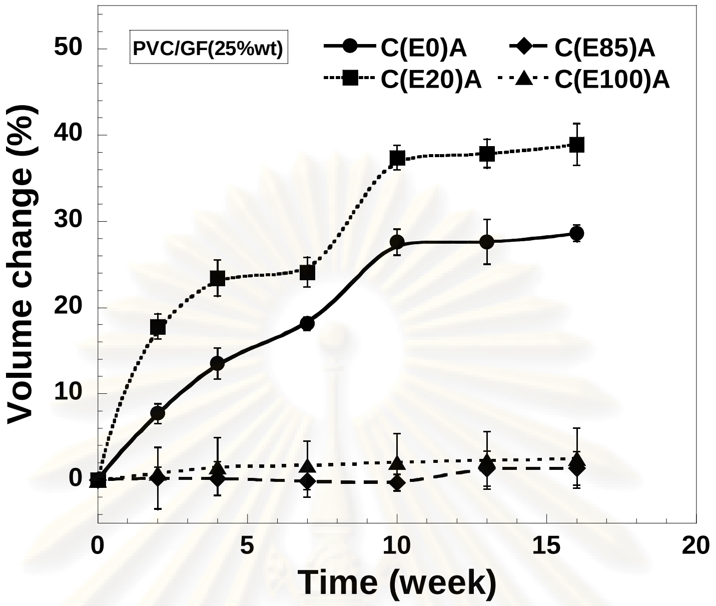


Figure 5.19 Effect of percent of ethanol in test fuel and immersion time on volume change of PVC/GF (25 wt%) composites

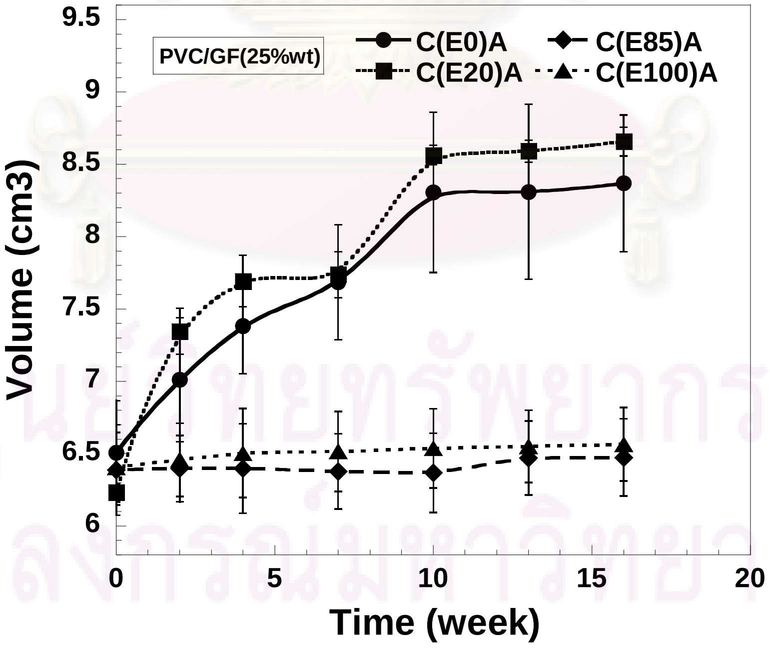


Figure 5.20 Effect of percent of ethanol in test fuel and immersion time on volume of PVC/GF (25 wt%) composites

Fig. 5.21-5.28 showed that the volume of composites with higher content of GF increased less than the volume of composites with lower content of GF. This was clearly due to less volume of PVC matrix in composites with higher GF content.

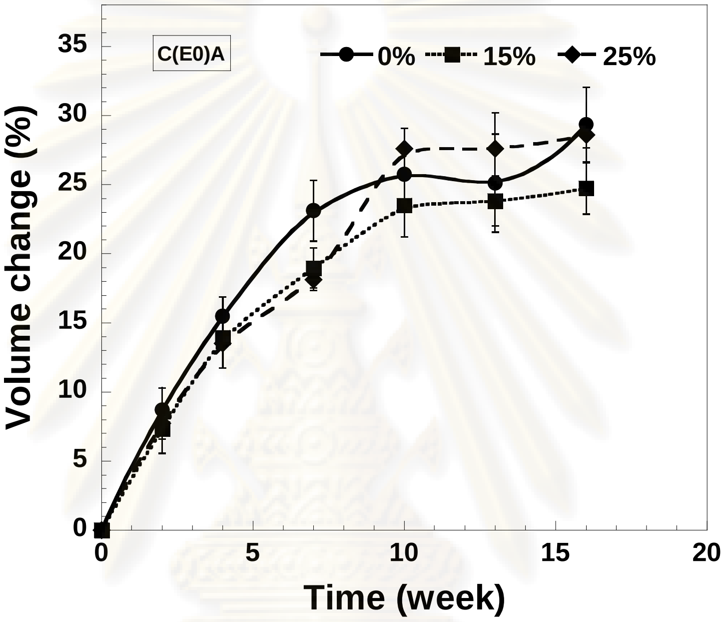


Figure 5.21 Effect of percent of GF in composites and immersion time on volume change of PVC/GF composites immersed in $C(E0)_A$ test fuel

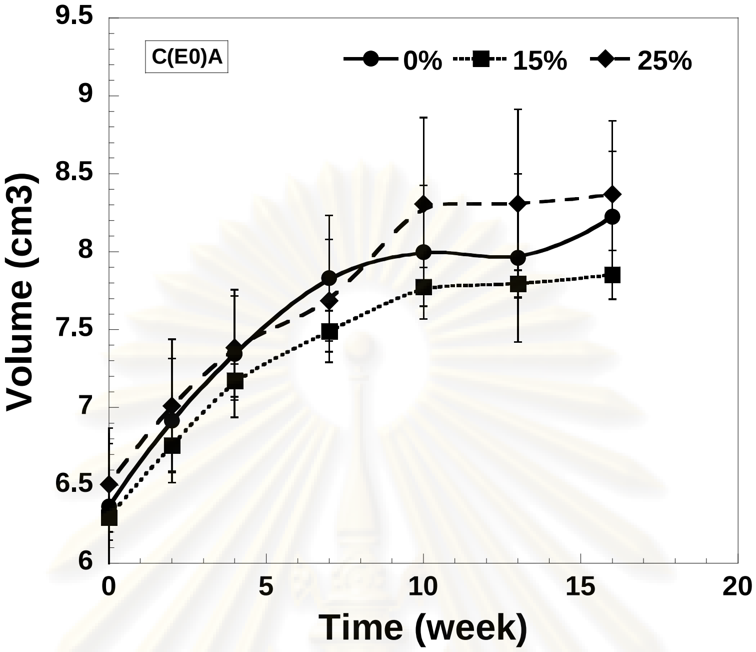


Figure 5.22 Effect of percent of GF in composites and immersion time on volume of PVC/GF composites immersed in C(E0)$_A$ test fuel

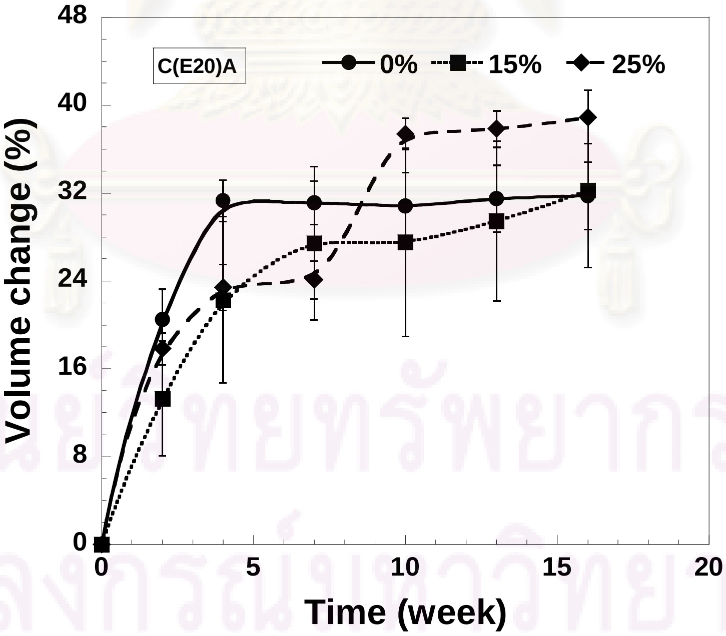


Figure 5.23 Effect of percent of GF in composites and immersion time on volume change of PVC/GF composites immersed in C(E20)$_A$ test fuel

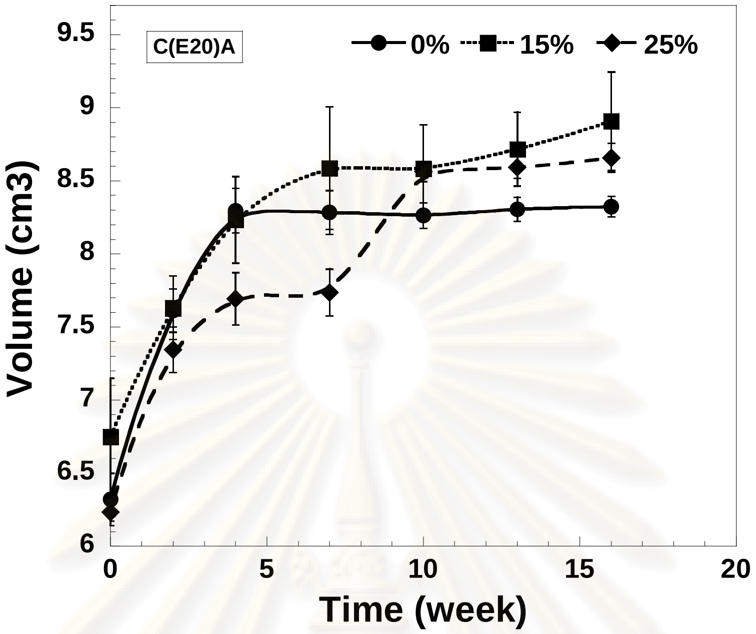


Figure 5.24 Effect of percent of GF in composites and immersion time on volume of PVC/GF composites immersed in $C(E20)_A$ test fuel

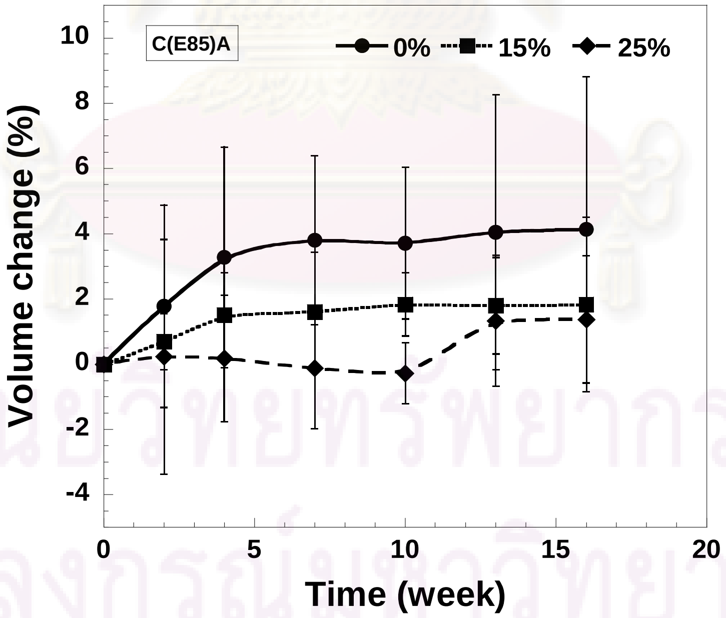


Figure 5.25 Effect of percent of GF in composites and immersion time on volume change of PVC/GF composites immersed in $C(E85)_A$ test fuel

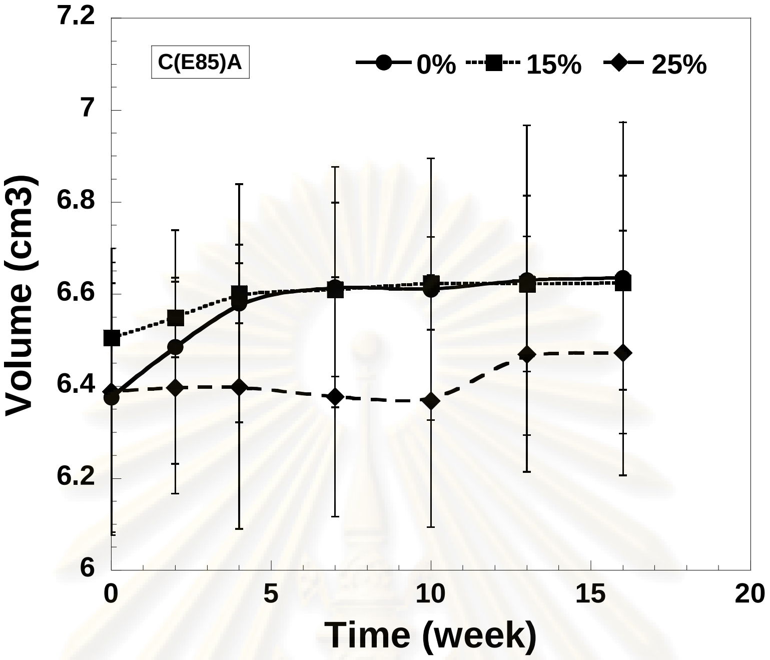


Figure 5.26 Effect of percent of GF in composites and immersion time on volume of PVC/GF composites immersed in C(E85)$_A$ test fuel

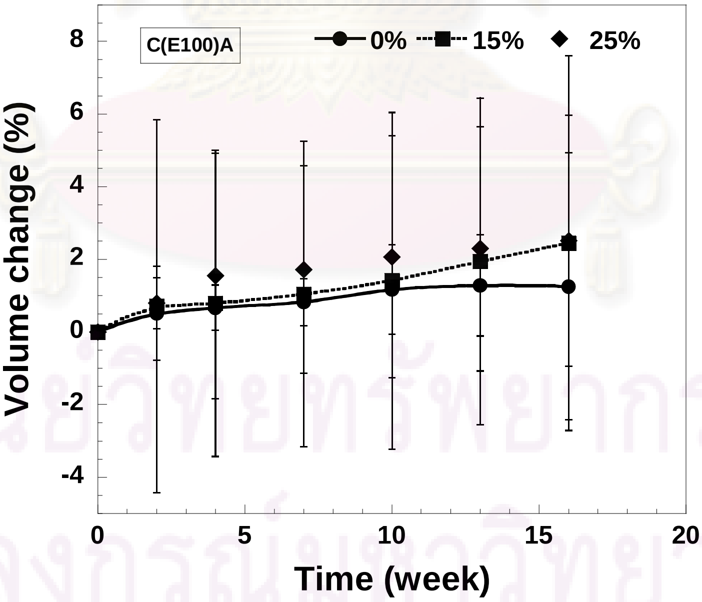


Figure 5.27 Effect of percent of GF in composites and immersion time on volume change of PVC/GF composites immersed in C(E100)$_A$ test fuel

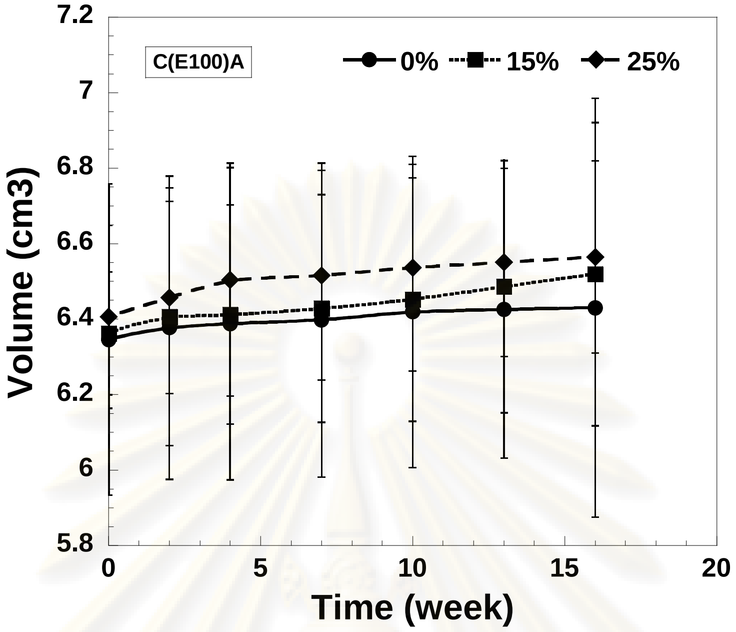


Figure 5.28 Effect of percent of GF in composites and immersion time on volume of PVC/GF composites immersed in $C(E100)_A$ test fuel

5.1.3 Water absorption

Fig. 5.29 showed that the water absorption of composites with higher content of GF increased less than the mass of composites with lower content of GF and stable in 34-56 day. This was clearly due to less mass of PVC matrix in composites with higher GF content.

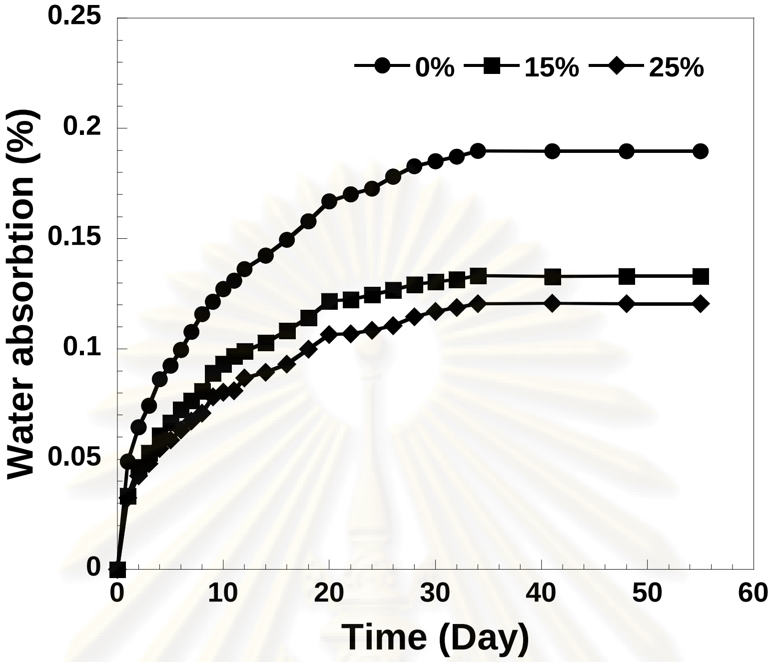


Figure 5.29 Effect of percent of GF in composites and immersion time on water absorption of PVC/GF composites immersed in water.

5.2 Mechanical properties evaluation

5.2.1 Tensile property

Fig. 5.30-5.35 showed that the tensile strength of PVC/GF (0-25 wt%) composites after immersed in $C(E0)_A$ and $C(E20)_A$ test fuels for 16 weeks were reduced by almost 80-90% from the original value and be stable in 10 until 16 week. However, the tensile strength of same composites after immersed in $C(E85)_A$ and $C(E100)_A$ test fuels for 16 weeks were reduced by only about 10% and be constant in 4 until 16 week. These were clearly due to results physical properties. The solubility parameter of the toluene is near that of PVC (Barton, Allan F. M.) [37] and PVC has low polar as $C(E0)_A$ and $C(E20)_A$ (R.L. Eissler et al.) [38] cause higher amount of absorption of iso-octane and toluene into PVC matrix from $C(E0)_A$ and $C(E20)_A$ than from $C(E85)_A$ and $C(E100)_A$ test fuels as discussed earlier (Fred W. Billmeyer et al.) [24]. Iso-octane and toluene clearly swelled and plasticized the PVC matrix causing its tensile strength to reduce.

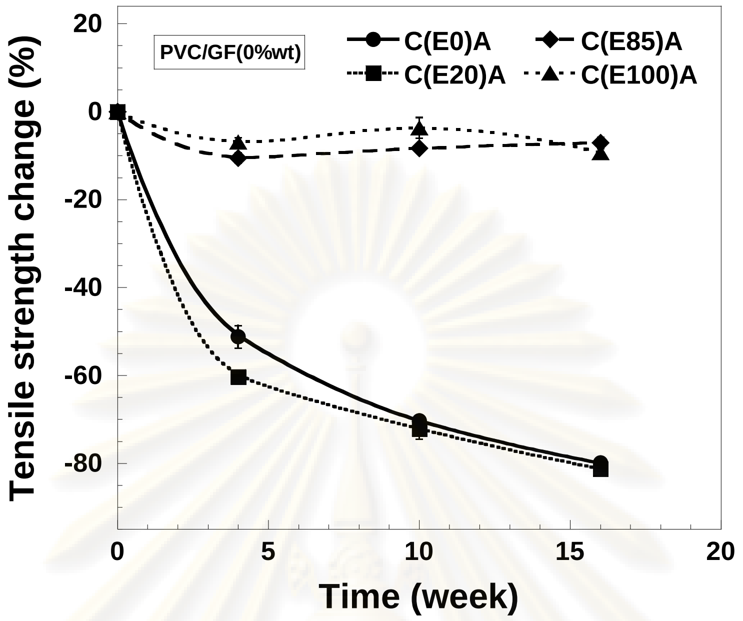


Figure 5.30 Effect of percent ethanol in test fuel and immersion time on tensile strength change of PVC/GF (0 wt%) composites

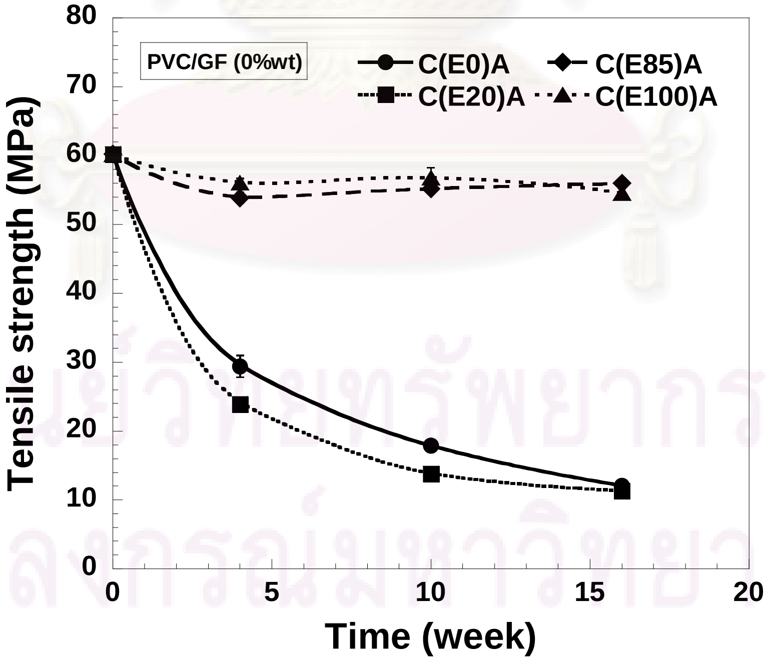


Figure 5.31 Effect of percent ethanol in test fuel and immersion time on tensile strength of PVC/GF (0 wt%) composites

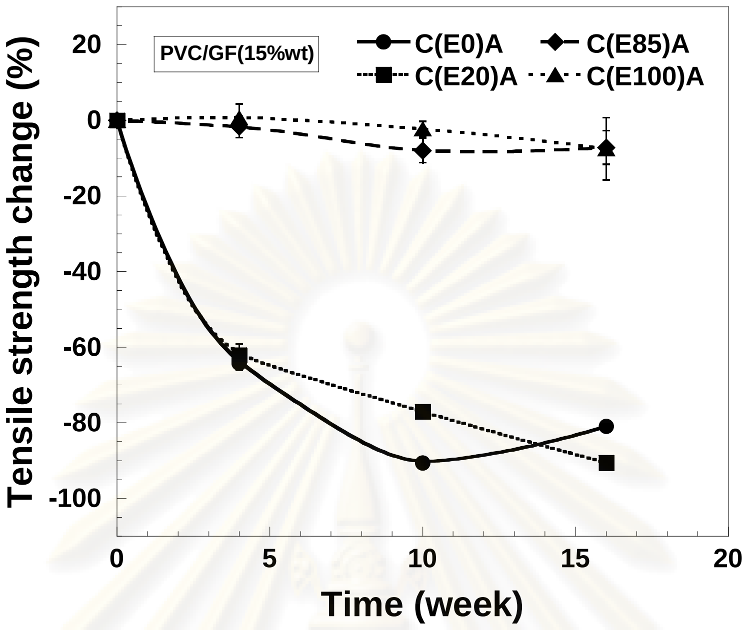


Figure 5.32 Effect of percent ethanol in test fuel and immersion time on tensile strength change of PVC/GF (15 wt%) composites

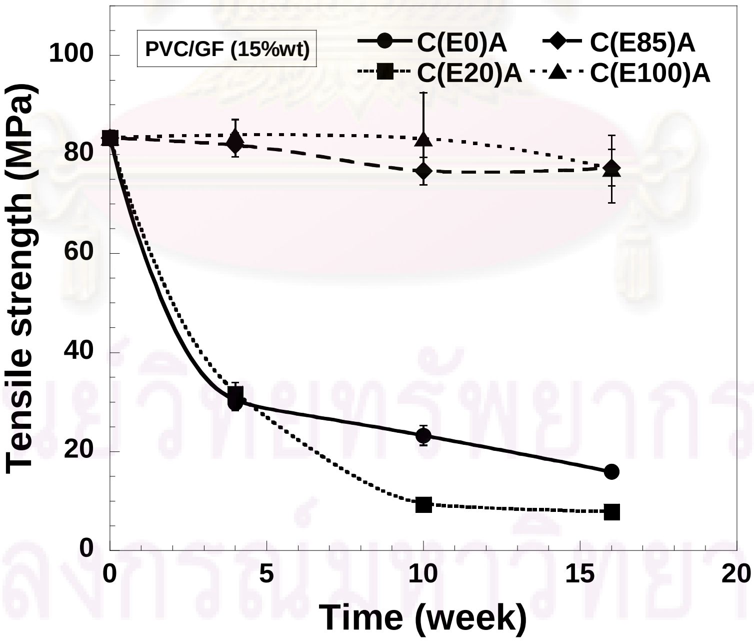


Figure 5.33 Effect of percent ethanol in test fuel and immersion time on tensile strength of PVC/GF (15 wt%) composites

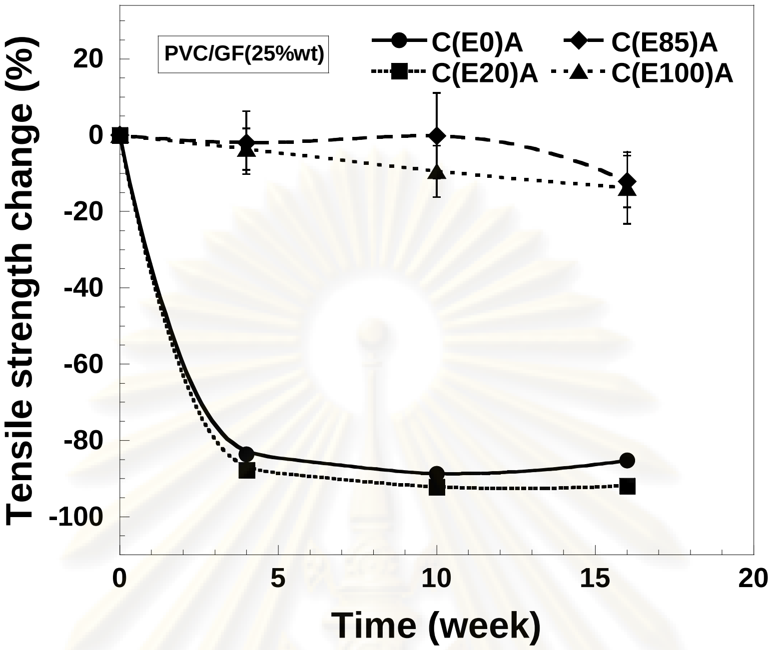


Figure 5.34 Effect of percent ethanol in test fuel and immersion time on tensile strength change of PVC/GF (25 wt%) composites

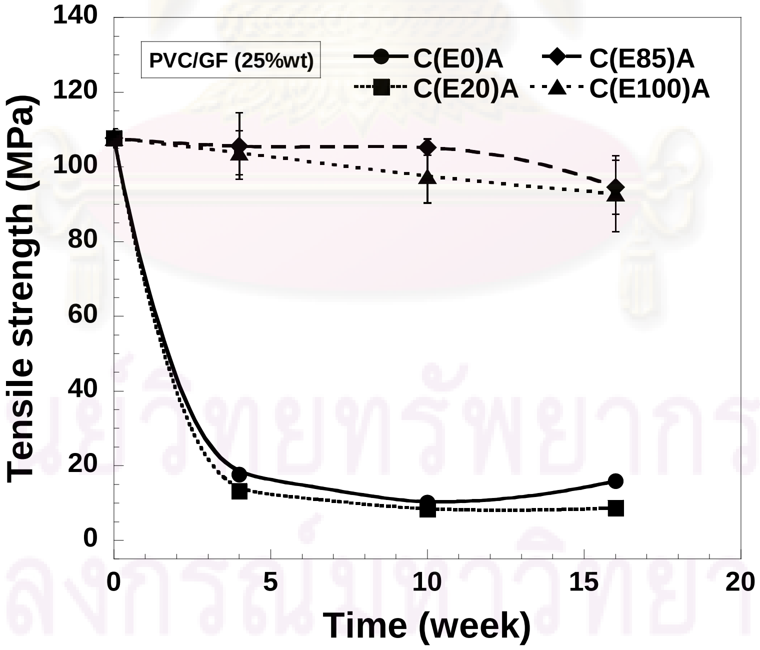


Figure 5.35 Effect of percent ethanol in test fuel and immersion time on tensile strength of PVC/GF (25 wt%) composites

Fig. 5.36-5.39 showed that, after immersion in $C(E0)_A$ and $C(E20)_A$ for 16 weeks, the tensile strength of PVC/GF composites were reduced by about 80-90% from original value. The composites with lower GF content had its tensile strength reduced less than composites with higher GF content. Fig. 5.39-5.42 showed that, after immersion in $C(E85)_A$ and $C(E100)_A$ for 16 weeks, the tensile strength of PVC/GF composites were reduced by about 8-13% from original value (B.Jones et al.)[26].

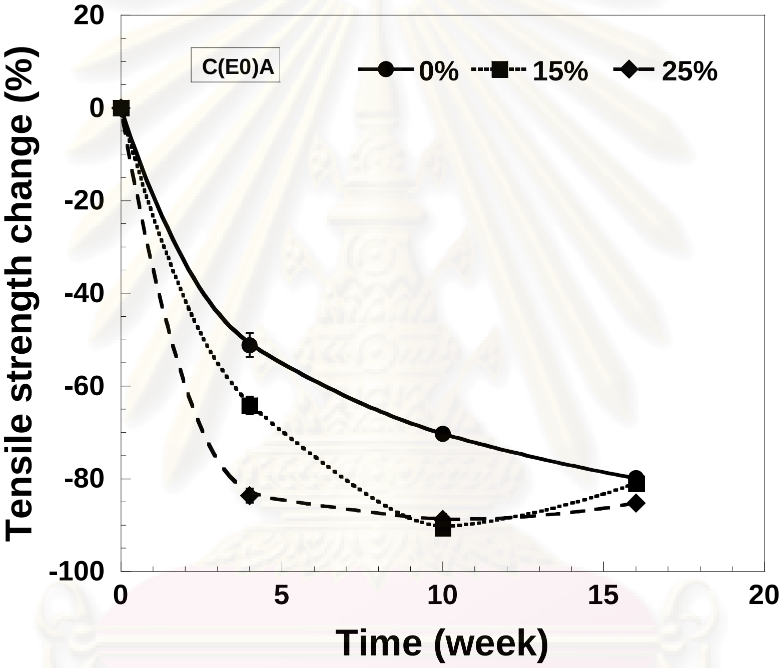


Figure 5.36 Effect of percent of GF in composites and immersion time on tensile strength change of PVC/GF composites immersed in $C(E0)_A$ test fuel

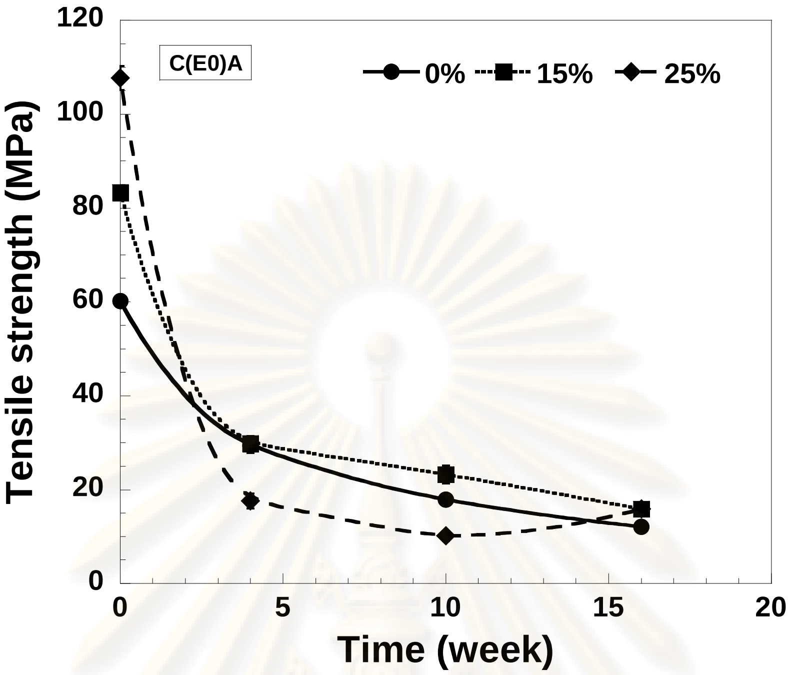


Figure 5.37 Effect of percent of GF in composites and immersion time on tensile strength of PVC/GF composites immersed in $C(E0)_A$ test fuel

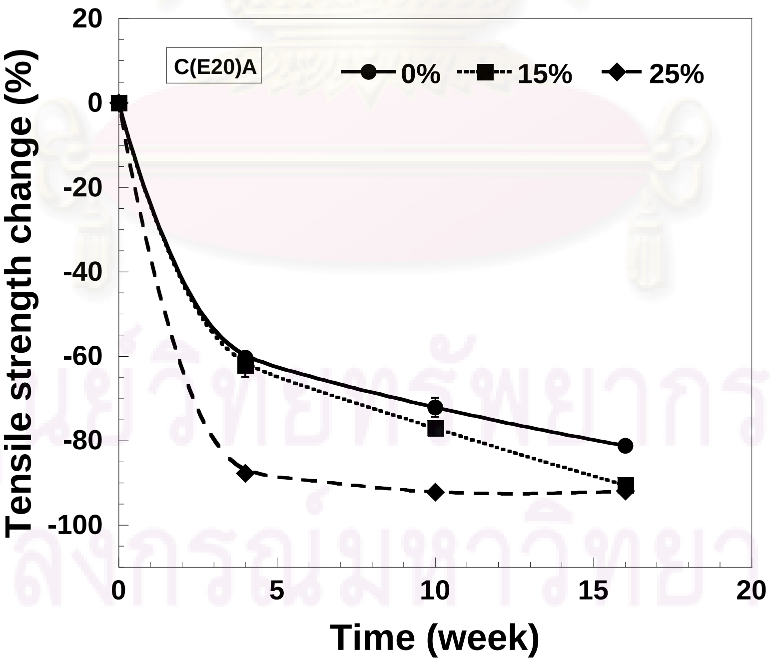


Figure 5.38 Effect of percent of GF in composites and immersion time on tensile strength change of PVC/GF composites immersed in $C(E20)_A$ test fuel

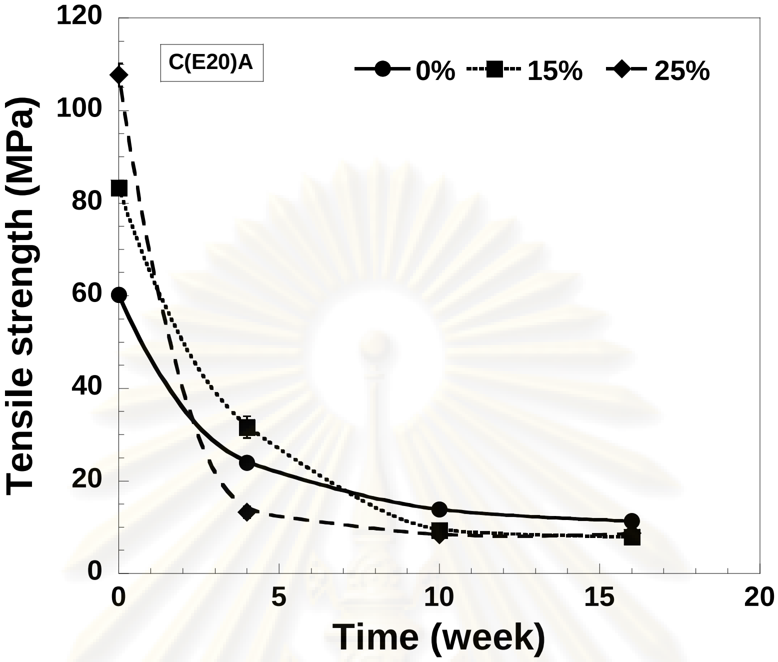


Figure 5.39 Effect of percent of GF in composites and immersion time on tensile strength of PVC/GF composites immersed in C(E20)$_A$ test fuel

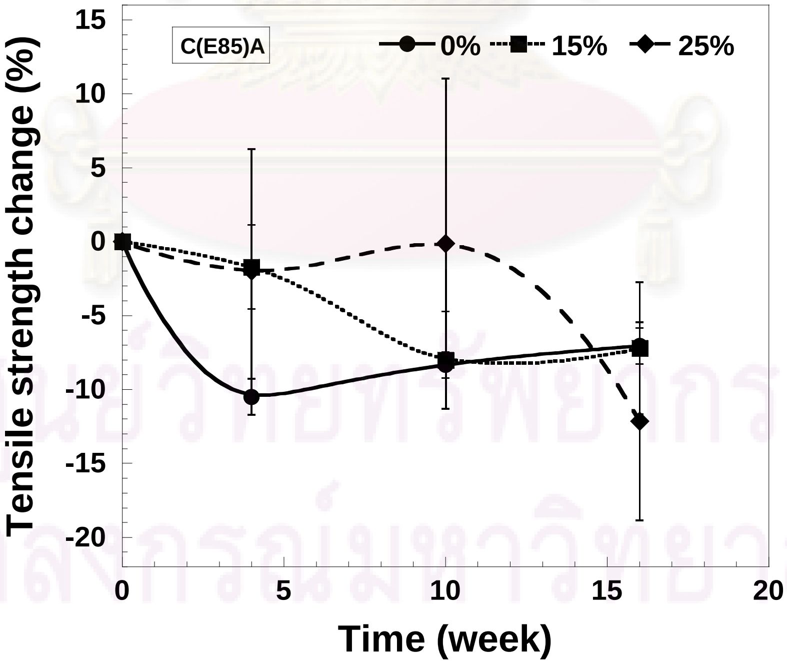


Figure 5.40 Effect of percent of GF in composites and immersion time on tensile strength change of PVC/GF composites immersed in C(E85)$_A$ test fuel

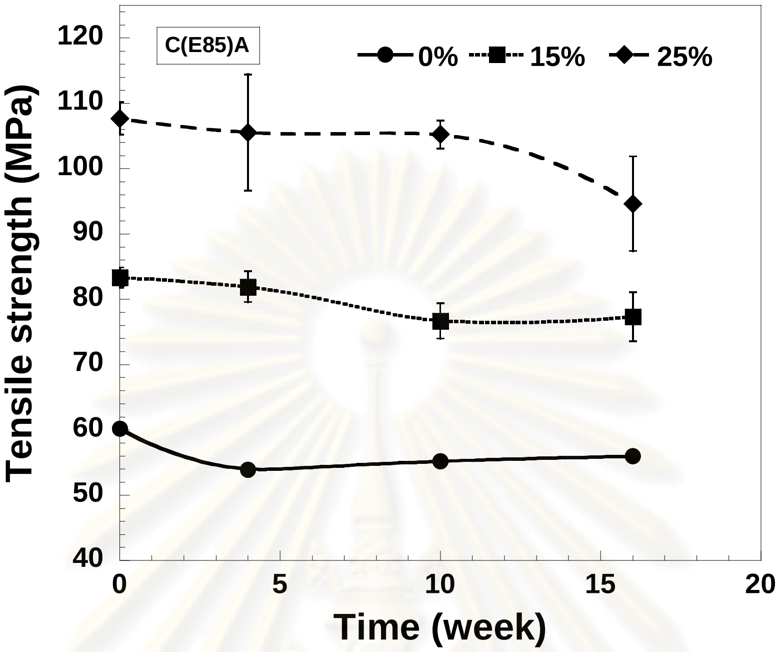


Figure 5.41 Effect of percent of GF in composites and immersion time on tensile strength of PVC/GF composites immersed in $C(E85)_A$ test fuel

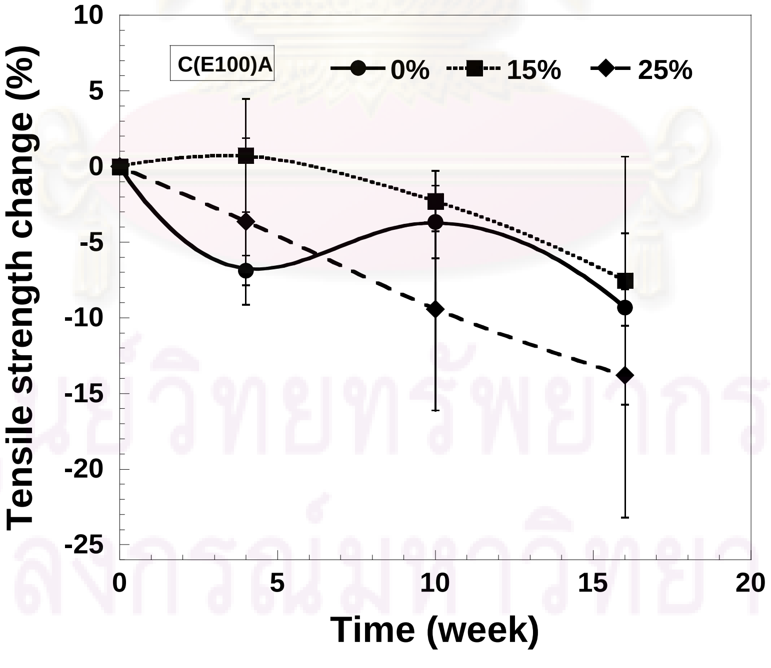


Figure 5.42 Effect of percent of GF in composites and immersion time on tensile strength change of PVC/GF composites immersed in $C(E100)_A$ test fuel

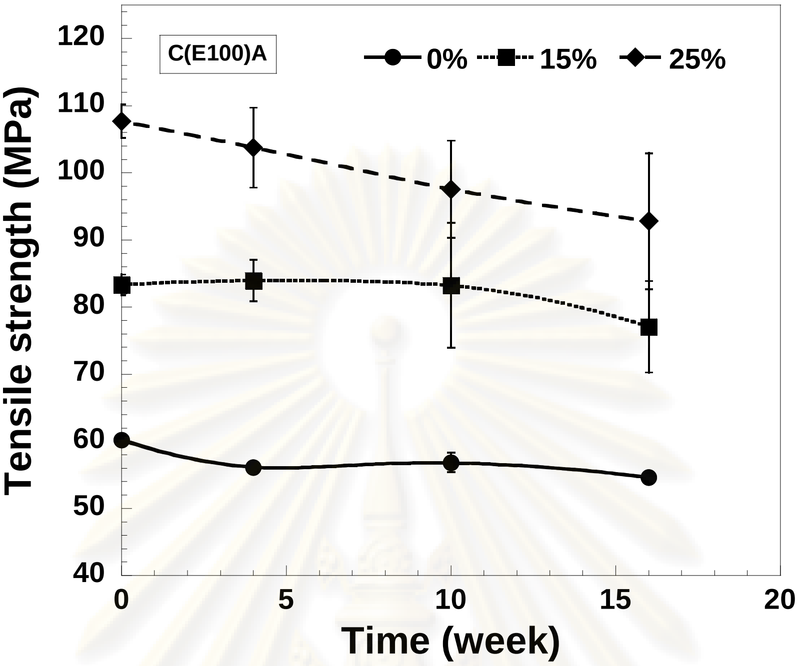


Figure 5.43 Effect of percent of GF in composites and immersion time on tensile strength of PVC/GF composites immersed in $C(E100)_A$ test fuel

Fig. 5.44-5.49 showed that the Young's modulus of PVC/GF (0-25 wt%) composites after immersed in $C(E0)_A$ and $C(E20)_A$ test fuels for 16 weeks were reduced by almost 80-90% from the original value and be constant in 4 until 16 weeks. However, the Young's modulus of same composites after immersed in $C(E85)_A$ and $C(E100)_A$ test fuels for 16 weeks were reduced by only about 5-10% and be constant in 4 until 16 weeks. These were clearly due to results physical properties. The solubility parameter of the toluene is near that of PVC (Barton, Allan F. M.) [37] and PVC has low polar as $C(E0)_A$ and $C(E20)_A$ (R.L. Eissler et al.) [38] cause higher amount of absorption of iso-octane and toluene into PVC matrix from $C(E0)_A$ and $C(E20)_A$ than from $C(E85)_A$ and $C(E100)_A$ test fuels as discussed earlier (Fred W. Billmeyer et al.) [24]. Iso-octane and toluene clearly swelled and plasticized the PVC matrix causing its Young's modulus to reduce.

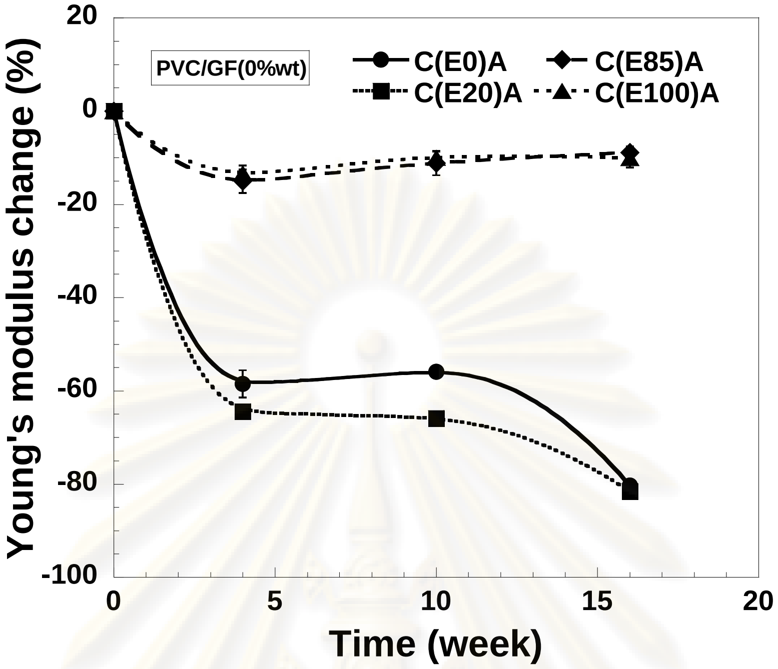


Figure 5.44 Effect of percent ethanol in test fuel and immersion time on Young's modulus change of PVC/GF (0 wt%) composites

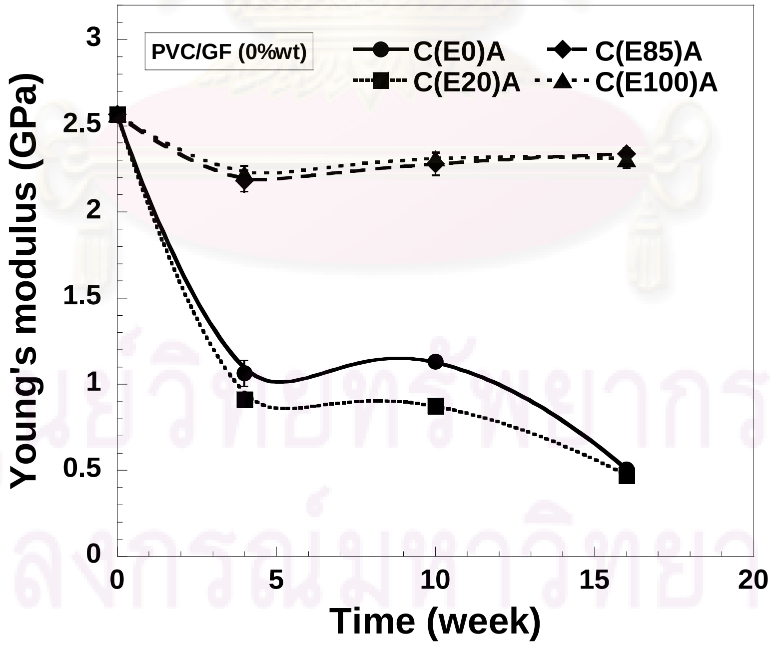


Figure 5.45 Effect of percent ethanol in test fuel and immersion time on Young's modulus of PVC/GF (0 wt%) composites

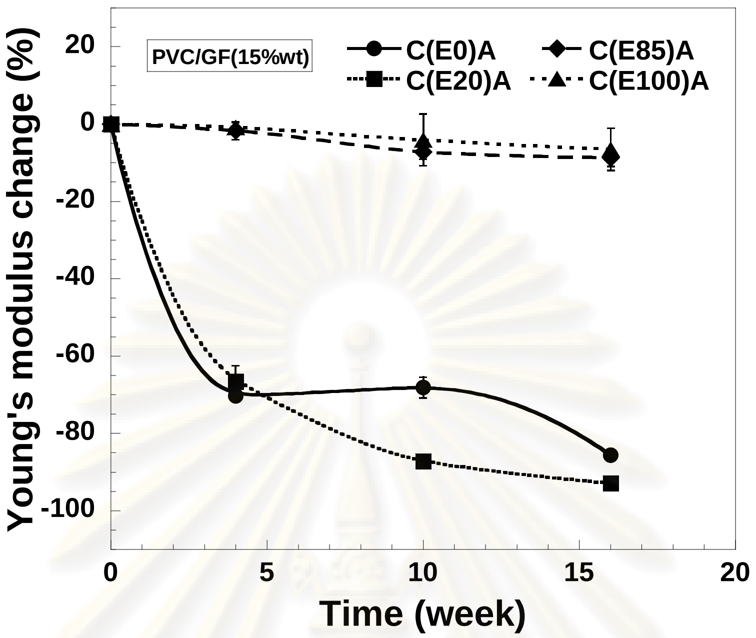


Figure 5.46 Effect of percent ethanol in test fuel and immersion time on Young's modulus change of PVC/GF (15 wt%) composites

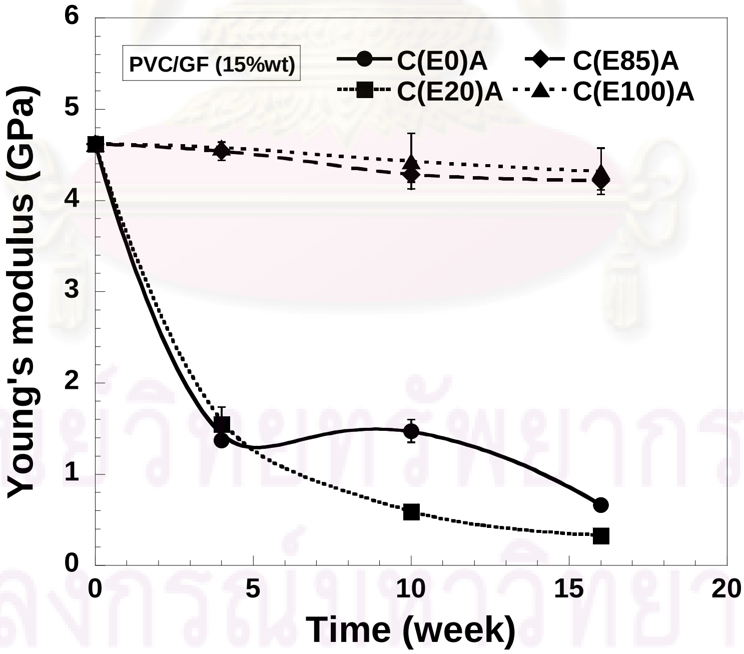


Figure 5.47 Effect of percent ethanol in test fuel and immersion time on Young's modulus of PVC/GF (15 wt%) composites

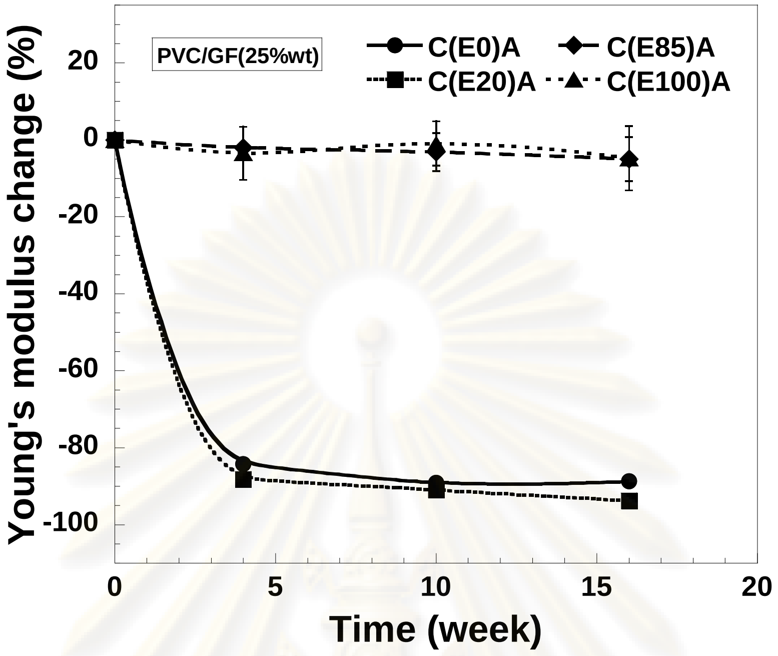


Figure 5.48 Effect of percent ethanol in test fuel and immersion time on Young's modulus change of PVC/GF (25 wt%) composites

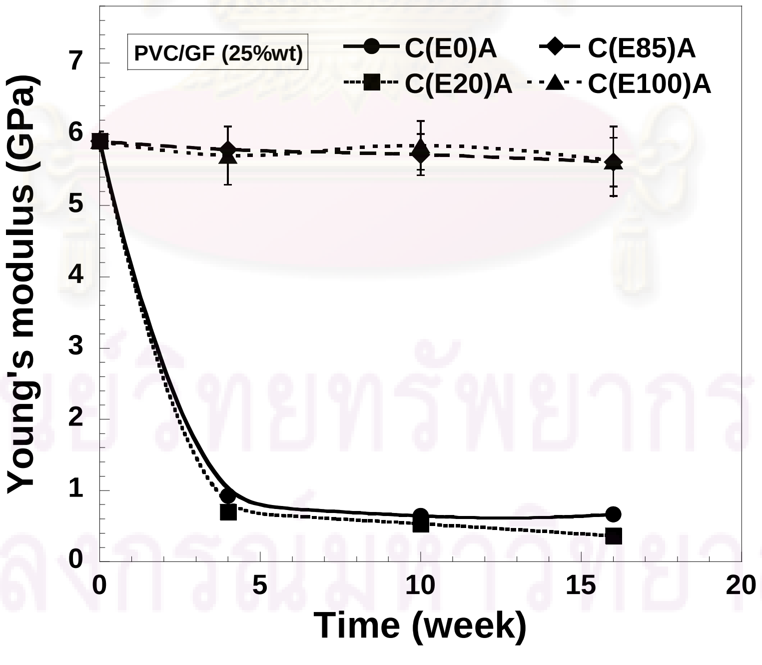


Figure 5.49 Effect of percent ethanol in test fuel and immersion time on Young's modulus of PVC/GF (25 wt%) composites

Fig. 5.50-5.53 showed that, after immersion in $C(E0)_A$ and $C(E20)_A$ for 16 weeks, the Young's modulus of PVC/GF composites were reduced by about 75-85% from original value. The composites with lower GF content had its Young's modulus reduced less than composites with higher GF content. Fig. 5.54-5.57 showed that, after immersion in $C(E85)_A$ and $C(E100)_A$ for 16 weeks, the Young's modulus of PVC/GF composites were reduced by about 5-10% from original value. The composites with higher GF content had its Young's modulus reduced less than composites with lower GF content (B.Jones et al.)[26].

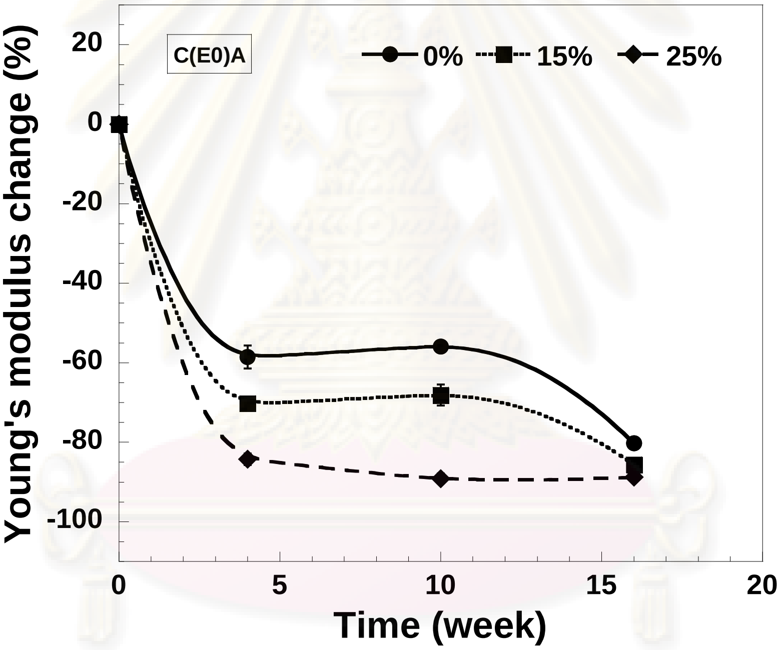


Figure 5.50 Effect of percent of GF in composites and immersion time on Young's modulus change of PVC/GF composites immersed in $C(E0)_A$ test fuel

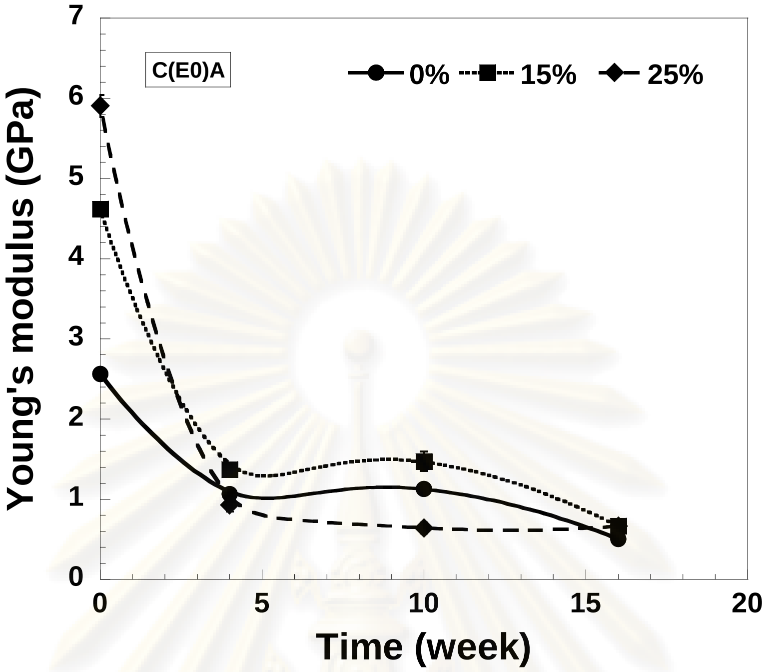


Figure 5.51 Effect of percent of GF in composites and immersion time on Young's modulus of PVC/GF composites immersed in $C(E0)_A$ test fuel

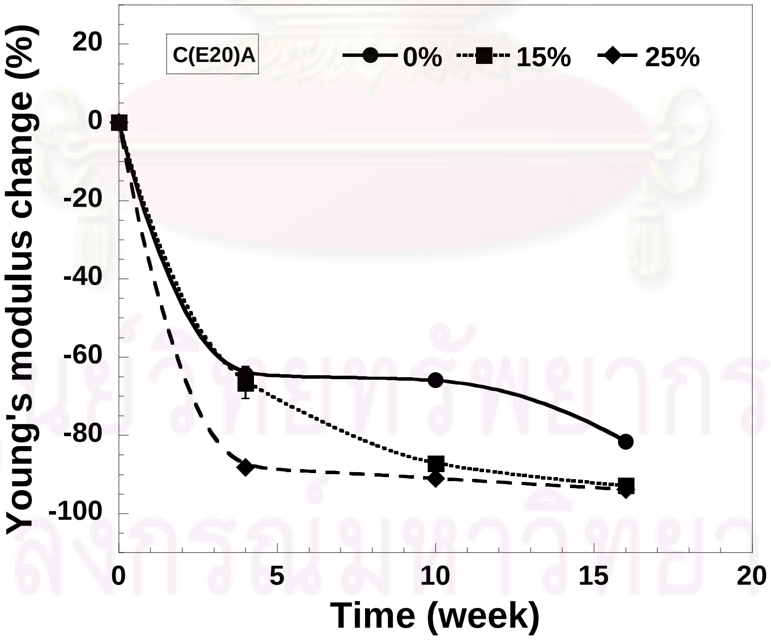


Figure 5.52 Effect of percent of GF in composites and immersion time on Young's modulus change of PVC/GF composites immersed in $C(E20)_A$ test fuel

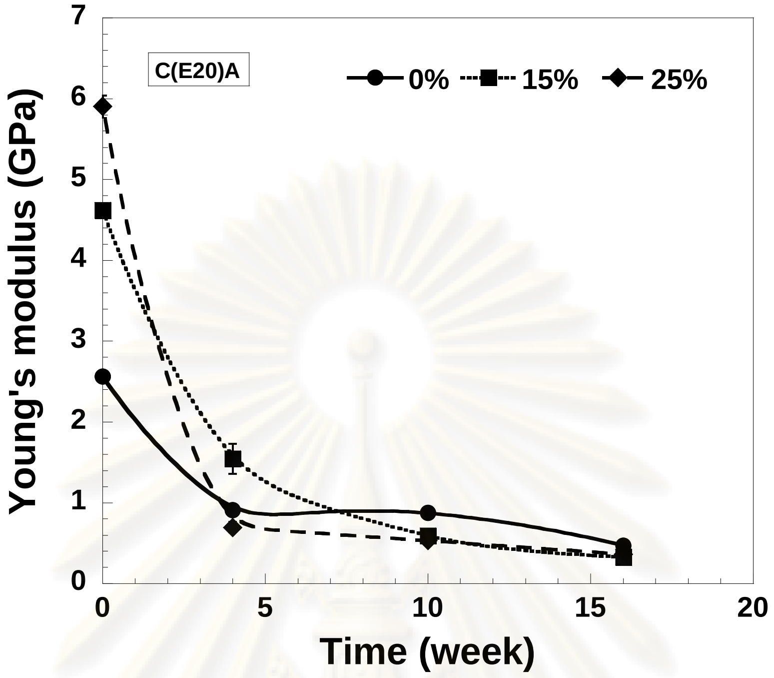


Figure 5.53 Effect of percent of GF in composites and immersion time on Young's modulus of PVC/GF composites immersed in $C(E20)_A$ test fuel

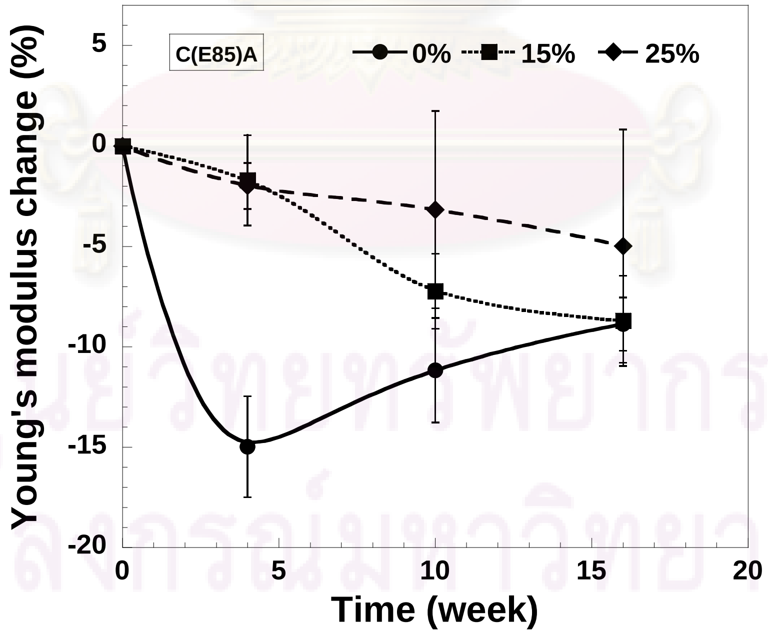


Figure 5.54 Effect of percent of GF in composites and immersion time on Young's modulus change of PVC/GF composites immersed in $C(E85)_A$ test fuel

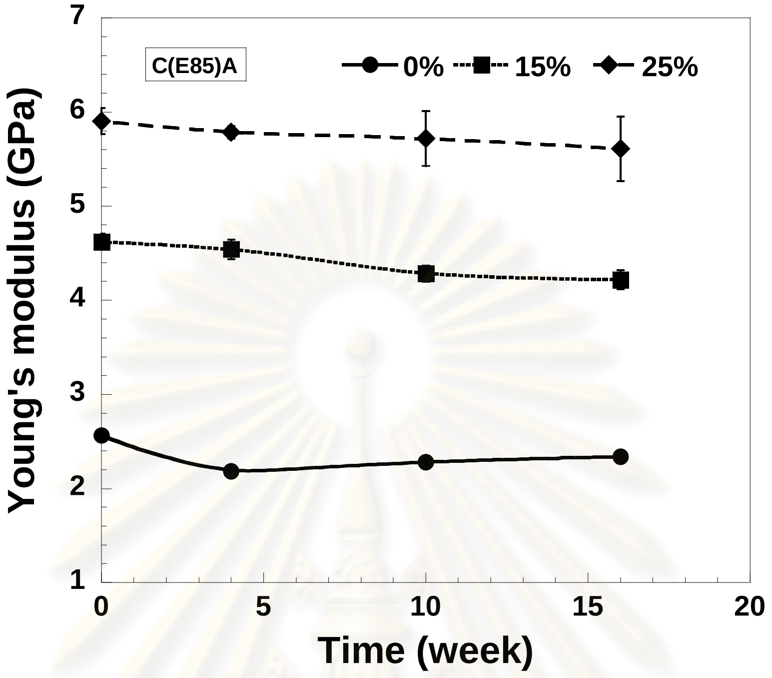


Figure 5.55 Effect of percent of GF in composites and immersion time on Young's modulus of PVC/GF composites immersed in C(E85)$_A$ test fuel

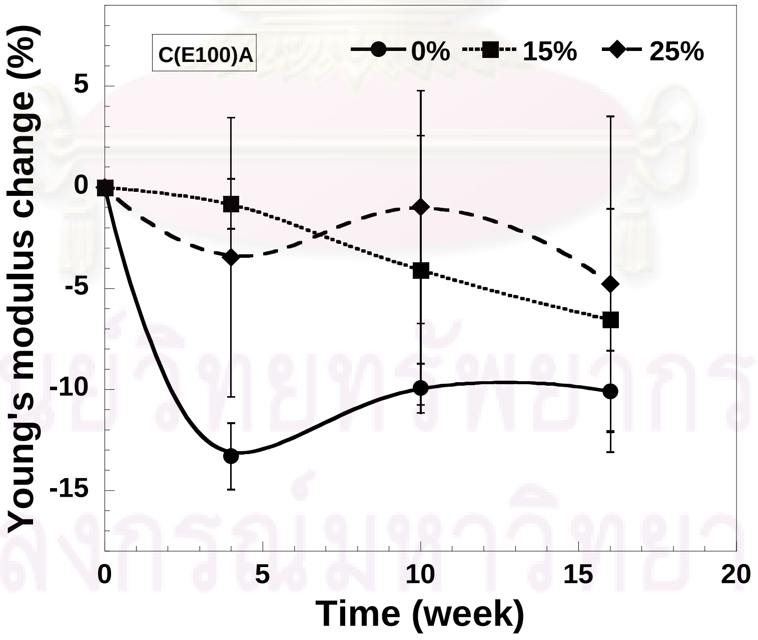


Figure 5.56 Effect of percent of GF in composites and immersion time on Young's modulus change of PVC/GF composites immersed in C(E100)$_A$ test fuel

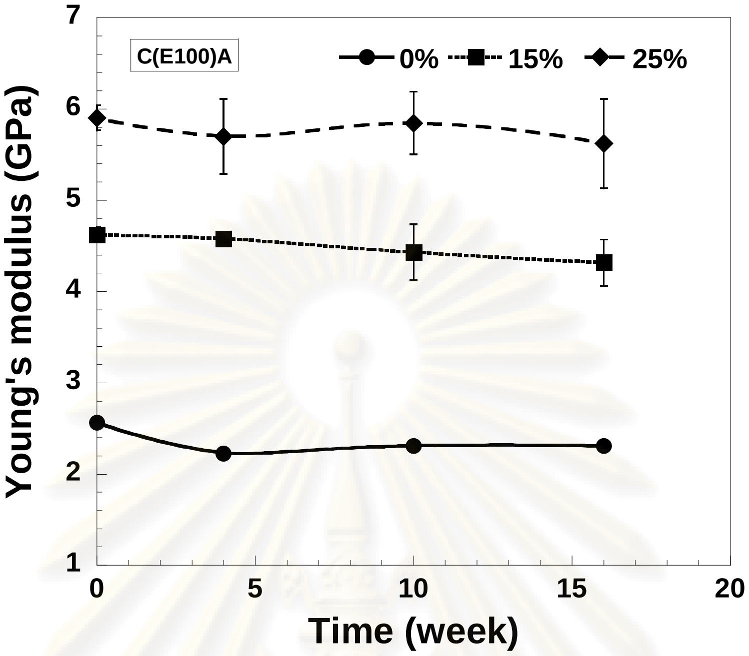


Figure 5.57 Effect of percent of GF in composites and immersion time on Young's modulus of PVC/GF composites immersed in $C(E100)_A$ test fuel

5.2.2 Flexural property

Fig. 5.58-5.63 showed that the flexural strength of PVC/GF (0-25 wt%) composites after immersed in $C(E0)_A$ and $C(E20)_A$ test fuels for 16 weeks were reduced by almost 90-100% from the original value and be stable in 10 until 16 weeks. However, the flexural strength of same composites after immersed in $C(E85)_A$ and $C(E100)_A$ test fuels for 16 weeks were reduced by only about 10% from the original value and be stable in 4 until 16 weeks. These were clearly due to results physical properties. The solubility parameter of the toluene is near that of PVC (Barton, Allan F. M.) [37] and PVC has low polar as $C(E0)_A$ and $C(E20)_A$ (R.L. Eissler et al.) [38] cause higher amount of absorption of iso-octane and toluene into PVC matrix from $C(E0)_A$ and $C(E20)_A$ than from $C(E85)_A$ and $C(E100)_A$ test fuels as discussed earlier (Fred W. Billmeyer et al.) [24]. Iso-octane and toluene clearly swelled and plasticized the PVC matrix causing its flexural strength to reduce

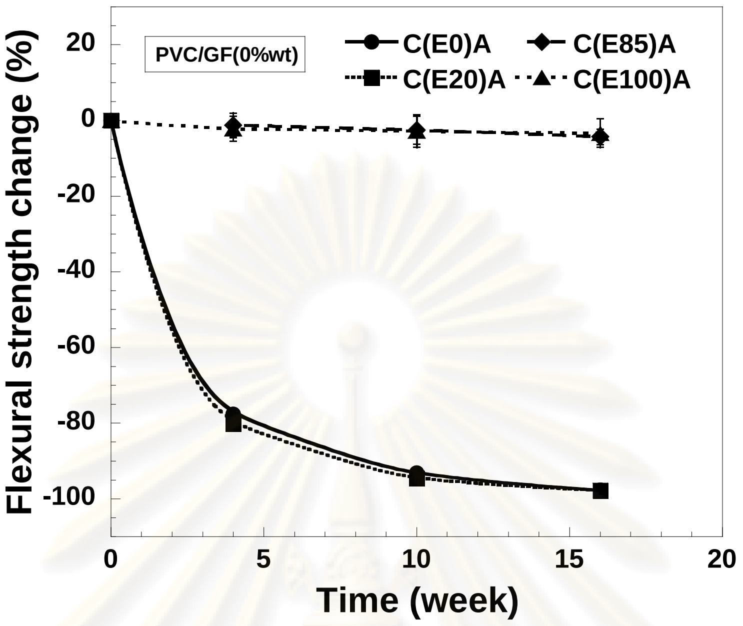


Figure 5.58 Effect of percent ethanol in test fuel and immersion time on flexural strength change of PVC/GF (0 wt%) composites

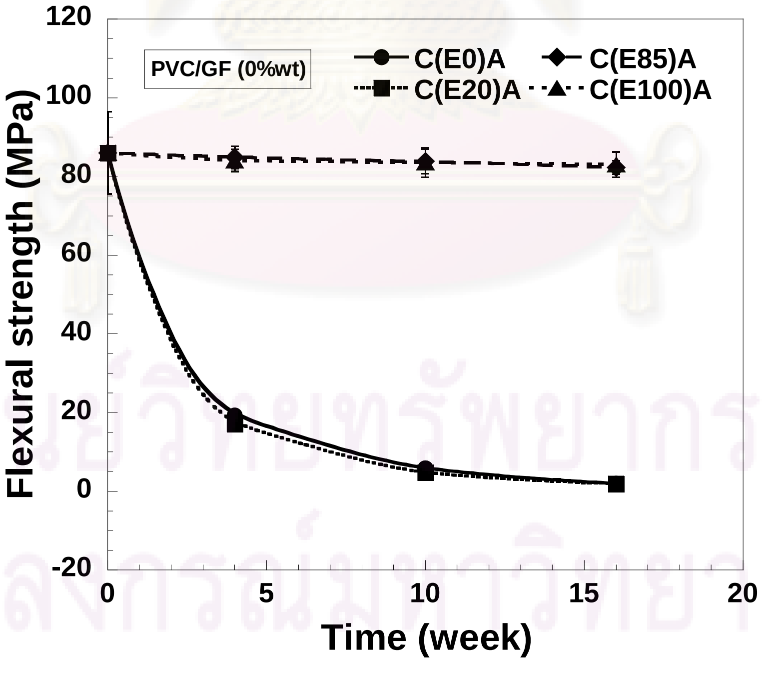


Figure 5.59 Effect of percent ethanol in test fuel and immersion time on flexural strength of PVC/GF (0 wt%) composites

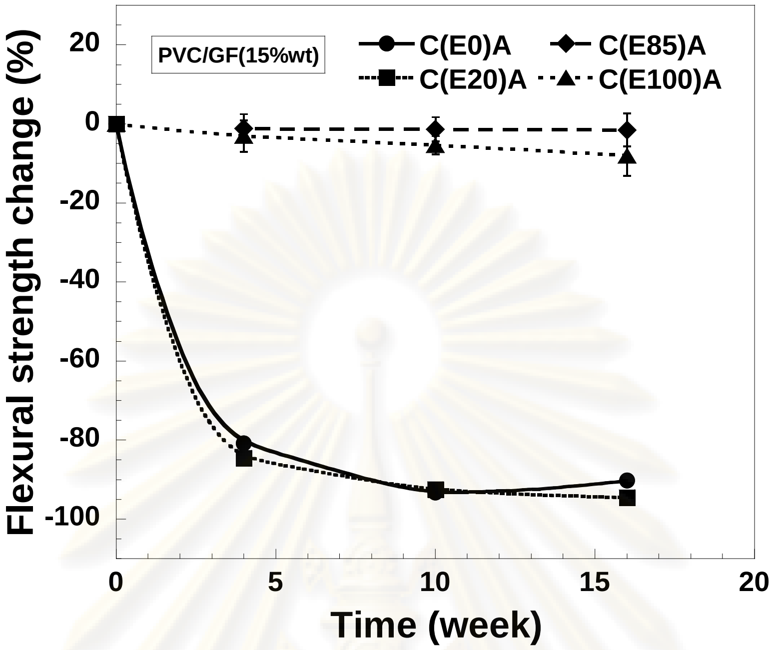


Figure 5.60 Effect of percent ethanol in test fuel and immersion time on flexural strength change of PVC/GF (15 wt%) composites

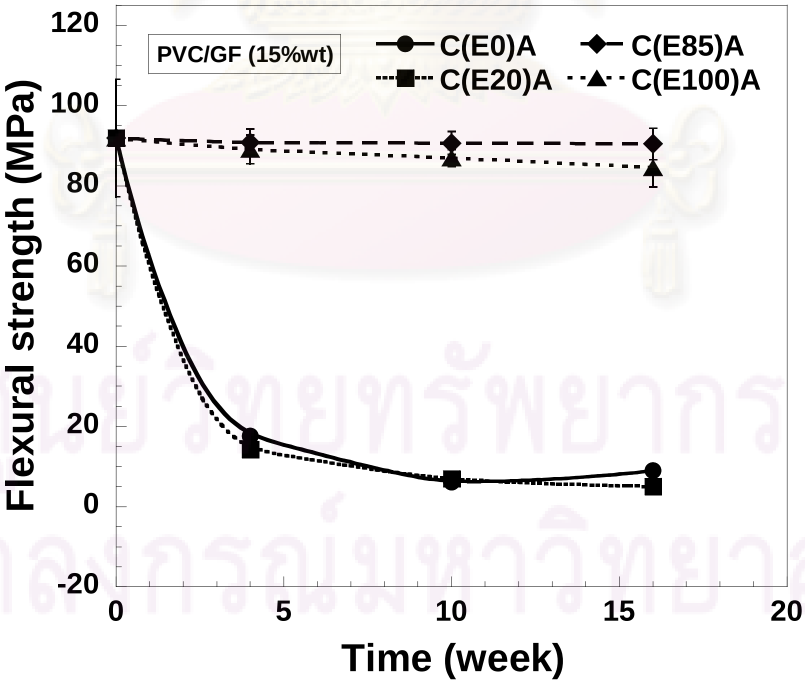


Figure 5.61 Effect of percent ethanol in test fuel and immersion time on flexural strength of PVC/GF (15 wt%) composites

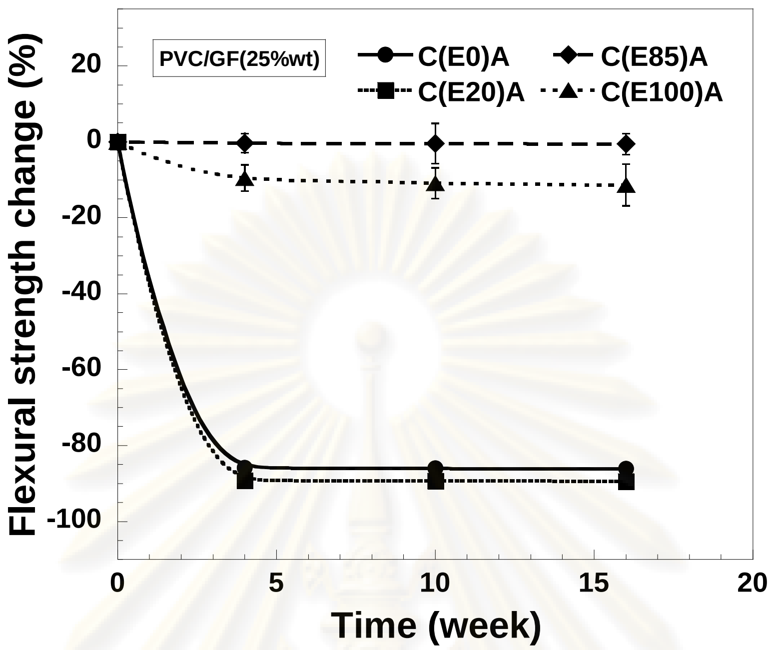


Figure 5.62 Effect of percent ethanol in test fuel and immersion time on flexural strength change of PVC/GF (25 wt%) composites

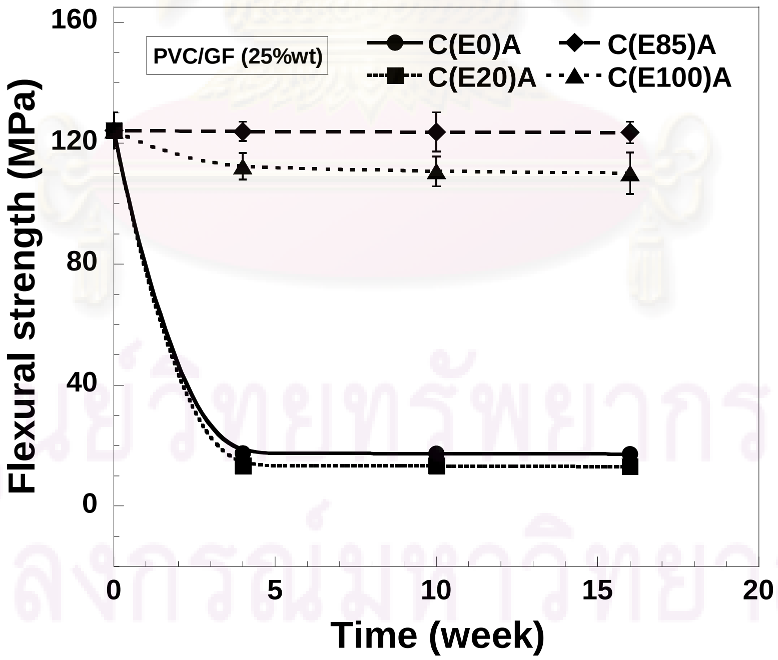


Figure 5.63 Effect of percent ethanol in test fuel and immersion time on flexural strength of PVC/GF (25 wt%) composites

Fig. 5.64-5.67 showed that, after immersion in $C(E0)_A$ and $C(E20)_A$ for 16 weeks, the flexural strength of PVC/GF composites were reduced by about 90% from original value. The composites with higher GF content had its flexural strength reduced less than composites with lower GF content. Fig. 5.68-5.71 showed that, after immersion in $C(E85)_A$ and $C(E100)_A$ for 16 weeks, the flexural strength of PVC/GF composites were reduced by about 2-4% and 2-11% from original value respectively.

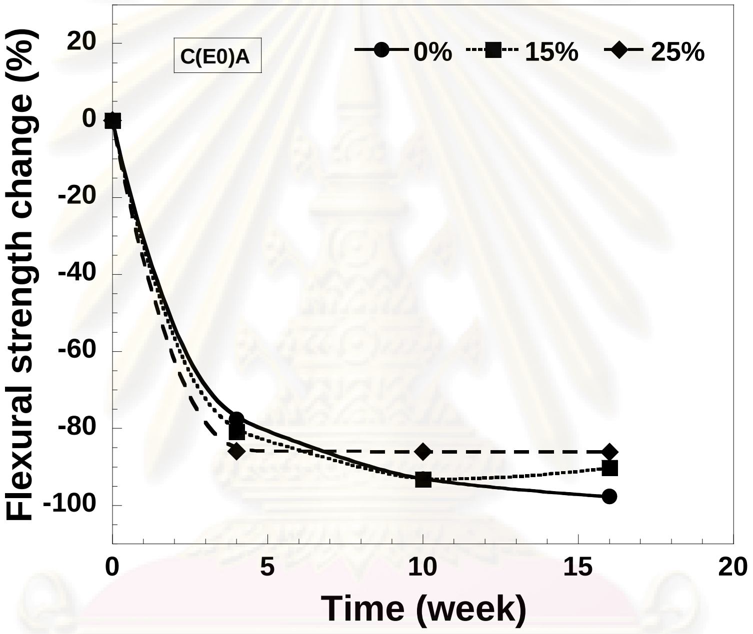


Figure 5.64 Effect of percent of GF in composites and immersion time on flexural strength change of PVC/GF composites immersed in $C(E0)_A$ test fuel

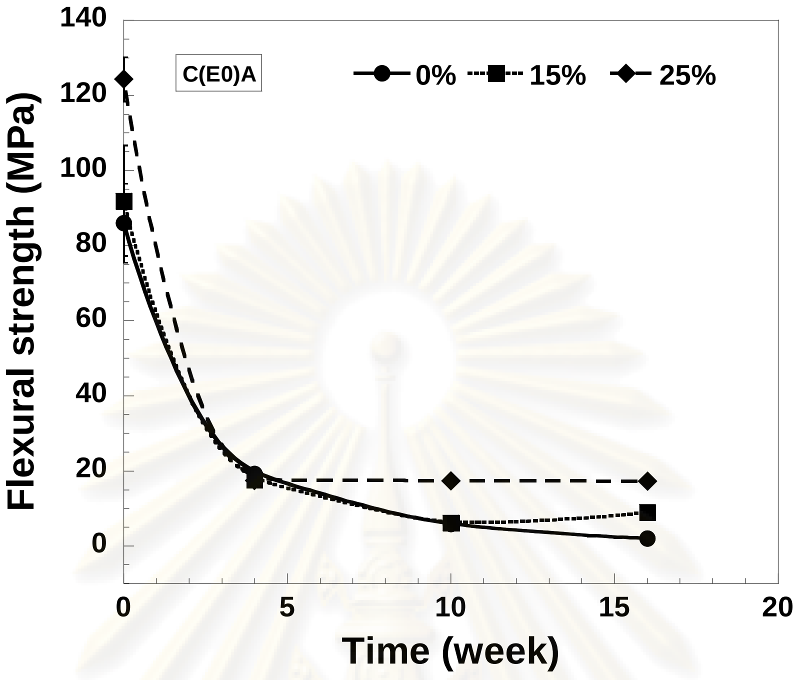


Figure 5.65 Effect of percent of GF in composites and immersion time on flexural strength of PVC/GF composites immersed in $C(E0)_A$ test fuel

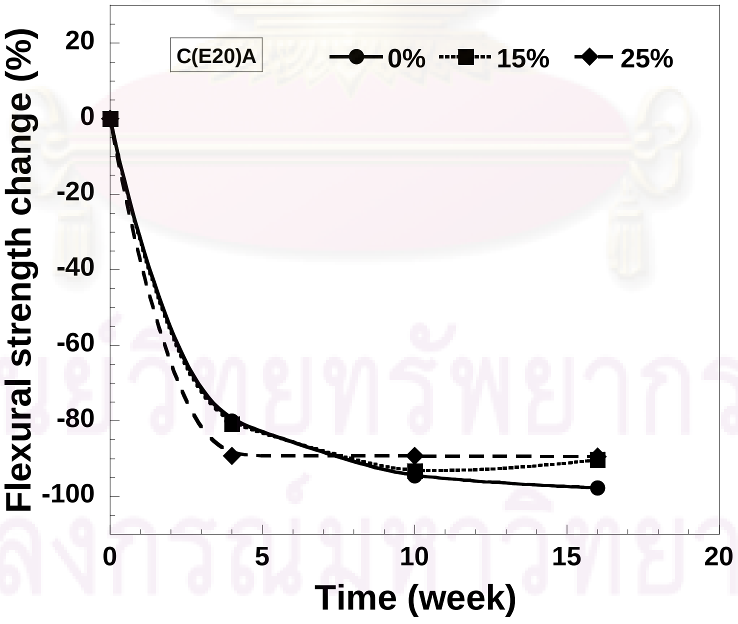


Figure 5.66 Effect of percent of GF in composites and immersion time on flexural strength change of PVC/GF composites immersed in $C(E20)_A$ test fuel

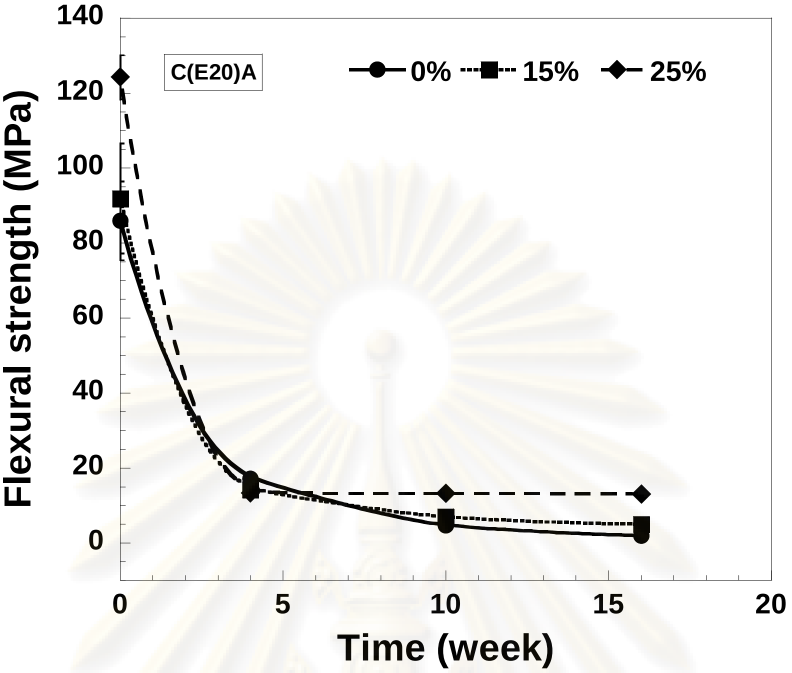


Figure 5.67 Effect of percent of GF in composites and immersion time on flexural strength of PVC/GF composites immersed in $C(E20)_A$ test fuel

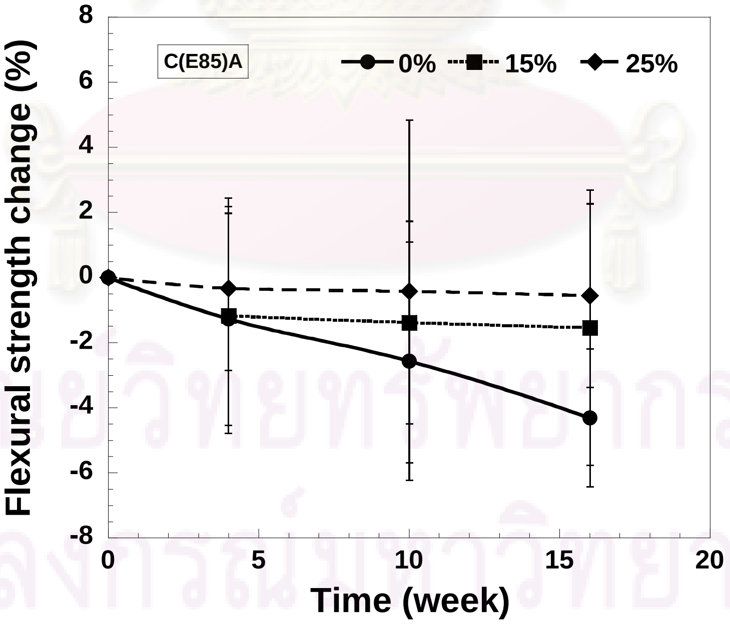


Figure 5.68 Effect of percent of GF in composites and immersion time on flexural strength change of PVC/GF composites immersed in $C(E85)_A$ test fuel

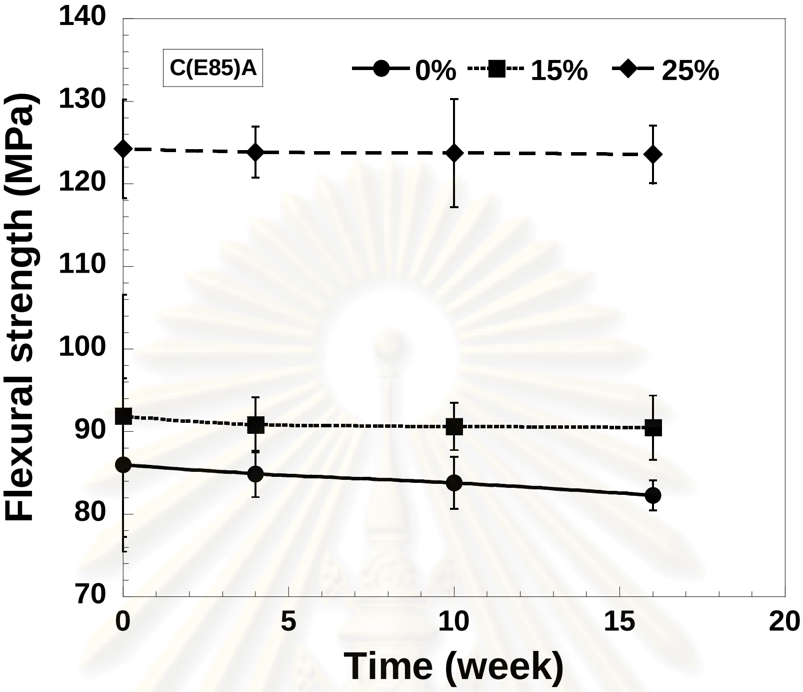


Figure 5.69 Effect of percent of GF in composites and immersion time on flexural strength of PVC/GF composites immersed in C(E85)$_A$ test fuel

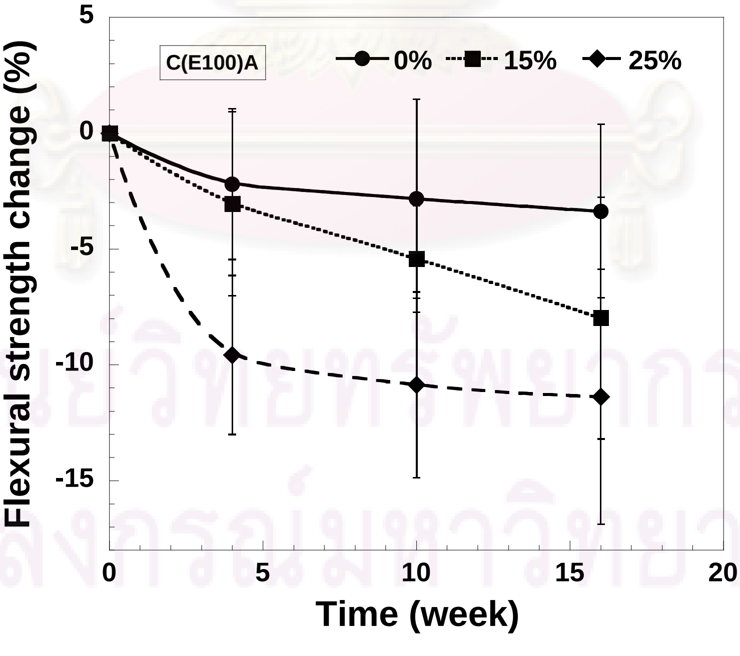


Figure 5.70 Effect of percent of GF in composites and immersion time on flexural strength change of PVC/GF composites immersed in C(E100)$_A$ test fuel

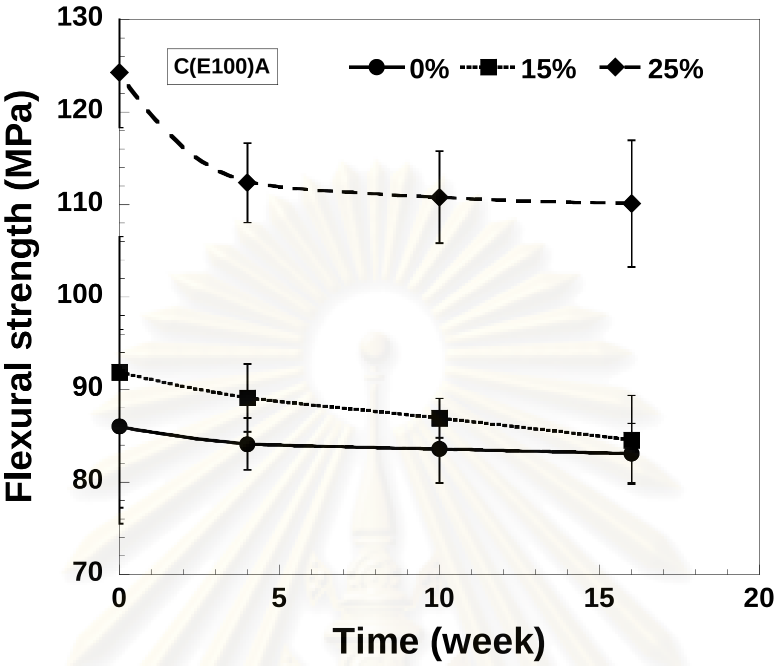


Figure 5.71 Effect of percent of GF in composites and immersion time on flexural strength of PVC/GF composites immersed in C(E100)$_A$ test fuel

5.2.3 Compressive property

Fig. 5.72-5.77 showed that the compressive strength of PVC/GF (0-25 wt%) composites after immersed in C(E0)$_A$ and C(E20)$_A$ test fuels for 16 weeks were reduced by almost 45-55% from the original value and be constant in 10 until 16 weeks. However, the compressive strength of same composites after immersed in C(E85)$_A$ and C(E100)$_A$ test fuels for 16 weeks were reduced by only about 5-15% from the original value and be constant in 10 until 16 weeks. These were clearly due to results physical properties. The solubility parameter of the toluene is near that of PVC (Barton, Allan F. M.) [37] and PVC has low polar as C(E0)$_A$ and C(E20)$_A$ (R.L. Eissler et al.) [38] cause higher amount of absorption of iso-octane and toluene into PVC matrix from C(E0)$_A$ and C(E20)$_A$ than from C(E85)$_A$ and C(E100)$_A$ test fuels as discussed earlier (Fred W. Billmeyer et al.) [24]. Iso-octane and toluene clearly swelled and plasticized the PVC matrix causing its tensile strength to reduce.

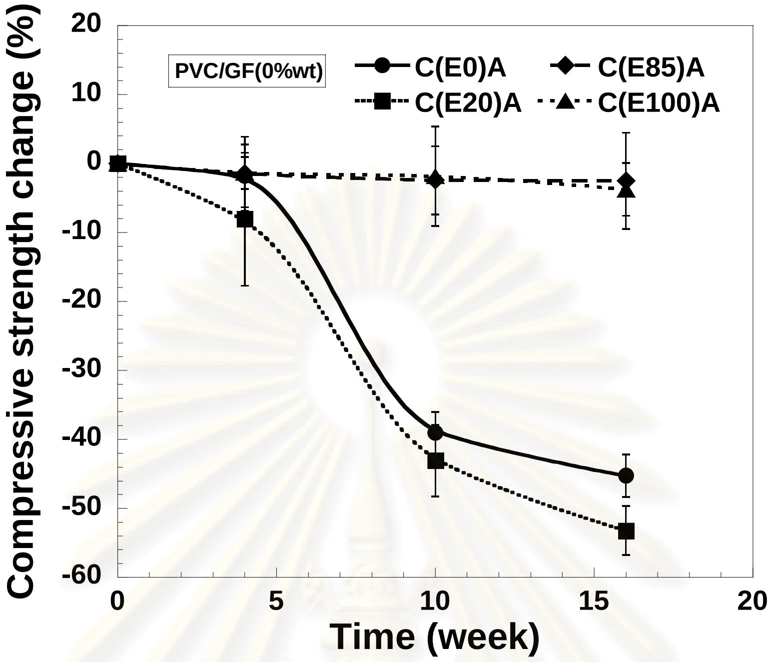


Figure 5.72 Effect of percent ethanol in test fuel and immersion time on compressive strength change of PVC/GF (0 wt%) composites

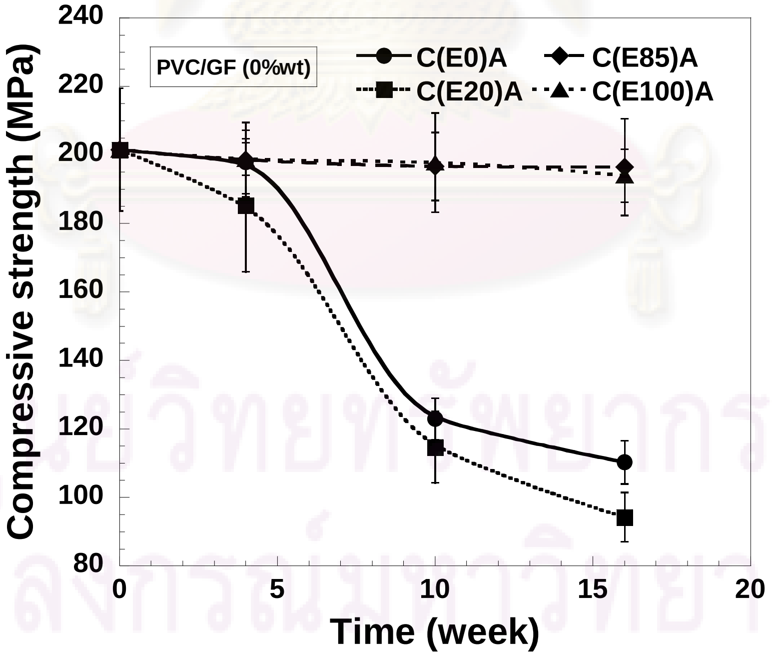


Figure 5.73 Effect of percent ethanol in test fuel and immersion time on compressive strength of PVC/GF (0 wt%) composites

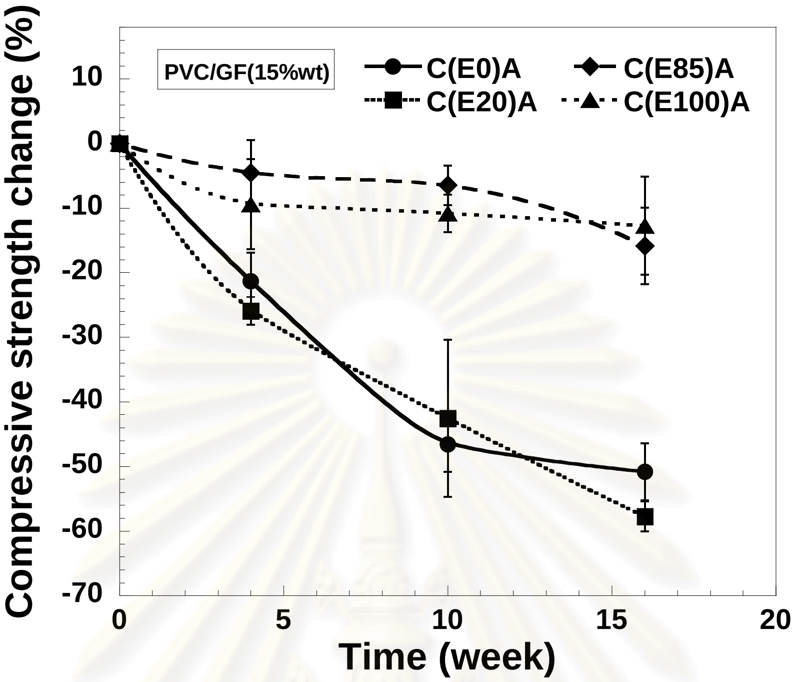


Figure 5.74 Effect of percent ethanol in test fuel and immersion time on compressive strength change of PVC/GF (15 wt%) composites

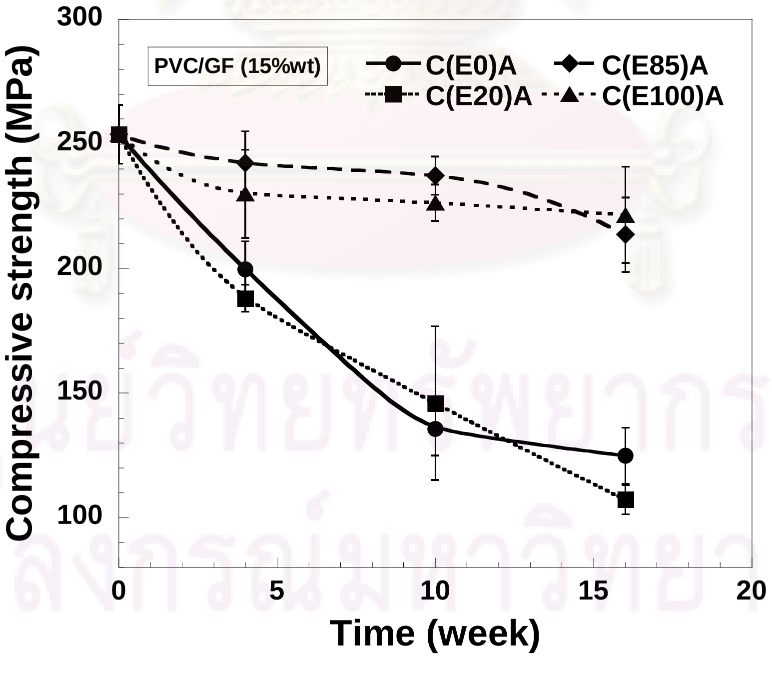


Figure 5.75 Effect of percent ethanol in test fuel and immersion time on compressive strength of PVC/GF (15 wt%) composites

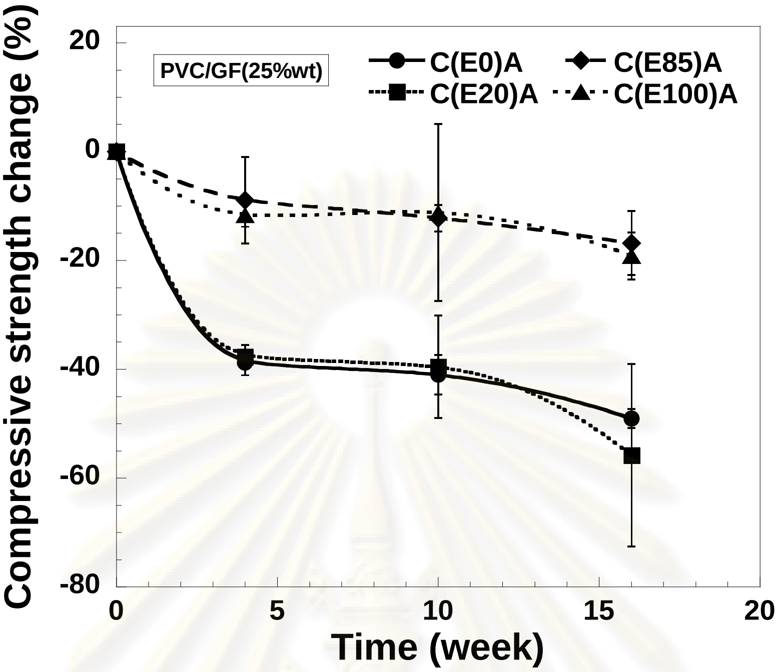


Figure 5.76 Effect of percent ethanol in test fuel and immersion time on compressive strength change of PVC/GF (25 wt%) composites

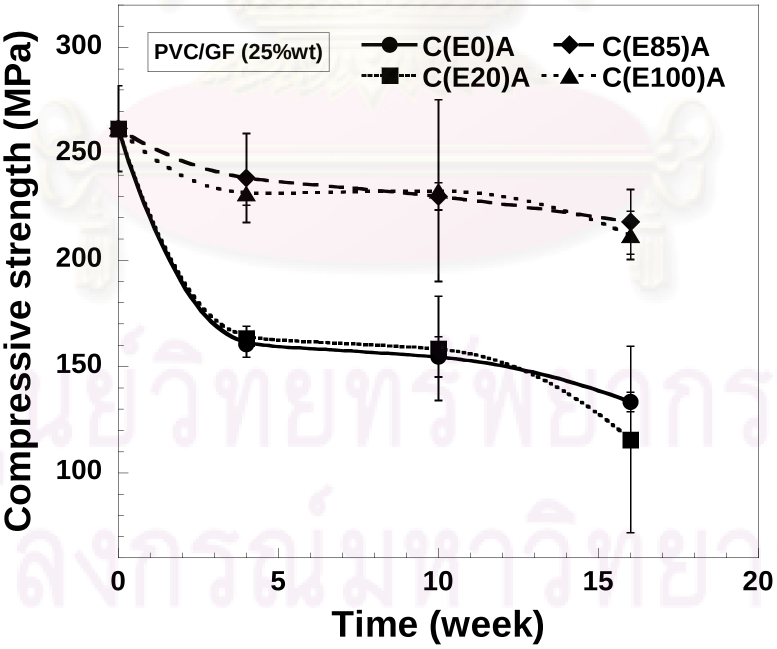


Figure 5.77 Effect of percent ethanol in test fuel and immersion time on compressive strength of PVC/GF (25 wt%) composite

Fig. 5.78-5.81 showed that, after immersion in C(E0)$_A$ and C(E20)$_A$ for 16 weeks, the compressive strength of PVC/GF composites were reduced by about 45-55% from original value. Fig. 5.82-5.85 showed that, after immersion in C(E85)$_A$ and C(E100)$_A$ for 16 weeks, the compressive strength of PVC/GF composites were reduced by about 2-18% from original value. The composites with lower GF content had its compressive strength reduced less than composites with higher GF content.

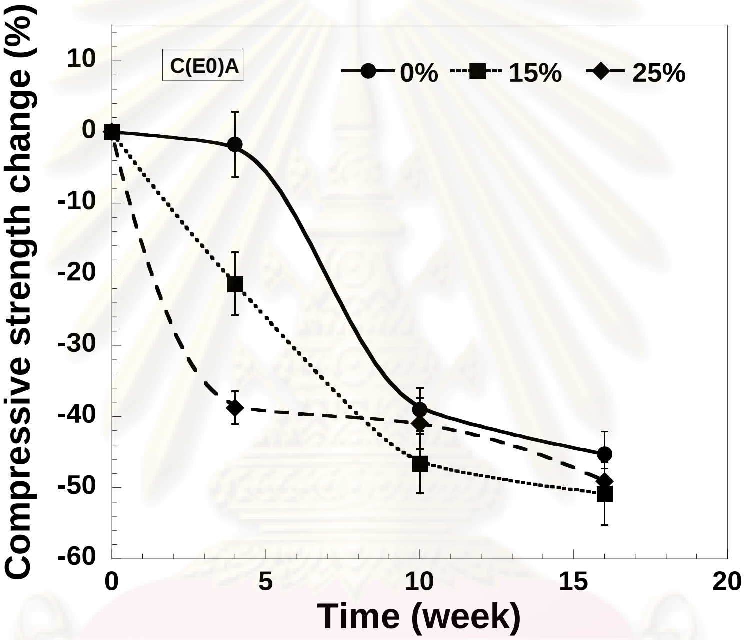


Figure 5.78 Effect of percent of GF in composites and immersion time on compressive strength change of PVC/GF composites immersed in C(E0)$_A$ test fuel

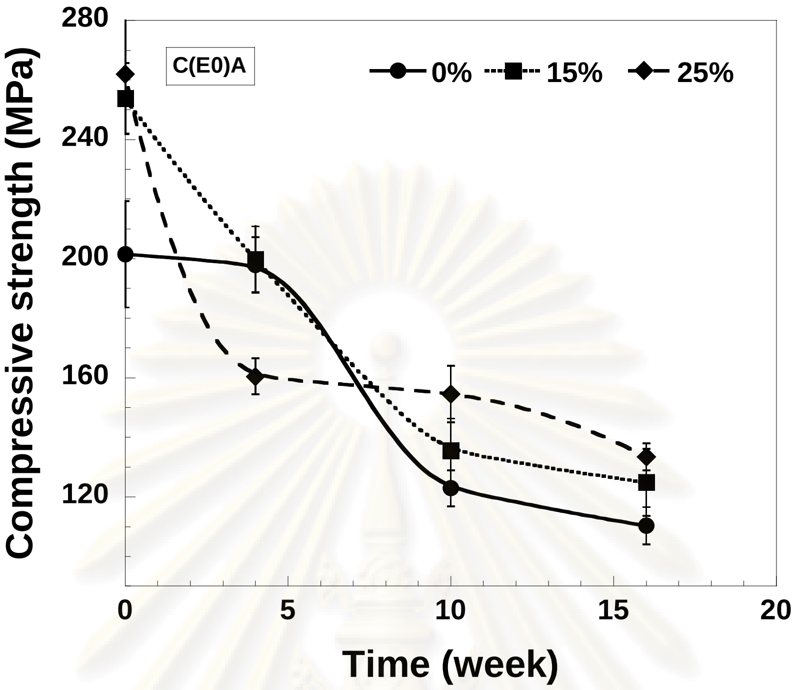


Figure 5.79 Effect of percent of GF in composites and immersion time on compressive strength of PVC/GF composites immersed in $C(E0)_A$ test fuel

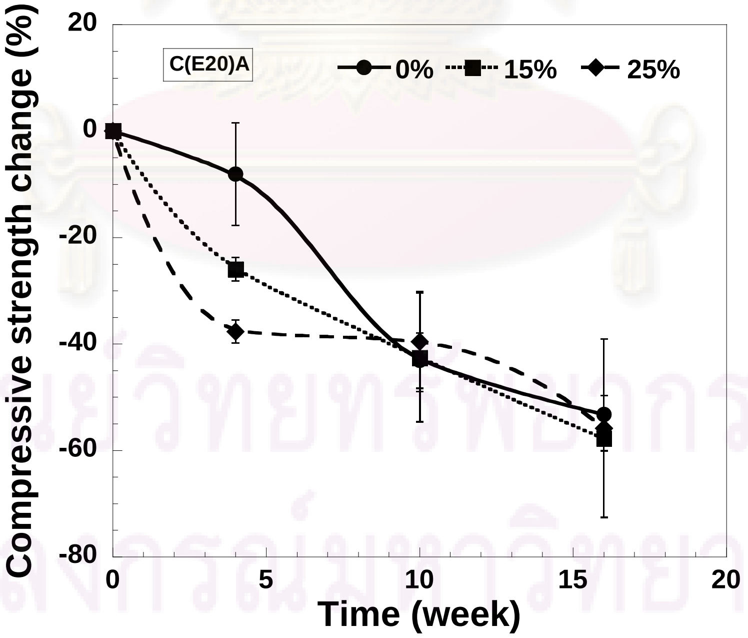


Figure 5.80 Effect of percent of GF in composites and immersion time on compressive strength change of PVC/GF composites immersed in $C(E20)_A$ test fuel

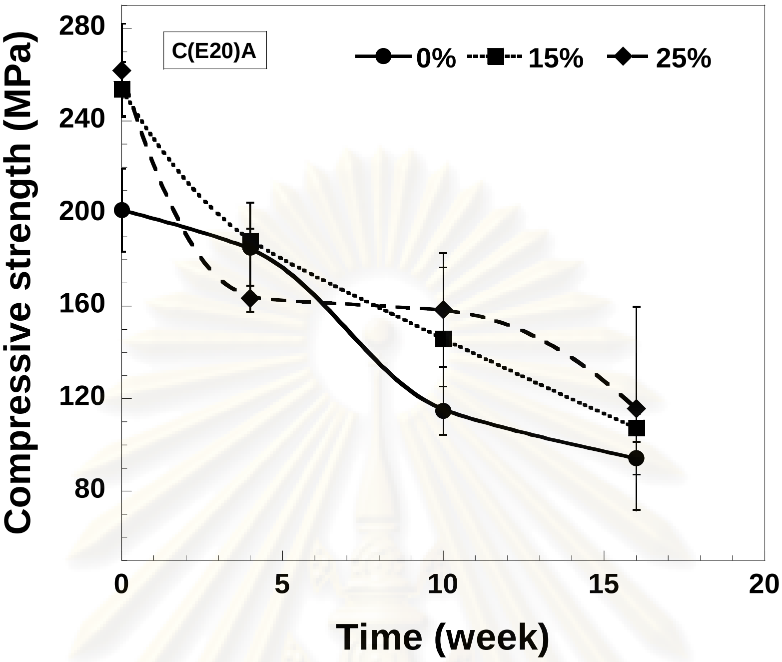


Figure 5.81 Effect of percent of GF in composites and immersion time on compressive strength of PVC/GF composites immersed in $C(E20)_A$ test fuel

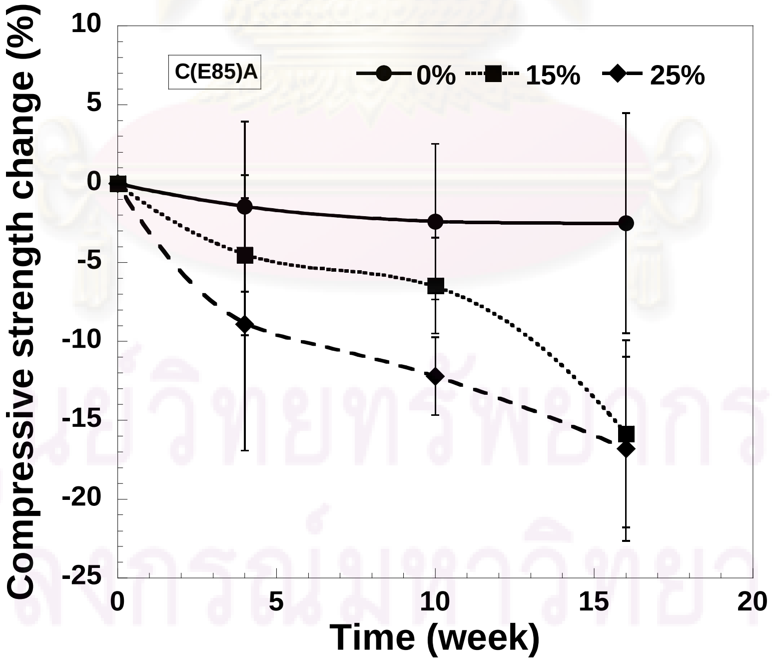


Figure 5.82 Effect of percent of GF in composites and immersion time on compressive strength change of PVC/GF composites immersed in $C(E85)_A$ test fuel

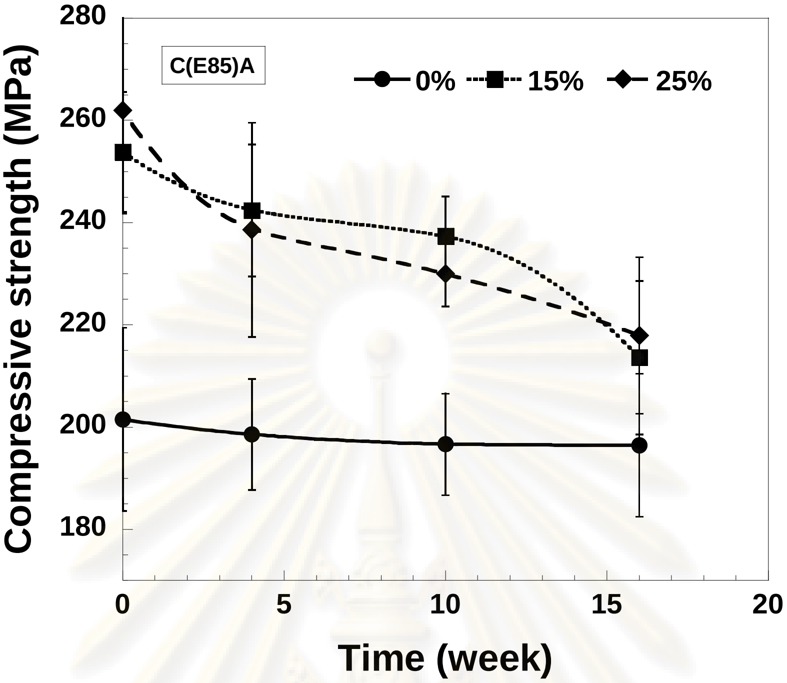


Figure 5.83 Effect of percent of GF in composites and immersion time on compressive strength of PVC/GF composites immersed in C(E85)$_A$ test fuel

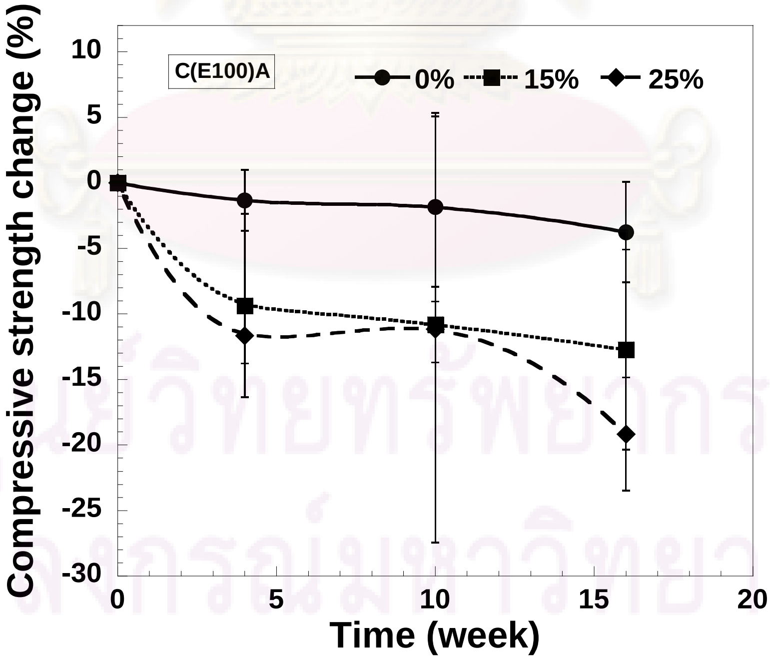


Figure 5.84 Effect of percent of GF in composites and immersion time on compressive strength change of PVC/GF composites immersed in C(E100)$_A$ test fuel

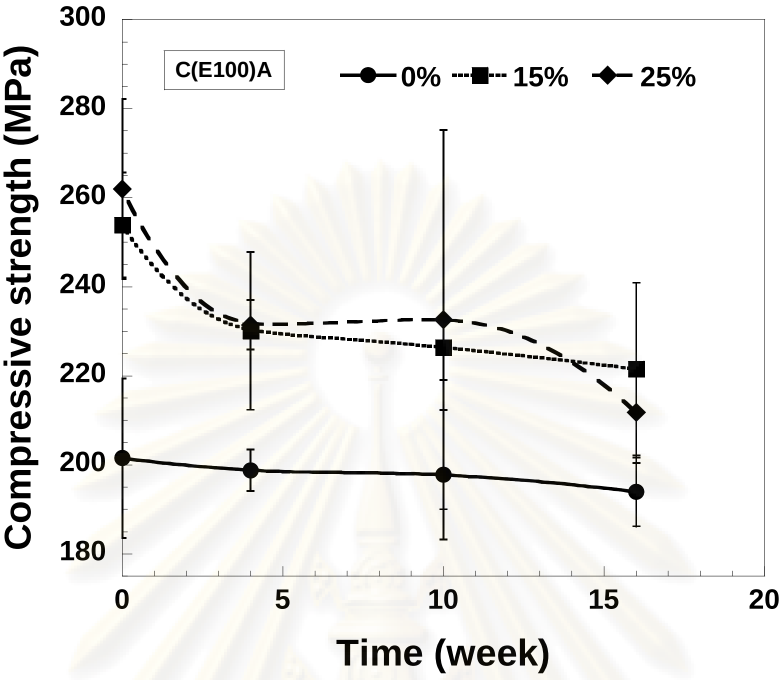


Figure 5.85 Effect of percent of GF in composites and immersion time on compressive strength of PVC/GF composites immersed in C(E100)$_A$ test fuel

5.2.4 Impact property

Fig. 5.86-5.91 showed that the impact strength of PVC/GF (0-25 wt%) composites after immersed in C(E0)$_A$ and C(E20)$_A$ test fuels for 16 weeks were increased by almost 1,000-1,300%, 500 - 700% and 90-320% from the original value respectively and be constant in 10 until 16 weeks. However, the impact strength of same composites after immersed in C(E85)$_A$ and C(E100)$_A$ test fuels for 16 weeks were reduced by only about 4% from the original value respectively and be constant in 4 until 16 weeks. These were clearly due to The solubility parameter of the toluene is near that of PVC (Barton, Allan F. M.) [37] and PVC has low polar as C(E0)$_A$ and C(E20)$_A$ (R.L. Eissler et al.) [38] cause higher amount of absorption of iso-octane and toluene into PVC matrix from C(E0)$_A$ and C(E20)$_A$ than from C(E85)$_A$ and C(E100)$_A$ test fuels as discussed earlier (Fred W. Billmeyer et al.) [24]. Iso-octane and toluene clearly swelled and plasticized the PVC matrix causing its impact strength to increased in C(E0)$_A$ and

C(E20)$_A$ because of high impact absorption of PVC/GF composites, this value can be used as an indicator to its ductility due to the reduction of mechanical properties of PVC matrix itself.

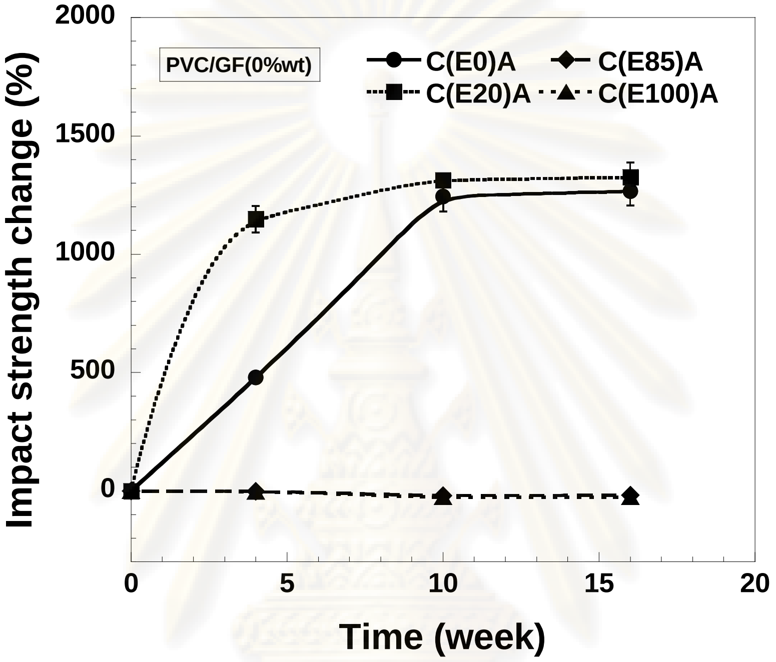


Figure 5.86 Effect of percent ethanol in test fuel and immersion time on impact strength change of PVC/GF (0 wt%) composites

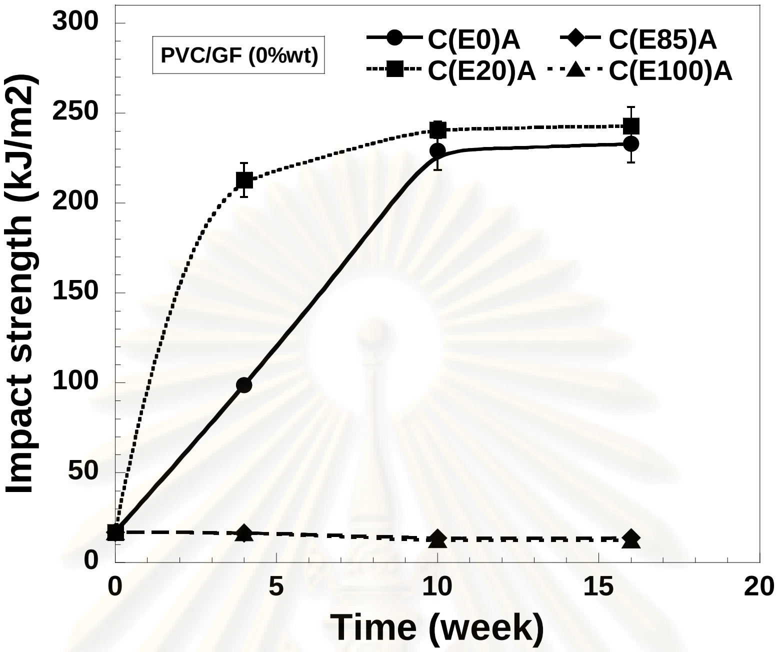


Figure 5.87 Effect of percent ethanol in test fuel and immersion time on impact strength of PVC/GF (0 wt%) composites

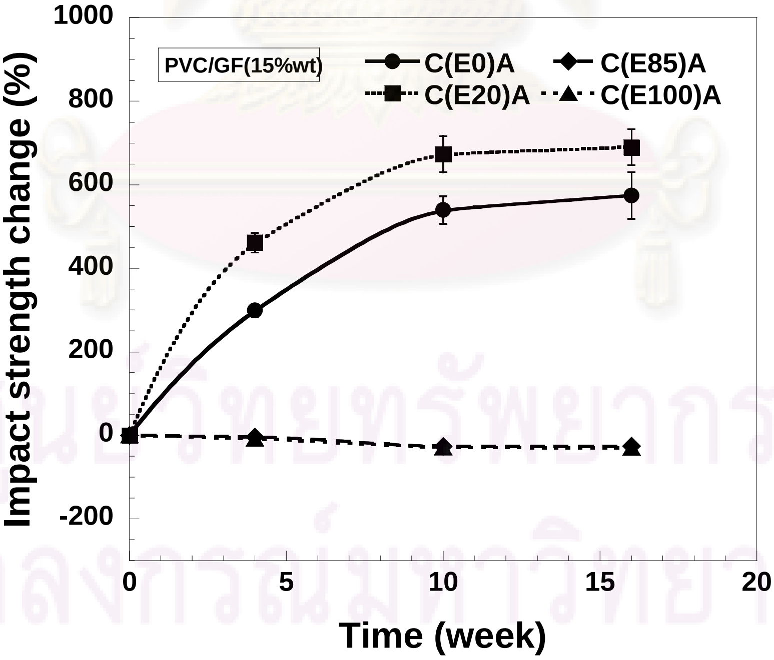


Figure 5.88 Effect of percent ethanol in test fuel and immersion time on impact strength change of PVC/GF (15 wt%) composites

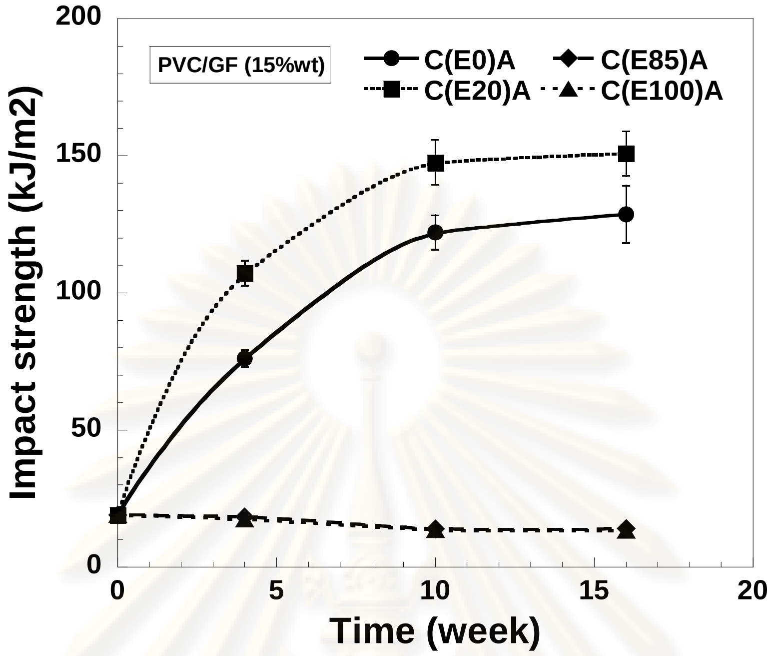


Figure 5.89 Effect of percent ethanol in test fuel and immersion time on impact strength of PVC/GF (15 wt%) composites

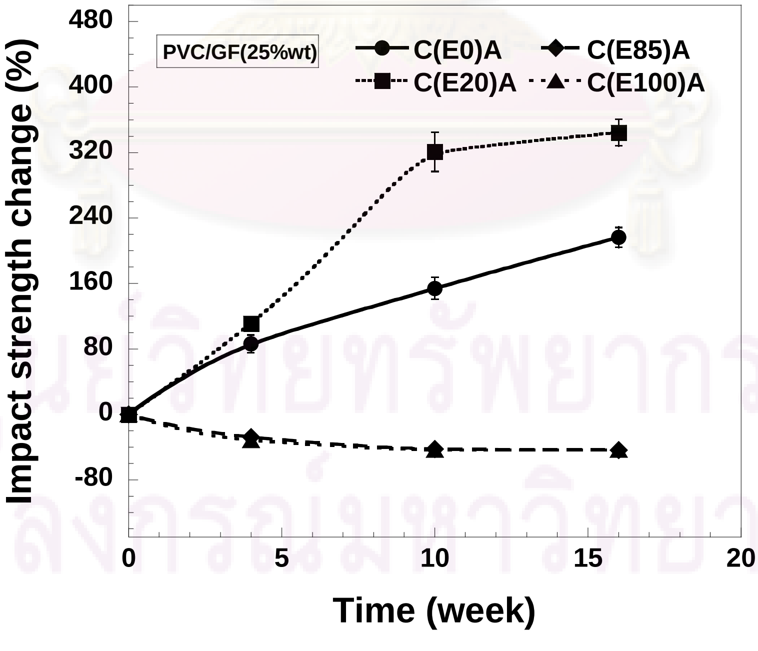


Figure 5.90 Effect of percent ethanol in test fuel and immersion time on impact strength change of PVC/GF (25 wt%) composites

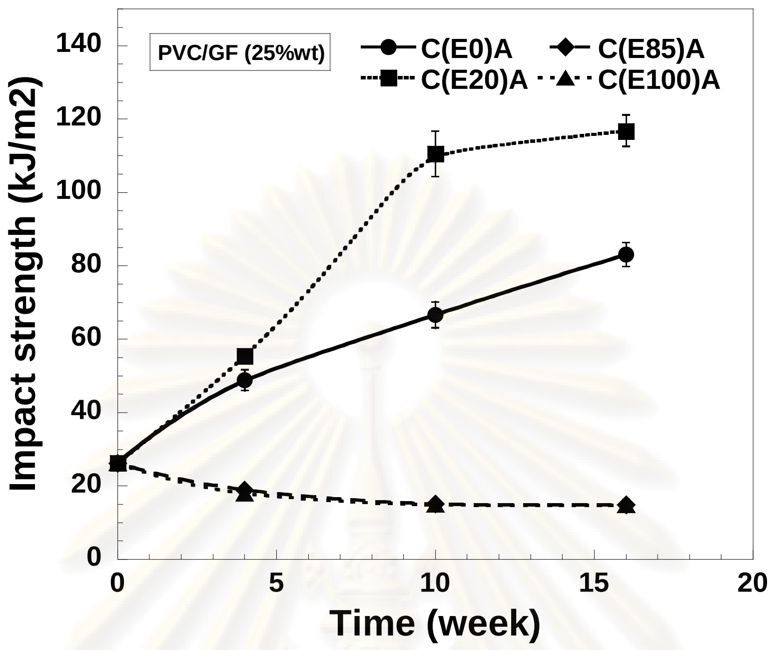


Figure 5.91 Effect of percent ethanol in test fuel and immersion time on impact strength of PVC/GF (25 wt%) composites

Fig. 5.92-5.95 showed that, after immersion in $C(E0)_A$ and $C(E20)_A$ for 16 weeks, the impact strength of PVC/GF composites were increased by about 100-1,300% from original value. The composites with lower GF content had its impact strength increased more than composites with higher GF content. Fig. 5.96-5.99 showed that, after immersion in $C(E85)_A$ and $C(E100)_A$ for 16 weeks, the impact strength of PVC/GF composites were reduced by about 5-40% from original value. The composites with lower GF content had its impact strength reduced less than composites with higher GF content.

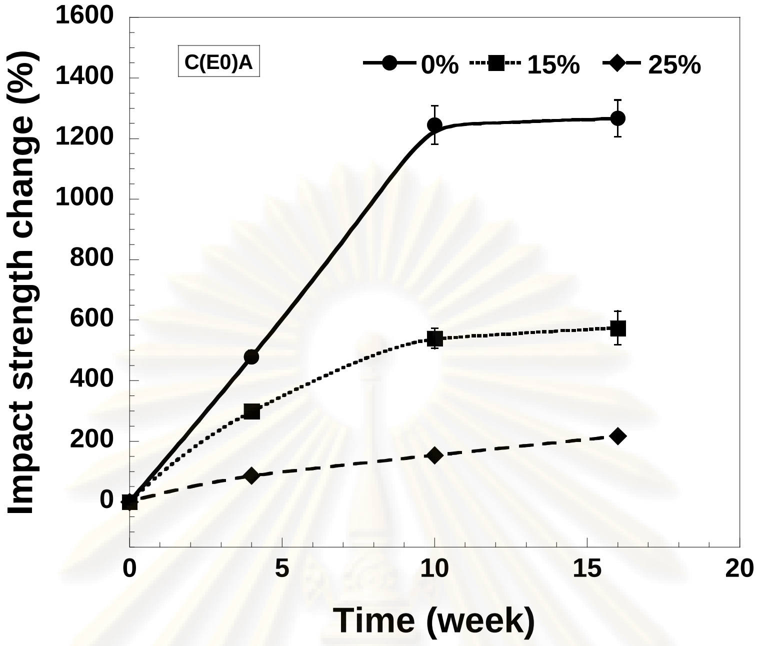


Figure 5.92 Effect of percent of GF in composites and immersion time on impact strength change of PVC/GF composites immersed in $C(E0)_A$ test fuel

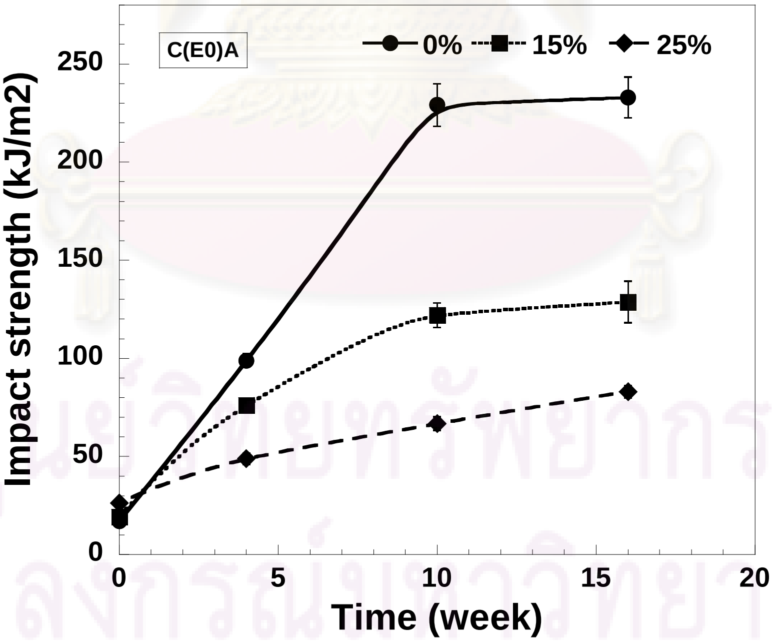


Figure 5.93 Effect of percent of GF in composites and immersion time on impact strength of PVC/GF composites immersed in $C(E0)_A$ test fuel

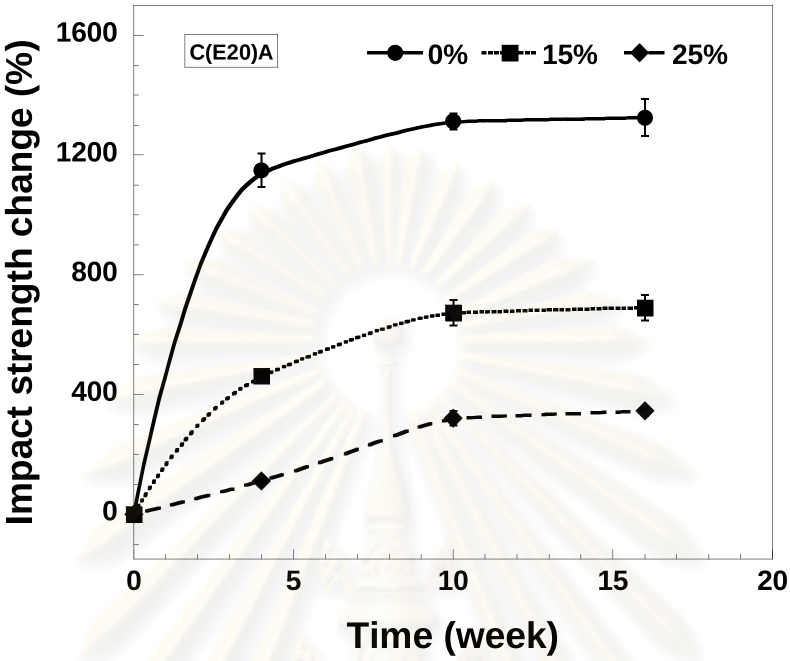


Figure 5.94 Effect of percent of GF in composites and immersion time on impact strength change of PVC/GF composites immersed in $C(E20)_A$ test fuel

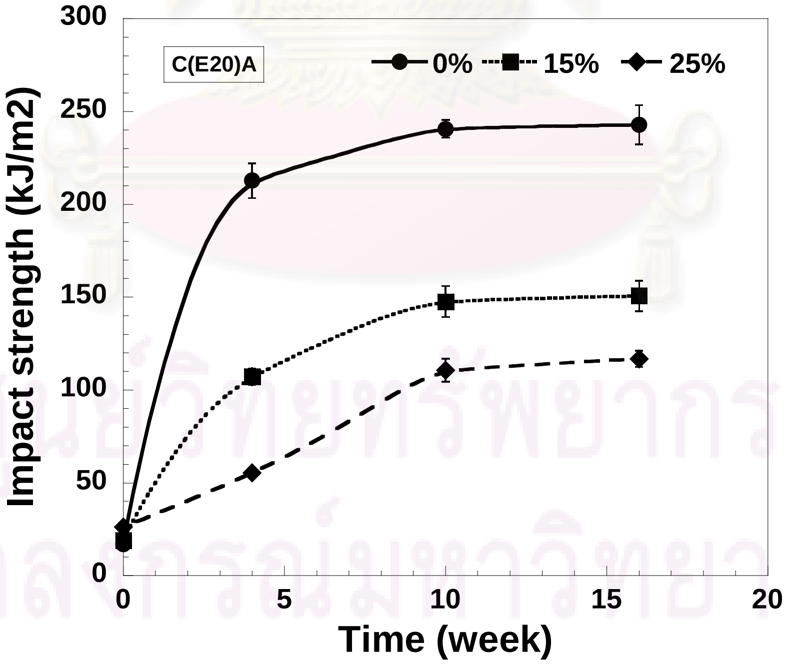


Figure 5.95 Effect of percent of GF in composites and immersion time on impact strength of PVC/GF composites immersed in $C(E20)_A$ test fuel

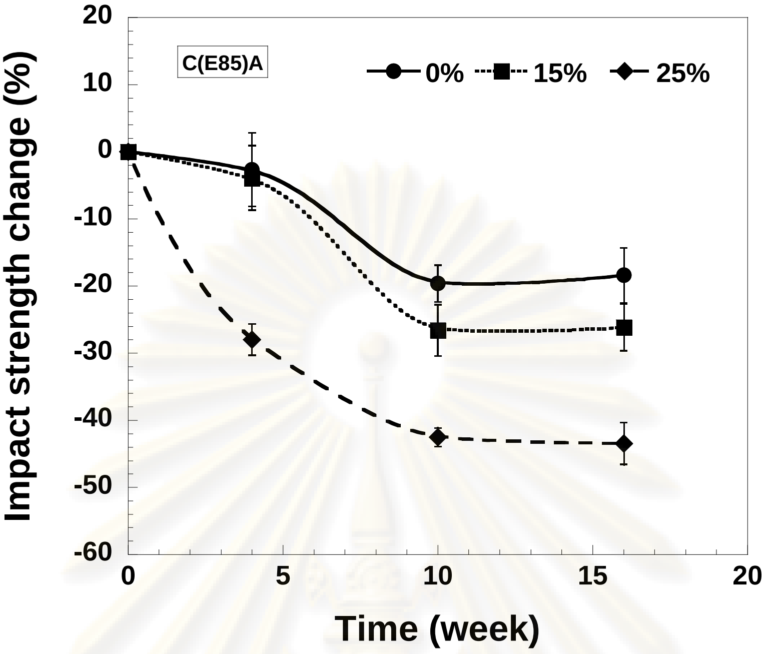


Figure 5.96 Effect of percent of GF in composites and immersion time on impact strength change of PVC/GF composites immersed in C(E85)$_A$ test fuel

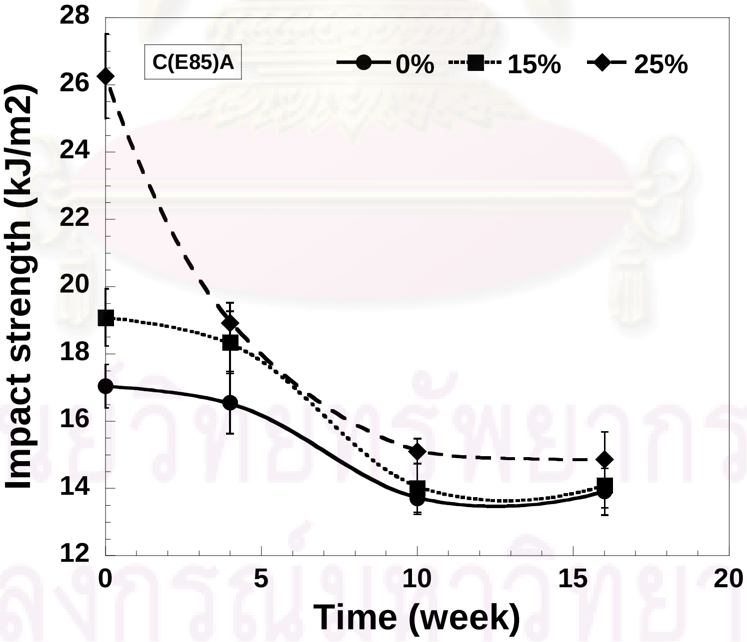


Figure 5.97 Effect of percent of GF in composites and immersion time on impact strength of PVC/GF composites immersed in C(E85)$_A$ test fuel

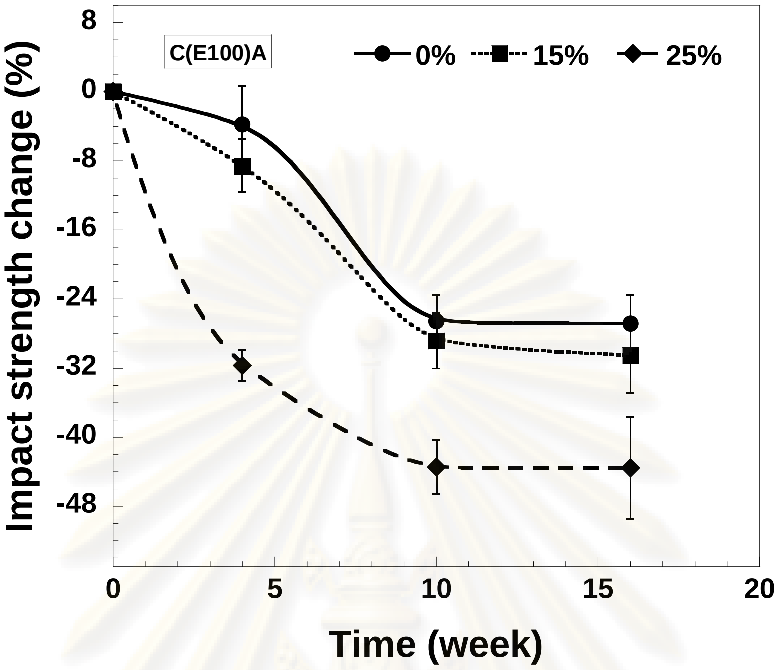


Figure 5.98 Effect of percent of GF in composites and immersion time on impact strength change of PVC/GF composites immersed in C(E100)$_A$ test fuel

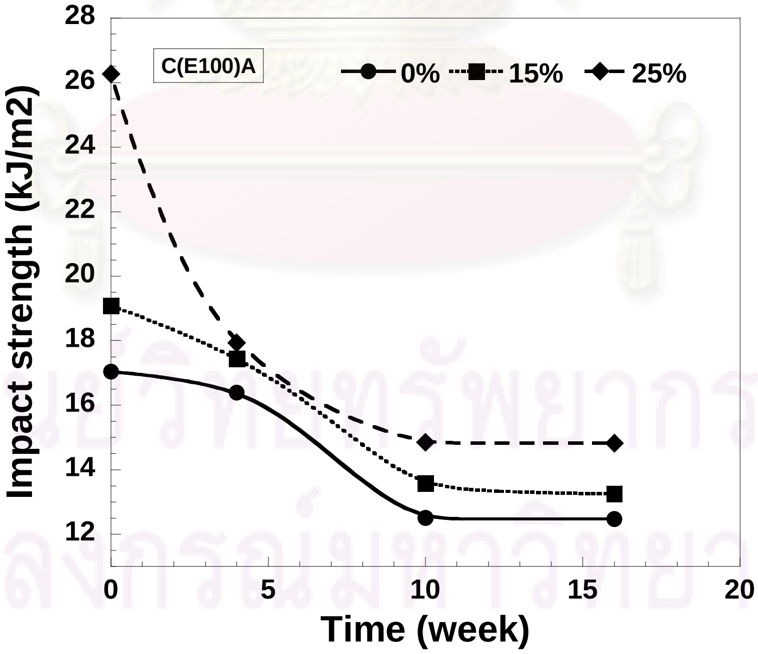
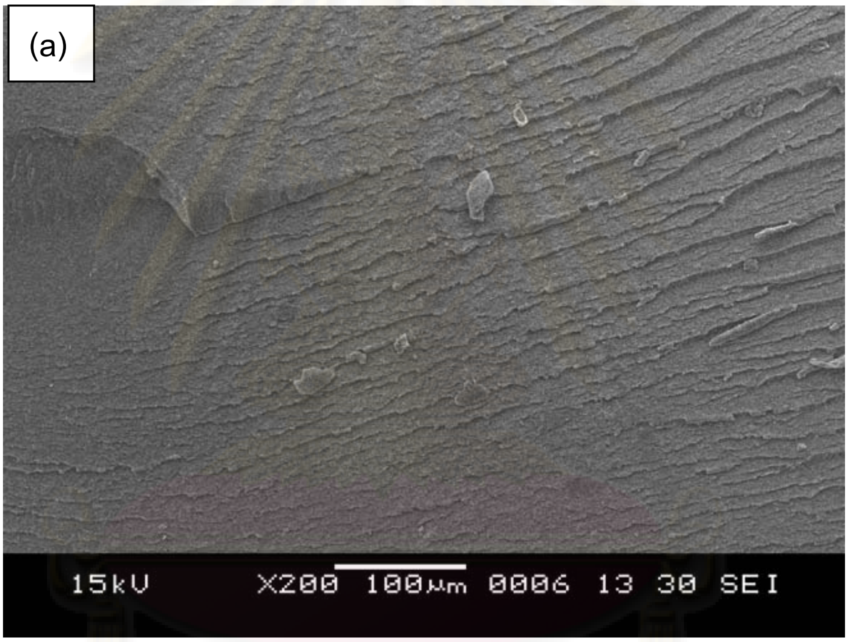


Figure 5.99 Effect of percent of GF in composites and immersion time on impact strength of PVC/GF composites immersed in C(E100)$_A$ test fuel

5.3 Scanning Electron Microscope (SEM)

Fig 5.100 showed that the morphology of PVC. Fig. 5.100 (a)-(b) PVC matrix is good dispersion. Fig 5.52-5.53 showed that the morphology of PVC/GF composites at 15-25%. Fig. 5.101-5.102 (a) reveals relatively good dispersion of the glass fiber in the composites. The interfacial adhesion between the PVC matrix and glass fiber was rather good shown in Fig. 5.101-5.102 (b) As a result, the mechanical properties of PVC/GF composites were increase with increasing glass fiber content noticed in our results (S. Tungjitpornkull et al.)[27].



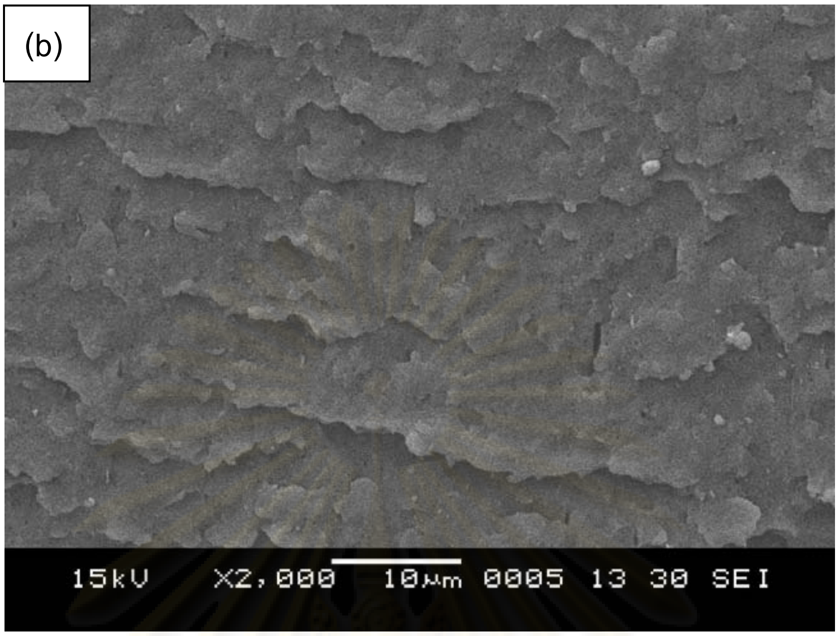
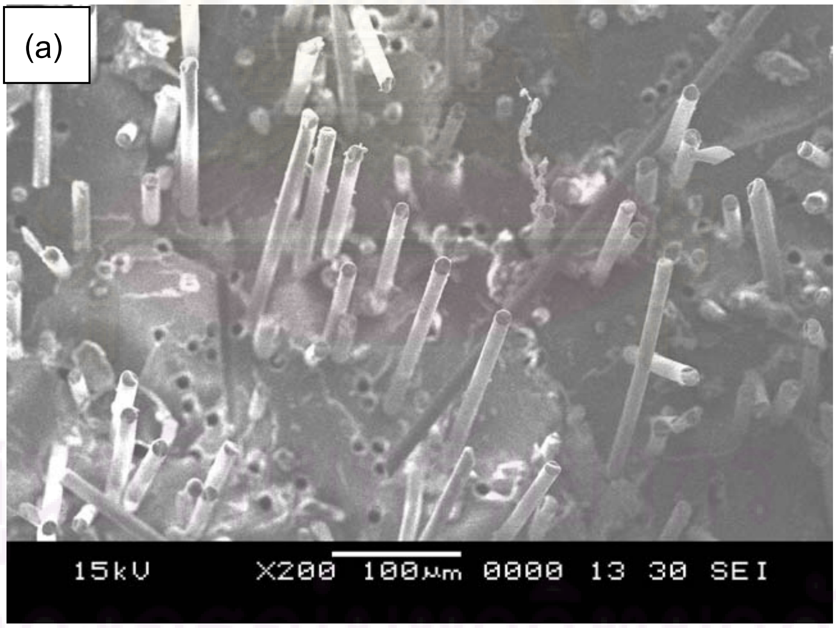


Figure 5.100 SEM micrographs of PVC/GF composites at 0 wt%: (a) 200 x magnification (b) 2,000 x magnification



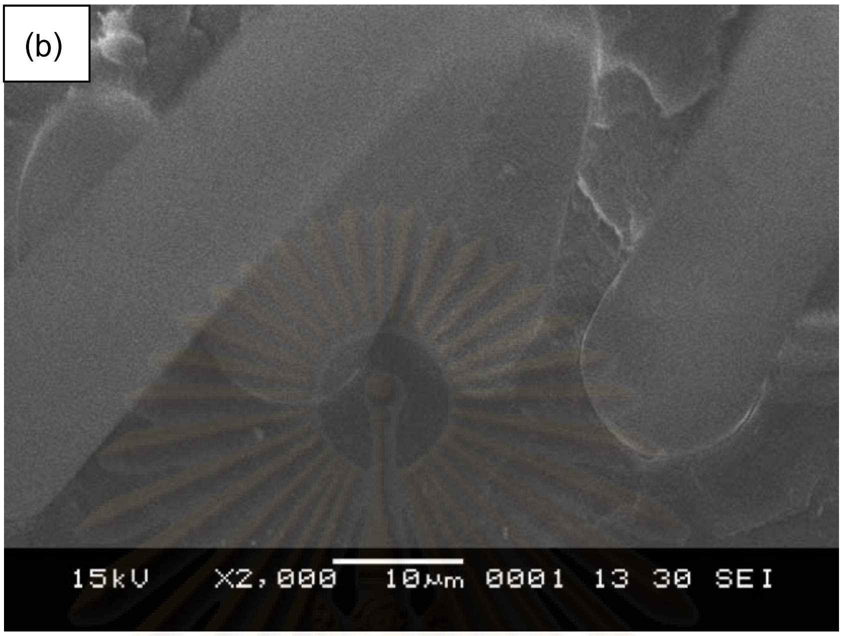
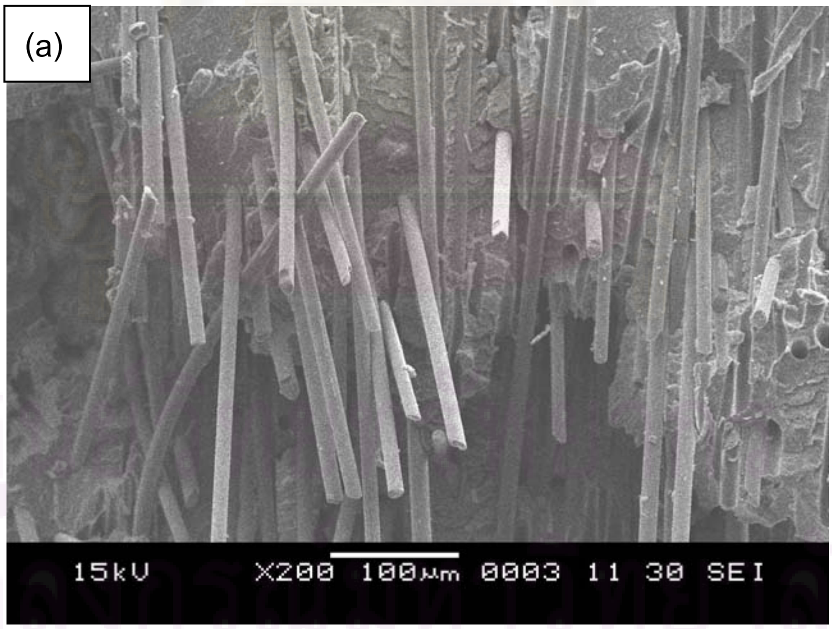


Figure 5.101 SEM micrographs of PVC/GF composites at 15 wt%: (a) 200 x magnification (b) 2,000 x magnification



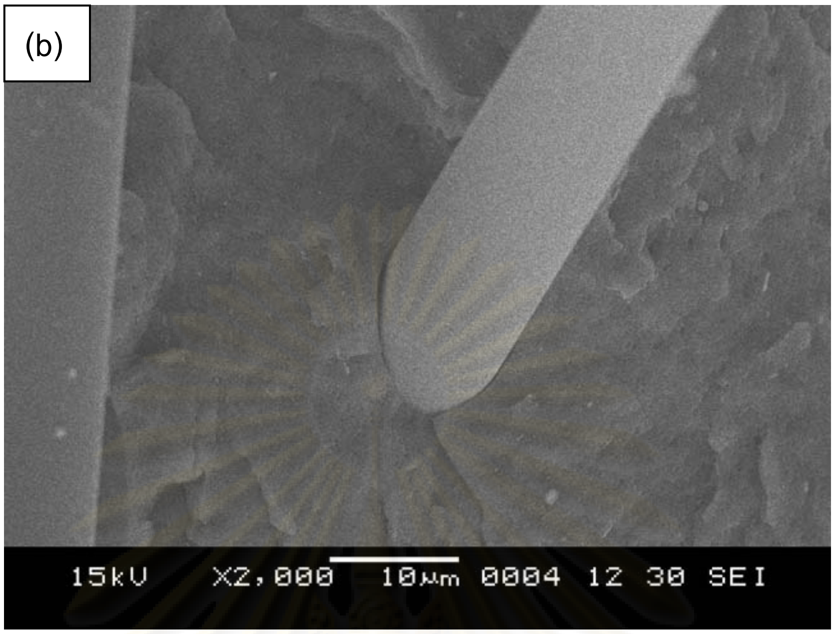


Figure 5.102 SEM micrographs of PVC/GF composites at 25 wt%: (a) 200 x magnification (b) 2,000 x magnification

CHAPTER VI

CONCLUSIONS

The results obtained in this work can be concluded as the followings:

1. The morphology of PVC/GF composites revealed relatively good dispersion of the glass fiber in the composites. The interfacial adhesion between the PVC matrix and glass fiber was rather good. As a result, the mechanical properties of PVC/GF composites increased with increasing glass fiber content.

2. The mass and volume of PVC/GF composites increased due to absorption of iso-octane and toluene into PVC matrix. The solubility parameter of the toluene is near that of PVC and PVC has low polarity as $C(E0)_A$ and $C(E20)_A$ test fuels. These caused PVC to have higher solubility in hydrocarbons than in alcohols. Hence, more absorption of iso-octane and toluene than alcohols into PVC matrix occurred.

3. Test fuels with low ethanol content, namely, $C(E0)_A$ and $CE(20)_A$, caused the tensile strength, Young's modulus, flexural strength and compressive strength of PVC/GF composites to decrease more than test fuels with high ethanol content, namely, $C(E85)_A$ and $CE(100)_A$, due to the reduction of mechanical properties of PVC matrix itself from absorption of iso-octane and toluene into PVC matrix.

4. Test fuels with low ethanol content, namely, $C(E0)_A$ and $CE(20)_A$, caused the impact strength of PVC/GF composites to increase more than test fuels with high ethanol content, namely, $C(E85)_A$ and $CE(100)_A$, due to the increase of impact strength of PVC matrix itself.

5. PVC/GF composites were not compatible with fuels with low ethanol content (≤ 20 vol%). However PVC/GF composites were not severely degraded by fuels with high ethanol content (≥ 85 vol%).

REFERENCES

[1] Orbital Engine Company. A Testing Based Assessment to Determine Impacts of a 10% and 20% Ethanol Gasoline Fuel Blend on Non-Automotive Engines 2000 hrs Material Compatibility Testing, *Report to Environment Australia*., 2003.

[2] Encyclopedia of Polymer science and technology, Concise 3rd edition Wiley-Interscience, Inc., Publication: Hoboken, NJ: A john wiley & Sons, 2007

[3] Vinyl Council of Australia and an initiative of the Plastic and Chemicals Industries Association about PVC: Its manufacture, use, and disposal (1998)

[4] British Plastics Federation PVC in Fires, London (1996)

[5] American Society of Mechanical Engineers, the relationship between chlorine in waste streams and dioxin emissions from waste combustor stacks, ASME Research report CRTD-Vol.36, 1995.

[6] Available from: http://en.wikipedia.org/wiki/Polyvinyl_chloride [2008, July 22]

[7] Jain Irrigation Systems Ltd. [Online]. Available from: http://www.jains.com/Plastic%20Products/Sheets/pvc%20rigid.htm [2009, September 13]

[8] Dynalab Corp [Online]. Available from: http://www.dynalabcorp.com/technical_info_pvc.asp [2008, July 22]

[9] C.A. Harper. Plastics materials and processes a concise encyclopedia, 3rd edition. New York: McGraw-Hill, 2003.

[10] Engineering fundamentals [Online]. Available from: http://www.efunda.com [2008, September 26]

[11] Available from: http://en.wikipedia.org/wiki/Fiberglass [2008, July 22]

[12] Petroleum Authority of Thailand (PTT) [Online]. Available from: http://www.pttplc.com/en/Default.aspx

[13] The Columbia Encyclopedia, Gasohol, 6th Edition (2007)

[14] Available from: http://encyclopedia.farlex.com/gasohol [2008, June 19]

[15] Ministry of energy [Online]. Available from: http://www.energy.go.th [2008, Jenuary19]

[16] Nicholas P.Cheremisinoff. Gasohol for Energy Production, 1979

[17] J.L. Smith and J.P. Workman, Alcohol for Motor Fuels, Available from: http://www.ext.colostate.edu/pubs/farmmgt/05010.html [2008, December 22]

[18] Common ethanol fuel mixtures, Available from: http://en.wikipedia.org/wiki/Gasohol [2008, December 11]

[19] Orbital Engine Company. A Literature Review Based Assessment on the Impacts of a 10% and 20% Ethanol Gasoline Fuel Blend on Non-Automotive Engines, Report to Environment Australia, December, 2002.

[20] Furey RL, Jackson MW. Exhaust and evaporative emissions from a Brazilian Chevrolet fuelled with ethanol-gasoline blends, SAE paper no.779008, 1977

[21] K. Owen and T. Coley. Automotive Fuels Reference Book, 1995

[22] T.P.Lyons Alltech, Inc., a Step to Energy Independence, 1981

[23] N. Alberto et.al, Plastics Testing and Characterization, 2008

[24] Fred W. Billmeyer, JR. Professor of Analytical Chemistry. Textbook of Polymer science; 3rd edition, New York, 1984

[25] Harold Belofsky. Plastics Product Design and Process Engineering, the University of Akron, Akron, 1995

[26] Bruce Jones, Gary Mead and Paul Steevens. The Effects of E20 on Plastic Automotive Fuel System Components, Minnesota Center for Automotive Research at Minnesota State University, Mankato, 2008

[27] S. Tungjitpornkull, K. Chaochanchaikul and N. Sombatsompop. Mechanical Characterization of E-Chopped Strand Glass Fiber Reinforced Wood/PVC Composite, Journal of Thermoplastic Composite Materials, 2007 Vol. 20; 535

[28] S. Tungjitpornkull and N. Sombatsompop. Processing technique and fiber orientation angle affecting the mechanical properties of E-glass fiber reinforced wood/PVC composites, Journal of materials processing technology, 2008

[29] A. Ranney and Louise V. Parker. Comparison of fiberglass and other polymeric well casings, Part I: Susceptibility to Degradation by Chemicals, 1997

[30] The plastic web [Online]. Available from: www.ides.com/property_deSCRIPTions/ASTMD638.asp [2008, December 30]

[31] Substances and Technologies [Online] Available from: http://www.substech.com/dokuwiki/doku.php?id=fracture_toughness (02 February 2009)

[32] Intertek Plastics Technology Laboratories [Online] Available from: http://www.ptli.com (18 October 2008)

[33] Instron the difference is measurable [Online]. Available from: http://www.instron.us/wa/applications.co.th (18 October 2008)

[34] Wolfgang Grellmann, Sabine seidler (Eds.). Polymer Testing, 2007

[35] MatWeb material property data [Online]. Available from: http://www.matweb.com/reference/izod-impact.aspx (09 October 2008)

[36] Mahmound Rajabian, Charles Dubois. Polymerization Compounding of HDPE/Kevlar Composite. I. Morphology and Mechanical Properties. Society of Plastics Engineers, 2006

[37] Barton, Allan F. M., *Handbook of Solubility Parameters and Other Cohesion Parameters*. Boca Raton, Florida: CRC Press, Inc., 1983.

[38] R.L.Eissler and J.P., Friedrich Estimation of Supercritical Fluid-Liquid Solubility Parameter Differences from Stirred Reactor Data Northern Regional Research Center, Agricultural Research Service,U.S. Department of Agriculture, Peoria, Illinois 61604

Appendices

Appendices

Data of PVC and PVC /GF Composites in testing fuels

Appendix 1 Mass change of PVC/GF composites at 0% in test fuel

At 0%, $C(E0)_A$	Mass change (g)						
Sample	0 week	2 week	4 week	7 week	10 week	13 week	16 week
1	8.23	8.83	9.14	9.51	9.63	9.81	9.90
2	9.02	9.64	9.97	10.33	10.45	10.67	10.82
3	8.03	8.64	8.95	9.36	9.46	9.60	9.68
4	9.00	9.60	9.92	10.31	10.43	10.64	10.80
5	8.43	9.03	9.35	9.75	9.86	10.05	10.14
AVG	8.54	9.15	9.47	9.85	9.97	10.15	10.27
SD	0.45	0.45	0.46	0.45	0.45	0.48	0.52
%SD	5.30	4.96	4.88	4.57	4.56	4.75	5.07

At 0%, $C(E20)_A$	Mass change (g)						
Sample	0 week	2 week	4 week	7 week	10 week	13 week	16 week
1	8.34	9.59	10.02	10.03	10.03	10.03	10.03
2	8.46	9.75	10.17	10.16	10.17	10.17	10.18
3	8.57	9.82	10.20	10.23	10.24	10.31	10.31
4	8.56	9.91	10.32	10.33	10.30	10.29	10.30
5	8.77	10.08	10.52	10.55	10.58	10.55	10.56
AVG	8.54	9.83	10.25	10.26	10.26	10.27	10.28
SD	0.16	0.18	0.19	0.19	0.20	0.19	0.19
%SD	1.82	1.88	1.82	1.89	1.98	1.87	1.88

At 0%, $C(E85)_A$	Mass change (g)						
Sample	0 week	2 week	4 week	7 week	10 week	13 week	16 week
1	8.39	8.39	8.40	8.40	8.40	8.40	8.41
2	8.66	8.66	8.67	8.67	8.67	8.68	8.68
3	8.89	8.90	8.91	8.91	8.91	8.91	8.91
4	8.88	8.89	8.90	8.90	8.90	8.90	8.90
5	9.02	9.02	9.04	9.04	9.04	9.04	9.04
AVG	8.77	8.77	8.78	8.78	8.79	8.79	8.79
SD	0.25	0.25	0.25	0.25	0.25	0.25	0.25
%SD	2.86	2.86	2.85	2.85	2.85	2.87	2.84

At 0%, $C(E100)_A$	Mass change (g)						
Sample	0 week	2 week	4 week	7 week	10 week	13 week	16 week
1	8.40	8.40	8.40	8.40	8.40	8.40	8.40
2	9.31	9.32	9.32	9.31	9.32	9.32	9.32
3	8.00	7.99	8.00	8.00	8.00	8.00	8.00
4	8.59	8.59	8.59	8.59	8.59	8.59	8.59
5	8.97	8.96	8.97	8.97	8.97	8.97	8.97
AVG	8.65	8.65	8.65	8.65	8.65	8.65	8.66
SD	0.51	0.51	0.51	0.51	0.51	0.51	0.51
%SD	5.89	5.90	5.87	5.88	5.88	5.89	5.88

Appendix 2 Mass change of PVC/GF composites at 15% in test fuel

At 15%, $C(E0)_A$	Mass change (g)						
Sample	0 week	2 week	4 week	7 week	10 week	13 week	16 week
1	8.99	9.51	9.82	10.15	10.36	10.35	10.35
2	9.31	9.77	10.04	10.19	10.52	10.55	10.60
3	9.10	9.56	9.83	10.09	10.37	10.38	10.40
4	9.40	9.89	10.16	10.45	10.73	10.73	10.76
5	9.43	9.90	10.17	10.45	10.70	10.72	10.76
AVG	9.24	9.73	10.01	10.27	10.54	10.54	10.57
SD	0.19	0.18	0.17	0.17	0.18	0.18	0.19
%SD	2.10	1.86	1.72	1.67	1.67	1.73	1.84

At 15%, $C(E20)_A$	Mass change (g)						
Sample	0 week	2 week	4 week	7 week	10 week	13 week	16 week
1	9.46	10.49	10.87	11.06	11.01	11.07	11.12
2	9.20	10.20	10.59	10.65	10.70	10.75	10.81
3	9.98	11.03	11.43	11.61	11.61	11.67	11.73
4	9.43	10.46	10.86	11.02	10.97	11.02	11.08
5	9.90	10.97	11.34	11.46	11.52	11.58	11.64
AVG	9.60	10.63	11.02	11.16	11.16	11.22	11.27
SD	0.33	0.35	0.35	0.38	0.39	0.39	0.39
%SD	3.46	3.34	3.20	3.43	3.46	3.49	3.50

At 15%, $C(E85)_A$	Mass change (g)						
Sample	0 week	2 week	4 week	7 week	10 week	13 week	16 week
1	9.42	9.42	9.43	9.43	9.43	9.44	9.44
2	9.60	9.60	9.61	9.61	9.59	9.59	9.60
3	9.61	9.61	9.63	9.63	9.63	9.63	9.63
4	9.83	9.83	9.84	9.82	9.82	9.82	9.82
5	9.26	9.26	9.28	9.28	9.28	9.28	9.28
AVG	9.55	9.55	9.56	9.55	9.55	9.55	9.55
SD	0.22	0.21	0.21	0.21	0.21	0.21	0.21
%SD	2.25	2.25	2.23	2.16	2.15	2.15	2.15

At 15%, $C(E100)_A$	Mass change (g)						
Sample	0 week	2 week	4 week	7 week	10 week	13 week	16 week
1	9.77	9.77	9.78	9.78	9.78	9.78	9.78
2	9.84	9.84	9.85	9.84	9.84	9.85	9.85
3	9.29	9.30	9.30	9.29	9.30	9.30	9.30
4	9.15	9.15	9.15	9.15	9.15	9.16	9.16
5	9.10	9.10	9.10	9.10	9.10	9.10	9.10
AVG	9.43	9.43	9.43	9.43	9.43	9.43	9.44
SD	0.35	0.35	0.35	0.35	0.35	0.35	0.35
%SD	3.74	3.73	3.75	3.73	3.73	3.73	3.74

Appendix 3 Mass change of PVC/GF composites at 25% in test fuel

At 25%, $C(E0)_A$	Mass change (g)						
Sample	0 week	2 week	4 week	7 week	10 week	13 week	16 week
1	10.15	10.60	10.87	11.20	11.58	11.61	11.60
2	10.01	10.44	10.72	10.03	11.39	11.41	11.42
3	9.50	9.93	10.20	10.46	10.84	10.85	10.87
4	10.58	11.03	11.31	11.63	12.04	12.14	12.17
5	9.53	9.98	10.27	10.58	10.89	11.02	11.03
AVG	9.95	10.40	10.68	10.78	11.35	11.41	11.42
SD	0.45	0.46	0.46	0.63	0.50	0.51	0.51
%SD	4.51	4.40	4.28	5.87	4.42	4.46	4.49

At 25%, $C(E20)_A$	Mass change (g)						
Sample	0 week	2 week	4 week	7 week	10 week	13 week	16 week
1	9.68	10.64	10.91	10.90	11.22	11.23	11.31
2	9.64	10.63	10.87	10.88	11.25	11.21	11.26
3	9.63	10.61	10.84	10.87	11.20	11.22	11.28
4	9.81	10.83	11.08	11.08	11.42	11.43	11.54
5	9.56	10.53	10.65	10.77	11.09	11.10	11.22
AVG	9.66	10.65	10.87	10.90	11.24	11.24	11.32
SD	0.09	0.11	0.15	0.11	0.12	0.12	0.12
%SD	0.98	1.02	1.41	1.03	1.07	1.06	1.10

At 25%, $C(E85)_A$	Mass change (g)						
Sample	0 week	2 week	4 week	7 week	10 week	13 week	16 week
1	9.34	9.34	9.34	9.34	9.35	9.35	9.35
2	10.27	10.27	10.27	10.28	10.26	10.26	10.26
3	9.95	9.95	9.95	9.96	9.94	9.94	9.94
4	9.66	9.66	9.66	9.66	9.66	9.66	9.66
5	9.69	9.69	9.70	9.70	9.70	9.70	9.71
AVG	9.78	9.78	9.79	9.79	9.78	9.78	9.78
SD	0.35	0.35	0.35	0.35	0.34	0.34	0.34
%SD	3.57	3.57	3.57	3.56	3.47	3.47	3.47

At 25%, $C(E100)_A$	Mass change (g)						
Sample	0 week	2 week	4 week	7 week	10 week	13 week	16 week
1	9.96	9.95	9.96	9.96	9.96	9.96	9.96
2	9.89	9.89	9.89	9.89	9.89	9.89	9.89
3	10.20	10.20	10.20	10.20	10.20	10.20	10.20
4	10.20	10.20	10.21	10.20	10.20	10.20	10.21
5	9.37	9.37	9.38	9.38	9.38	9.38	9.38
AVG	9.92	9.92	9.93	9.92	9.93	9.93	9.93
SD	0.34	0.34	0.34	0.34	0.34	0.34	0.34
%SD	3.41	3.41	3.41	3.41	3.41	3.38	3.41

Appendix 4 Tensile strength of PVC/GF composites at 0 week

At 0 week	Tensile strength (MPa)		
Sample	0%	15%	25%
1	59.70	82.58	104.56
2	59.68	82.30	109.78
3	59.84	82.16	108.51
4	60.29	83.10	110.34
5	59.59	82.25	103.86
6	60.78	85.24	107.77
7	61.68	85.76	109.01
AVG	60.22	83.34	107.69
SD	0.77	1.51	2.53
%SD	1.28	1.82	2.35

Appendix 5 Tensile strength of PVC/GF composites at 4 week in test fuel

At 4 week	Tensile strength (MPa)					
Sample	$C(E0)_A$			$C(E20)_A$		
	0%	15%	25%	0%	15%	25%
1	28.20	28.99	16.13	23.30	33.01	12.53
2	30.59	27.68	19.90	24.20	34.77	14.13
3	27.29	31.59	17.89	23.50	29.32	14.89
4	30.19	31.19	18.10	24.24	31.67	12.46
5	30.76	29.79	16.06	24.26	29.33	12.06
AVG	29.41	29.85	17.61	23.90	31.62	13.21
SD	1.56	1.60	1.59	0.46	2.37	1.23
%SD	5.32	5.37	9.05	1.94	7.49	9.28

At 4 week	Tensile strength (MPa)					
Sample	$C(E85)_A$			$C(E100)_A$		
	0%	15%	25%	0%	15%	25%
1	53.83	81.24	99.59	56.20	82.39	99.82
2	52.83	80.05	112.51	55.90	80.10	107.74
3	54.44	80.23	110.85	56.92	85.26	106.93
4	54.71	82.18	111.99	56.13	83.59	95.34
5	53.64	85.90	92.76	55.27	88.37	109.01
AVG	53.89	81.92	105.54	56.08	83.94	103.77
SD	0.73	2.38	8.90	0.59	3.11	5.91
%SD	1.36	2.91	8.44	1.06	3.70	5.70

Appendix 6 Tensile strength of PVC/GF composites at 10 week in test fuel

At 10 week	Tensile strength (MPa)					
Sample	$C(E0)_A$			$C(E20)_A$		
	0%	15%	25%	0%	15%	25%
1	17.88	20.23	8.28	13.50	10.95	9.24
2	17.98	25.06	10.13	13.79	8.70	8.76
3	18.09	23.30	10.57	13.77	9.72	7.77
4	17.84	22.79	10.48	14.04	8.54	8.13
5	17.56	24.88	11.24	13.97	8.77	8.08
AVG	17.87	23.25	10.14	13.81	9.34	8.40
SD	0.20	1.95	1.12	0.21	1.02	0.59
%SD	1.12	8.40	11.00	1.53	10.88	7.04

At 10 week	Tensile strength (MPa)					
Sample	$C(E85)_A$			$C(E100)_A$		
	0%	15%	25%	0%	15%	25%
1	55.50	76.57	103.11	58.02	90.49	95.45
2	54.71	77.98	105.50	55.69	90.84	105.42
3	54.77	72.48	108.61	58.49	88.54	93.37
4	55.04	79.92	103.67	58.26	74.58	88.88
5	55.98	76.41	105.29	59.62	71.70	104.59
AVG	55.20	76.67	105.23	58.02	83.23	97.54
SD	0.54	2.74	2.15	1.44	9.31	7.22
%SD	0.97	3.57	2.04	2.48	11.18	7.40

Appendix 7 Tensile strength of PVC/GF composites at 16 week in test fuel

At 16 week	Tensile strength (MPa)					
Sample	$C(E0)_A$			$C(E20)_A$		
	0%	15%	25%	0%	15%	25%
1	11.89	16.72	16.13	11.04	8.67	8.98
2	11.69	15.91	16.39	11.37	6.87	8.15
3	12.44	16.77	16.49	11.46	8.31	8.08
4	12.62	14.42	14.13	11.66	7.64	9.48
5	11.87	15.63	16.36	11.07	7.94	8.91
AVG	12.10	15.89	15.90	11.32	7.88	8.72
SD	0.40	0.96	1.00	0.26	0.69	0.59
%SD	3.33	6.05	6.28	2.33	8.73	6.82

At 16 week	Tensile strength (MPa)					
Sample	$C(E85)_A$			$C(E100)_A$		
	0%	15%	25%	0%	15%	25%
1	56.13	81.71	99.64	53.70	66.84	89.82
2	55.39	74.33	103.37	54.96	83.29	81.58
3	55.02	80.89	95.34	54.56	78.92	102.16
4	56.66	73.77	87.71	55.58	82.48	85.93
5	56.64	75.98	86.93	54.24	73.74	104.61
AVG	55.97	77.34	94.60	54.61	77.06	92.82
SD	0.74	3.72	7.23	0.71	6.84	10.11
%SD	1.32	4.81	7.65	1.31	8.87	10.90

Appendix 8 Young’s modulus of PVC/GF composites at 0 week

At 0 week	Young's modulus (GPa)		
Sample	0%	15%	25%
1	2.54	4.58	5.73
2	2.54	4.56	6.02
3	2.55	4.55	5.95
4	2.57	4.61	6.05
5	2.54	4.56	5.69
6	2.59	4.72	5.91
7	2.63	4.75	5.98
AVG	2.57	4.62	5.90
SD	0.03	0.08	0.14
%SD	1.28	1.82	2.35

Appendix 9 Young's modulus of PVC/GF composites at 4 week in test fuel

At 4 week	Young's modulus (GPa)					
Sample	$C(E0)_A$			$C(E20)_A$		
	0%	15%	25%	0%	15%	25%
1	1.00	1.34	0.85	0.93	1.69	0.66
2	1.12	1.33	1.05	0.89	1.78	0.74
3	0.98	1.49	0.94	0.93	1.38	0.78
4	1.08	1.35	0.95	0.89	1.35	0.66
5	1.15	1.35	0.85	0.92	1.54	0.64
AVG	1.06	1.37	0.93	0.91	1.55	0.70
SD	0.07	0.07	0.08	0.02	0.19	0.06
%SD	7.03	4.76	9.05	2.22	12.08	9.28

At 4 week	Young's modulus (GPa)					
Sample	$C(E85)_A$			$C(E100)_A$		
	0%	15%	25%	0%	15%	25%
1	2.26	4.52	5.70	2.22	4.50	5.58
2	2.11	4.45	5.78	2.25	4.64	5.89
3	2.20	4.46	5.84	2.28	4.62	5.52
4	2.22	4.57	5.74	2.20	4.57	5.22
5	2.12	4.71	5.86	2.17	4.57	6.29
AVG	2.18	4.54	5.79	2.22	4.58	5.70
SD	0.06	0.10	0.07	0.04	0.06	0.41
%SD	2.95	2.28	1.16	1.88	1.23	7.16

Appendix 10 Young’s modulus of PVC/GF composites at 10 week in test fuel

At 10 week	Young's modulus (GPa)					
Sample	$C(E0)_A$			$C(E20)_A$		
	0%	15%	25%	0%	15%	25%
1	1.13	1.28	0.52	0.85	0.69	0.59
2	1.14	1.59	0.64	0.87	0.55	0.55
3	1.15	1.48	0.67	0.87	0.62	0.49
4	1.13	1.44	0.66	0.89	0.54	0.51
5	1.11	1.58	0.71	0.88	0.56	0.51
AVG	1.13	1.47	0.64	0.87	0.59	0.53
SD	0.01	0.12	0.07	0.01	0.06	0.04
%SD	1.12	8.40	11.00	1.53	10.88	7.04

At 10 week	Young's modulus (GPa)					
Sample	$C(E85)_A$			$C(E100)_A$		
	0%	15%	25%	0%	15%	25%
1	2.36	4.21	5.96	2.28	4.55	6.28
2	2.23	4.35	5.74	2.31	4.46	5.70
3	2.24	4.17	5.72	2.34	4.85	6.11
4	2.34	4.37	5.93	2.28	4.24	5.44
5	2.23	4.31	5.24	2.35	4.04	5.70
AVG	2.28	4.28	5.72	2.31	4.43	5.85
SD	0.07	0.09	0.29	0.03	0.31	0.34
%SD	2.92	2.01	5.08	1.36	6.95	5.82

Appendix 11 Young's modulus of PVC/GF composites at 16 week in test fuel

At 16 week	Young's modulus (GPa)					
Sample	$C(E0)_A$			$C(E20)_A$		
	0%	15%	25%	0%	15%	25%
1	0.50	0.70	0.67	0.46	0.36	0.37
2	0.49	0.66	0.68	0.47	0.29	0.34
3	0.52	0.70	0.69	0.48	0.35	0.34
4	0.53	0.60	0.59	0.49	0.32	0.40
5	0.50	0.65	0.68	0.46	0.33	0.37
AVG	0.51	0.66	0.66	0.47	0.33	0.36
SD	0.02	0.04	0.04	0.01	0.03	0.02
%SD	3.33	6.05	6.28	2.33	8.73	6.82

At 16 week	Young's modulus (GPa)					
Sample	$C(E85)_A$			$C(E100)_A$		
	0%	15%	25%	0%	15%	25%
1	2.31	4.40	5.89	2.24	4.03	6.17
2	2.38	4.19	5.68	2.37	4.72	6.09
3	2.30	4.14	5.97	2.34	4.24	5.40
4	2.35	4.20	5.29	2.31	4.25	5.03
5	2.35	4.16	5.22	2.27	4.35	5.42
AVG	2.34	4.22	5.61	2.31	4.32	5.62
SD	0.03	0.10	0.34	0.05	0.25	0.49
%SD	1.45	2.47	6.11	2.24	5.87	8.72

Appendix 12 Flexural strength of PVC/GF composites at 0 week

At 0 week	Flexural strength (MPa)		
Sample	0%	15%	25%
1	97.50	95.58	132.21
2	92.91	112.74	123.12
3	71.32	89.24	128.16
4	79.81	90.10	117.53
5	88.42	71.82	120.29
AVG	85.99	91.89	124.26
STD	10.48	14.67	5.93
%STD	12.19	15.97	4.77

Appendix 13 Flexural strength of PVC/GF composites at 4 week in test fuel

At 4 week	Flexural strength (MPa)					
Sample	$C(E0)_A$			$C(E20)_A$		
	0%	15%	25%	0%	15%	25%
1	19.33	17.43	16.47	17.35	14.38	13.18
2	19.60	18.13	17.72	17.49	14.64	13.66
3	18.73	16.80	18.09	16.57	14.45	13.03
4	20.33	18.04	17.51	18.13	13.94	13.50
5	18.10	17.61	17.83	16.12	13.57	13.51
AVG	19.22	17.60	17.52	17.13	14.20	13.38
SD	0.85	0.54	0.62	0.79	0.43	0.26
%SD	4.42	3.04	3.56	4.62	3.05	1.95

At 4 week	Flexural strength (MPa)					
Sample	$C(E85)_A$			$C(E100)_A$		
	0%	15%	25%	0%	15%	25%
1	83.23	93.28	119.42	82.91	90.44	114.57
2	84.77	95.36	126.59	82.74	87.54	112.25
3	87.73	89.16	125.75	89.07	88.69	112.40
4	87.53	88.53	121.70	83.30	84.46	117.03
5	81.22	87.76	125.77	82.47	94.33	105.54
AVG	84.89	90.82	123.84	84.10	89.09	112.36
SD	2.80	3.32	3.12	2.80	3.65	4.28
%SD	3.29	3.65	2.52	3.32	4.09	3.81

Appendix 14 Flexural strength of PVC/GF composites at 10 week in test fuel

At 10 week	Flexural strength (MPa)					
Sample	$C(E0)_A$			$C(E20)_A$		
	0%	15%	25%	0%	15%	25%
1	5.95	5.92	18.66	4.48	6.74	12.96
2	5.80	5.76	17.55	5.17	7.22	13.42
3	5.58	6.35	16.37	5.12	6.46	14.49
4	5.83	6.58	16.20	4.50	6.95	13.49
5	6.09	6.41	18.11	4.47	7.33	12.05
AVG	5.85	6.20	17.38	4.75	6.94	13.28
SD	0.19	0.35	1.08	0.36	0.35	0.89
%SD	3.25	5.57	6.19	7.57	5.12	6.67

At 10 week	Flexural strength (MPa)					
Sample	$C(E85)_A$			$C(E100)_A$		
	0%	15%	25%	0%	15%	25%
1	86.37	91.26	118.50	86.68	87.38	111.61
2	85.12	86.91	124.69	83.17	89.06	115.11
3	86.50	93.48	115.67	78.14	84.15	115.74
4	81.47	88.44	129.05	87.30	85.32	104.36
5	79.48	93.03	130.77	82.51	88.64	107.01
AVG	83.79	90.62	123.74	83.56	86.91	110.77
SD	3.15	2.87	6.54	3.69	2.12	4.99
%SD	3.76	3.16	5.29	4.41	2.44	4.50

Appendix 15 Flexural strength of PVC/GF composites at 16 week in test fuel

At 16 week	Flexural strength (MPa)					
Sample	$C(E0)_A$			$C(E20)_A$		
	0%	15%	25%	0%	15%	25%
1	2.08	8.39	17.12	1.92	4.70	12.47
2	2.02	8.13	17.24	1.80	4.99	13.69
3	2.01	8.51	17.30	1.77	5.53	13.69
4	1.82	8.85	16.96	2.07	4.59	12.72
5	1.91	10.82	17.89	2.09	5.20	13.04
AVG	1.97	8.94	17.30	1.93	5.00	13.12
SD	0.10	1.08	0.35	0.15	0.38	0.56
%SD	5.27	12.09	2.05	7.65	7.66	4.25

At 16 week	Flexural strength (MPa)					
Sample	$C(E85)_A$			$C(E100)_A$		
	0%	15%	25%	0%	15%	25%
1	81.05	92.10	125.07	87.19	86.41	108.72
2	83.03	91.22	126.15	84.47	87.68	110.02
3	84.38	95.71	126.08	83.61	89.76	112.39
4	83.12	87.57	117.82	81.61	79.39	100.27
5	79.83	85.83	122.72	78.59	79.57	119.22
AVG	82.28	90.48	123.57	83.09	84.56	110.12
STD	1.82	3.89	3.50	3.22	4.79	6.84
%STD	2.21	4.30	2.83	3.87	5.67	6.21

Appendix 16 Compressive strength of PVC/GF composites at 0 week

At 0 week	Compressive strength (MPa)		
Sample	0%	15%	25%
1	185.52	266.24	263.66
2	183.25	246.84	227.04
3	221.06	266.01	275.60
4	218.93	240.11	268.39
5	198.76	250.05	275.12
AVG	201.50	253.85	261.96
SD	17.90	11.77	20.14
%SD	8.88	4.64	7.69

Appendix 17 Compressive strength of PVC/GF composites at 4 week in test fuel

At 4 week	Compressive strength (MPa)					
Sample	$C(E0)_A$			$C(E20)_A$		
	0%	15%	25%	0%	15%	25%
1	182.83	193.35	161.86	155.61	190.28	165.74
2	200.80	190.57	167.32	187.73	186.79	157.09
3	196.45	202.45	154.67	209.84	181.76	158.91
4	202.81	218.09	153.65	183.87	196.29	171.19
5	206.76	194.11	164.55	189.22	185.30	163.48
AVG	197.93	199.71	160.41	185.25	188.08	163.28
STD	9.22	11.18	6.04	19.41	5.51	5.61
%STD	4.66	5.60	3.76	10.48	2.93	3.44

At 4 week	Compressive strength (MPa)					
Sample	$C(E85)_A$			$C(E100)_A$		
	0%	15%	25%	0%	15%	25%
1	189.64	252.01	263.21	204.29	223.23	230.35
2	195.53	240.03	247.86	196.18	228.55	236.80
3	217.32	221.07	230.37	192.32	234.51	223.79
4	197.27	251.98	207.54	199.49	256.34	229.29
5	193.11	246.79	244.03	201.67	207.76	236.92
AVG	198.57	242.37	238.60	198.79	230.08	231.43
STD	10.86	12.88	20.94	4.68	17.73	5.55
%STD	5.47	5.32	8.78	2.36	7.70	2.40

Appendix 18 Compressive strength of PVC/GF composites at 10 week in test fuel

At 10 week	Compressive strength (MPa)					
Sample	$C(E0)_A$			$C(E20)_A$		
	0%	15%	25%	0%	15%	25%
1	130.54	123.03	167.46	124.16	117.70	139.24
2	126.63	128.88	155.09	111.55	190.99	186.16
3	115.51	132.75	149.64	107.71	134.90	177.12
4	118.32	147.29	142.20	127.16	163.50	161.30
5	123.34	145.97	158.42	103.04	122.53	128.22
AVG	122.87	135.59	154.56	114.72	145.93	158.41
STD	6.08	10.67	9.47	10.48	30.84	24.53
%STD	4.95	7.87	6.13	9.14	21.14	15.49

At 10 week	Compressive strength (MPa)					
Sample	$C(E85)_A$			$C(E100)_A$		
	0%	15%	25%	0%	15%	25%
1	202.29	250.40	226.08	178.70	238.58	193.77
2	185.68	234.29	229.25	209.71	221.13	242.09
3	186.10	238.16	232.34	213.42	226.87	240.35
4	202.94	231.50	239.52	198.86	220.32	191.80
5	206.27	232.65	222.75	188.15	225.01	295.35
AVG	196.66	237.40	229.99	197.77	226.38	232.67
STD	9.94	7.69	6.41	14.53	7.34	42.60
%STD	5.06	3.24	2.79	7.35	3.24	18.31

Appendix 19 Compressive strength of PVC/GF composites at 16 week in test fuel

At 16 week	Compressive strength (MPa)					
Sample	$C(E0)_A$			$C(E20)_A$		
	0%	15%	25%	0%	15%	25%
1	106.02	116.49	130.68	95.16	105.09	109.10
2	119.58	109.98	135.73	100.96	104.23	111.23
3	107.28	136.62	131.33	101.12	115.15	95.96
4	104.65	132.22	129.12	85.12	100.62	189.30
5	113.89	129.07	140.23	88.90	111.45	72.92
AVG	110.28	124.88	133.42	94.25	107.31	115.70
STD	6.29	11.20	4.53	7.16	5.87	43.87
%STD	5.71	8.97	3.40	7.60	5.47	37.92

At 16 week	Compressive strength (MPa)					
Sample	$C(E85)_A$			$C(E100)_A$		
	0%	15%	25%	0%	15%	25%
1	181.15	216.34	209.45	197.44	240.06	210.41
2	195.32	232.22	211.98	200.18	221.65	197.68
3	211.19	193.26	204.42	199.93	207.31	224.03
4	210.25	204.97	243.16	182.37	197.63	222.19
5	184.39	221.22	220.71	189.73	241.05	204.39
AVG	196.46	213.60	217.94	193.93	221.54	211.74
STD	14.04	15.00	15.28	7.73	19.35	11.33
%STD	7.15	7.02	7.01	3.98	8.74	5.35

Appendix 20 Impact strength of PVC/GF composites at 0 week

At 0 week	Impact strength (kJ/m2)		
Sample	0%	15%	25%
1	16.63	18.36	26.94
2	16.36	19.30	25.31
3	16.65	18.30	26.33
4	16.43	18.35	27.63
5	17.75	20.33	28.88
6	18.11	18.34	24.89
7	16.48	18.78	25.57
8	17.83	19.34	25.12
9	17.00	19.12	25.67
10	17.17	20.64	26.32
AVG	17.04	19.08	26.27
STD	0.65	0.85	1.25
%STD	3.80	4.43	4.77

Appendix 21 Impact strength of PVC/GF composites at 4 week in test fuel

At 4 week	Impact strength (kJ/m2)					
Sample	$C(E0)_A$			$C(E20)_A$		
	0%	15%	25%	0%	15%	25%
1	101.69	72.70	45.81	228.02	106.99	55.63
2	100.99	74.91	52.29	223.70	113.09	52.85
3	97.79	73.40	45.37	208.60	115.93	52.77
4	98.28	80.54	50.83	213.09	105.02	56.18
5	91.47	74.49	51.46	202.05	107.29	55.78
6	102.28	80.63	46.39	197.33	103.82	55.94
7	102.81	75.87	46.61	207.05	101.49	57.29
8	97.45	79.42	51.48	218.40	104.22	56.59
9	96.54	72.98	46.64	216.10	110.04	55.70
10	97.01	76.64	51.51	213.37	104.26	55.46
AVG	98.81	76.16	48.84	212.77	107.21	55.42
SD	3.44	3.06	2.87	9.42	4.54	1.48
%SD	3.48	4.02	5.87	4.43	4.23	2.67

At 4 week	Impact strength (kJ/m2)					
Sample	$C(E85)_A$			$C(E100)_A$		
	0%	15%	25%	0%	15%	25%
1	15.95	19.32	18.63	16.67	17.99	18.63
2	17.41	19.69	18.58	15.70	17.33	17.48
3	16.90	17.01	18.63	16.74	16.94	18.67
4	17.86	17.36	20.00	15.62	16.73	17.88
5	15.72	17.47	18.53	16.16	17.28	17.73
6	15.95	18.30	18.07	17.07	16.99	17.93
7	17.80	18.20	19.86	16.90	18.04	17.19
8	17.04	17.93	18.96	17.75	18.50	17.60
9	16.04	18.84	19.02	16.09	17.70	18.21
10	15.22	19.34	18.93	15.22	16.96	18.07
AVG	16.55	18.34	18.92	16.39	17.45	17.94
SD	0.93	0.92	0.60	0.77	0.59	0.48
%SD	5.62	5.04	3.17	4.70	3.35	2.66

Appendix 22 Impact strength of PVC/GF composites at 10 week in test fuel

At 10 week	Impact strength (kJ/m2)					
Sample	$C(E0)_A$			$C(E20)_A$		
	0%	15%	25%	0%	15%	25%
1	231.56	126.37	66.48	239.39	157.15	114.69
2	213.67	120.32	72.08	248.95	139.11	108.67
3	234.79	131.62	70.31	238.62	139.38	99.62
4	234.40	122.71	62.92	244.38	155.36	109.92
5	237.10	108.08	63.72	240.40	159.67	116.01
6	231.94	122.08	64.34	240.16	143.83	105.41
7	224.28	126.73	61.81	236.88	139.28	114.17
8	211.39	120.03	65.74	232.62	140.12	104.27
9	224.86	124.61	69.47	246.19	148.89	120.18
10	247.02	118.16	69.81	239.01	153.16	112.71
AVG	229.10	122.07	66.67	240.66	147.59	110.57
SD	10.81	6.29	3.54	4.73	8.22	6.21
%SD	4.72	5.16	5.31	1.96	5.57	5.61

At 10 week	Impact strength (kJ/m2)					
Sample	$C(E85)_A$			$C(E100)_A$		
	0%	15%	25%	0%	15%	25%
1	13.80	13.19	15.38	11.89	13.53	14.83
2	13.46	13.39	15.18	13.63	12.36	15.76
3	14.72	13.98	14.73	12.38	13.78	15.17
4	13.82	14.17	15.41	12.44	13.45	14.89
5	13.82	13.56	14.84	12.38	13.69	15.17
6	13.81	13.19	14.65	12.31	13.48	15.91
7	13.07	14.01	15.40	12.06	14.16	14.80
8	13.79	15.03	15.49	13.11	13.59	13.07
9	13.05	15.26	15.40	12.58	14.68	14.74
10	13.65	14.40	14.54	12.36	13.12	14.09
AVG	13.70	14.02	15.10	12.51	13.58	14.84
SD	0.47	0.72	0.37	0.51	0.61	0.81
%SD	3.41	5.17	2.46	4.04	4.48	5.48

Appendix 23 Impact strength of PVC/GF composites at 16 week in test fuel

At 16 week	Impact strength (kJ/m2)					
Sample	$\mathrm{C(E0)}_A$			$\mathrm{C(E20)}_A$		
	0%	15%	25%	0%	15%	25%
1	235.10	124.85	85.08	241.82	143.20	116.16
2	230.77	142.39	81.67	226.93	153.84	118.66
3	249.71	144.85	84.45	229.87	151.50	120.29
4	232.94	140.73	80.58	254.80	162.91	120.89
5	241.25	116.96	81.14	241.78	161.43	120.05
6	214.36	117.89	90.05	257.54	140.99	106.50
7	238.71	128.61	78.81	238.57	138.95	115.33
8	222.13	119.30	81.86	237.45	151.67	116.80
9	224.65	121.73	85.35	255.68	147.54	119.09
10	239.18	129.21	81.61	243.66	155.79	113.85
AVG	232.88	128.65	83.06	242.81	150.78	116.76
SD	10.34	10.54	3.22	10.52	8.17	4.29
%SD	4.44	8.19	3.88	4.33	5.42	3.67

At 16 week	Impact strength (kJ/m2)					
Sample	$C(E85)_A$			$C(E100)_A$		
	0%	15%	25%	0%	15%	25%
1	13.58	14.48	15.87	11.52	14.53	13.29
2	14.59	14.21	14.89	12.31	13.95	12.79
3	13.85	14.52	14.39	12.40	13.52	14.68
4	13.78	14.61	14.31	13.33	13.84	13.95
5	15.11	14.17	16.08	12.74	12.18	14.83
6	13.26	12.31	14.61	12.59	12.46	15.52
7	13.41	14.43	15.51	11.61	13.68	13.05
8	13.22	13.82	14.03	12.91	13.62	16.39
9	13.41	14.38	13.56	12.90	12.35	16.43
10	14.88	14.02	15.31	12.36	12.47	17.27
AVG	13.91	14.09	14.86	12.47	13.26	14.82
SD	0.70	0.67	0.82	0.57	0.82	1.56
%SD	5.03	4.77	5.55	4.54	6.19	10.53

Appendix 24 Average water absorption of PVC/GF composites

Time (day)	Water absorption					
	0%		15%		25%	
	AVG (g)	% Change	AVG (g)	% Change	AVG (g)	% Change
1	8.65±0.46	0.05	9.30±0.20	0.03	9.52±0.19	0.03
2	8.66±0.46	0.06	9.30±0.20	0.05	9.52±0.19	0.04
3	8.66±0.46	0.07	9.30±0.20	0.05	9.52±0.19	0.05
4	8.66±0.46	0.09	9.30±0.20	0.06	9.52±0.19	0.05
5	8.66±0.46	0.09	9.30±0.20	0.07	9.52±0.19	0.06
6	8.66±0.46	0.10	9.30±0.20	0.07	9.52±0.19	0.06
7	8.66±0.46	0.11	9.30±0.20	0.08	9.53±0.19	0.07
8	8.66±0.46	0.12	9.30±0.20	0.08	9.53±0.19	0.07
9	8.66±0.46	0.12	9.30±0.20	0.09	9.53±0.19	0.08
10	8.66±0.46	0.13	9.30±0.20	0.09	9.53±0.19	0.08
11	8.66±0.46	0.13	9.30±0.20	0.10	9.53±0.19	0.08
12	8.67±0.46	0.14	9.30±0.20	0.10	9.53±0.19	0.09
14	8.67±0.46	0.14	9.31±0.20	0.10	9.53±0.19	0.09
16	8.67±0.46	0.15	9.31±0.20	0.11	9.53±0.19	0.09

Time (day)	Water absorption					
	0%		15%		25%	
	AVG (g)	% Change	AVG (g)	% Change	AVG (g)	% Change
18	8.67±0.46	0.16	9.31±0.20	0.11	9.53±0.19	0.10
20	8.67±0.46	0.17	9.31±0.20	0.12	9.53±0.19	0.11
22	8.67±0.46	0.17	9.31±0.20	0.12	9.53±0.19	0.11
24	8.67±0.46	0.17	9.31±0.20	0.12	9.53±0.19	0.11
26	8.67±0.46	0.18	9.31±0.20	0.13	9.53±0.19	0.11
28	8.67±0.46	0.18	9.31±0.20	0.13	9.53±0.19	0.11
30	8.67±0.46	0.19	9.31±0.20	0.13	9.53±0.19	0.12
32	8.67±0.46	0.19	9.31±0.20	0.13	9.53±0.19	0.12
34	8.67±0.46	0.19	9.31±0.20	0.13	9.53±0.19	0.12
41	8.67±0.46	0.19	9.31±0.20	0.13	9.53±0.19	0.12
48	8.67±0.46	0.19	9.31±0.20	0.13	9.53±0.19	0.12
55	8.67±0.46	0.19	9.31±0.20	0.13	9.53±0.19	0.12

Appendix 25 Average and percent change tensile strength of PVC/GF composites

0%wt	Tensile strength (MPa)							
Time (week)	C(E0)A		C(E20)A		C(E85)A		C(E100)A	
	AVG	% Change	AVG	% Change	AVG	% Change	AVG	% Change
0	60.22±0.77	0.00	60.22±0.77	0.00	60.22±0.77	0.00	60.22±0.77	0.00
4	29.41±1.56	-51.17	23.90±0.46	-60.31	53.89±0.73	-10.51	56.08±0.59	-6.87
10	17.87±0.20	-70.32	13.81±0.21	-77.06	55.20±0.54	-8.34	56.82±1.44	-5.65
16	12.10±0.40	-79.91	11.32±0.26	-81.20	55.97±0.74	-7.06	54.61±0.71	-9.32

15%wt	Tensile strength (MPa)							
Time (week)	C(E0)A		C(E20)A		C(E85)A		C(E100)A	
	AVG	% Change	AVG	% Change	AVG	% Change	AVG	% Change
0	83.34±1.51	0.00	83.34±1.51	0.00	83.34±1.51	0.00	83.34±1.51	0.00
4	29.85±1.60	-64.19	31.62±2.37	-62.06	81.92±2.38	-1.71	83.94±3.11	0.72
10	23.25±1.95	-72.10	9.34±1.02	-88.80	76.67±2.74	-8.00	83.23±9.31	-0.13
16	15.89±0.96	-80.94	7.88±0.69	-90.54	77.34±3.72	-7.21	77.06±6.84	-7.54

25%wt	Tensile strength (MPa)							
Time (week)	C(E0)A		C(E20)A		C(E85)A		C(E100)A	
	AVG	% Change	AVG	% Change	AVG	% Change	AVG	% Change
0	107.69±2.53	0.00	107.69±2.53	0.00	107.69±2.53	0.00	107.69±2.53	0.00
4	17.61±1.59	-83.64	13.21±1.23	-87.73	105.54±8.90	-2.00	103.77±5.91	-3.64
10	10.14±1.12	-90.58	8.40±0.59	-92.20	105.23±2.15	-2.28	97.54±7.22	-9.43
16	15.90±1.00	-85.24	8.72±0.59	-91.90	94.60±7.23	-12.16	92.82±10.11	-13.81

Appendix 26 Average and percent change young's modulus of PVC/GF composites

0%wt	Young's modulus (GPa)							
Time (week)	C(E0)A		C(E20)A		C(E85)A		C(E100)A	
	AVG	% Change	AVG	% Change	AVG	% Change	AVG	% Change
0	2.57±0.03	0.00	2.57±0.03	0.00	2.57±0.03	0.00	2.57±0.03	0.00
4	1.06±0.07	-58.53	0.91±0.02	-64.48	2.18±0.06	-14.98	2.22±0.04	-13.31
10	1.13±0.01	-55.88	0.87±0.01	-65.90	2.28±0.07	-11.17	2.31±0.03	-9.94
16	0.51±0.02	-80.31	0.47±0.01	-81.58	2.34±0.03	-8.87	2.31±0.05	-10.10

15%wt	Young's modulus (GPa)							
Time (week)	C(E0)A		C(E20)A		C(E85)A		C(E100)A	
	AVG	% Change	AVG	% Change	AVG	% Change	AVG	% Change
0	4.62±0.08	0.00	4.62±0.08	0.00	4.62±0.08	0.00	4.62±0.08	0.00
4	1.37±0.07	-70.31	1.55±0.19	-66.52	4.54±0.10	-1.71	4.58±0.06	-0.82
10	1.47±0.12	-68.12	0.59±0.06	-87.20	4.28±0.09	-7.24	4.43±0.31	-4.10
16	0.66±0.04	-85.64	0.33±0.03	-92.87	4.22±0.10	-8.71	4.32±0.25	-6.54

25%wt	Young's modulus (GPa)							
Time (week)	C(E0)A		C(E20)A		C(E85)A		C(E100)A	
	AVG	% Change	AVG	% Change	AVG	% Change	AVG	% Change
0	5.90±0.14	0.00	5.90±0.12	0.00	5.90±0.12	0.00	5.90±0.12	0.00
4	0.93±0.08	-84.27	0.70±0.06	-88.20	5.79±0.07	-2.00	5.70±0.41	-3.46
10	0.64±0.07	-89.12	0.53±0.04	-90.99	5.72±0.29	-3.17	5.85±0.34	-0.97
16	0.66±0.04	-88.76	0.36±0.02	-93.83	5.61±0.34	-4.98	5.62±0.49	-4.78

Appendix 27 Average and percent change flexural strength of PVC/GF composites

0%wt	Flexural strength (MPa)							
Time (week)	C(E0)A		C(E20)A		C(E85)A		C(E100)A	
	AVG	% Change	AVG	% Change	AVG	% Change	AVG	% Change
0	85.99±10.48	0.00	85.99±10.48	0.00	85.99±10.48	0.00	85.99±10.48	0.00
4	19.22±0.85	-77.65	17.13±0.79	-80.08	84.89±2.80	-1.28	84.10±2.80	-2.20
10	5.85±0.19	-93.20	4.75±0.36	-94.48	83.79±3.15	-2.56	83.56±3.69	-2.83
16	1.97±0.10	-97.71	1.93±0.15	-97.75	82.28±1.82	-4.31	83.09±3.22	-3.37

15%wt	Flexural strength (MPa)							
Time (week)	C(E0)A		C(E20)A		C(E85)A		C(E100)A	
	AVG	% Change	AVG	% Change	AVG	% Change	AVG	% Change
0	91.89±14.67	0.00	91.89±14.67	0.00	91.89±14.67	0.00	91.89±14.67	0.00
4	17.60±0.54	-80.85	14.20±0.43	-84.55	90.82±3.32	-1.17	89.09±3.65	-3.05
10	6.20±0.35	-93.25	6.94±0.35	-92.45	90.62±2.87	-1.38	86.91±2.12	-5.42
16	8.94±1.08	-90.27	5.00±0.38	-94.56	90.48±3.89	-1.54	84.56±4.79	-7.98

25%wt	Flexural strength (MPa)							
Time (week)	C(E0)A		C(E20)A		C(E85)A		C(E100)A	
	AVG	% Change	AVG	% Change	AVG	% Change	AVG	% Change
0	124.26±5.93	0.00	124.26±5.93	0.00	124.26±5.93	0.00	124.26±5.93	0.00
4	17.52±0.62	-85.90	13.38±0.26	-89.24	123.84±3.12	-0.34	112.36±4.28	-9.58
10	17.38±1.08	-86.02	13.28±0.89	-89.31	123.74±6.54	-0.42	110.77±4.99	-10.86
16	17.30±0.35	-86.07	13.12±0.56	-89.44	123.57±3.50	-0.56	110.12±6.84	-11.38

Appendix 28 Average and percent change compressive strength of PVC/GF composites

0%wt	Compressive strength (Mpa)							
Time (week)	C(E0)A		C(E20)A		C(E85)A		C(E100)A	
	AVG	% Change	AVG	% Change	AVG	% Change	AVG	% Change
0	201.50±17.90	0.00	201.50±17.90	0.00	201.50±17.90	0.00	201.50±17.90	0.00
4	197.93±9.22	-1.77	185.25±19.41	-8.06	198.57±10.86	-1.45	198.79±4.68	-1.35
10	122.87±6.08	-39.02	114.72±10.48	-43.07	196.66±9.94	-2.41	197.77±14.53	-1.85
16	110.28±6.29	-45.27	94.25±7.16	-53.23	196.46±14.04	-2.50	193.93±7.73	-3.76

15%wt	Compressive strength (MPa)							
Time (week)	C(E0)A		C(E20)A		C(E85)A		C(E100)A	
	AVG	% Change	AVG	% Change	AVG	% Change	AVG	% Change
0	253.85±11.77	0.00	253.85±11.77	0.00	253.85±11.77	0.00	253.85±11.77	0.00
4	199.71±11.18	-21.33	188.08±5.51	-25.91	242.37±12.88	-4.52	230.08±17.73	-9.36
10	135.59±10.67	-46.59	145.93±30.84	-42.51	237.40±7.69	-6.48	226.38±7.34	-10.82
16	124.88±11.20	-50.81	107.31±5.87	-57.73	213.60±15.00	-15.85	221.54±19.35	-12.73

25%wt	Compressive strength (MPa)							
Time (week)	C(E0)A		C(E20)A		C(E85)A		C(E100)A	
	AVG	% Change	AVG	% Change	AVG	% Change	AVG	% Change
0	261.96±20.14	0.00	261.96±20.14	0.00	261.96±20.14	0.00	261.96±20.14	0.00
4	160.41±6.04	-38.77	163.28±5.61	-37.67	238.60±20.94	-8.92	231.43±5.55	-11.66
10	154.56±9.47	-41.00	158.41±24.53	-39.53	229.99±6.41	-12.20	232.67±42.60	-11.18
16	133.42±4.53	-49.07	115.70±43.87	-55.83	217.94±15.28	-16.80	211.74±11.33	-19.17

Appendix 29 Average and percent change impact strength of PVC/GF composites

0%wt	Impact strength (kJ/m2)							
Time (week)	C(E0)A		C(E20)A		C(E85)A		C(E100)A	
	AVG	% Change	AVG	% Change	AVG	% Change	AVG	% Change
0	17.04±0.65	0.00	17.04±0.65	0.00	17.04±0.65	0.00	17.04±0.65	0.00
4	98.81±3.44	479.81	212.77±9.42	1148.51	16.55±0.93	-2.90	16.39±0.77	-3.81
10	229.10±10.81	1244.35	240.66±4.73	1312.17	13.70±0.47	-19.62	12.51±0.51	-26.57
16	232.88±10.34	1266.51	242.81±10.52	1324.78	13.91±0.70	-18.38	12.47±0.57	-26.84

15%wt	Impact strength (kJ/m2)							
Time (week)	C(E0)A		C(E20)A		C(E85)A		C(E100)A	
	AVG	% Change	AVG	% Change	AVG	% Change	AVG	% Change
0	19.08±0.85	0.00	19.08±0.85	0.00	19.08±0.85	0.00	19.08±0.85	0.00
4	76.16±3.06	299.04	107.21±4.54	461.78	18.34±0.92	-3.88	17.45±0.59	-8.58
10	122.07±6.29	539.61	147.59±8.22	673.36	14.02±0.72	-26.55	13.58±0.61	-28.82
16	128.65±10.54	574.11	150.78±8.17	690.06	14.09±0.67	-26.15	13.26±0.82	-30.52

25%wt	Impact strength (kJ/m2)							
Time (week)	C(E0)A		C(E20)A		C(E85)A		C(E100)A	
	AVG	% Change	AVG	% Change	AVG	% Change	AVG	% Change
0	26.27±1.25	0.00	26.27±1.25	0.00	26.27±1.25	0.00	26.27±1.25	0.00
4	48.84±2.87	85.94	55.42±1.48	110.99	18.92±0.60	-27.96	17.94±0.48	-31.71
10	66.67±3.54	153.82	110.57±6.21	320.95	15.10±0.37	-42.50	14.84±0.81	-43.49
16	83.06±3.22	216.23	116.76±4.29	344.54	14.86±0.82	-43.43	14.82±1.56	-43.57

VITAE

Miss Kangsadan Ekcharoen was born in Saraburi, Thailand on December 22, 1984. She graduated at high school level at Saraburiwitthayakhom School, Thailand in 2003. In 2007, she received a Bachelor’s Degree of Engineering with a major in Chemical Engineering from the Faculty of Engineering, Burapha University, Thailand. After graduation, she continues her studies on a Master’s Degree of Chemical Engineering at the Department of Chemical Engineering, Faculty of Engineering, Chulalongkorn University Bangkok, Thailand.