การศึกษาสมบัติของพอลิเมอร์ผสมระหว่างยางอะคริโลไนไตร์ลบิวทาไดอีน กับพลาสติกอะคริโลไนไตร์ลบิวทาไดอีนสไตรีน หรือพลาสติกโพลีสไตรีนโคอะคริโลไนไตร์ล

นางสาวญาสินี วุฒิสันต์

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิศวกรรมศาสตรมหาบัณฑิต
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STUDY PROPERTIES OF BLENDS BETWEEN ACRYLONITRILE-BUTADIENE RUBBER AND ACRYLONITRILE-BUTADIENE-STYRENE OR POLY(STYRENE-CO-ACRYLONITRILE)

Ms. Yasinee Wuttison

A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Engineering Program in Chemical Engineering
Department of Chemical Engineering
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Chulalongkorn University
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Thesis Title	STUDY PROPERTIES OF BLENDS BETWEEN ACRYLONITRILE-BUTADIENE RUBBER AND ACRYLONITRILE-BUTADIENE-STYRENE OR POLY(STYRENE-CO-ACRYLONITRILE)
By	Ms. Yasinee Wuttison
Field of study	Chemical Engineering
Thesis Advisor	Associate Professor ML. Supakanok Thongyai, Ph.D.

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

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ญาสินี วุฒิสันต์: การศึกษาสมบัติของพอลิเมอร์ผสมระหว่างยางอะคริโลไนไตร์ลบิวทาไดอีน กับพลาสติกอะคริโลไนไตร์ลบิวทาไดอีนสไตรีน หรือพลาสติกโพลีสไตรีนโคอะคริโลไนไตร์ล(STUDY PROPERTIES OF BLENDS BETWEEN ACRYLONITRILE-BUTADIENE RUBBER AND ACRYLONITRILE-BUTADIENE-STYRENE OR POLY(STYRENE-CO-ACRYLONITRILE)) อ. ที่ปรึกษาวิทยานิพนธ์หลัก: รศ. ดร. มล. ศุภกนก ทองใหญ่, 136 หน้า

งานวิจัยนี้มีจุดมุ่งหมายเพื่อศึกษาอิทธิพลของแอลกอฮอล์ และน้ำมันเชื้อเพลิงเบนซิน 95 ต่อสมบัติเชิงกลและสมบัติทางกายภาพ ของพอลิเมอร์ผสมระหว่างยางอะคริโลไนไตร์ลบิวทาไดอีน กับพลาสติกอะคริโลไนไตร์ลบิวทาไดอีนสไตรีน หรือพลาสติกโพลีสไตรีนโคอะคริโลไนไตร์ล และยางไฮโดรจีเนทอะคริโลไนไตร์ลบิวทาไดอีน ชิ้นงานทดสอบเตรียมโดยเครื่องผสมภายในแบบปิด เครื่องผสมยาง เครื่องบดแบบสองลูกกลิ้ง และเครื่องอัดขึ้นรูป โดยชิ้นงานถูกนำมาแช่ในสารทดสอบ 4 ชนิด ได้แก่ น้ำมันเชื้อเพลิงเบนซิน 95 น้ำมันเชื้อเพลิง E20 ที่เติมกรด น้ำมันเชื้อเพลิง E85 และเอทานอล ที่อุณหภูมิห้องเป็นเวลา 56 วัน วัดสมบัติเชิงกลของตัวอย่างด้วยเครื่องทดสอบเชิงกล ตรวจสอบลักษณะโครงสร้างทางสัณฐานวิทยาของพอลิเมอร์ผสมด้วยกล้องจุลทรรศน์อิเล็กตรอน และใช้ข้อมูลจากอินฟราเรดสเปกตรัมวิเคราะห์ความสามารถในการละลายของชิ้นงาน

ผลการทดลองพบว่าพลาสติกโพลีสไตรีนโคอะคริโลไนไตร์ล และพลาสติกอะคริโลไนไตร์ลบิวทาไดอีนสไตรีนสามารถผสมเข้ากันได้กับยางอะคริโลไนไตร์ลบิวทาไดอีนได้เล็กน้อย และสารเคมีที่ใช้แช่ทุกชนิดส่งผลต่อสมบัติการทนแรงดึง ความแข็ง ความสามารถในการคืนรูปของชิ้นงาน ความเสถียรของขนาด และการเปลี่ยนแปลงทางปริมาตรของชิ้นงาน โดยน้ำมันเชื้อเพลิง E20 ที่เติมกรดส่งผลให้ชิ้นงานบวมมากที่สุด ในขณะที่การเปลี่ยนแปลงปริมาตรของชิ้นงานทั้งยางและพอลิเมอร์ผสมไม่แตกต่างกันมากนักที่ช่วงเวลาสิ้นสุดการทดลอง ยกเว้นยางไฮโดรจีเนทอะคริโลไนไตร์ลบิวทาไดอีนซึ่งสามารถทนต่อแอลกอฮอร์ได้ดี แต่ไม่ทนต่อน้ำมันเชื้อเพลิง แนวโน้มการละลายในสารเคมีเรียงลำดับจากมากไปน้อยได้ดังนี้ ยางอะคริโลไนไตร์ลบิวทาไดอีนที่สุกแล้ว ยางอะคริโลไนไตร์ลบิวทาไดอีน และพลาสติกอะคริโลไนไตร์ลบิวทาไดอีนสไตรีน โดยไม่คำนึงถึงยางไฮโดรจีเนทอะคริโลไนไตร์ลบิวทาไดอีน

ภาควิชา วิศวกรรมเคมี ลายมือชื่อนิสิต

สาขาวิชา วิศวกรรมเคมี ลายมือชื่อ อ. ที่ปรึกษาวิทยานิพนธ์หลัก

ปีการศึกษา 2556

5470525421: MAJOR CHEMICAL ENGINEERING
KEY WORD: NBR, SAN, ABS, RUBBER BLENDS, BLEND COMPATIBILITY

YASINEE WUTTISON: STUDY PROPERTIES OF BLENDS BETWEEN ACRYLONITRILE-BUTADIENE RUBBER AND ACRYLONITRILE-BUTADIENE-STYRENE OR POLY(STYRENE-CO-ACRYLONITRILE). ADVISOR: ASSOC. PROF. ML. SUPAKANOK THONGYAI, Ph.D., 136 pp.

In this study, the influences of alcohol and gasoline on mechanical and physical properties of blends between acrylonitrile-butadiene rubber (NBR) with acrylonitrile-butadiene-styrene (ABS) orpoly(styrene-co-acrylonitrile) (SAN), and hydrogenated acrylonitrile-butadiene rubber (HNBR) were investigated. Test specimens were prepared by internal mixer, kneader, two-roll mill, and compression molding machines. Theses specimens were immersed in 4 chemical solutions (gasoline 95, acidic E20, E85, and ethanol) at room temperature for 56 days. Mechanical properties were determined using the tensile testing machine. The morphologies of polymer blends were investigated using scanning electron microscope (SEM). The susceptibility to dissolve of sample were confirmed by Infrared spectrum (IR).

It had been found that SAN and ABS were partially compatible with NBR. All chemical solutions affected tensile strength, hardness, compression set, dimension change, and volume change. Acidic E20 led to the most swollen samples. The volume change of NBR, NBR/SAN, and NBR/SAN were not quite difference at the ended of test, except HNBR with mostly resisted to alcohol rich but not to gasoline rich. The most susceptible for dissolve in solvents were cure-NBR, NBR and ABS, respectively if HNBR was not concerned in simulation.

Department Chemical Engineering Student's Signature
Field of study Chemical Engineering Advisor's Signature
Academic Year 2013

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CHAPTER I
INTRODUCTION

Gasohol is a mixture of gasoline and alcohol (mostly ethanol, acts as an antiknock agent). Nowadays the usage of gasohol in car fuel has been increasing because it is environment-friendly and emission contents of carbon dioxide (CO), hydrocarbon (HC) and nitrogen oxides (NO_x) lower than common gasoline. Moreover, it is typically cheaper than petroleum as it is cheaper to manufacture [1-3]. But there are effects of gasohol on rubber parts in automobiles. Alcohol may weaken and eventually destroy rubber parts such as gaskets, seals and fuel hoses. So, these parts are needed to be designed to resist alcohol corrosion.

In automotive industry, the rubber parts that contact with fuel are acrylonitrile-butadiene rubber (NBR), hydrogenated nitrile butadiene rubber (HNBR), chloroprene rubber (CR or neoprene rubber), and fluorocarbon rubber (FKM or viton) because of their good oil resistance. Acrylonitrile-butadiene rubber (NBR) or nitrile rubber is an unsaturated copolymers of butadiene and acrylonitrile. NBR has been widely used for fuel hoses, fuel pumps diaphragm, seals and gaskets because of their excellent oil and fuel resistance [4-6]. Because the usage of gasohol has been increasing, so proprietary products have to develop to have NBR with alcohol resistance property. To improve the properties of NBR, it can be blended with the other polymers [7]. In recent years considerable researches are interested in new polymeric materials that obtained by blending of two or more conventional polymers [8]. The general usages of polymer blends are for combining characteristic properties of several polymers in order to improve specific properties such as mechanical properties or chemical resistance, and also improved processability [9]. However, the mechanical properties and other properties of polymer blends were depended on theirs state of miscibility [10].

There have been many studies in polymer blend to improve NBR’s properties. In recent years, the acrylonitrile-butadiene rubber (NBR) and polyvinyl chloride (PVC) blends have been widely used in industries [11]. Many research results have shown that NBR and PVC is a miscible physical mixture. The presence of PVC improves the ozone resistance, chemical resistance, thermal ageing and abrasion resistance of NBR, which has given the possibility of using this blend in industries.

The major applications of NBR/PVC composites include conveyor belt covers, cable jackets, hose cover linings, gaskets, sealing joint strip, petroleum hoses, cable sheeting, shoe soles, auto parts, o-rings, and cellular products [12-16].

Poly(styrene-co-acrylonitrile) (SAN) is a thermoplastic with high transparency, excellent gross, high mechanical strength, dimensional stability, and good chemical resistance [17-18]. There were researches that studied about the miscibility and mechanical properties of SAN blends with NBR. The results of the research showed that NBR/SAN blends were compatible [19-23]. Addition the miscibility increased when using higher content of acrylonitrile [20, 21]. With increasing SAN content of the blend, the tensile strength, tension set, and hardness were increased, whereas the elongation at break was decreased [22].

Moreover, a few researches had found that NBR could be compatible with acrylonitrile-butadiene-styrene (ABS). ABS is prepared from acrylonitrile, butadiene, and styrene monomers and commonly used thermoplastic material. The advantage of ABS, material combines the strength and rigidity and also oil resistance due to the presence of polar of nitrile group [19, 23, 24]. ABS not only improves chemical resistance to NBR but also enhances tensile strength and modulus, heat deflection temperature, and thermal expansion coefficients [25].

In this study, the effects of SAN or ABS on mechanical, thermal, morphological properties, and swelling characteristic of thermoplastic vulcanizated from NBR/SAN blends or NBR/ABS blends were investigated compared with NBR, H-NBR that used in commercials. Two polymer blends were prepared by melted mixing technique. The morphologies of polymer blends were investigated by scanning electron microscope (SEM). The thermal properties were investigated by differential scanning calorimeter (DSC), thermogravimetric analysis (TGA), and dynamic mechanical analyzer (DMA). The mechanical properties of polymer blends were investigated by tensile testing. The swelling characteristic was studied by immersion of the samples in various solvents such as gasoline 95, acidic E20, E85, and ethanol.

1.1 THE OBJECTIVE OF THIS THESIS

This work investigated the effects of SAN, and ABS on mechanical, thermal and morphological properties of NBR, HNBR, NBR/SAN, and NBR/ABS blends.

1.2 THE SCOPE OF THIS THESIS

1.2.1 NBR was used as the polymer matrix.

1.2.2 ABS or SAN were utilized as NBR property modifier.

1.2.3 Polymer blends were melted mixing by internal mixer and molded by a compression molding method.

1.2.4 Mechanical properties of NBR/SAN and NBR/ABS were investigated by tensile testing then compared to NBR and H-NBR.

1.2.5 Thermal properties of polymer blends were investigated by DSC, TGA, and DMA.

1.2.6 Morphology of polymer blends was observed by SEM.

1.2.7 Swelling characteristic was studied by electronic densimeter to measure volume changes.

1.3 BENEFITS OF THE THESIS

1) New NBR-based polymer that possibly can be used in auto parts industry such as fuel hose, and gaskets.

2) Understanding the effect on properties of new systems of polymer blends by blending several plastics (SAN or ABS) with nitrile rubber.

3) Developing the chemical resistance, mechanical, and thermal properties of NBR possibly.

4) Possibly applying in auto parts industry to improve chemical and physical properties.

CHAPTER II

THEORY

2.1 ACRYLONITRILE BUTADIENE RUBBER (NBR)

Acrylonitrile butadiene rubber (NBR) is well known as nitrile rubber. NBR are high molecular weight amorphous random copolymers of 1, 3 butadiene and acrylonitrile. NBR has been widely used in many applications, especially fuel and oil handling hose, and sealing applications because of its fuel and oil resistance, which comes from polar functionality of acrylonitrile [26]. The structure of NBR is shown in Figure 2.1.

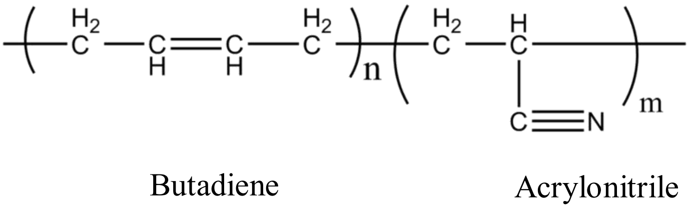

Figure 2.1 A structure of NBR

The removal of double bond in the backbone of NBR results in improved UV and ozone resistance and this rubber called hydrogenated nitrile butadiene rubber (HNBR).Mooney viscosity and acrylonitrile content are commonly cited criteria for defining the specific NBR grade.

2.1.1 Grade of NBR

2.1.1.1 Mooney viscosity

Mooney viscosity is a common test property that used in the rubber industry. Mooney viscosity of polymers is related to the way to process the rubber. For NBR, the lower mooney viscosity (30 to 50) is used for injection molding, while higher mooney viscosity (60 to 80) is used for extrusion and compression molding. However, it is believed that acrylonitrile content has more effects on the properties of NBR.

2.1.1.2 Acrylonitrile (ACN) content

Acrylonitrile content of NBR may vary from a minimum of 15 wt% to a maximum of 50 wt%. As the level of ACN increases, such properties as solvent, oil, and abrasion resistances, and hardness have increased. The lower content of ACN in the polymer provides the better of low temperature flexibility but poor of solvent and oil resistance. However, at higher level of ACN, NBR becomes more brittle (higher glass transition temperature).

NBR with a medium ACN content (33 wt%) have good oil and low temperature resistance down to the region of -40 ^{o}C. Low ACN content (18 wt%) of nitrile rubber would be useful down to -55 ^{o}C [4]. The relationship of NBR properties and ACN content had shown in Table 2.1.

Table 2.2 showed the properties of NBR by varying ACN content from 19 to 47 wt%. It is believed that at atmospheric condition when ACN content increases, hardness and tensile strength are increased. Moreover, at medium ACN content (32-34 wt%), the NBR gives the best compression set as a result. The NBR samples, that was heat to 120 ºC for 72 hours, indicating that tensile strength and hardness were increased, while elongation at break was decreased. Moreover, from the results showed that when using higher ACN content, NBR provides better chemical resistance. To use NBR parts to contact with alcohol as concentrations around 10% could cause a problem. NBR is a distinctly polar rubber, hence its excellent resistance to non-polar petroleum oils. This also means that NBR has poor resistance to polar liquids such as ketones, esters, chlorinated solvents, and highly aromatic solvents such as benzene and toluene.

Table 2.1 The relationship between NBR properties and acrylonitrile content. [27]

NBR with lower ACN content		NBR with Higher ACN content
	Processability	→
	Cure Rate w/Sulfur Cure System	→
	Oil/Fuel Resistance	→
	Compatibility w/Polar Polymers	→
	Air/Gas Impermeability	→
	Tensile Strength	→
	Abrasion Resistance	→
	Heat-Aging	→
←	Cure Rate w/Peroxide Cure System	
←	Compression Set	
←	Resilience	
←	Hysteresis	
←	Low Temperature Flexibility	

Table 2.2 Compared properties of NBR at many ACN contents [28]

Acrilonitrile (%)	**19-21**	**27-29**	**32-34**	**37-39**	**45-47**
Hardness ShA (pti)	70	72	73	75	78
Tensile strength (MPa)	15	17	17	16	17
Elongation (%)	350	380	360	380	380
Compression set 22 hours at 100ºC (%)	13	13	12	15	25
Heat resistance 72 hours at 120ºC					
Tensile strength (% changed)	-15	+7	+4	+5	+1
Elongation (% changed)	-35	-25	-27	-30	-35
Hardness ShA (% changed)	+5	+4	+6	+4	+3
ASTM N.3 70 hours at 120ºC					
Tensile strength (% changed)	-35	-30	-20	-11	-5
Elongation (% changed)	-35	-30	-21	-22	-24
Hardness ShA (% changed)	-18	-15	-11	-8	-8
Volume (% changed)	+55	+27	+16	+8	+6
ASTM Fuel B 48 hours at 40ºC					
Tensile strength (% changed)	-65	-60	-60	-40	-30
Elongation (% changed)	-60	-55	-50	-38	-25
Hardness ShA (% changed)	-18	-15	-13	-13	-11
Volume (% changed)	+70	+43	+28	+20	+16

2.1.2 Additional information of NBR

- Good oil and chemical resistance
- Good resistance to acids and bases except those having strong oxidizing effects
- Poor resistance of oxygenated solvents such as acetone and ketone
- Low ozone and heat resistance
- Low electrical-insulation
- Higher ACN contents increase solvent resistance but decrease low-temperature flexibility
- Reinforcing materials such as carbon black are required to obtain high strength
- Tear resistance and electrical insulation properties are inferior to natural rubber

2.1.3 Applications

NBR is excellent for sealing applications. The popularity of nitrile material results from its excellent petroleum products resistance and its ability to be compounded for service at temperatures up to 250 °F. NBR is mostly used for automotive applications. Other applications of NBR which can be custom compounded and molded include:

- Oil resistant applications
- Low temperature applications
- Automotive, marine and aircraft fuel systems
- Nitrile roll covers
- Hydraulic hoses
- Conveyer belting
- Nitrile tubing

2.1.4 Vulcanization

The process by which a network of crosslinks (shown in Figure 2.2) is introduced into an elastomer is called vulcanization. The first commercial method for vulcanization has been attributed to Charles Goodyear in 1893. Vulcanization transforms an elastomer from a weak, useless and without desired mechanical properties into a strong, elastic, and tough materials. The tensile strength, stiffness, and hysteresis of rubber before and after vulcanization can be shown in Figure 2.3.

Dynamic vulcanization (DV) is the method discovered by Gessler and Haslett. Dynamic vulcanization is the process of crosslinking of one polymer in a blend of polymers during its melt-mixing (molten state). The process is used in the preparation of thermoplastic elastomeric compositions from rubber–plastic blends. Rubber and plastic are firstly applied by melt mixed in an internal mixer. After sufficient melt mixing in the internal mixer, vulcanizing agents (sulphur) are added. Vulcanization then occurs while mixing continues.

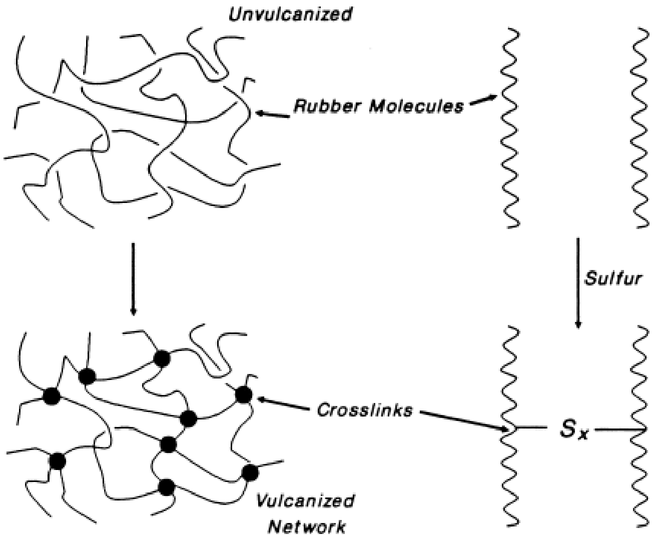

Figure 2.2 Network formation [29]

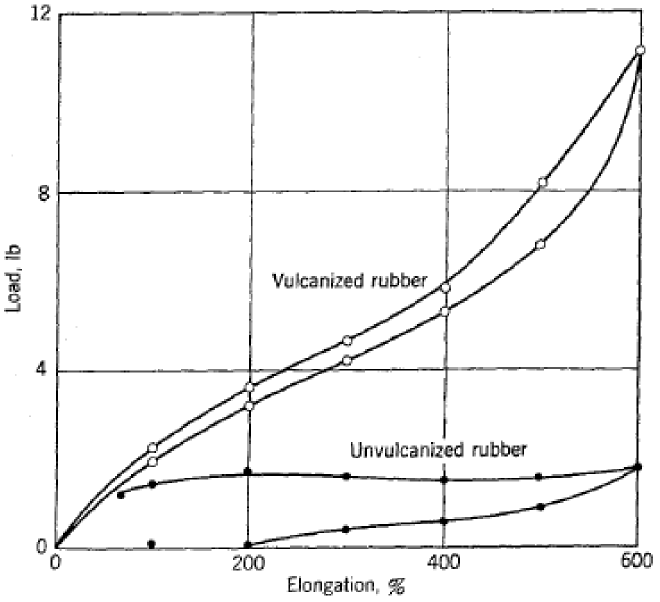

Figure 2.3 Stress-strain curves to 600% elongation and back, typical of unvulcanized and vulcanized natural rubber [29]

2.1.4.1 Sulphur vulcanization without accelerator [30, 31]

It has been found that sulphur is essential for the vulcanization process. Rubber can be vulcanized or cured without heat by the action of sulphur. But the curing of rubber with only sulphur is quite slow. Vulcanization was accomplished by using sulphur at a concentration of 8 phr takes 5 hours at 140°C. The usage of accelerators in concentrations as low as 0.5 phr can reduce the time to around 1 to 3 minutes. The chemistry of unaccelerated vulcanization is very slow reaction occured over a long period of vulcanization. Some investigators believed that the mechanisms involved free radicals.

2.1.4.2 Accelerated sulphur vulcanization

Accelerated-sulphur vulcanization is the most widely used method. It is the only rapid crosslinking technique that can, in a practical manner, give the delayed action required for processing, shaping, and forming before the formation of the intractable vulcanized network. Typical accelerators for sulfur vulcanization include:

1. Thiazoles, for example, 2-mercaptobenzothiazole (MBT), dibenzo-thiazole disulfide (MBTS)
2. Dithiocarbamate, for example, zinc dimethyl dithiocarbamate (ZDMC), piperidyl ammonium-piperidyl dithiocarbamate (PPC)

3. Thiuram, for example, tetramethyl thiuram disulfide (TMTD), tetramethyl thiuram monosulfide (TMTM)
4. Guanidine, for example, diphenyl guanidine (DPG), di-o-tolyguanidine (DOTG)

2.2 POLYMER BLENDS

A single polymer might not give the combination of properties required for a specific application. The blending of two or more conventional polymers would develop new polymeric materials and improves property. The following are a few examples of blends.

1. NBR blended with the PVC , is used for weather and ozone resistance.
2. For chloroprene (CR), if the full level of properties of CR is not required from blending, NBR might be blended with styrene butadiene rubber (SBR) to reduce cost.
3. Ethylene propylene diene monomer (M-class) rubber (EPDM) mixed in with natural rubber lends to some weather resistance.

However, because of unfavorable enthalpy of mixing between two polymers, most polymer blends are immiscible. The miscibility of polymer blends depends on the balance of small enthalpic and non-configurational entropic effects [9, 32].

2.2.1 Benefits of blending

- Providing materials with full set of desired properties at the lowest price.
- Improving a specific property such as impact strength, rigidity, ductility, chemical-cum-solvent resistance, barrier properties, abrasion resistance, flammability, gloss, and etc.
- Improved processability, product uniformity, and scrap reduction.
- Quick formulation changes.

2.2.2 Blending technique

The polymer blending involves:

- Preparation of ingredients (drying, sizing, heating, etc.)
- Premixing (dry blending, breakage of agglomerates, etc.)
- Melt-mixing (usually with degassing)
- Forming, e.g., granulation, pelletization, or dicing.

The most frequently applied operations are mixing, milling, extrusion, molding, and curing.

The level of homogeneity obtained depends on the nature of the components to be blended and the blending technique employed.

1. Blending

1.1 Mechanical blending

This technique produces a coarse dispersion in blends. The properties of the blends are strongly influenced by the speed and temperature of mixing. Homogeneous mixing of blends is only achieved after the appropriate melt processing stage.

1.2 Solution blending

For this method, the preparation of blends requires that the polymer components can be dissolved in a common solvent.

2. Polymerization

Emulsion polymerization is employed for the preparation of rubber-toughen plastic blends. The polymers are required to be in the emulsion or latex form The mixing process of these micro-size latexes and the subsequent removal of water produce excellent dispersion and distribution of discrete phase.

3. Reactive blending

This method facilitates the development of novel blends from highly incompatible pairs. A more homogeneous blending can be obtained with this method but with the penalty of involving a more stringent production control.

2.2.3 Mixing equipment (Internal mixer) [33]

The internal mixer is consists of a cylindrical chamber holding two rotors as shown schematically in Figure 2.4. The rotors are driven by a motor. At the first step, the rubber and solid components are fed into the mixing chamber. A hydraulically-operated ram closes the top of the chamber, subjecting the rubber mix to a controlled pressure. In the operating cycle, the components are added to the chamber with or without rotor movement. The cycle begins when the ram squeezes the rubber into the region between the rotors. After the mixing time, a drop door at the bottom of the chamber opens and the batch falls out of the mixer and is transported to the next processing operation.

For mixing rotors, there are basic types to choose to obtain a good mixing. The types of mixing rotors are as follows:

1. Roller type : used to blend plastic
2. Cam type : used to blend rubber and plastic
3. Banbury type : used to blend rubber

To improve the chemical resistance of NBR can be enhanced by blending with other polymers. For this study SAN, and ABS were chosen.

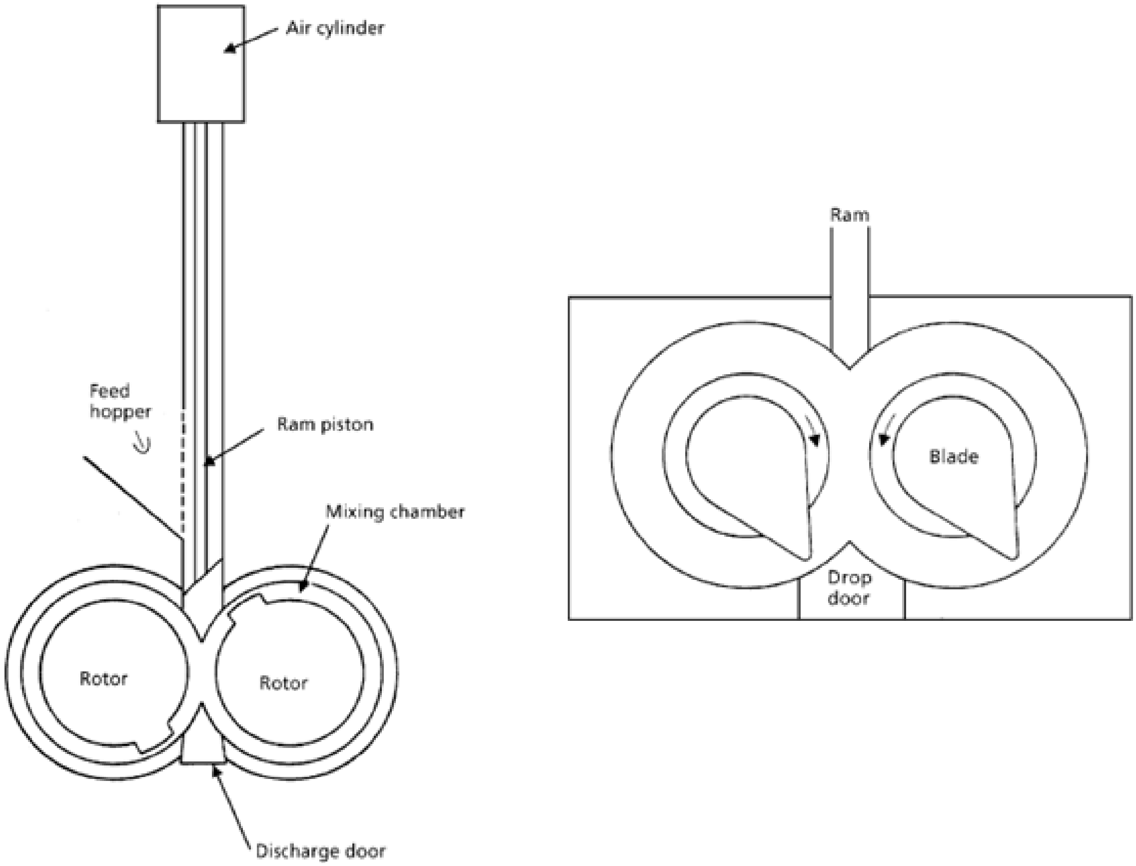

Figure 2.4 (Left) Schematic view of an internal mixer (Right) Mixing chamber cross-section

2.3 POLYVINYL CHLORIDE (PVC)

Polyvinylchloride (PVC) is the third-most widely produced plastic, after polyethylene and polypropylene. PVC can be flexible or rigid material that process chemically nonreactive properties. It was firstly synthesized by Regnault in 1835. PVC is often compounded with additives to improve its properties. PVC prepared by the polymerization of vinyl chloride in a free radical addition polymerization reaction. Polyvinylchloride has a linear structure similar to polyethylene but with a chlorine atom replacing a hydrogen atom on alternate carbon atoms as shown in Figure 2.5 [34].

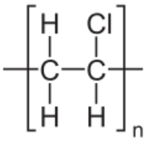

Figure 2.5 A structure of PVC

2.3.1 Advantages and Disadvantages

Advantages of PVC

- Excellent resistance to acids and alkalis
- Excellent all inorganic chemicals resistance
- Good resistance oxidizing agents
- Limited resistance (suitable for short term use only) to aldehydes
- Poor resistance (swells) to esters, aromatic hydrocarbons, and ketones
- Good electrical and insulation properties over a wide temperature range
- Excellent durability and long-life expectancy
- Easy processing characteristics to achieve desired specification
- Non-flammable
- Dimensional stability
- Low cost

Disadvantages of PVC

- Sensitive to UV and oxidative degradation
- Over heating may cause harmful vapors
- Stained by sulfur compounds

2.3.2 Applications

PVC has a broad range of applications. There are essentially two types of PVC:

1. Rigid PVC, without plasticizers, exhibits high surface strength and very good rigidity. It is used mainly for extrusion of profiles for windows, piping and other applications in widely differing sectors.
2. Plasticized PVC, added with plasticizers to obtain usage in manufacture of films, gaskets, expanded products, sheets, jacketing for electrical cables, and etc.

Moreover, PVC is used:

- In building and construction: for examples, PVC windows and doors, doors and frames, also shutters, panels, piping for drinking water distribution and exhaust, flooring, sheeting for waterproofing of roofing and swimming pools, wall cladding, electrical ductwork, plumbing, and etc.

- In packaging: for foodstuffs and pharmaceuticals.

- In cars: for examples, panels for car doors, dashboards, trimming profiles, electrical cabinets, window gasket, matting, various accessories, and etc.

- In electricity and electronics: for examples, electrical household appliances, telephones, control panels, simple electric wire insulation, coatings, substations distribution boxes, electrical ducting, pipes, sockets, etc.

- In many applications in which it replaces rubber.

2.4 POLY(STYRENE-CO-ACRYLONITRILE) (SAN)

Poly(styrene-co-acrylonitrile) (SAN) polymers are copolymers prepared from styrene and acrylonitrile monomers. SAN has been available since the 1940s. The SAN copolymer generally contains 70–80 wt% styrene and 20–30 wt% acrylonitrile (ACN). The ACN content of SAN influences the final properties such as tensile strength, elongation, and heat distortion temperature. As increasing the amount of acrylonitrile, the greater heat and chemical resistance, impact strength, toughness, scratch resistance and barrier properties. SAN is transparent but may have a yellow color as the ACN content increases. It can be processed by injection molding and also be processed by blow molding, extrusion, casting, and thermoforming. The general structure of SAN is shown in Figure 2.6 [35, 36].

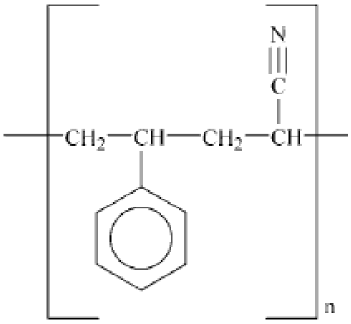

Figure 2.6 Structure of SAN

2.4.1 Advantages and Disadvantages

Advantages of SAN

- Good chemical resistance
- High heat resistance
- Good combination of rigidity, strength, toughness and transparency
- High Flow
- Good processability
- Good flow
- Food contact acceptable
- Dimensional stability

Disadvantages of SAN

- Higher water absorption than polystyrene
- Higher processing temperatures
- Low thermal capability
- Low impact strength
- Yellows more quickly than PS
- Flammable with high smoke generation

2.4.2 Applications

The major uses of SAN resins are

- In houseware items, for examples, dishwasher-safe mugs, dinnerware, bathroom fixtures, ice buckets, toothbrush handles, food containers and stationery supplies.
- In packaging, for examples, cosmetics packaging, lipstick tubes, compact cases, bottle caps, nozzles.
- In appliance parts, including electrical/electronics, for examples, inner shelf liners for refrigerators, washer/dryer instrument panels and clear fronts, blender and mixer components, food trays, fans for air conditioners, and electric fan blades.
- In medical instruments and utensils.
- In industrial battery cases.
- In automotive applications such as instrument panel lenses or covers.

Moreover, SAN is used in compounding with such as acrylonitrile-butadiene-styrene, polyvinyl chloride, styrene-butadiene, polyesters, methyl methacrylate polymers, and polycarbonate.

2.5 ACRYLONITRILE-BUTADIENE-STYRENE (ABS)

Acrylonitrile butadiene styrene (ABS) is a common thermoplastic. It is a terpolymer made by polymerizing styrene and acrylonitrile in the presence of polybutadiene. The proportions of the monomers typically range from 15-35 wt% acrylonitrile, 5-30 wt% butadiene, and 40–60 wt% styrene. This polymer combines the strength and rigidity of the acrylonitrile and styrene polymers with the toughness of the polybutadiene rubber. ABS became available in the 1950s and the availability of its and ease of processing led ABS to become one of the most popular engineering polymers. The styrene gives the plastic a shiny, impervious surface. The butadiene, a rubbery substance, provides resilience. The structure of ABS can be shown in Figure 2.7.

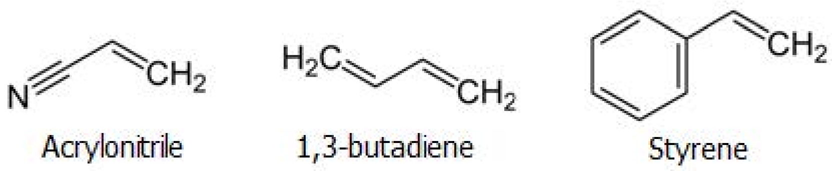

Figure 2.7 Structure of acrylonitrile, butadiene and styrene (monomers of ABS)

2.5.1 Advantages and Disadvantages

Advantages of ABS

- Excellent resistance to glycerine, inorganic salts, alkalis,
- Excellent most alcohols and hydrocarbons resistance
- Excellent processability and appearance
- Good impact resistance with toughness and rigidity
- Dimensional stability
- Toughness (even at low temperatures)
- Low cost

Disadvantages of ABS

- Poor resistance to strong acids and solvents, ketones, aldehydes, esters, and some chlorinated hydrocarbons
- Poor weather ability
- Poor solvent resistance
- Low dielectric strength (not a good insulator)
- High smoke generation when burned
- Limited resistance (suitable for short term use only) to weak acids

2.5.2 Applications

Typical applications of ABS including:

- Automotive parts
- Household appliances
- Electrical and electronic industries
- Pipe
- Telephone components

2.6 PHYSICAL AND MECHANICAL PROPERTIES TESTING

2.6.1 Morphology Characterization

The morphology of fracture surface of polymer blends were investigated by scanning electron microscopy (SEM, Hitachi S-3400n). The samples were scanning with high energy beam of electron onto fracture surface in a raster scan pattern to obtain the images of sample surface. The polymer blends were broken in liquid nitrogen and then coated with platinum [45].

2.6.2 Tensile Test

The stress-strain behavior of materials can be obtained during the tensile test. Tensile test shall be performed to measure the maximum stress at which breaking of the samples occurs, the elongation at the time of breaking and the stress corresponding to the specified elongation. The modulus of elasticity is obtained by plotting the stress force against strain in a tensile test. This modulus is simply the initial slope of the stress/strain straight line in the region of elastic ideality where Hooke's law holds:

$$E = \sigma/\varepsilon$$

The linearity constant E is called the elastic modulus or Yong's modulus and stress (σ) is proportional to strain (ε). For engineering stress is obtained by dividing the load by the original area of the cross section of the specimen.

$$\sigma = F/A$$

Where F = Load applied [N], A =Initial cross-sectional area [m^2]

$$\varepsilon = \Delta l/lo$$

Where Δl = Elongation, lo = Initial gauge length

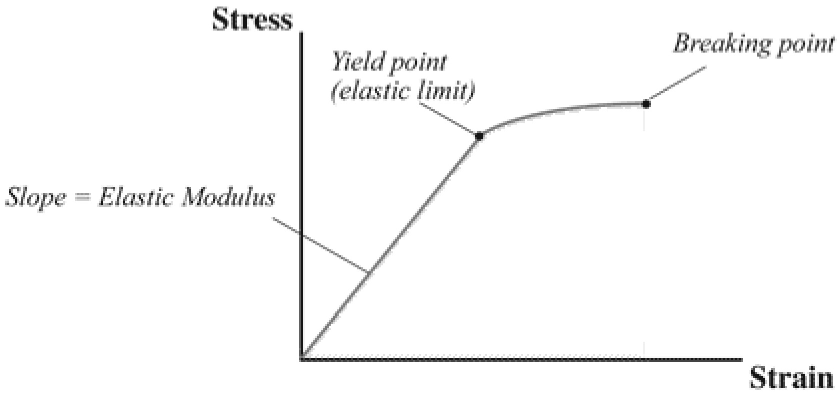

Figure 2.8 Stress-strain curve [46]

Tensile properties were characterized using an Instron universal testing machine with a test speed of 500 mm/min with gauge length of 20.0 mm. The tests were conducted according to JIS K6301. The dimension of sample is shown in Figure 2.9.

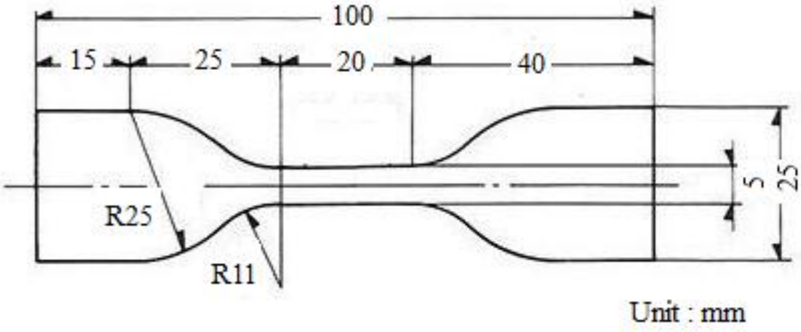

Figure 2.9 Dimension of dumbbell shape specimen (JIS K6301)

2.6.3 Compression set Test

The compression set is the permanent deformation remaining. The samples were compressed to 25% of its original thickness for a set time and at a set temperature to defined the percentage of original thickness after it has been removed in ambient for 30 minutes [47]. This test performed for the measurement of the residual strain due to the compression caused by heating of the samples.

According to JIS K6301, three carefully measured samples (The test piece shall be a right cylindrical shape 12.70 ± 0.13 mm in thickness and 29.00 mm in diameter) were placed between metal plates and compressed to 25% of the sample’s original thickness. The samples are held at 60°C for 22 hours, removed from the apparatus, allowed to recover for 30 minutes, and re-measured the thickness. Rate of compression set can be calculates by the following formula:

$$CS = \frac{To - T1}{To - T2} \times 100$$

Where CS = Rate of compression set [%]

To = Original thickness of sample [mm]

T1 = Thickness of sample measured 30 min after it was taken out from the compression device [mm]

T2 = Thickness of spacer [mm]

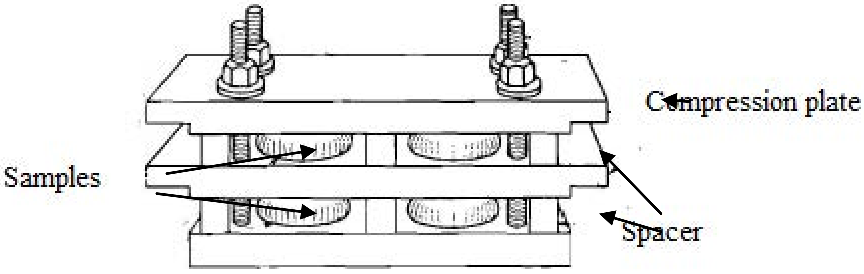

Figure 2.10 Compression set devices (JIS K6301)

CHAPTER III

LITERATURE REVIEWS

The blending of conventional polymers induced extensive scientific activity because they could be employed to develop new polymeric materials with improvement in processing, and various physical properties of the materials such as mechanical strength, and heat deflection temperature. Acrylonitrile-butadiene rubber (NBR) has been widely used for various types of fuels because of its excellent fuel and oil resistance but its electrical-insulation and ozone resistance are relatively low [7]. Efforts have been made in the polymer blends of novel NBR-based polymer in order to enhance their chemical resistance. However, the properties of a polymeric blend depends strongly on the compatibility of polymer pair. This chapter describes the literature reviews of the previous works related to the polymer blends in the field of NBR-based composites.

3.1 NBR/PVC BLENDS

PVC blended with crosslinked NBR have been formed since the 1940's (B. F. Goodrich patented). For NBR/PVC blends, the ACN content in NBR should be at least 25 wt%. Acrylonitrile-butadiene rubber and polyvinyl chloride are fairly compatible. As NBR/PVC blends, NBR acts as a permanent plasticizer in PVC appliances. NBR/PVC blends are rubber-like in appearance and feel. The polymer blends are flexible at low temperatures and have good tear strength, low compression set, good abrasion resistance, and exhibited minimum swelling when immersed in oils or solvents [37]. The literature reviews of NBR/PVC blends can be shown as below.

Vera Lu´cia da C. L. et al (2002) [38] prepared physical mixture of NBR/PVC (70/30 w/w) by using two-roll-mill for investigation about the influence of aluminum hydroxide (AH) and carbon black (CB) by varying the AH:CB (w:w) ratio. NBR that has 33 wt% of acrylonitrile was used and the aluminum hydroxide with and without surface treatment were used together with CB, the main reinforcing agent for elastomeric vulcanizates. Highly reinforced polymers frequently exhibited poor filler dispersion and processability. For this studied it was found that the unfilled elastomeric matrix, that introduced with filler, made processing more difficult (especially in case of CB). But the scorch time of NBR/PVC blends were increased by increasing of CB content. AH made the mixing easier than CB because of the required energy to process the matrix was decreases and also vulcanization was faster too. The surface treatment of aluminum hydroxide with silane was not effective for NBR/PVC to promote an interaction between the inorganic filler and the polymer matrix.

Mahshid H. et. al. (2006) [15] applied the Taguchi method to determine the optimum level of curing system (sulphur, MBTS, and CBS) in a NBR/PVC blend. Taguchi method focuses on improving functions of products or processes. It was an excellent method, which was accessible to reduce cost and improve the quality. There were two major tools to utilize. The first concept was the signal to noise ratio, which measured the quality by emphasizing on variation, and the second concept was orthogonal arrays, which accommodated many design factors simultaneously. Fixed master batch formulation that used for studied can be shown in Table 3.1. The amount of sulphur curing system can be show in Table 3.2. The results of Taguchi method showed that sulphur was the most important factor in vulcanization for NBR/PVC. The incorporation of sulphur resulted in a increasing of tensile strength and elongation at break. Sulphur loading increased hardness and decreased %abrasion. This was due to the increasing crosslinking with increasing the amount of curing factor in vulcanization. And the best composition to get the best mechanical properties was at 2 Phr sulphur, 2 Phr MBTS, and 0.5 Phr of CBS.

Table 3.1 Formulation of rubber batch.

Material	phr	Producer
NBR/PVC (60/40 w/w)	100	Bayer Co., Germany
Carbon black N330	40	Ahvaz Factory, Iran
Zinc oxide	3	Gostar Jam, Iran
Stearic acid	1	Minko, Malaysia

Table 3.2 Sulphur curing system.

Material	phr	Producer
Sulphur	1-2	RPC, Iran
MBTS	1-2	Bayer Co., Germany
CBS	0.3 - 0.7	Bayer Co., Germany

Xinwu H. et. al. (2006) [14] studied the effect of PVC content on the mechanical strength and tribological properties of NBR/PVC composites. NBR/PVC blended was prepared by internal mixer with different PVC content (0, 10%, 20%, 30%, 40%, and 50% by weight). It was found that the NBR/PVC with 30 wt% PVC content showed the best mechanical and tribological properties. PVC played an important role to decrease the friction coefficient and reduce wear of composites because of the higher PVC content made the area of real contact between NBR composites and stainless ball decreasing (for friction and wear resistant test). The reason that made the elongation at break of NBR/PVC blends decreased with the increase in PVC content was because the elastic properties of composite decreased while the plastic properties increased. This effect leading to friction force of NBR rubber composites to decrease, so the friction and wear were lower.

Pappa A. et. al. (2011) [16] used TG-MS technique for revealing the details of the degradation mechanism or thermal degradation of NBR/PVC (65/35 by weight), and NBR/PVC with 50 phr $Mg(OH)_2$, and NBR/PVC with 10 phr nano clay, and NBR/PVC with 10 phr china clay. NBR that used in this work had acrylonitrile content 34 wt%. The organic modification of the clay aimed to improve the compatibility of inorganic composites with polymer blends matrix. All results from this studied were as follows;

TG-MS of PVC showed two main degradation steps, at the first stage the mass loss of 65.2% at temperature of 210 to 370 °C. The first step was believed to be the dehydrochlorination and the formation of macromolecules with conjugated double (C=C) bonds. For second stage the mass loss of 29.7% at temperature of 370 to 530 °C was due to cracking and pyrolysis of low hydrocarbons of linear or cyclic structures.

TG-MS of NBR showed single degradation step, mass loss of 87.7% at temperature of 300 to 500 °C.

TG-MS of NBR/PVC blends had two steps of degradation. At first step was the PVC decomposition and next step was the NBR decomposition. Total char residue of NBR/PVC blends was higher than pure PVC and NBR, indicating that

NBR/PVC blends leading to a more stabilized product when compare to the individual components.

TG-MS of NBR/PVC blends with inorganic filler was founded that inorganic fillers led to a slightly increase in the mass of residue. $Mg(OH)_2$ and china clay seemed to suppress PVC decomposition (acted like thermal barrier for PVC).

3.2 NBR/SAN and NBR/ABS BLENDS

Poly(styrene-co-acrylonitrile), SAN copolymer generally contains 70 to 80 wt% styrene and 20 to 30 wt% acrylonitrile. The features of SAN are good chemical resistance, high heat resistance, and good processability but low impact strength and higher processing temperature. However, at higher acrylonitrile content, SAN will have greater chemical and heat resistance, impact strength, and toughness.

Poly(acrylonitrile-co-butadiene-styrene), ABS is widely used thermoplastic material. The most desired mechanical properties of ABS are resistance, dimensional stability, and toughness. ABS may used to improve impact resistance, toughness and heat resistance to acrylonitrile-butadiene rubber or NBR. Because there have a few research publications of NBR/ABS blended, and almost all researches studied NBR/ABS and NBR/SAN simultaneously. So this topic combined NBR/SAN and NBR/ABS together. The literature reviews of NBR/SAN and NBR/ABS blends can be shown as below.

Mathew M. et. al (1997) [19] studied the compatibility of a NBR-based polymer blend by viscometric technique. The polymer-polymer interaction parameter, the interaction parameter term Δb, specific viscosity, and dilute solution density were used for prediction of the compatibility of polymer blend. The individual polymer solutions were obtained by dissolving the polymers in solvents, then stirred for 24 hours. For preparing the blend solutions, the polymer solutions were subsequently blended in the appropriate ratio. They founded that NBR/SAN blends had similar behavior to the NBR/ABS blends. As NBR/SAN ratio of 70/30 by weight and 50/50 by weight were compatible and specific gravity values implied miscibility with increasing weight percent of NBR, that meant a ratio NBR/SAN 70/30 by weight had a better compatibility that correlated to the interaction parameter term Δb. For

NBR/ABS ratio of 70/30 by weight was also the best ratio for compatibility because of at this ratio NBR and ABS had a good attractive interactions. Finally, the results were correlated with spectroscopic evidence.

Anandhan S. et. al. (2004) [23] investigated the thermal degradation and swelling of thermoplastic vulcanizates from NBR/SAN and NBR/Scrap computer plastics blends (SCP). ABS was the major constituent of SCP used in this study. They founded that the dynamically vulcanized system gave higher amount of activation energies for thermal degradation than the unvulcanised systems and could improve swelling resistance. Moreover, the dynamically vulcanised or curing agent blends gave the higher activation energies for the thermal degradation than the unvulcanised blends. Polymer blended were prepared by mixing NBR and thermoplastic (SAN or SCP) in an internal mixer at 180 °C and then polymer blended were removed in hot condition and sheeted out in a water-cooled two-roll mill at 25 °C. For dynamic vulcanisation, a rubber-curative masterbatch was prepared first, which was then mixed with molten thermoplastic. They observed the rate of degradation of SAN was faster than NBR and also NBR/SAN blends. The onset temperature of degradation of SAN was higher than NBR, but the onset temperature of NBR/SAN blends was slightly higher than both NBR and SAN, meaning the thermal stability of NBR could be improved by blending it with SAN. Swelling studies were carried in toluene (δ = 18.2), methyl ethyl ketone (δ = 19.0), 1,4-dioxan (δ = 20.4), dimethyl formamide (δ = 24.7) (The values in parentheses indicate solubility parameter 'δ' in $MPa^{1/2}$). They founded that when the blend component had a solubility parameter closer to the solvent, the swelling index would be higher. For NBR/SAN blended the maximum swelling occurs in 1,4-dioxan (δ = 20.4) and the δ of NBR = 19.9, δ of SAN = 20.3 because of the solubility parameter of SAN and NBR are closer to 1,4-dioxan solvent. For NBR/ABS the swelling index values increased as a function of weight percent of NBR, the dynamically vulcanised blends had a lower swelling index than the unvulcanised blends because of the presence of crosslinks in the NBR phase that restricted the transport of the solvent molecules.

Sang J. A. et. al. (1998) [20] investigated the effect of acrylonitrile content of NBR (18 wt%, 28 wt%, 34 wt%, 42 wt%, and 50 wt%) to SAN/NBR blends. The physical properties of SAN/NBR (70/30 by weight) blends were studied too. SAN/NBR blended were prepared by corotating twin-screw extruder at the zone temperature profile of 190 to 210°C, then they were quenched in water and pelletized subsequently. After drying at 80°C for 3 hours, it was injected into mold. They founded that all the blends showed NBR as particles dispersed phase in SAN matrix and the size of dispersed NBR particles decreased as the ACN content in NBR was increased. The TEM photographs of SAN/NBR blends was shown in Figure 3.1. The miscibility increased as the acrylonitrile in NBR was increased up to 50 wt%. The impact strengths reached the highest values when the ACN content in NBR was 34 wt%. On the other hands, tensile strength, flexural strength, and flexural modulus had minimum values.

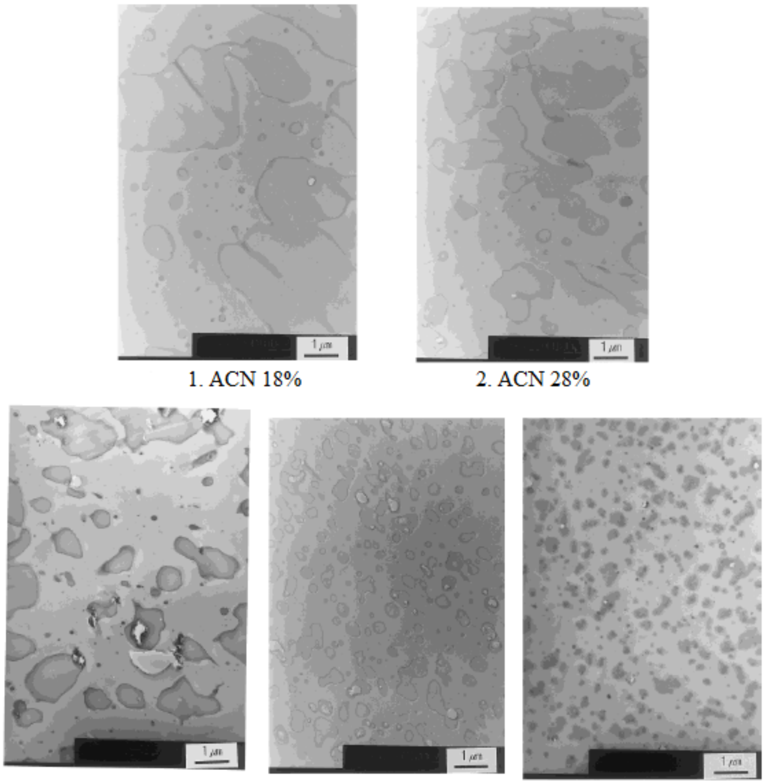
1. ACN 18%
2. ACN 28%
3. ACN 34%
4. ACN 42%
5. ACN 50%

Figure 3.1 Transmission electron micrographs of SAN/NBR

Zhongjian W. et. al. (2003) [39] compared the impact properties, mechanical properties and morphologies of Nylon/SAN/NBR (50/25/25 by weight) by using different curing systems, phenolic formaldehyde (PF), dicumylperoxide (DCP), and sulfur system. A mixture of nylon, SAN, NBR, and additives were prepared and mixed in a mixing chamber. It was observed that as uncured system of

Nylon/SAN/NBR blends were typical immiscible blends with poor mechanical properties. Phenolic formaldehyde system made the Nylon/SAN/NBR blends attained the better impact strength and excellent mechanical properties than the other curing system because the dynamic vulcanized blends could be attributed to the stabilization of the rubber particle morphology, espacially when increasing phenolic formaldehyde content the particle size became more uniform and smaller as shown in Figure 3.2. About other curing systems, DCP and sulfur system showed that the dispersed phase particles appear in relatively large particle size distribution as shown in Figure 3.3. Poor morphology in the blends gave the poor mechanical properties. Good morphology of the blends did not only depend on dynamic vulcanization but also on the type of curing system.

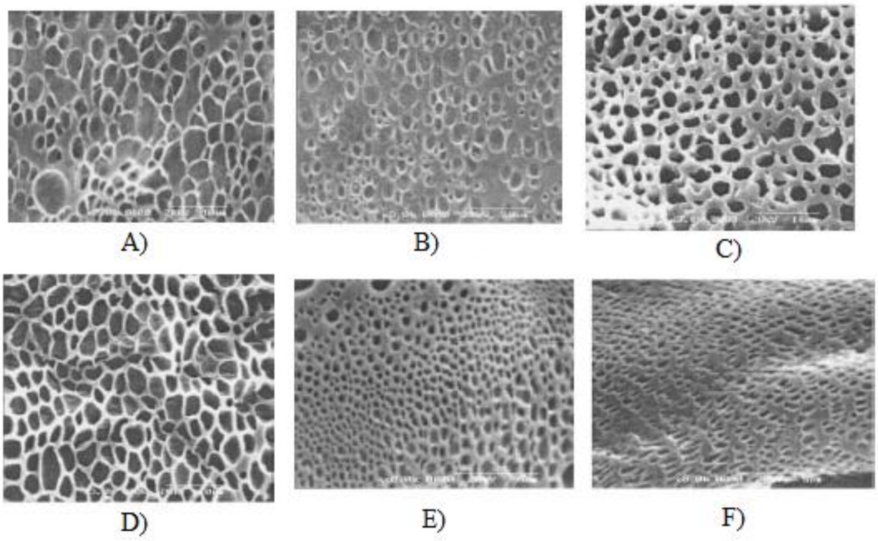

Figure 3.2 SEM photomicrographs of the nylon/SAN/NBR blends vulcanized with different PF content: A) unvulcanized, B) 2 phr, C) 4 phr, D) 6 phr, E) 8 phr F) 10 phr. The blends are all etched by THF (solvent for SAN and NBR) and photographed at 3000 x magnification except for E) and F) at 8000 x magnification

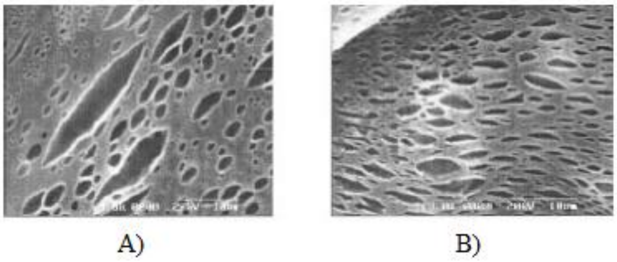

Figure 3.3 SEM photomicrographs of the nylon/SAN/NBR blends vulcanized with different curing systems: A) DCP system; B) sulfur system. The blends are all etched by THF (solvent for SAN and NBR) and photographed at 3000 x magnification

Francine Z. et. al. (2005) [21] prepared SAN/NBR blends with varying acrylonitrile content from 21 to 45 wt% by casting, co-precipitation, and processing by mono-screw extrusion followed by injection molding. The SAN/NBR blends were prepared as many compositions: 90/10, 80/20, 70/30, 60/40 and 50/50 by weight. The details of material were given in Table 3.3. The DSC results from casting methods with acrylonitrile with NBR 33 wt%, casting, and co-precipotation method with acrylonitrile of NBR 39 wt% is shown in Table 3.4, 3.5, and 3.6 respectively.

Table 3.3 Characteristics of copolymers used in this study.

Material	Acrylonitrile (wt%)	Tg (°C)
SAN	32	109
NBR 33	32.7	-28
NBR 3960	39	-16.6
NBR 4560	45	-9.6

Table 3.4 DSC data for casted films of SAN/NBR 33 systems.

SAN/NBR 33	Tg (°C)			
50/50	-33.5			110.3
60/40	-29.4			107.2
70/30	-33.5	5.1		108.8
80/20	-28.1	0.2	84.8	107.6
90/10	-4.2			94.9

Table 3.5 DSC analyses of SAN/NBR 39 casted films.

SAN/NBR 33	Tg (°C)			
50/50	-14.3			87.9
60/40	-14.9		80.3	97.3
70/30	-14.9	7.5		90.1
80/20	-17.2			93.3

90/10	-2.0			99.0

Table 3.6 DSC analyses of SAN/NBR 39 coprecipitates.

SAN/NBR 33	**Tg (°C)**			
50/50	-12.7			88.2
60/40	-15.9		73.8	97.2
70/30	-25.7	3.7		93.1
80/20	-10.0			96.6
90/10		7.9		95.3

From Table 3.4, it was observed that 50/50 and 60/40 compositions by weight blends were immiscible because two glass transition temperatures occurred which corresponding to the pure copolymers. The 70/30 by weight blends showed a new NBR-rich phase, while 80/20 by weight presented both of NBR-rich phase and SAN-rich phase. From Table 3.5 and 3.6, they were also observed that the blend preparation method had no influence on the DSC behavior of these systems. Mechanical tests were investigated and it was found that the addition of NBR resulted in a significant increase in the impact resistance, but depended on blend composition and the ACN content. The higher NBR content resulted in a significant increase in the impact resistance but the tensile modulus were decreased.

CHAPTER IV

EXPERIMENT

4.1 Rubber materials, chemicals and equipment

4.1.1. Rubber materials

Details of the rubber materials are given in Table 4.1

Table 4.1 Detail of the rubber materials

Material	Supplier/manufacturer
NBR	Channel Chemical Co., Ltd./
Grade : DN3350	Nipol, Japan
ACN content : 33 wt%	
Mooney viscosity : ML_{1+4} at 100 °C : 50	
HNBR	Caldic Thailand, LANXESS
Grade : Therban 3446	
ACN content : 34 wt%	
Mooney viscosity : ML_{1+4} at 100 °C : 61±7	
NBR/PVC	Channel Chemical Co., Ltd./
Grade : P-70K	Nipol, Japan
ACN content : 23.5 wt%	
Mooney viscosity : ML_{1+4} at 100 °C : 62.5	
SAN	Sy smile Co., Ltd., Styrolution
Grade : Lustran SAN C	(Thailand) Co., Ltd.
MFI : 23 g/10 min at 220 °C under a load of 10 kg	
ABS	Sy smile Co., Ltd., INEOS ABS
Grade : Lustran ABS 250	(Thailand) Co., Ltd.,
MFI : 38 g/10 min at 220 °C under a load of 10 kg	
Carbon black N220	Thai tokai carbon product Co., Ltd.
Sulphur	MDR International Co., Ltd.
Zinc Oxide	MDR International Co., Ltd.
Stearic acid	MDR International Co., Ltd.
MBT[a]	MDR International Co., Ltd.
TMTD[b]	MDR International Co., Ltd.

[a] 2-Mercaptobenzothiazole (Accerelator)

[b] Tetramethyl thiuram disulfide (Accerelator)

4.1.2 Chemicals

All chemicals used for resistance tests in this study included: gasoline 95, E85, 95% ethanol, and acidic E20 (SAE J1681's criteria). The chemicals required for acidic E20 preparation were obtained from Merck Chemical (AR grade). Acidic E20 is 50 vol% iso-octane and 50 vol% toluene with aggressive ethanol. Ingredients of acidic E20 for one glass jar (5.0 L) were as follows:

- Isooctane	2.00 L
- Toluene	2.00 L
- Ethanol	816.00 g
- De-ionized water	8.103 g
- Sodium chloride	0.004 g
- Sulfuric acid	0.021 g
- Glacial acetic acid	0.061 g

4.1.3 Equipments

- Internal mixer with cam type rotor from Chareon tut was used to mixing rubber and plastic
- Kneader from Yi Tzung Precision Machinery (3 L) was used for mixing polymer blended with rubber chemical except curing agent
- Two roll mill Yi Tzung Precision Machinery was used for mixing polymer blended with curing agent
- Compression molding
- Moving die rheometer (TECHPRO, rheotech MF+) at 165 ^{o}C with frequency 1.7 Hz and amplitude 0.5 degree was used for find the cure time of samples
- Universal testing machine was used for test mechanical properties according to JIS K6301 with a test speed of 500 mm/min with gauge length of 20.0 mm
- Compression set device was used for test compression set of sample according to JIS K6301 The samples were compressed to 25% at 60 ^{o}C for 22 hours
- Hardness shore A according to JIS K6301

- Electronic densimeter for measure volume of sample
- Digital vernier calipers
- Differential scanning calorimetric (DSC) from -50 to 200 °C at 5 °C/min
- Thermogravimetric analysis (TGA) from ambient temperature to 800 °C at 10 °C/min under a dynamic nitrogen atmosphere flowing at 400 mL/min
- Dynamic mechanical analyzer (DMA) from ambient temperature to 200 °C at 5 °C/min
- Scaning eletron microscopy (SEM, Hitachi S-3400n)
- Fourier transform infrared spectroscopy (FTIR)

4.2 Preparation of Polymer Blends

4.2.1 Preparation of NBR/SAN and NBR/ABS blends

Mixing step 1 using internal mixer

1. SAN or ABS were dried in an oven at 80 °C for 4 hours.
2. Weight in the desired amount of NBR, SAN or ABS on the electronic balance.
3. Prepare a rubber-plastic blends, Put ABS or SAN in an internal mixer at 180 °C and 50 rpm for 4 minutes or until molten state.
4. Add NBR, then mixing for 3 minutes.
5. Take the polymer blends out off the internal mixer.

Figure 4.1 Internal mixer

Mixing step 2 using kneader

1. Weight in the desired amount of Polymer blends from mixing step 1, carbon black, zinc oxide, stearic acid, MBT, and TMTD on the electronic balance.
2. Put polymer blends in a kneader at 60 ^{o}C melt for 2 minutes.
3. Add zinc oxide and stearic acid, then mixing for 2 minutes afterwards add , MBT, and TMTD then mixing until temperature in kneader up to 140 ^{o}C.
4. Take the sample out of the kneader.

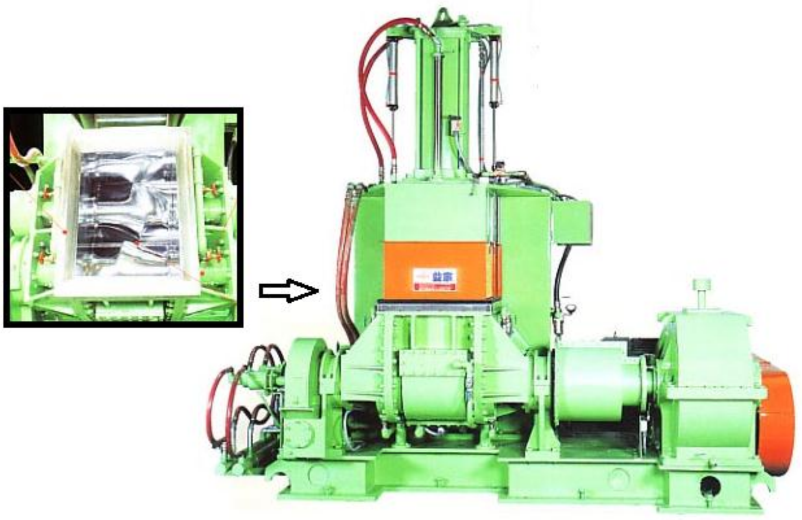

Figure 4.2 Kneader

Mixing step 3 using two roll mill

1. Weigh in the desired amount of sulphur on the electronic balance.
2. Put polymer blends into two roll mill at ambient and roll sample around 3 minutes.
5. Add sulphur on sample then roll, cut and fold sample around 10 times or until it has smooth surface.
6. Sheet out the sample.

Figure 4.3 Two roll mill

4.2.2 Preparation of HNBR and NBR/PVC blends

As same as mixing step 2-3, the preparation of NBR/SAN and NBR/ABS blends but were repeated, but for NBR/PVC, carbon black was not added into polymer.

Table 4.2 Composition of polymer blends without carbon black

Code	1	2	3	4	5	6	7	8
Material	phr	phr	phr	phr	phr	phr	phr	phr
NBR	100	60	70	80	60	70	80	-
SAN	-	40	30	20	-	-	-	-
ABS	-	-	-	-	40	30	20	-
NBR/PVC (70/30 w/w)	-	-	-	-	-	-	-	100
Zinc oxide	3.00	1.8	2.1	2.4	1.8	2.1	2.4	2.1
Stearic acid	2.00	1.2	1.4	1.6	1.2	1.4	1.6	1.4
Sulphur	0.75	0.45	0.53	0.6	0.45	0.53	0.6	0.53
MBT	1.00	0.6	0.7	0.8	0.6	0.7	0.8	0.7
TMTD	0.50	0.3	0.35	0.4	0.3	0.35	0.4	0.35

Table 4.3 Composition of polymer blends with carbon black

Code	1	2	3	4
Material	phr	phr	phr	phr
NBR	100	-	80	80
HNBR	-	100	-	-
SAN	-	-	20	-
ABS	-	-	-	20
Carbon black	20.00	20.00	16.00	16.00
Zinc oxide	3.00	3.00	2.4	2.4
Stearic acid	2.00	2.00	1.6	1.6
Sulphur	0.75	0.75	0.6	0.6
MBT	1.00	1.00	0.8	0.8
TMTD	0.50	0.50	0.4	0.4

4.3 Polymer Processing

The polymer blends were compressed at 165 ^{o}C in a hydraulic press for 12 minutes to a form sheet then punched out as dumbbell shape according to JIS K6301 as shown in Figure 4.4. And the sheet will be cut into a piece for chemical resistance test too.

Figure 4.4 Dumbbell shape

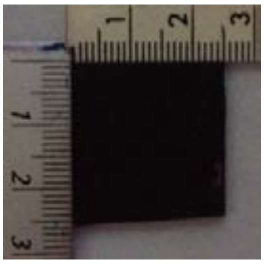

Figure 4.5 Chemical resistance test piece

For hardness and compression set the test pieces were compressed at165 °C in a hydraulic press as cylindrical shape according to JIS K6301 for 12 and 25 minutes respectively.

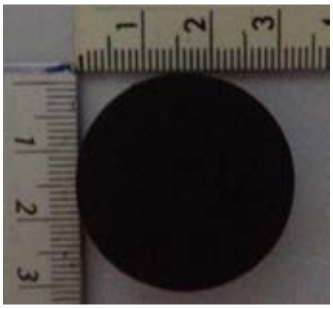

Figure 4.6 Cylindrical shape for testing hardness, compression set and dimension change

4.4 Chemicals resistance test

The test specimens were placed in glass jars with 5.0 L chemical solution. The specimens were immersed in chemicals solution: gasoline 95, E85, 95% ethanol and acidic E20 for 8 weeks at room temperature.

The specimens were taken out from the jars and wipe out chemical solution on surface by soft tissue paper before testing. Mechanical properties, weights, hardness and dimensions were measured at 0, 1th, 2nd, 3rd days and 1th, 2nd, 4th and 8th weeks. Figure 4.7 showed samples in glass jar.

Figure 4.7 Test container

CHAPTER V

RESULTS AND DISCUSSION

5.1 The influences of plastic loading and mixing time on physical, thermal, and mechanical properties of blends

5.1.1 Morphology observation

The morphologies were investigated using scanning electron microscope to analyze the fracture surfaces of samples. Figure 5.1 showed SEM photomicrograph of NBR (8,000x). It could be seen that NBR is the matrix phase and there is no clearly dispersed phase, since NBR is the only polymer presence.

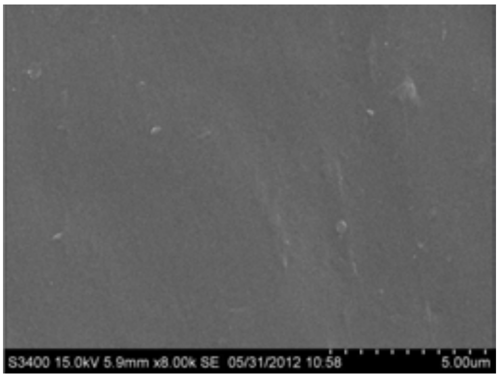

Figure 5.1 SEM photomicrographs of NBR [at 8000 x magnification]

Figure 5.2-5.7 showed typical results of SEM photomicrographs of NBR/ABS and NBR/SAN blends with different plastic loading and mixing time of rubber and plastic. For polymer blended, NBR was the matrix phase and plastics (ABS or SAN) are the dispersed phase. With increasing plastic level, the particle size became smaller and better distributed into matrix phase and there are no different morphology when using mixing time of rubber and plastic at 3 and 4 minutes.

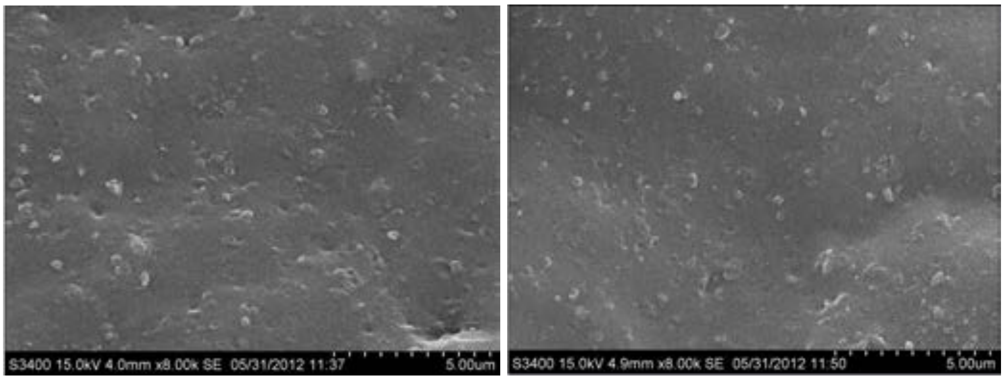

Figure 5.2 SEM photomicrographs of NBR/ABS (80/20 w/w) at mixing time 3 and 4 minutes (Left and Right), respectively [at 8000 x magnification]

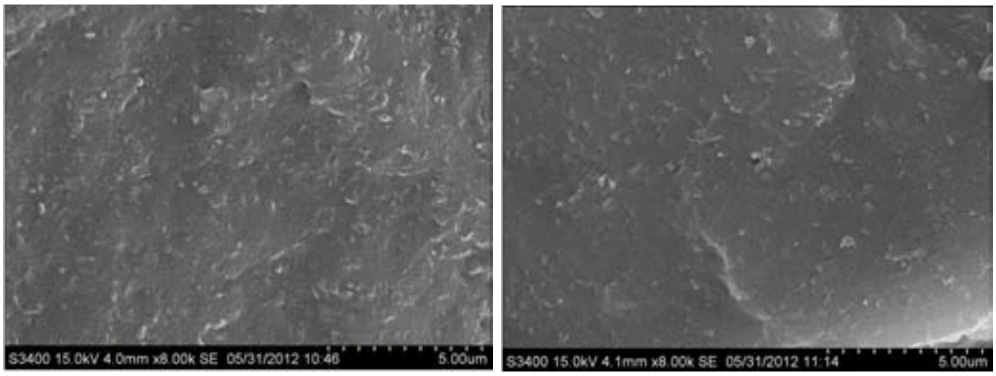

Figure 5.3 SEM photomicrographs of NBR/ABS (70/30 w/w) at mixing time 3 and 4 minutes (Left and Right), respectively [at 8000 x magnification]

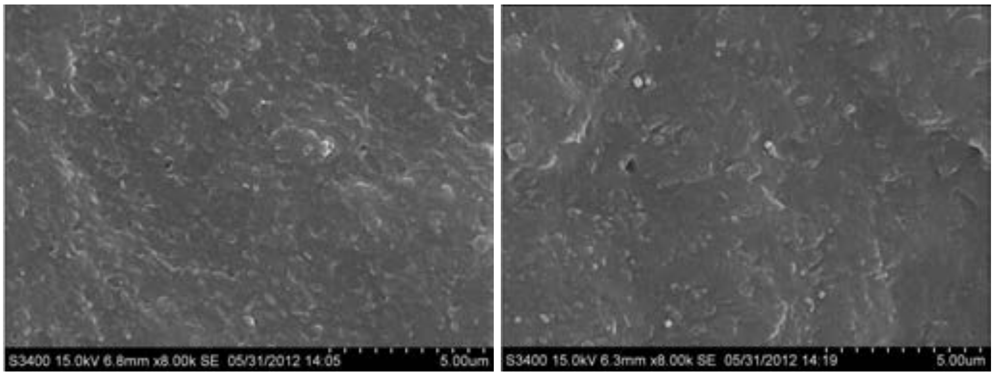

Figure 5.4 SEM photomicrographs of NBR/ABS (60/40 w/w) at mixing time 3 and 4 minutes (Left and Right), respectively [at 8000 x magnification]

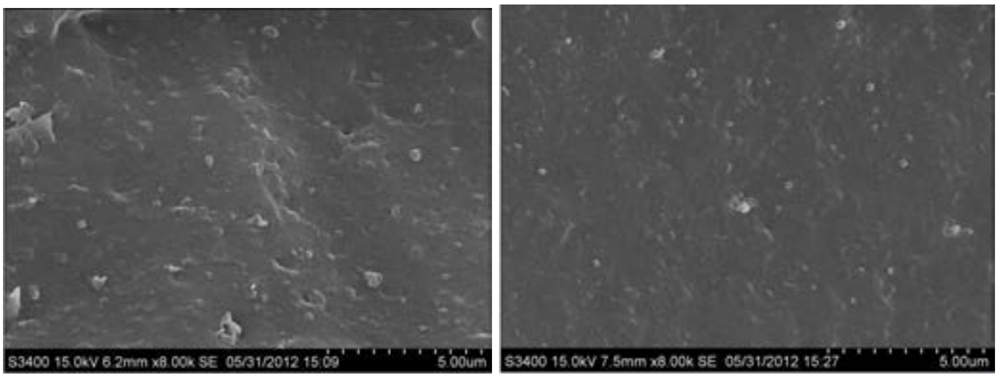

Figure 5.5 SEM photomicrographs of NBR/SAN (80/20 w/w) at mixing time 3 and 4 minutes (Left and Right), respectively [at 8000 x magnification]

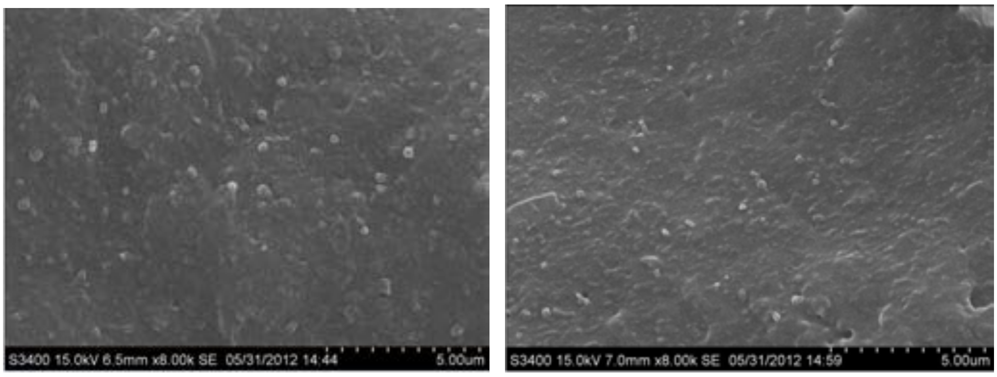

Figure 5.6 SEM photomicrographs of NBR/SAN (70/30 w/w) at mixing time 3 and 4 minutes (Left and Right), respectively [at 8000 x magnification]

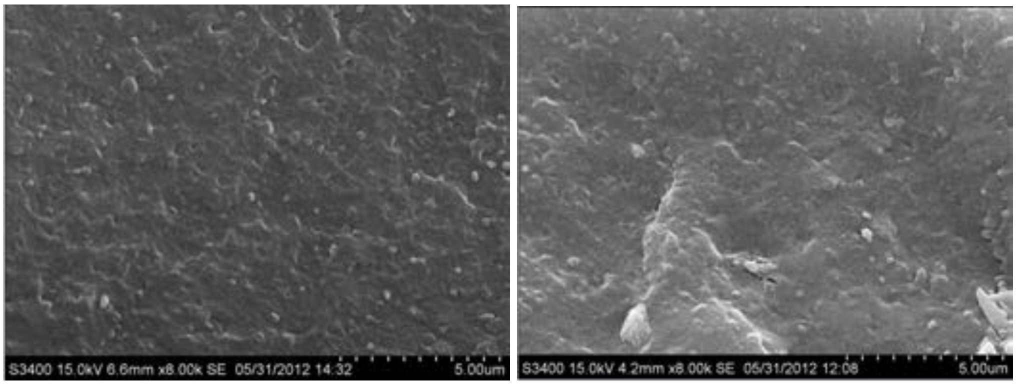

Figure 5.7 SEM photomicrographs of NBR/SAN (60/40 w/w) at mixing time 3 and 4 minutes (Left and Right), respectively [at 8000 x magnification]

5.1.2 Mixing torque

The appropriate of mixing time of polymer blends (80/20 w/w of NBR/SAN and NBR/ABS) were investigated by torque and thermal measurements. Figure 5.8 and 5.9 showed mixing torque curves of rubber and plastic blends. The polymer blends were processed at 180 °C at rotor speed of 50 rpm. The ABS or SAN pellets were added in an internal mixer within the first 4 minutes. When plastic melting, the melt reached a state that closer to steady state condition, NBR should be added at this time because at this state, incorporation of NBR was easier due to low shear stress of the system. Both NBR/ABS and NBR/SAN systems, NBR and plastics were closer to steady state after mixing around 2 minutes.

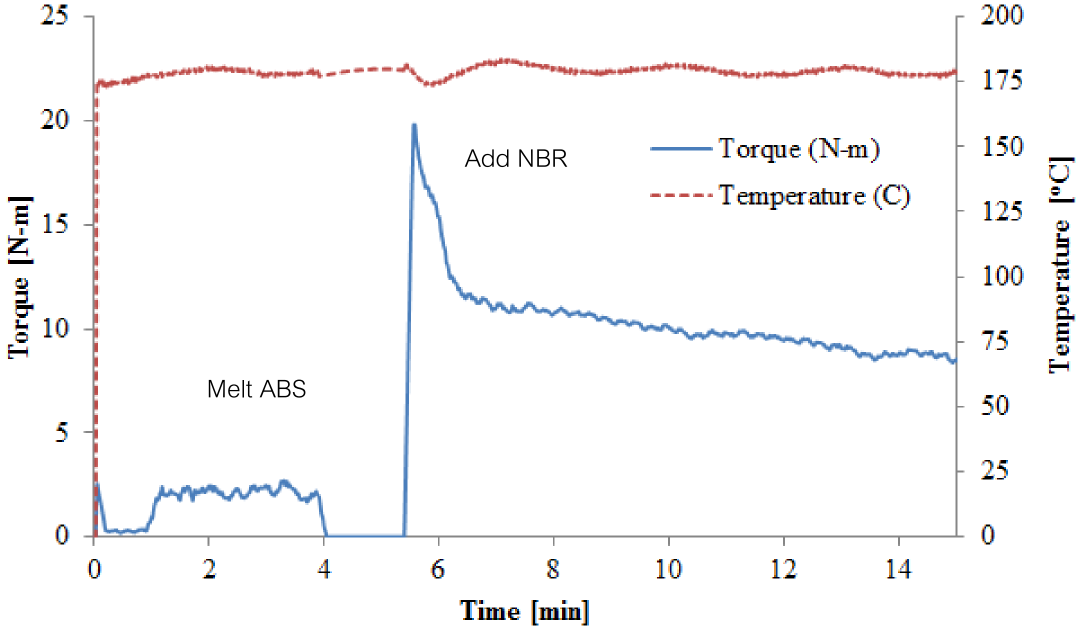

Figure 5.8 Mixing torque curves of NBR and ABS [80/20 w/w] blended

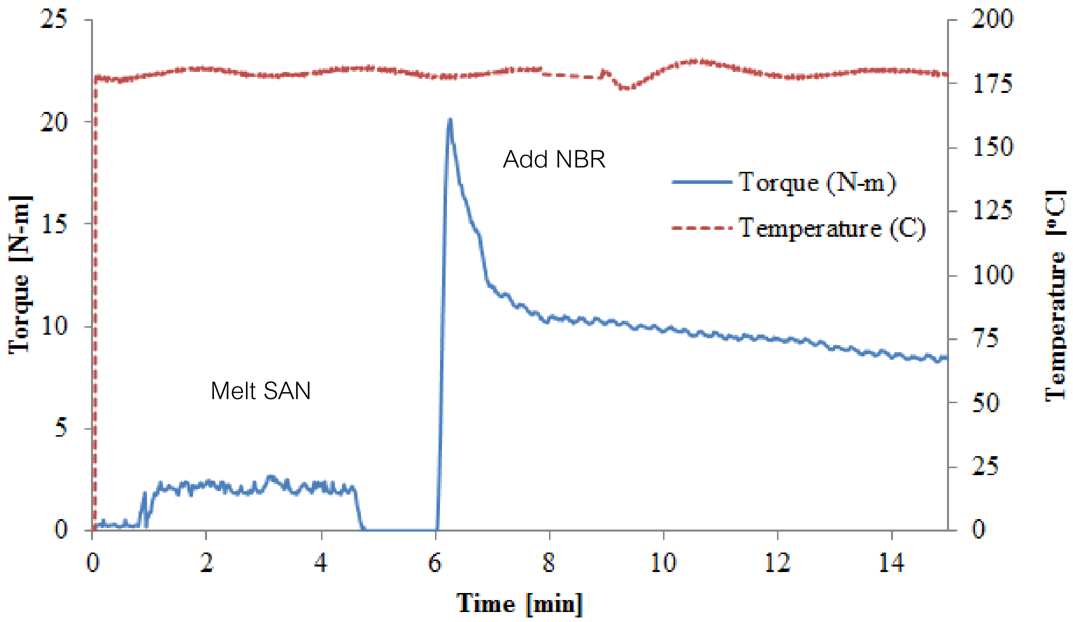

Figure 5.9 Mixing torque curves of NBR/SAN blended

5.1.3 The cure characteristics

Cure characteristics of polymers were investigated using moving die rheometer and test 3 times for one formulation. Table 5.1 and Figure 5.10-5.13 demonstrated the rheometric characteristics of NBR, NBR/PVC, NBR/SAN, and NBR/ABS respectively. It is observed that NBR matrix exhibits longer cure time than NBR/SAN and NBR/ABS blends. SAN and ABS decreases the maximum torque and increases of minimum torque. NBR showed more scorch and faster cure time than NBR/PVC (showing relatively low scorch and cure time). And NBR showed higher both of maximum and minimum torque than NBR/PVC blended.

Table 5.1 Cure characteristics of samples

Samples	Cure characteristics			
	Scorch time (min)	Cure time, t_c90 (min)	Maximum torque (lb*in)	Minimum torque (lb*in)
NBR	1.15 ± 0.01	1.47 ± 0.02	2.67 ± 0.02	0.32 ± 0.01
NBR/PVC	1.71 ± 0.18	1.71 ± 0.09	2.40 ± 0.11	0.23 ± 0.01
NBR/SAN	-	0.99 ± 0.10	1.66 ± 0.06	0.59 ± 0.08
NBR/ABS	-	0.81 ± 0.01	2.12 ± 0.02	0.56 ± 0.03

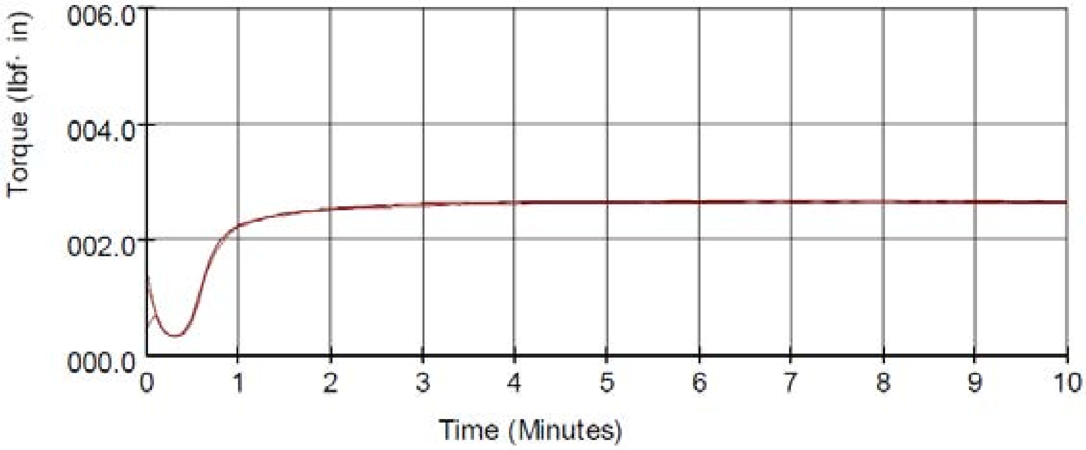

Figure 5.10 Rheometric characteristics of NBR curve

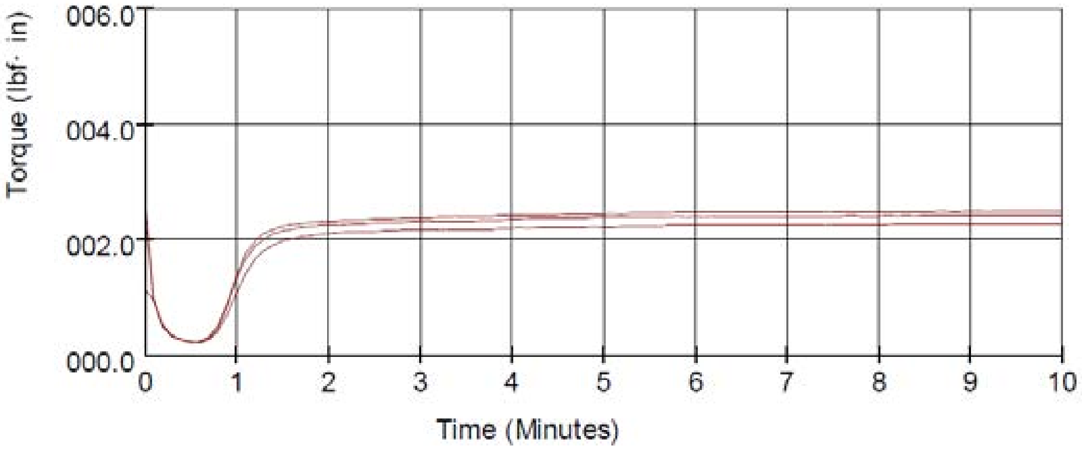

Figure 5.11 Rheometric characteristics of NBR/PVC curve

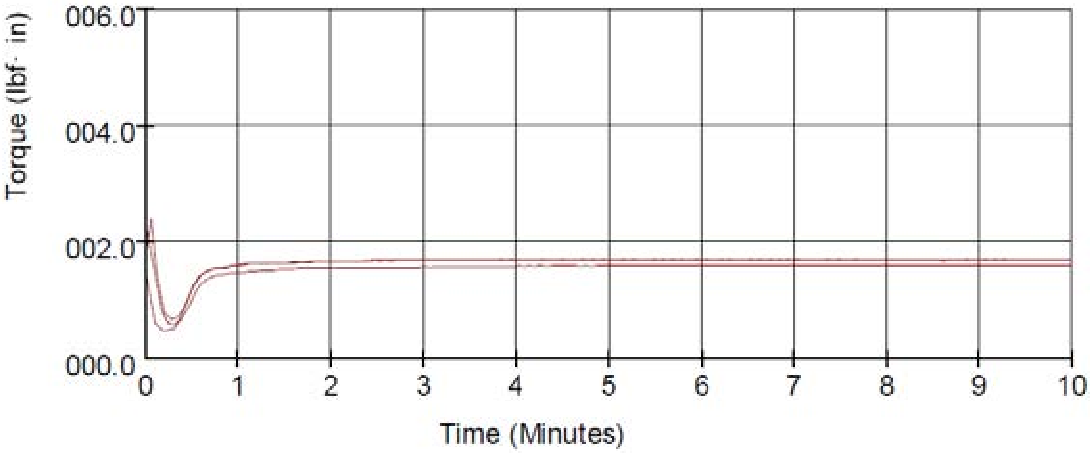

Figure 5.12 Rheometric characteristics of NBR/SAN curve

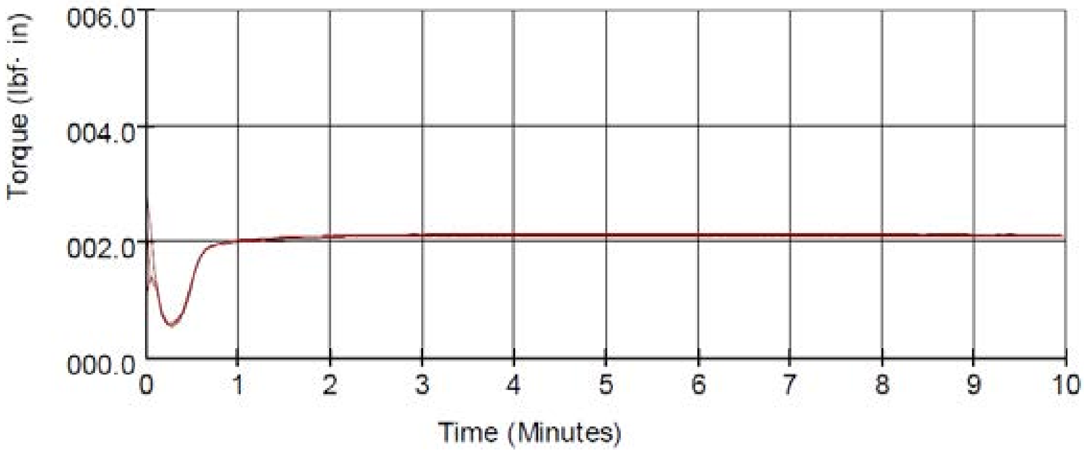

Figure 5.13 Rheometric characteristics of NBR/ABS curve

5.1.4 Mechanical properties

Table 5.2-5.3 provided an interesting summary of mechanical properties of the blends with ABS and SAN respectively with various plastic contents. The results indicated that when increasing the content of plastic, tensile strength and 100%-modulus increased due to the increasing rigidity of blend. With increasing NBR content also increases the elongation at break of the blends due to the decreasing stiffness of polymer blend. Comparing with pure NBR, at the 80/20 ratio at mixing time of 3 min, both polymer blends, and the vulcanizates were the most rubberlike. In this study, the rubber-plastic mixing time of 3 min gave better mechanical properties than 4 min.

Table 5.2 Tensile properties of NBR/ABS blends

NBR/ABS [w/w]	100/0	80/20		70/30		60/40	
Mixing time [min]	-	3	4	3	4	3	4
Tensile strength [kg_f/cm^2]	22	69	55	85	65	101	87
Elongation at break [%]	417	343	248	220	127	149	148
100% Modulus [kg_f/cm^2]	13.2	22.4	26.5	38.6	54.1	74.9	59.1

Table 5.3 Tensile properties of NBR/SAN blends

NBR/SAN [w/w]	100/0	80/20		70/30		60/40	
Mixing time [min]	-	3	4	3	4	3	4
Tensile strength [kg$_f$/cm^2]	22	78	59	121	126	98	105
Elongation at break [%]	417	333	267	344	261	129	166
100% Modulus [kg$_f$/cm^2]	13.2	24.0	24.2	34.6	43.0	82.9	82.9

Table 5.4 compared tensile properties between NBR, NBR/PVC (70/30 w/w), NBR/SAN (70/30 w/w), and NBR/ABS (70/30 w/w) at mixing time of rubber and plastic for 3 minutes. It was observed that NBR has the lowest tensile strength and modulus-100%, whereas elongation at break of NBR was highest. NBR/SAN blended has the highest tensile strength and NBR/ABS has the highest 100% modulus because of their rigidity. For tensile properties, NBR/PVC much more closer to NBR than NBR/SAN and NBR/ABS, which means that NBR/PVC was the most rubberlike when compared with NBR/SAN and NBR/ABS blends.

Table 5.4 Compare tensile properties of NBR, NBR/PVC, NBR/SAN, and NBR/ABS blends at a composition of 70/30 w/w of rubber and plastic (mixing time 3 minutes)

Details	NBR	NBR/PVC	NBR/SAN	NBR/ABS
Tensile strength [kg$_f$/cm^2]	22	63	121	85
Elongation at break [%]	417	396	344	220
Modulus 100% [kg$_f$/cm^2]	13.2	16.5	34.6	38.6

5.1.5 Differential scanning calorimeter

To analyze the compatibility of polymer blends, T_g of blends were observed using DSC. All results were given in Table 5.5. It could be seen that all the blends had two separated T_gs, but came closer to each other. Fox equation was used to calculate of the percent miscibility [21, 40] of ABS and SAN in NBR rich phase. Compatibility in percentage was calculated using the following equation:

$$\frac{1}{T_g} = \frac{M_1}{T_{g1}} + \frac{M_2}{T_{g2}} \qquad (1)$$

Where, T_g = glass transition temperature of rich phase [K]

T_{g1}, T_{g2} = glass transition temperature of NBR and ABS or SAN [K]

M_1, M_2 = mass fraction of NBR and ABS or SAN

Table 5.5 The glass transition temperature of NBR, ABS, SAN, NBR/SAN, and NBR/ABS blends

Composition of rubber/plastic [w/w]	T_g [°C] of NBR/ABS blends		T_g [°C] of NBR/SAN blends	
100/0	-26.0		-26.0	
80/20 [3 min]	-24.5	95.7	-24.3	N/A
80/20 [4 min]	-25.3	95.7	-25.2	93.5
70/30 [3 min]	-24.8	93.5	-25.3	94.3
70/30 [4 min]	-24.0	93.3	-23.5	93.3
60/40 [3 min]	-23.7	93.7	-24.7	94.3
60/40 [4 min]	-24.4	94.0	-25.6	93.3
0/100		102.3		101.9

In this study, it was found that theoretical percent compatibility of ABS into NBR rich phase as a composition of 60/40, 70/30, and 80/20 w/w were 2.69, 1.88 and 1.77 wt% respectively. Percent compatibility of SAN into NBR rich phase as a composition of 60/40, 70/30, and 80/20 w/w were 1.53, 0.83 and 2.00 wt% respectively. It could be concluded that ABS and SAN were partially compatible with NBR, while ABS easier compatible with NBR than SAN because ABS has butadiene as same as NBR. However, this samples obtained from melt mixing were different from solvent casting done in previous publications [19, 21], so the degree of compatibility also depended on the mixing method as well.

5.1.6 Thermo gravimetric analysis

Figure 5.14 and 5.15 showed that all samples had single step degradation. From DTG curves SAN had sharper peak than others, indicating that SAN has faster degradation rate than NBR, ABS and the polymer blends. Both NBR/ABS and

NBR/SAN at all compositions (60/40, 70/30 and 80/20 w/w) had closer degradation rate profiles, so only one composition (80/20 w/w) was presented. Comparing DTG curves of NBR with other polymer blends, they exhibited quite similar profiles. This result is in agreement with that has been reported by S. Anandhan, 2009 [23]. The effects of ABS and SAN are interpreted in Table 5.14.

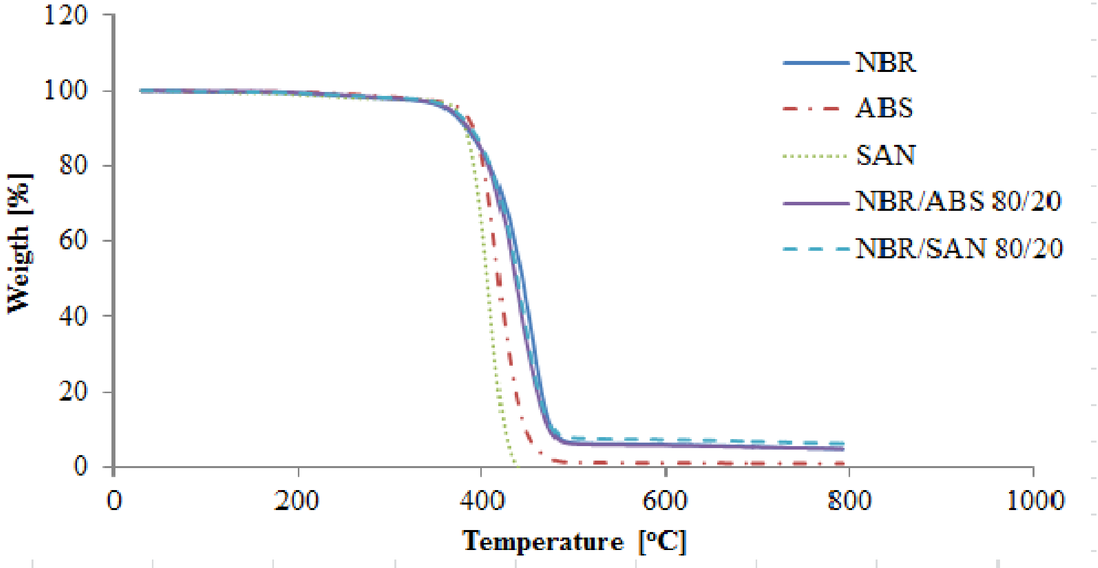

Figure 5.14 TG curves of NBR, ABS, SAN, NBR/ABS 80/20, and NBR/SAN 80/20

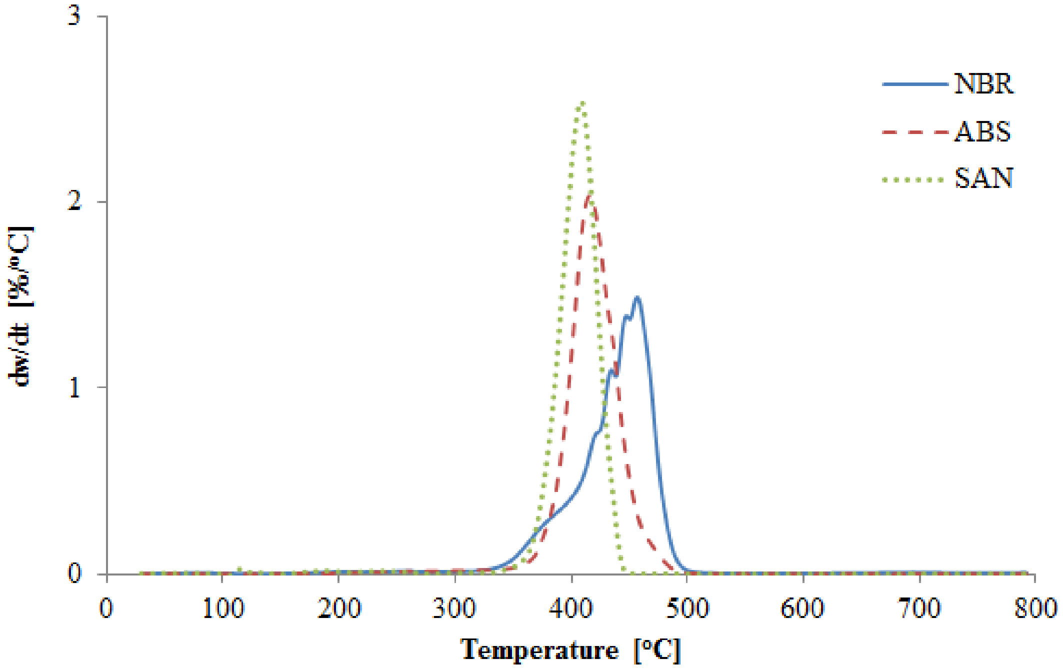

Figure 5.15 DTG curves of NBR, ABS, SAN

From Table 5.6, T_{max} was the temperature corresponding to maximum rate of decomposition. Both ABS and SAN had T_{max} lower than NBR and the other blends. NBR/ABS blends had lower rate of degradation than NBR. SAN had the highest rate of degradation. NBR produced more char residue at 800 ^{o}C than ABS and SAN due to cyclisation of nitrile component [41]. NBR/ABS at the composition of 70/30 and 80/20 w/w and NBR/SAN at the composition of 80/20 w/w gave the higher char residue than NBR. This indicated that thermal stability of NBR could be improved by blending with ABS or SAN. This was due to the presence of cross-linked between NBR with ABS and SAN, sulphur could be abstract some hydrogen from ABS and SAN and create cross-link which could be proved by DMA.

Table 5.6 TGA results of NBR, ABS, SAN, and polymer blends (mixing time 3 min)

Polymer blends	T_{max} [^{o}C]	dw/dt [%/^{o}C]	Char residue at 800 ^{o}C [%]
NBR	457	1.49	4.72
ABS	416	2.04	0.86
SAN	409	2.54	0.06
NBR/ABS (60/40)	431	1.34	2.93
NBR/ABS (70/30)	428	1.32	6.27
NBR/ABS (80/20)	432	1.42	4.81
NBR/SAN (60/40)	439	1.57	2.19
NBR/SAN (70/30)	435	1.59	2.49
NBR/SAN (80/20)	438	1.50	6.20

5.1.7 Dynamic mechanical analysis

Considering the results of DMA from Figure 5.16, T_g of NBR/ABS blends have no obvious change from ABS as same as NBR/SAN blended. E'(storage modulus) of NBR/ABS blends at the composition of 60/40, 70/30, and 80/20 w/w were reduced by 42.37%, 73.11%, and 79.42%, respectively when compared with ABS. E' of NBR/SAN blends at the composition of 60/40, 70/30, and 80/20 w/w were reduced by 66.90%, 79.58%, and 83.06%, respectively when compared with SAN. E'' (loss modulus) of NBR/ABS blends at the composition of 60/40, 70/30, and 80/20 w/w were also decreased 93.41%, 97.66%, and 98.85%, respectively when compared with ABS. E'' (loss modulus) of NBR/SAN blends at the composition of 60/40, 70/30, and 80/20 w/w were also decreased 94.43%, 97.99%, and 98.90%, respectively when compared with SAN. For this study, it could be concluded that the increasing of NBR leads to decreasing of stiffness and rigidity of polymer blends.

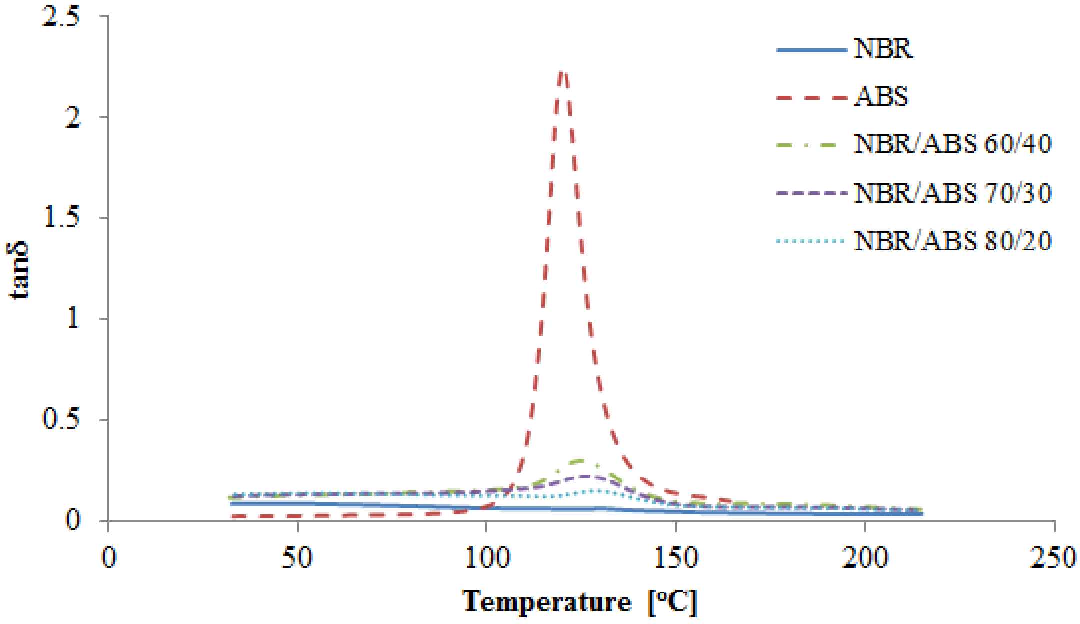

Figure 5.16 tanδ versus temperature of NBR, ABS, and NBR/ABS blends

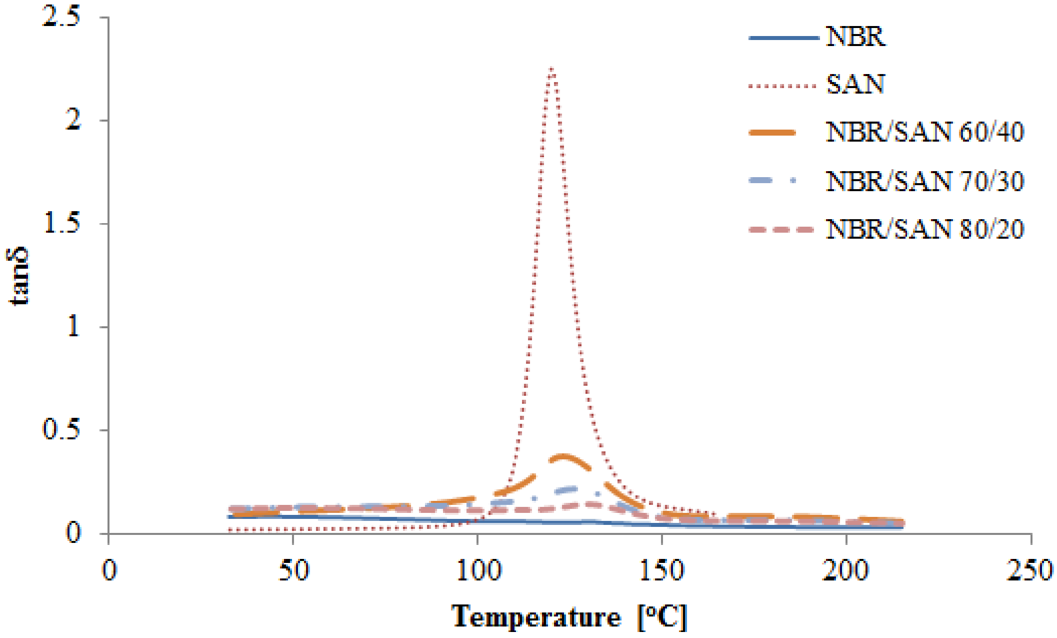

Figure 5.17 tanδ versus temperature of NBR, SAN, and NBR/SAN blends

At figure 5.18 the large decreased in the storage modulus at temperature above 100 °C indicated the beginning of the corresponding glass transition region of ABS. However, in the blend, the storage modulus decrease down to NBR cross-link level which showed that some cross-link occurred in those samples, but the amount of sulphur used was limited to equal NBR amount, so the cross-link were quite similar in all samples. For figure 5.19-5.20 NBR/ABS and NBR/SAN blends exhibited higher the storage modulus than NBR. R. Sirichai's, 2006 [42] had been reported DMA result which could be explain about cross-link of sample, figure 5.21 represent the cross-linked polyimides with NCO/OH equal to 1.0 called PI50-C1.0 and PI50. The PI50-C1.0 showed higher storage modulus than the PI50 in the high temperature range (above 350 °C) which confirm about cross-linked of PI50-C1.0 in itself. That could be confirmed about cross-linked between NBR with ABS and SAN.

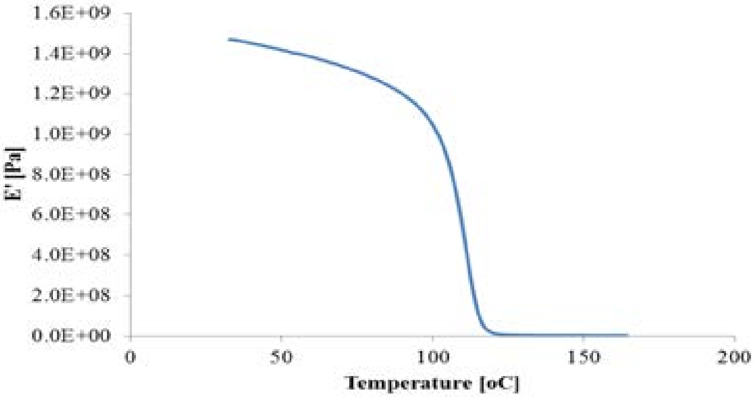

Figure 5.18 DMA curves (storage modulus (E') and temperature) for ABS

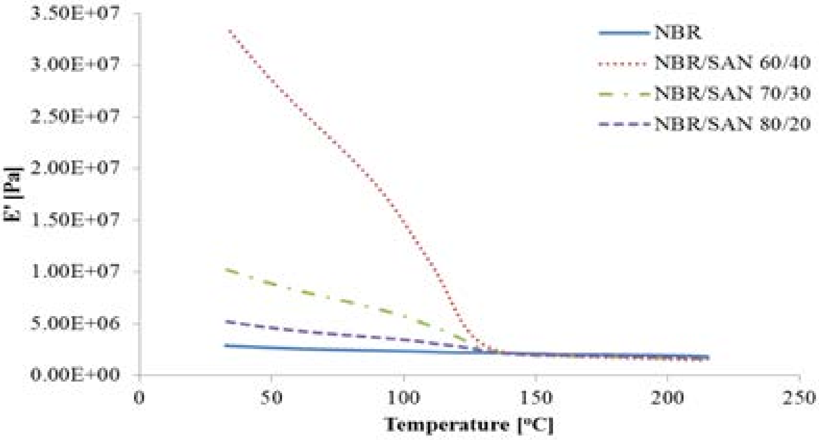

Figure 5.19 DMA curves (storage modulus (E') and temperature) for NBR and NBR/SAN blends

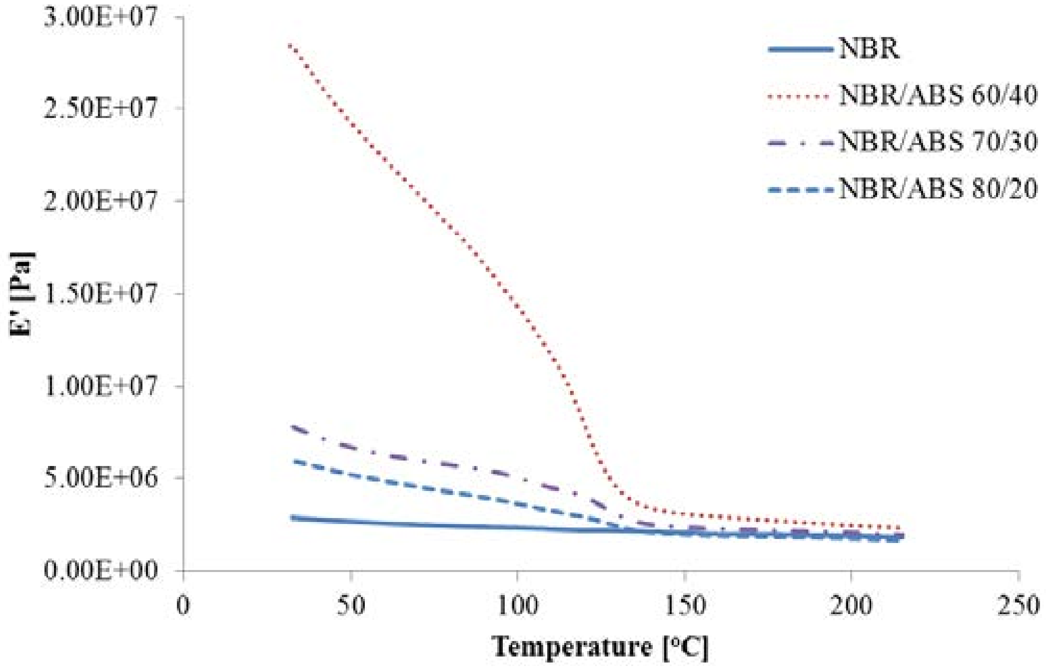

Figure 5.20 DMA curves (storage modulus (E') and temperature) for NBR and NBR/ABS blends

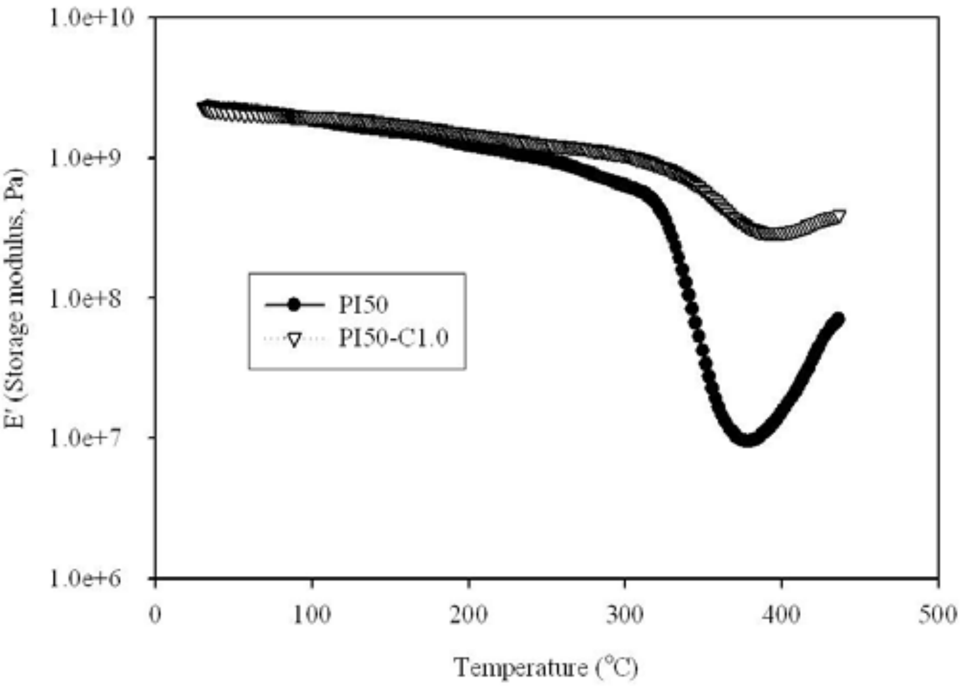

Figure 5.21 DMA curves (storage modulus (E') and temperature) for PI50 and PI50-C1.0

5.2 The influences of chemical solutions on physical and mechanical properties

For mechanical properties in this study included tensile strength, elongation at break, modulus 100%, hardness, and compression set tests. The aim of testing was to study the influence of fuel and ethanol to NBR, HNBR, NBR/SAN, and NBR/ABS blends and compare results which material gave the best properties. For physical properties included volume change, and dimension change after immersed in different chemical solutions.

The specimens were took to measure these properties on day 1st, 2nd, and 3nd and on week 1st, 2nd, 4th, and 8th then compared with the valued recorded before immersion. The average and standard deviation were used to compare to determine test variance. Three pieces of samples were used to collect for tensile strength, elongation at break, modulus 100%, volume change, dimension change, and compression set test and one piece was used for hardness test.

5.2.1 Tensile properties

Four test polymers (NBR, HNBR, NBR/SAN, and NBR/ABS at a composition of 80/20 w/w of rubber and plastic) were immersed in four chemical solutions (gasoline 95, E85, ethanol, and acidic E20) to compare results and investigate the effect of chemical solution to materials. Figure 5.18-5.21 showed tensile strength after immersed in gasoline 95, acidic E20, E85, and ethanol respectively. When immersed samples in each test chemical solution, tensile strength, was rapidly decreased in the first day. For gasoline 95, HNBR, NBR/SAN, and NBR/ABS had similarly trend line and closed values, tensile strength of samples were increased to 7 days and decreased at 14th days and increased again at 28th days then slightly decreased until 56 days while NBR has the highest tensile strength at 14th days then slightly decreased until 56 days as well. Tensile strength showed all samples could be resist to acidic E20 for 30 days especially HNBR and NBR/ABS. Moreover, NBR and NBR/SAN had the close trend line and closed value, tensile strength of sample was peak at 7th days and decreased at 14th days after that slightly changed until finish test. For E85, all materials had similarly trend line. Tensile strength slightly decreased through 3 days then rapidly increased at 7th days after that decreased until finish test. Ethanol affected to tensile strength of all samples similar to E85 and all samples could be resisted to ethanol for 30 days.

When chemical solutions have higher ethanol content HNBR could be had the higher tensile strength than other polymer which means that HNBR could be better resist to ethanol than NBR, NBR/SAN, and NBR/ABS. Almost all tensile strength had the same pattern of graph increase first and then have the second increase and then drop down slightly. This might be because tensile strength is the product of force per unit cross section area, so if the cross section area was less in the first 7 days, tensile strength should be higher. After 14 days, it might be that the all the samples has loss the real strength but cross section area changes a lot during second 7 days, so the tensile strength were increase again. After that the tensile strengths were loss rapidly than the swelling of cross section, so the tensile strength dropdown.

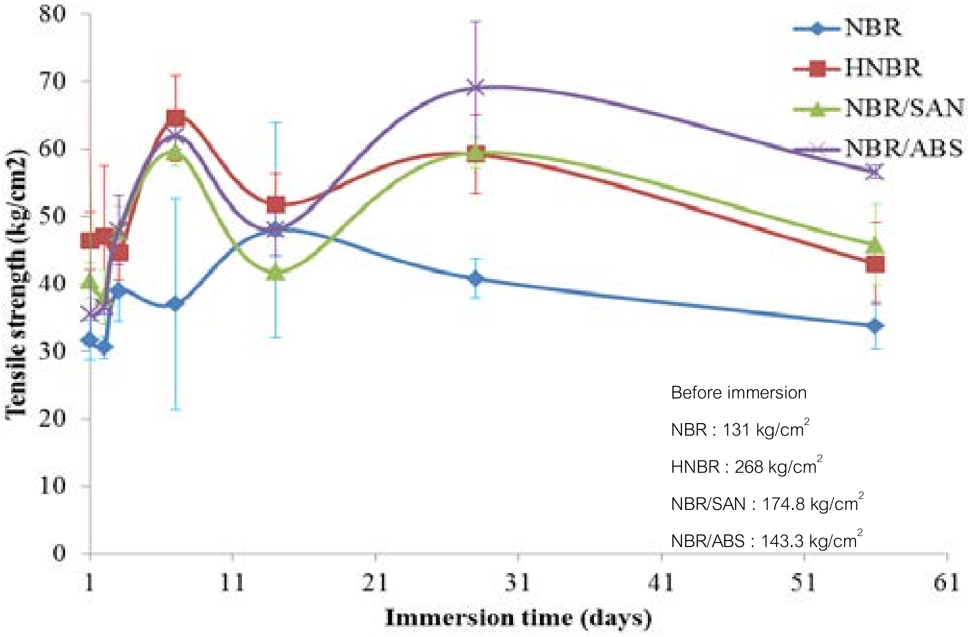

Figure 5.22 Tensile strength of samples immersed in gasoline 95 (Error bar is one standard deviation)

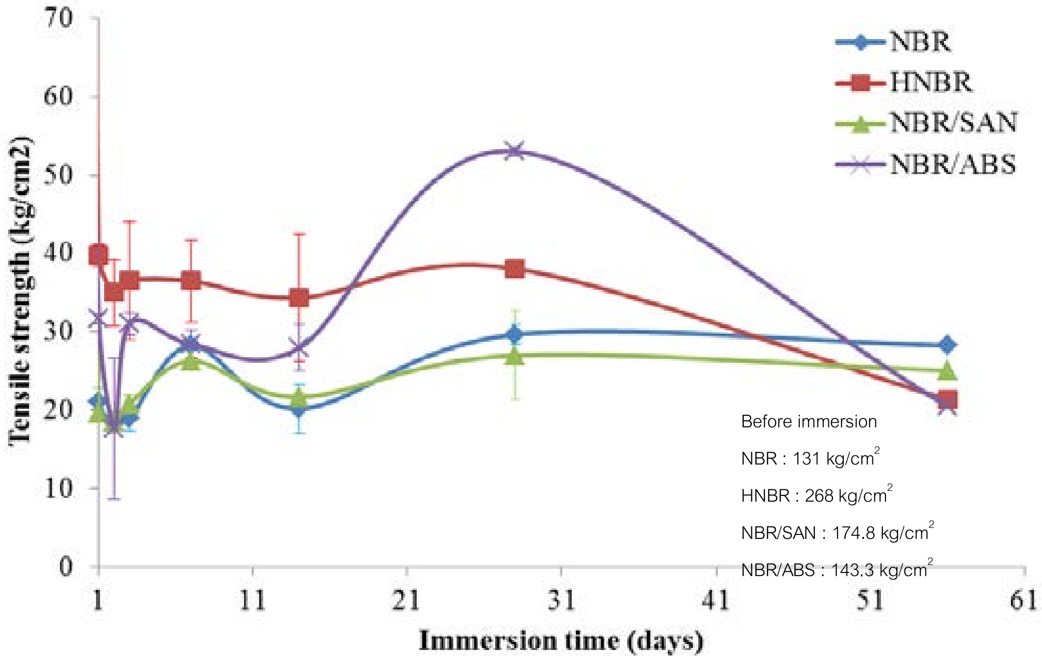

Figure 5.23 Tensile strength of samples immersed in acidic E20 (Error bar is one standard deviation)

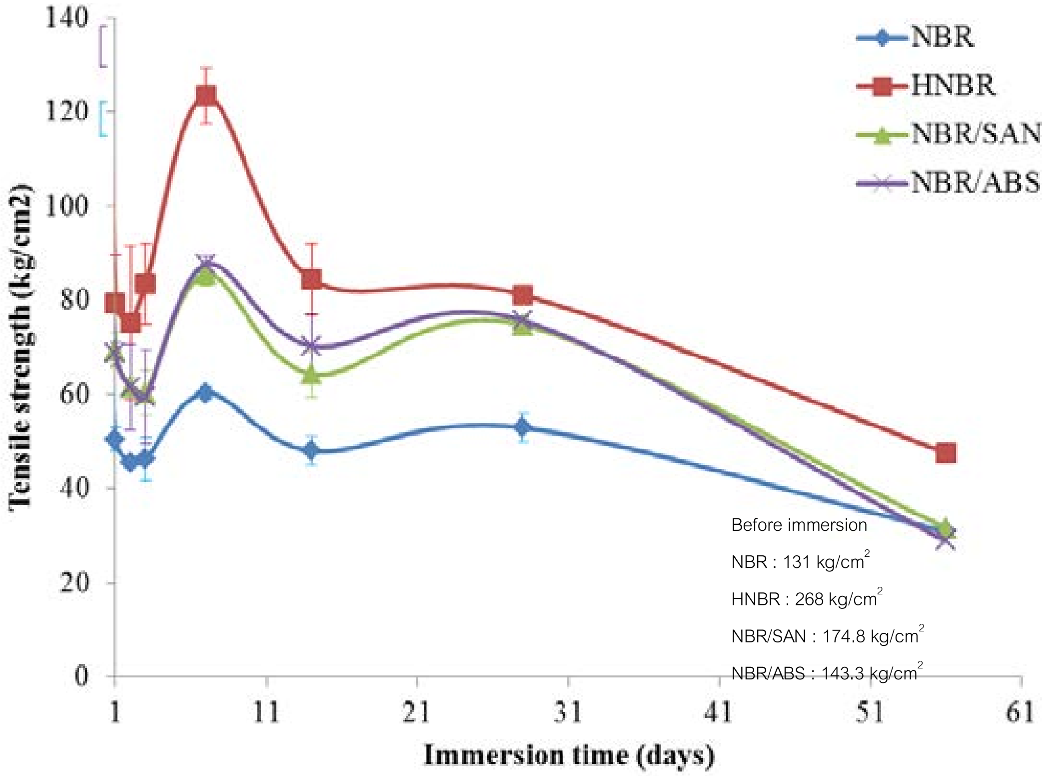

Figure 5.24 Tensile strength of samples immersed in E85 (Error bar is one standard deviation)

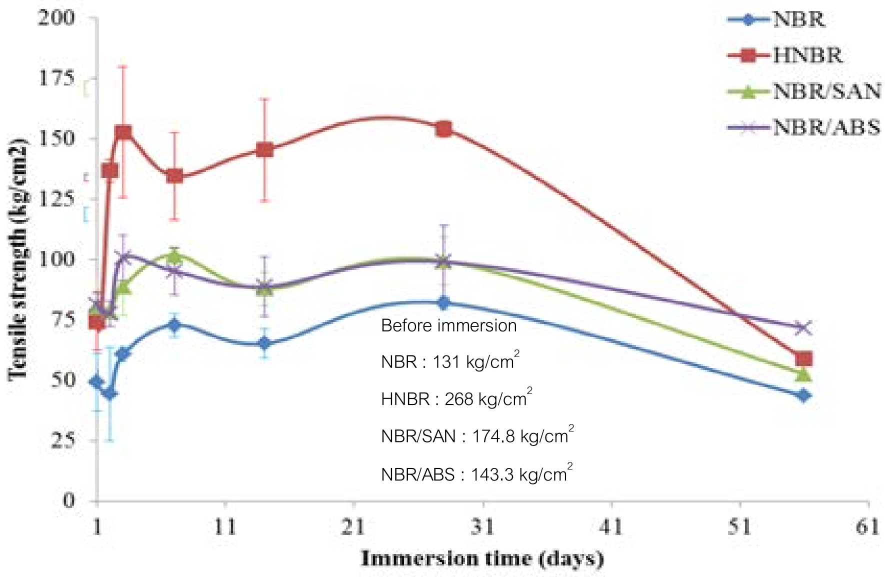

Figure 5.25 Tensile strength of samples immersed in ethanol (Error bar is one standard deviation)

Figure 5.22-5.25 showed elogation at breaak of samples after immered. As same as tensile strength results, after immersed samples in each test chemical solution, elongation at break was rapidly decreased in the first day. HNBR, NBR/SAN, and NBR/ABS had similarly trend line, elogation at break rapidly increasing from first day to 7th days and decreased at 14th days then increased through 28th days and finally decreased untill finish test. Elogation at break of NBR increased for 2 days but decreased at 3rd days then slightly increased until 56 days. After immersed samples into acidic E20, the trend line of elogation at break of HNB and NBR/ABS were similar to samples that immersed in gasoline 95 but had clearly highest value at 28th days. NBR had slightly increased elongation at break from first day through 28th days after that was decreased. In the other hand, elongation at break of NBR/SAN increased for 3 days then decreased at 14th days after that the value was increased until finish test. E85, the values of elongation at break of NBR, NBR/SAN, and NBR/ABS were fluctuated until 28 days and then were slightly decreased. Elongation at break of HNBR decreased for the first 3 days then rapidly increased at

7th days and decreased until 28th days and slightly increased until 56th days. For ethanol, the values of elongation at break were fluctuated for 7 days first after that slightly changed until finish test.

Acidic E20 made all samples had the lowest elongation at break when compared with other chemical solution because acidic E20 contained aggressive ethanol that consist of de-ionize water, sodium chloride, ethanol, acetic acid, and sulfuric acid which means acidic E20 had stronger affect to polymer than other chemical solution, that especially affected the flexibility of rubber.

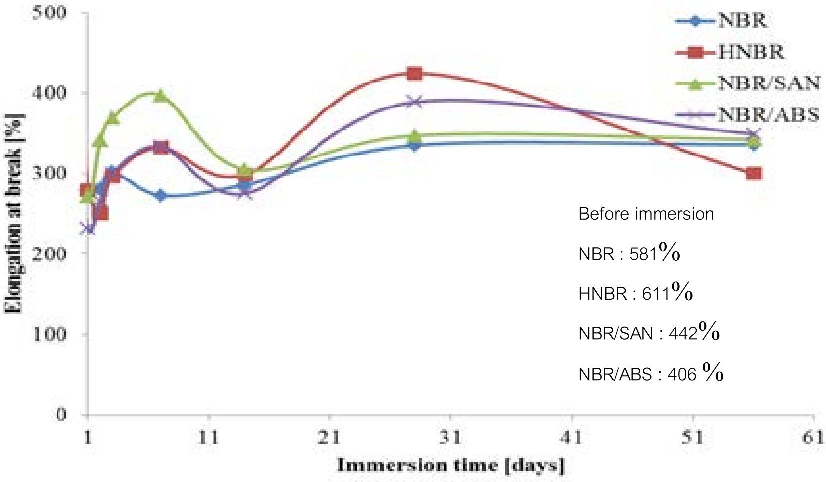

Figure 5.26 Elongation at break of samples immersed in gasoline 95 (Error bar is one standard deviation)

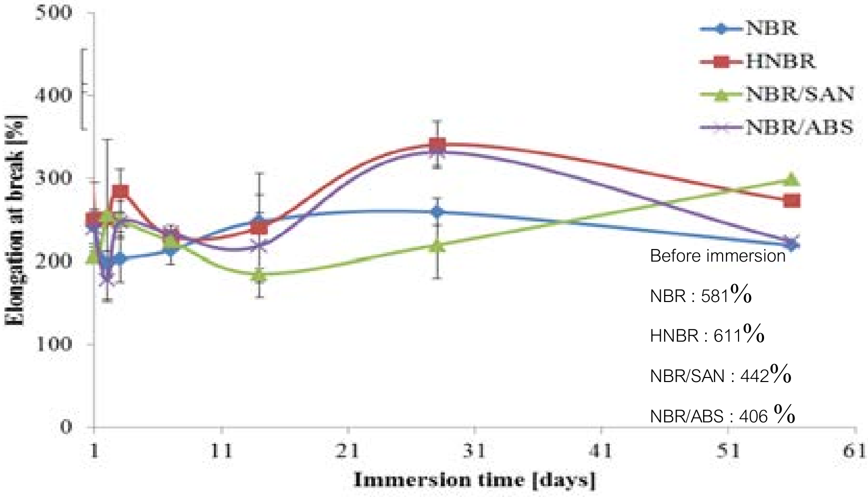

Figure 5.27 Elongation at break of samples immersed in acidic E20 (Error bar is one standard deviation)

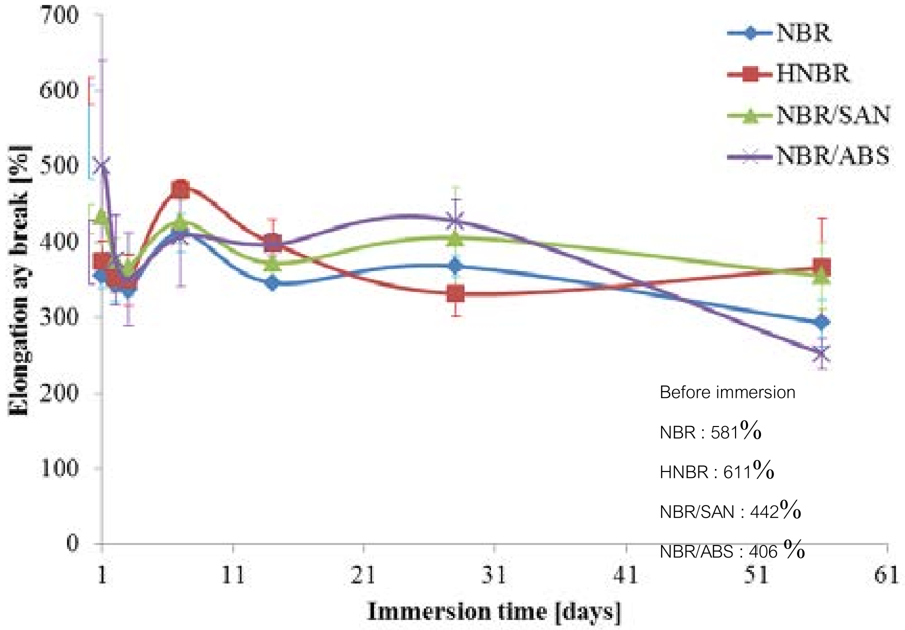

Figure 5.28 Elongation at break of samples immersed in E85 (Error bar is one standard deviation)

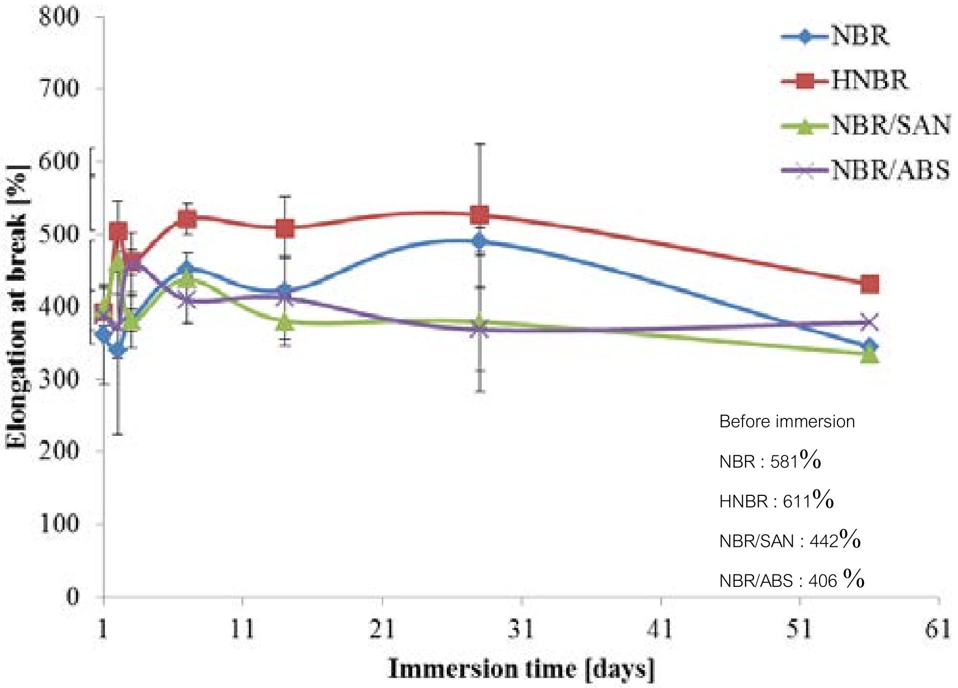

Figure 5.29 Elongation at break of samples immersed in ethanol (Error bar is one standard deviation)

Normally, elongation represented the flexiblity of rubber and how it contain rigid part inside. The ABS and SAN by theoretical would reduced the elongation of the speciments, comprise them. However, elongation was the product of increase length when subject to force divided by total length. Almost all the curves had similar trends, to increase in first 7 days and have the second increase and died down. However, this also depended on the solvent, it had been soaked too. This might be because of the results of loss the plastic dissolved out fast in the first 7 day, leaving crosslink that show the properties of rubber clearly. The second peak might be because the plastic at the depth of the specimen is totally washed out compare to results from cross-link, so it gave a second increase. After that, was the process of degradation because soaking in solvents, so the elongation drop down.

Figure 5.26-5.29 showed modulus 100% of samples after immered. The results after immersed agree with tensile strength and elongation at break, the values of all samples were dropped after immersed 1st day. All samples that were immersed in gasoline 95 had similarly trend line, modulus 100% of samples were decreased at 2nd days then increased through 7th days and slightly increased until finish test but NBR/SAN blended had the highest peak at 28th days then decreased until finish test. NBR/ABS had oscillated value when immersed in acidic E20 and had highest modulus 100% at 28th days then rapidly decreased until finish test. NBR had similarly trend line to NBR/ABS but had the maximim value at 3rd days and minmum value at 14th days, the mosulus 100% was unchanged since 28th days until 56th days. HNBR that was immersed in acidic E20 was decreased for the first 3 days then raised at 7th days and after that the value was decreased until ended test. NBR/SAN had minimum value at 2nd days and the value were slightly changed until finish test. E85, modulus 100% of NBR/ABS blended was increasd through 7th days and decresed until ended test. The value of NBR/SAN quite fluctuated but after 28th days was rapidly decreased. HNBR's modulus 100% was sligthly raised from start test until 3rd days and decreased at 7th days then had the highest value at 28th days and was rapidly decreased until finish test. The value of NBR slightly decreased along testing, the modulus 100% of NBR/SAN blended was minimum at 2nd days. For ethanol testing, HNBR and NBR had similarly trend line, NBR/SAN and NBR/ABS had similarly trend line as well. HNBR and NBR had maximum modulus 100% at 2nd days and then slightly changed until ended test. The results of NBR/SAN and NBR/ABS were quite oscillated, both NBR/SAN and NBR/ABS blended had the maximum value of modulus 100% at 28th days and then decreased until 56th days.

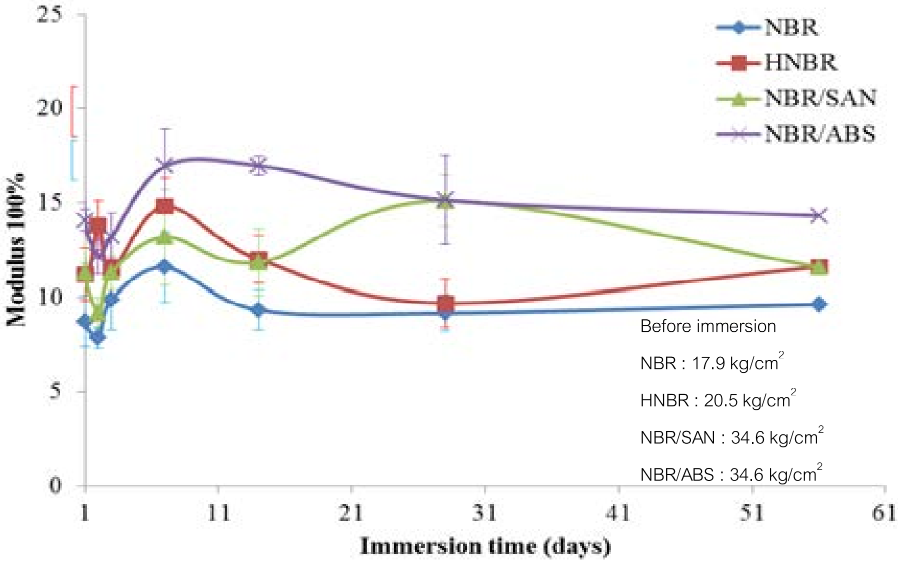

Figure 5.30 Modulus 100% of samples immersed in gasoline 95 (Error bar is one standard deviation)

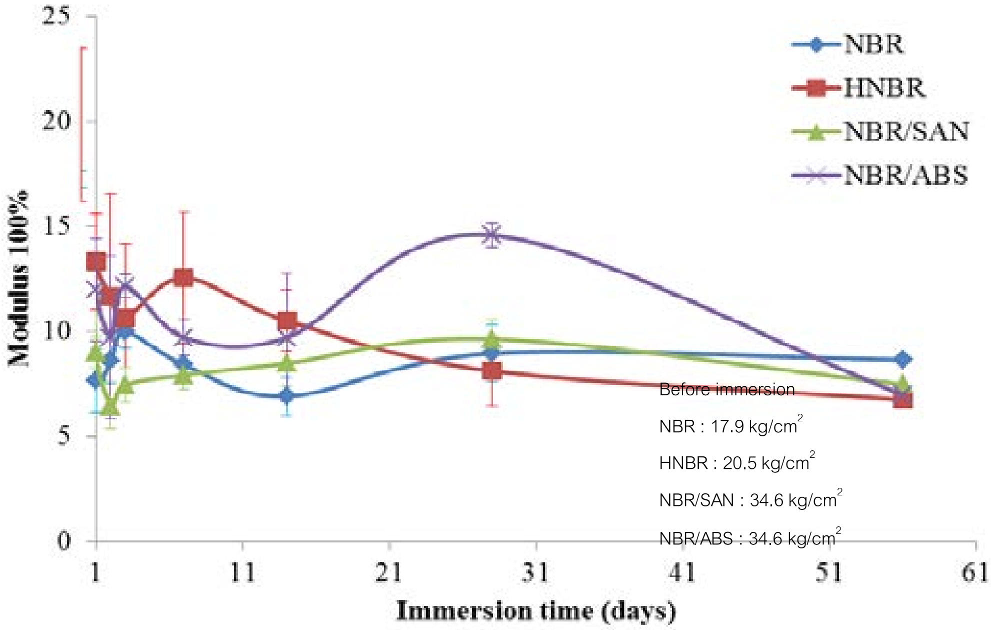

Figure 5.31 Modulus 100% of samples immersed in acidic E20 (Error bar is one standard deviation)

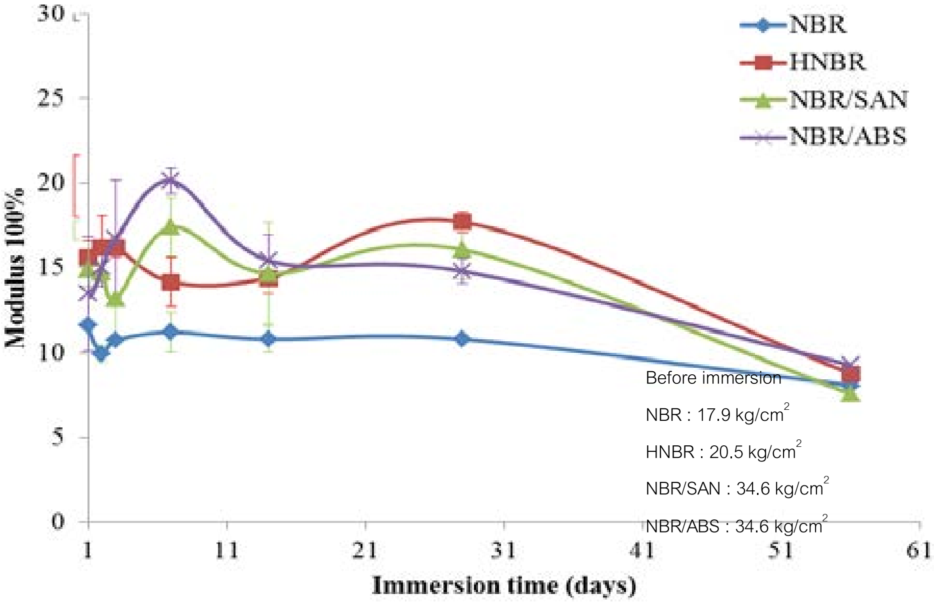

Figure 5.32 Modulus 100% of samples immersed in E85 (Error bar is one standard deviation)

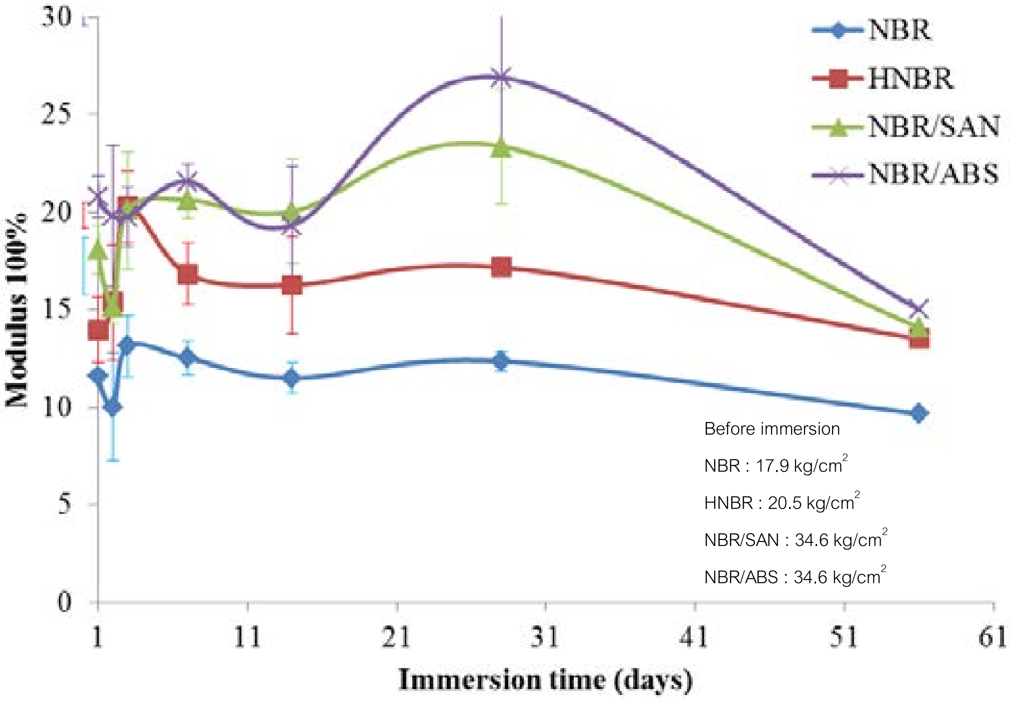

Figure 5.33 Modulus 100% of samples immersed in ethanol (Error bar is one standard deviation)

5.2.2 Hardness

Figure 5.30-5.33 showed hardness of samples that were immersed in gasoline 95, acidic E20, E85, and ethanol respectively. The hardness of all samples were rapidly decreased in the first day of immersion. After 7th days, all samples in all chemical solutions had slightly changed of hardness until ended test.

Normally, hardness depended on level of cross-link and amount of thermoplastic inside the specimens. So, after first day, the plastic at surface or free molecules without cross-link were washed out first created lower hardness at surface. Moreover, hardness mostly depended on surface properties, so properties in the bulk at later days had less affected to hardness.

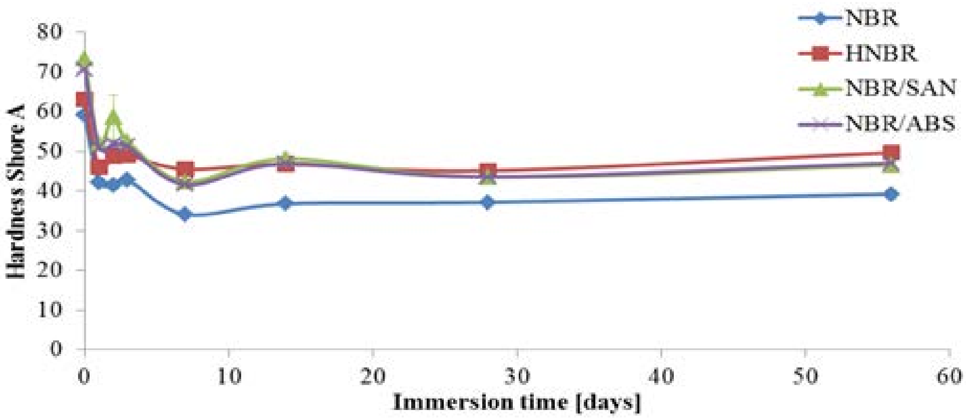

Figure 5.34 Hardness of samples immersed in gasoline 95 (Error bar is one standard deviation)

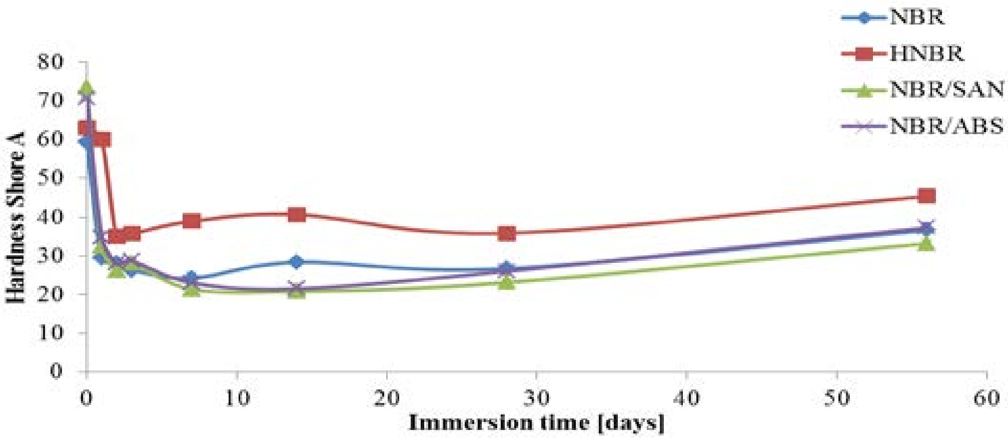

Figure 5.35 Hardness of samples immersed in acidic E20 (Error bar is one standard deviation)

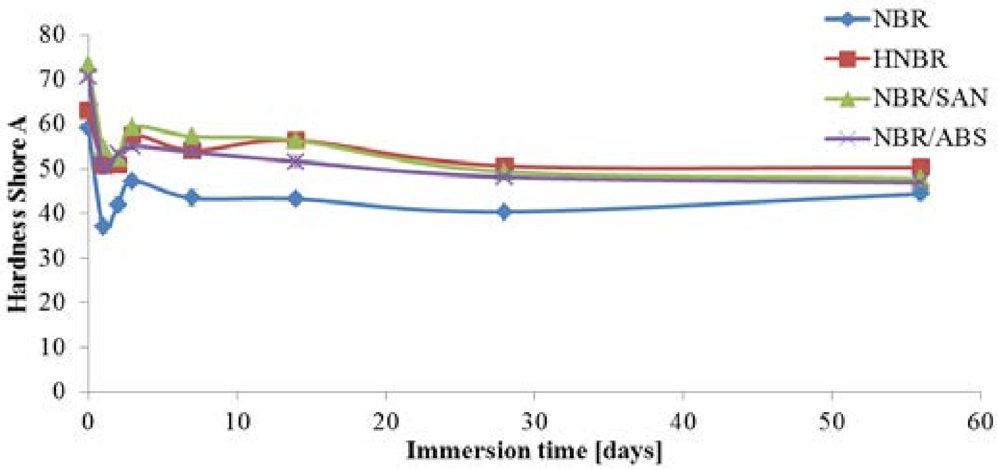

Figure 5.36 Hardness of samples immersed in E85 (Error bar is one standard deviation)

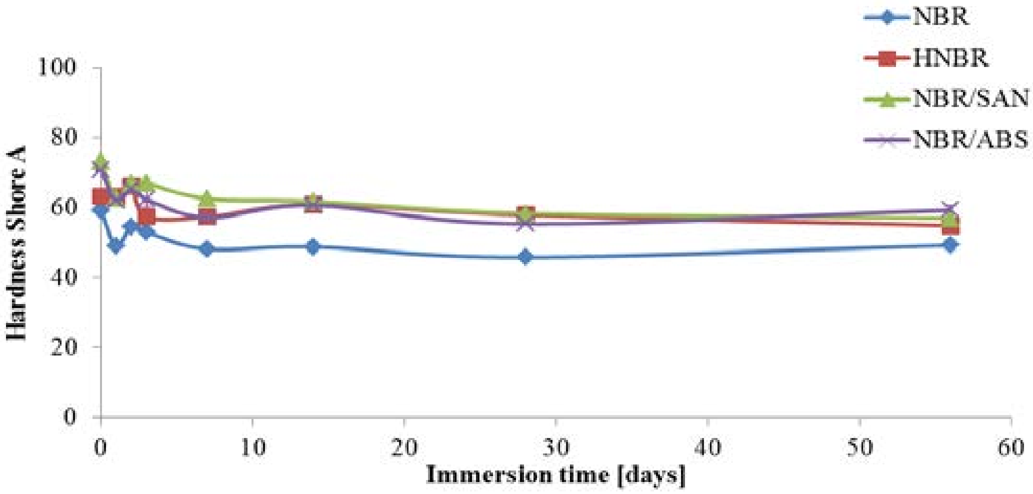

Figure 5.37 Hardness of samples immersed in ethanol (Error bar is one standard deviation)

5.2.3 Compression set

The cylindrical disk samples will be compressed under constant deflection. Compression set tests were intended to measure the ability of sample to retain elastic properties after pro-longed action of compressive stresses. Figure 5.34-5.41 showed compression set of samples that were immersed in gasoline 95, acidic E20, E85, and ethanol. Refer to figure 5.34-5.34, the samples were immersed in gasoline 95. All samples showed agreement results, the compression set had the worst case at 3rd days and showed slightly better results after 3 days until ended test. HNBR, NBR/SAN, and NBR/ABS showed quite closed results while NBR had the lowest compression set which means NBR had the best revert results. The results of acidic E20 were showed at figure 5.36-5.37, all samples had the highest compression set at the first day immersion. HNBR, NBR/SAN, and NBR/ABS showed the similarly values while NBR showed lower value for 3 days immersed and at 7 days passed the compression set of all samples came closed to each other and slightly changed until finish test. E85, HNBR showed the worst results at the first day immersion and the compression set rapidly decreased through 28th days then quite stable until the end. NBR/SAN and NBR/ABS showed the similarly trend line and the result of NBR/SAN worse than NBR/ABS. Both NBR/SAN and NBR/ABS had the worse result at 7th days and then slightly changed until finish test. Ethanol made HNBR, and NBR/ABS had the worst compression set at the 3rd days while NBR got worst at the first day immersion and NBR/SAN had the worse value at 7th days. After 28 days passed, HNBR, NBR/SAN, and NBR/ABS had the quite closed compression set until the finish test.

NBR had the best compression set at all chemical solutions which means NBR could be retain elastic properties after pro-longed action of compressive stresses than other polymer in this study while HNBR, NBR/SAN, and NBR/ABS had no quite different of compression set in the long term of testing.

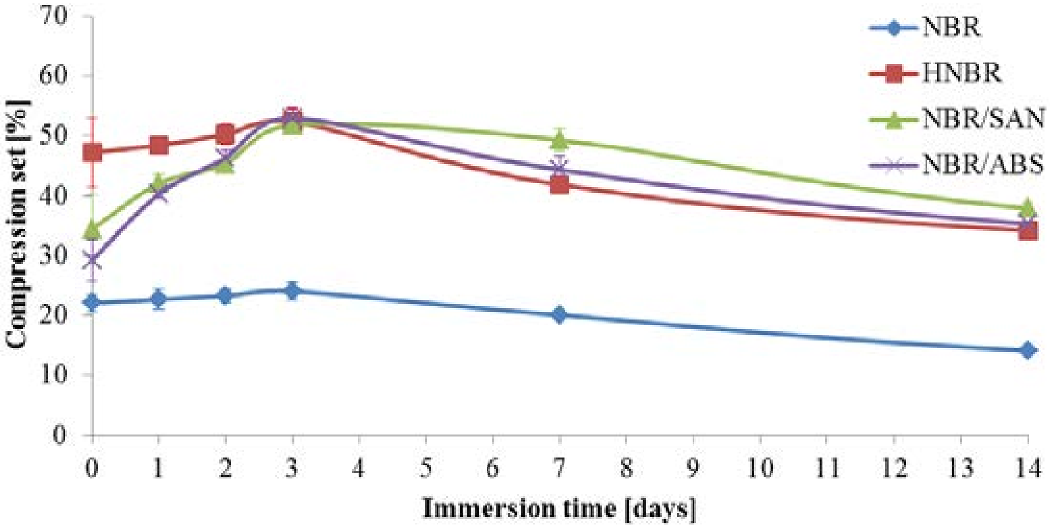

Figure 5.38 Compression set of samples immersed in gasoline 95 (Error bar is one standard deviation)

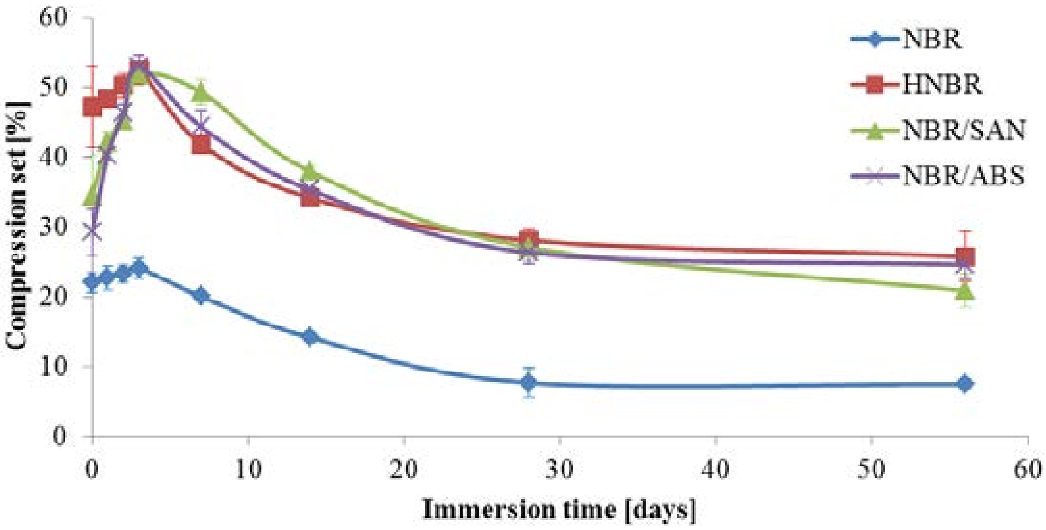

Figure 5.39 Compression set of samples immersed in gasoline 95 (Error bar is one standard deviation)

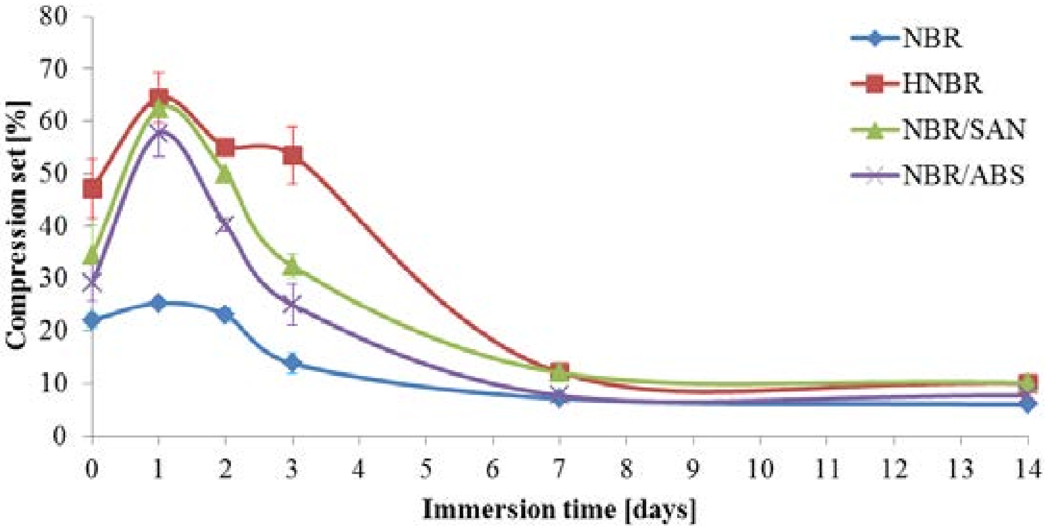

Figure 5.40 Compression set of samples immersed in acidic E20 (Error bar is one standard deviation)

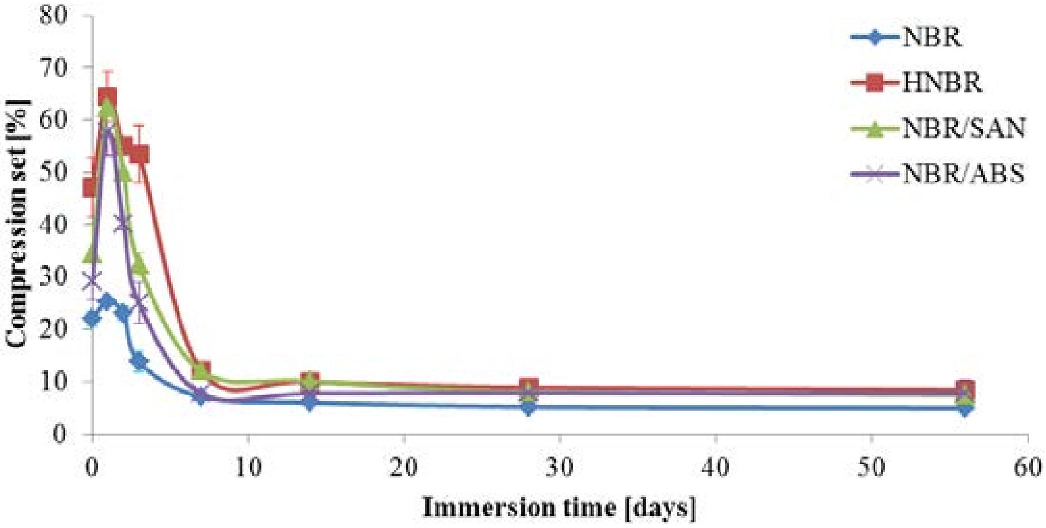

Figure 5.41 Compression set of samples immersed in acidic E20 (Error bar is one standard deviation)

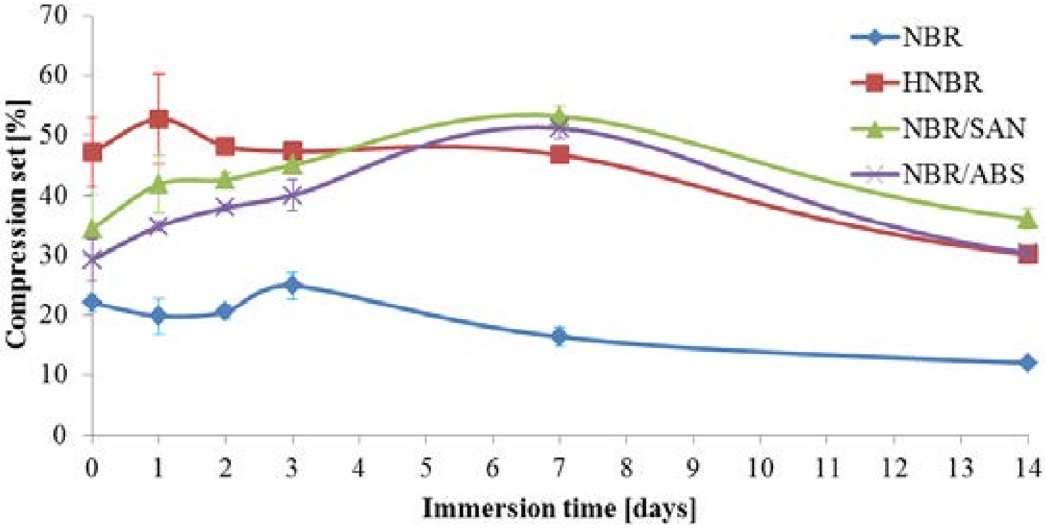

Figure 5.42 Compression set of samples immersed in E85 (Error bar is one standard deviation)

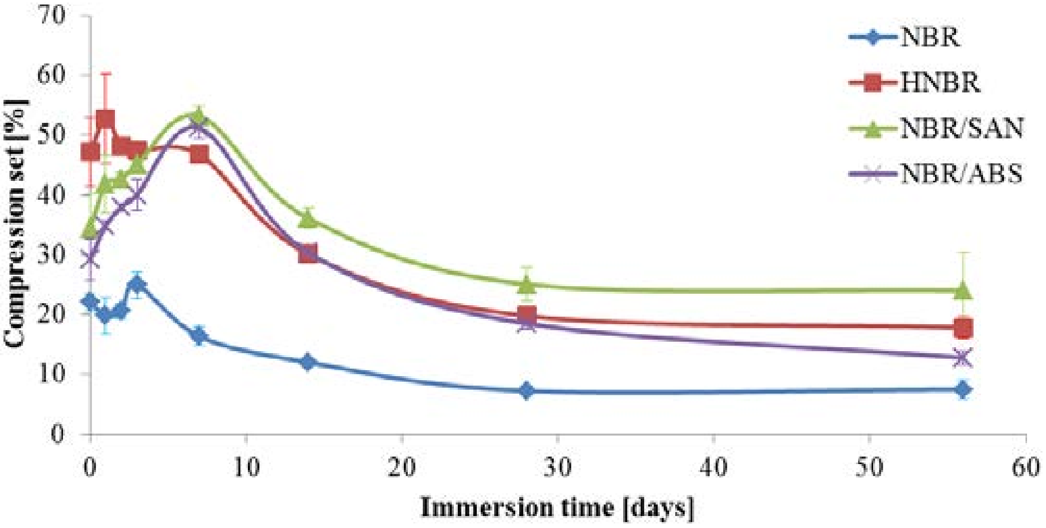

Figure 5.43 Compression set of samples immersed in E85 (Error bar is one standard deviation)

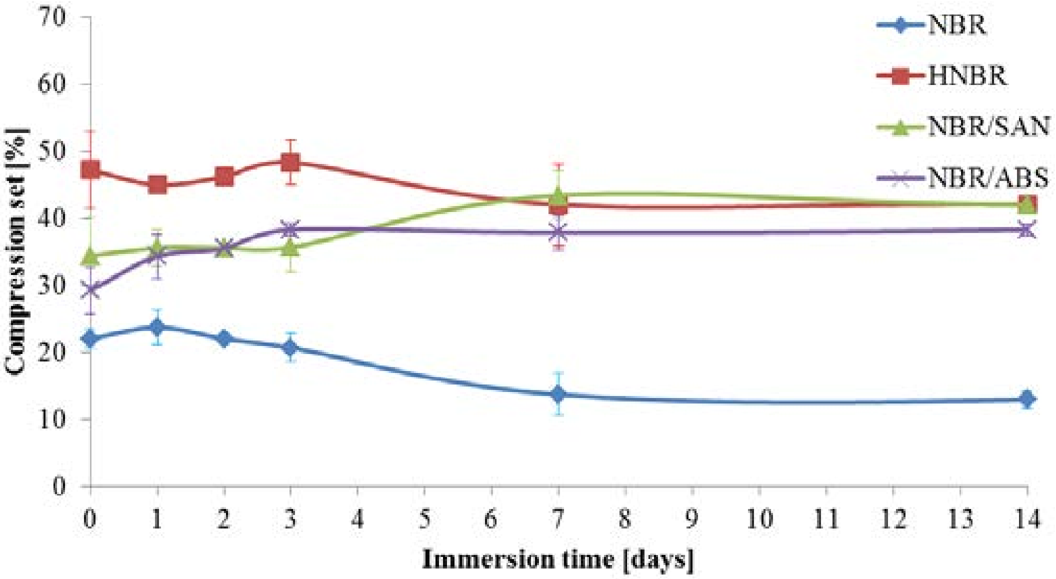

Figure 5.44 Compression set of samples immersed in ethanol (Error bar is one standard deviation)

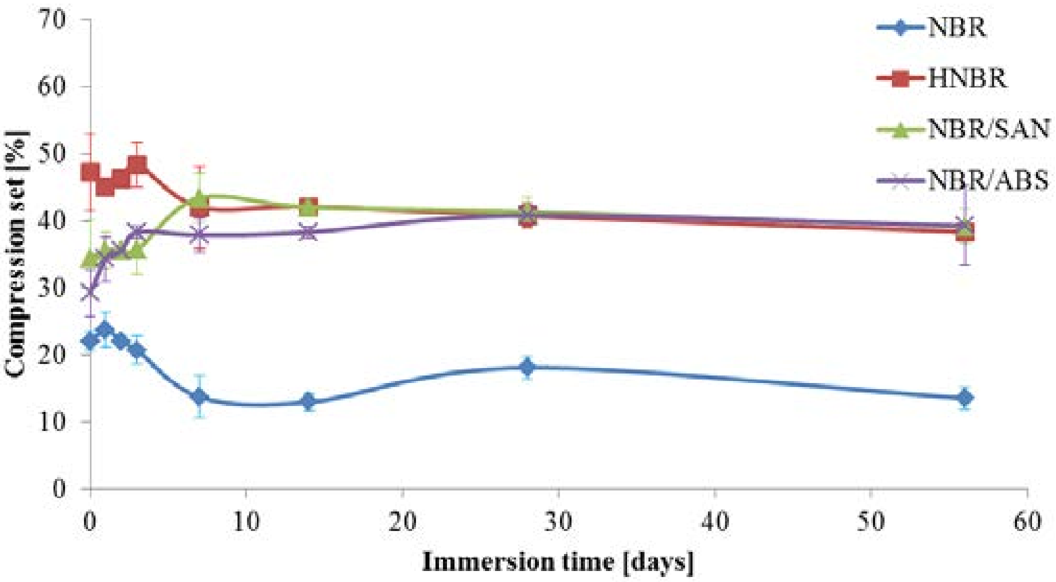

Figure 5.45 Compression set of samples immersed in ethanol (Error bar is one standard deviation)

5.2.5 Dimension change

The thickness and diameter of samples as cylindrical shape at 12.70 ± 0.13 mm in thickness and 29.0 mm in diameter were measured before and after immersed into chemical solutions then reported as percent of dimension change. The results of dimension change by thickness and diameter showed the same trends, so only dimension change in thickness was presented because thickness was the most venerable part to expansion.

Figure 5.46-5.53 represented dimension change of NBR, HNBR, NBR/SAN, and NBR/ABS after immersed in chemical solutions, the chemical solutions could be affected dimensional stability. All samples that were immersed in all chemical solutions exhibited similar trends, at 7th days first the samples had rapidly increased of dimension after that all samples had slightly increased in thickness until the ended of test. For more details, the samples that were immersed in gasoline 95, HNBR showed the highest of dimension change for 14 days first while NBR, NBR/SAN, and NBR/ABS exhibited the closed results. After 28 days, NBR/ABS showed the highest dimension change until finish test and NBR showed the lowest value at the ended. As acidic E20, NBR/SAN showed lower dimension change in 28 days first. NBR and NBR/ABS showed the quiet similar dimension change and NBR/ABS blends show the lower value at 56th days of testing. Moreover, after 28 days immersion, dimension change of NBR/ABS showed the decreased value while HNBR had the highest dimension change until finish immersion. In the other hand, HNBR exhibited the lowest dimension change when immersed in E85 and NBR/SAN showed the most increased of percent dimension changed. NBR/ABS showed the similarly trend line to NBR/SAN. NBR showed the closed value of percent dimension change to HNBR until 7 days of immersion, except at 3rd days NBR exhibited quite high dimension change in percent. From days 28 to days 56, NBR showed the same trend to NBR/ABS but had slightly higher value than NBR/ABS. Ethanol soak solvent, NBR showed oscillate value for 7 days immersed and rapidly increased to days 14 then slightly increased until finish test. NBR/SAN and NBR/ABS blends showed similarly trend line, dimension changes were rapidly increased for 2 days first then slightly increased till the ended. HNBR showed the least changed in dimension change. Considering the influences of soak solvents, HNBR had less percent of dimension change than other polymer in this study when increasing ethanol content in immersion chemical which means that HNBR could be better resist to ethanol than NBR, NBR/SAN, and NBR/ABS, this conclusion was conform to tensile strength results. The more gasoline in the ingredients would result in poorer properties of HNBR. This might be because the HNBR has the least free butadiene and comprise some part of aliphatic main chain which will resist more to alcohol but less in gasoline. While NBR and the polymer comprised of NBR showed the similar results, better in gasoline rich fuel, but less in the alcohol rich fuel.

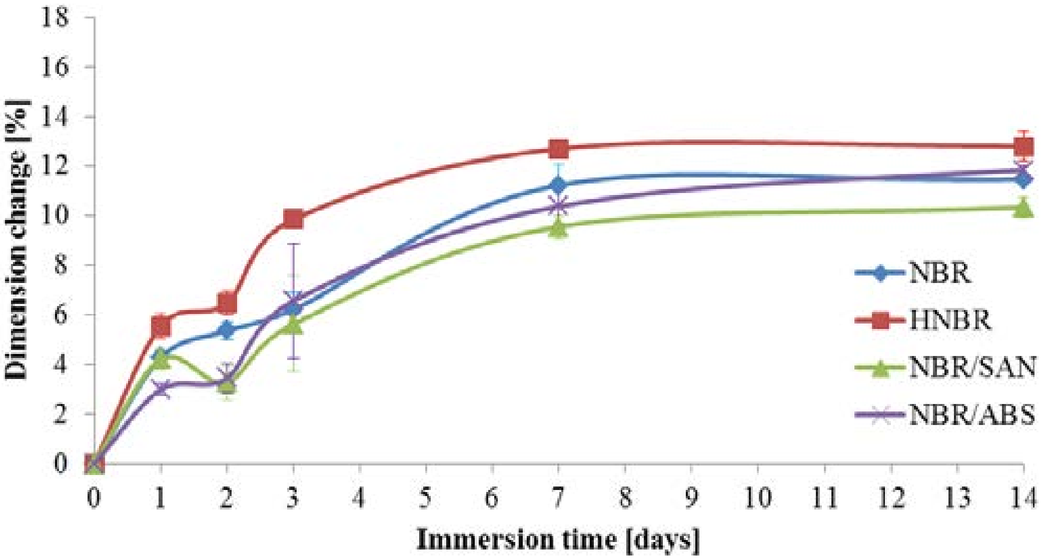

Figure 5.46 Dimension change of samples immersed in gasoline 95 (Error bar is one standard deviation)

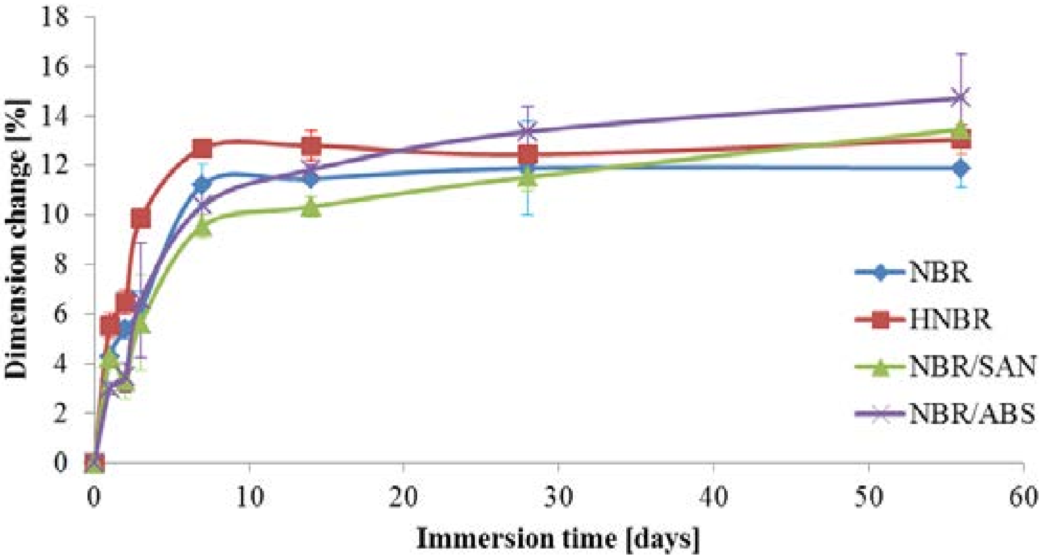

Figure 5.47 Dimension change of samples immersed in gasoline 95 (Error bar is one standard deviation)

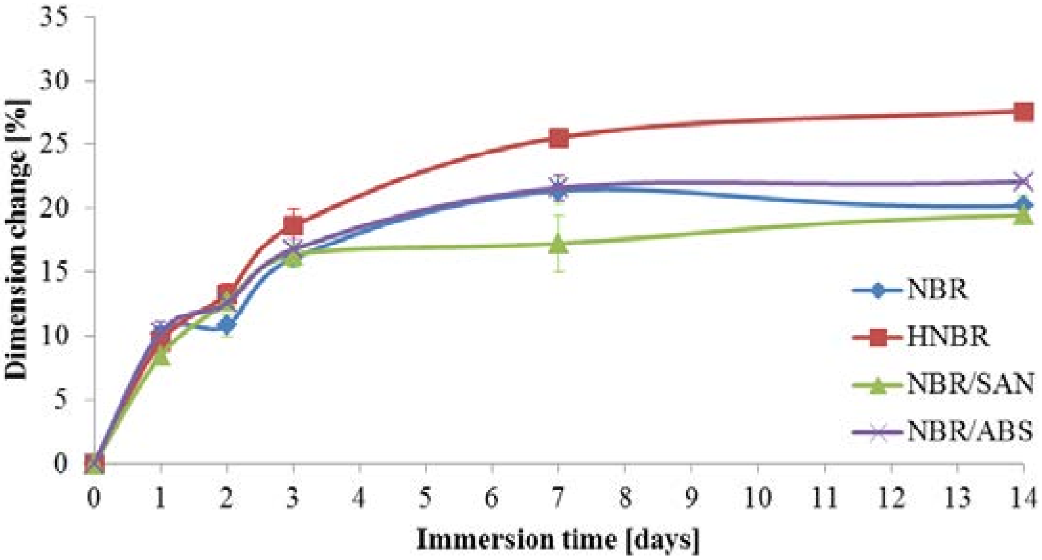

Figure 5.48 Dimension change of samples immersed in acidic E20 (Error bar is one standard deviation)

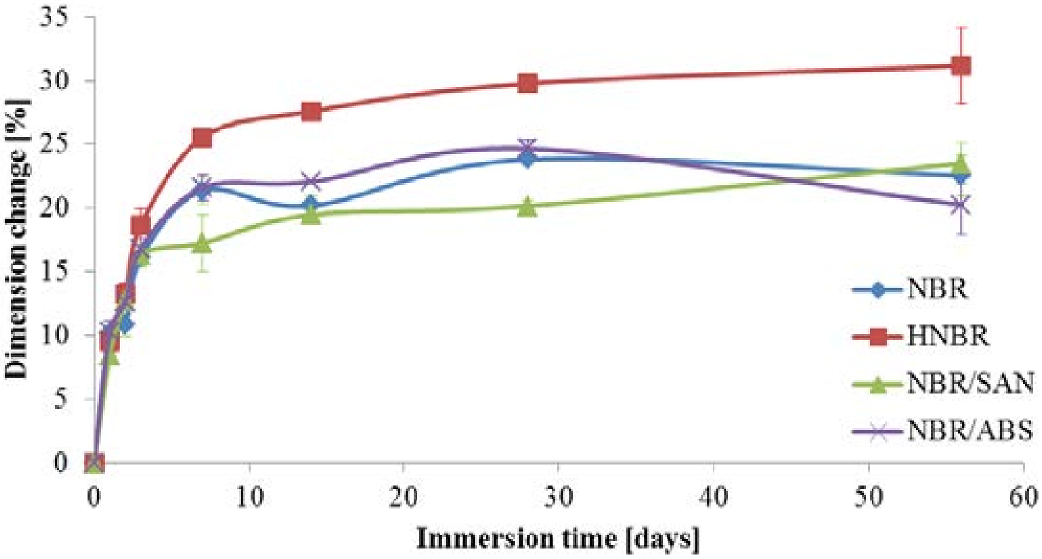

Figure 5.49 Dimension change of samples immersed in acidic E20 (Error bar is one standard deviation)

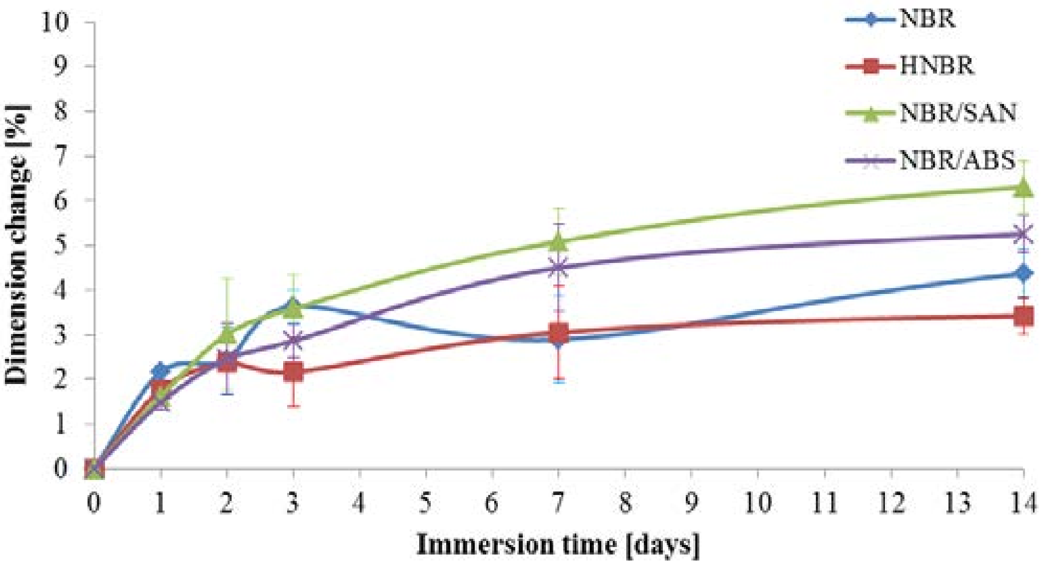

Figure 5.50 Dimension change of samples immersed in E85 (Error bar is one standard deviation)

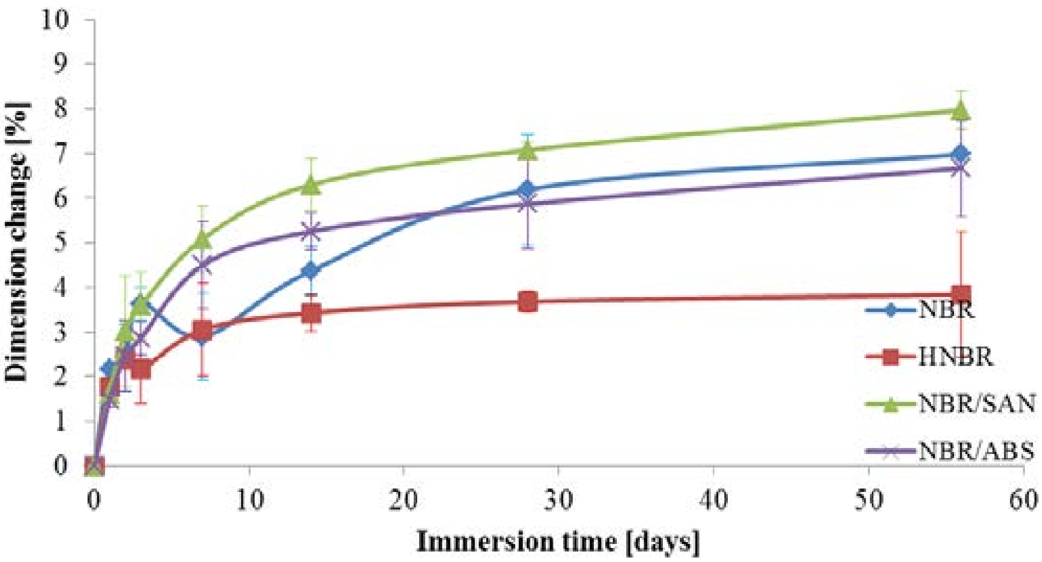

Figure 5.51 Dimension change of samples immersed in E85 (Error bar is one standard deviation)

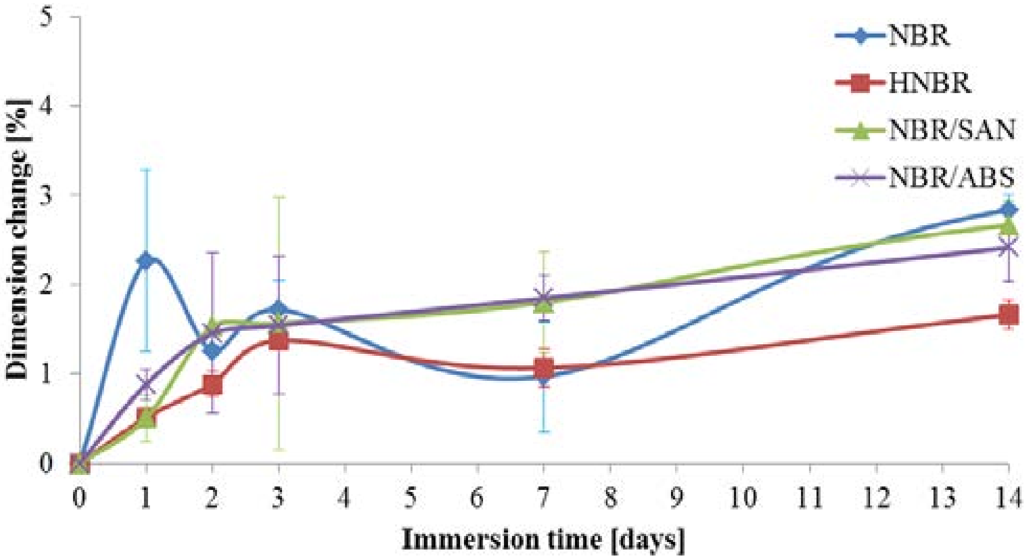

Figure 5.52 Dimension change of samples immersed in ethanol (Error bar is one standard deviation)

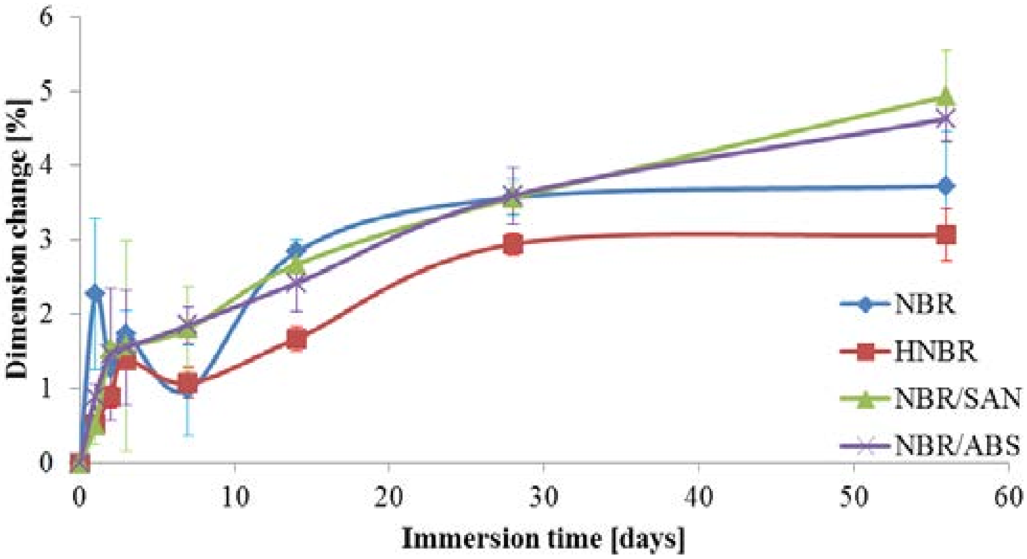

Figure 5.53 Dimension change of samples immersed in ethanol (Error bar is one standard deviation)

5.2.6 Volume change

Swelling experiments were conducted on small rectangular (approximately 25 mm x 25 mm x 2 mm). Considering volume change as shown in figure 5.54-5.61, chemical solutions could be affected to dimension stability because the samples were swollen. The swelling result revealed consistent to weight change. All the weight of the samples results were similar to volume changed results, so the weight changes data were appeared again at appendix. The dry weight after anneal the samples at 120°C for 2 weeks or until dried did not show significant changed compare to weight at semi-wet, so we have left them out. This might be because the soaking solvents are harder to get rid out of the specimens after soaked for many days.

For gasoline 95, at first 14 days HNBR showed the most swelling when compared with other polymer in this study and then the swelling decreased until the ended experiment. NBR, NBR/SAN, and NBR/ABS had similar swelling value. In this study, at long time of immersion the samples had quite closed swelling. Volume change was drop at 7th days for all samples. It might be because some rubber or plastic at the surface of samples were dissolved in soaked solvent then the solvent was absorb into sample again, so the volume of sample increased again and then some rubber and plastic that were internal of samples were dissolve again lead to the decreasing of volume. Acidic E20, at first 2 days all samples exhibited rapidly increased of volume then slowly decreased till days 7th and raised again at days 14th after that the volume decreased until finish test. At the beginning of immersed, HNBR showed the worse result but at the ended all samples had closed value of swelling and NBR/ABS was the best resist to Acidic E20. For E85, whole samples had the same trend and very closed volume change. NBR/SAN and NBR/ABS had the worst case on days 2 while NBR and HNBR were most swollen on days 3. NBR, NBR/SAN, and NBR/ABS had the similar trend when immersed in ethanol. The volumes rose for 2 days first then rose again at days 7 to days 14. The volume change of NBR/SAN rapidly decreased from days 14 to the ended of test. HNBR had the lower swelling than the other until days 28. After days 28, HNBR's volume change rapidly decreased until finish test.

The crosslinking of polymer chains is importance to controlling polymer properties. Large increased degree of crosslinking made amorphous polymers more rigid and could be reduce swelling by solvent [43]. Moreover, solubility parameter was important concept for predict polymer/solvent interaction. Solubility parameter of nitrile rubber, SAN, ABS, and ethanol were 9.4-10.3, 9.1, 9.2 and 12.7 $cal^{1/2}$ $cm^{3/2}$ respectively. And solubility parameter of isooctane and toluene (component of acidic E20) were 7.4, 8.91 $cal^{1/2}$ $cm^{3/2}$ respectively [19, 44]. So for swelling data, the closeness between acidic E20 solubility and SAN and ABS, showed the trend that this two polymer without cross-linked protection would dissolve out if the cure blends were soaking in acidic E20 by the closeness of solubility between them, and might be also NBR was also similar but slightly harder. The higher swelling degree of HNBR in gasoline rich solvent come from free alkyl that changed to aliphatic main chain, the ease the solubility and swelling in HNBR in gasoline rich phases.

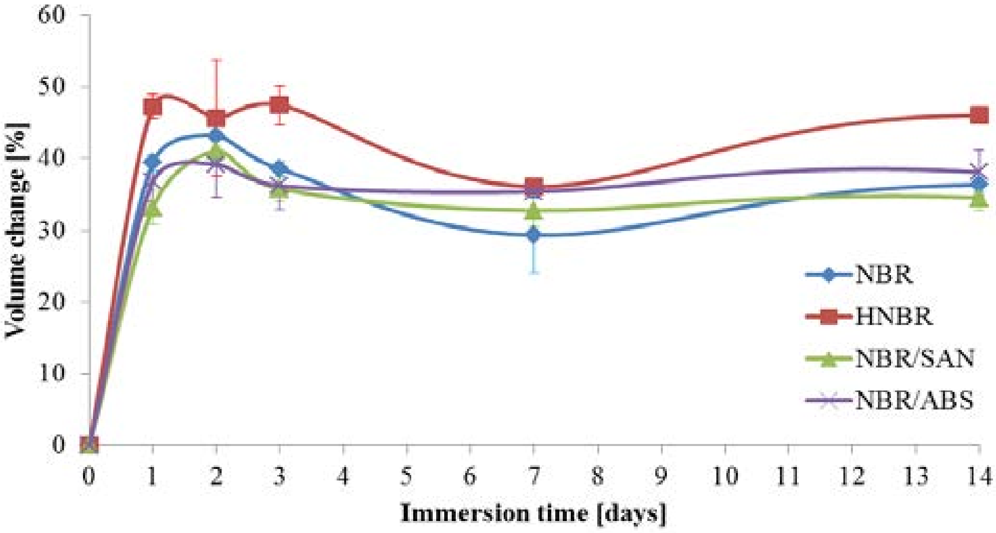

Figure 5.54 Volume change of samples immersed in gasoline 95 (Error bar is one standard deviation)

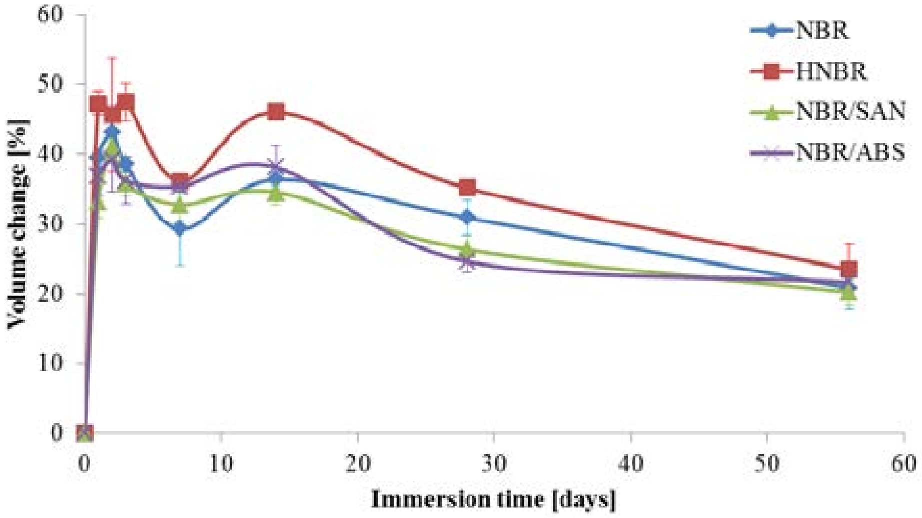

Figure 5.55 Volume change of samples immersed in gasoline 95 (Error bar is one standard deviation)

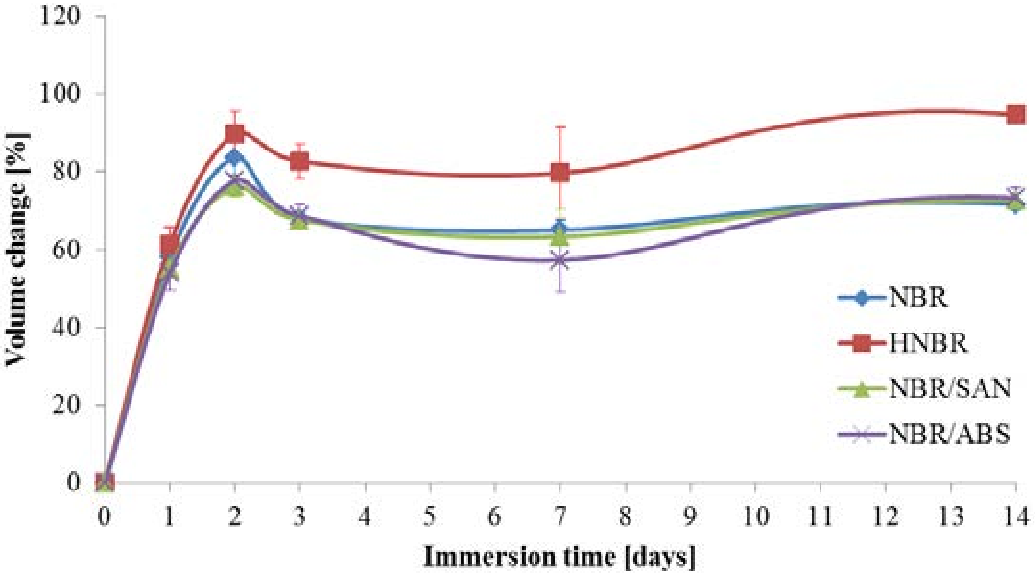

Figure 5.56 Volume change of samples immersed in acidic E20 (Error bar is one standard deviation)

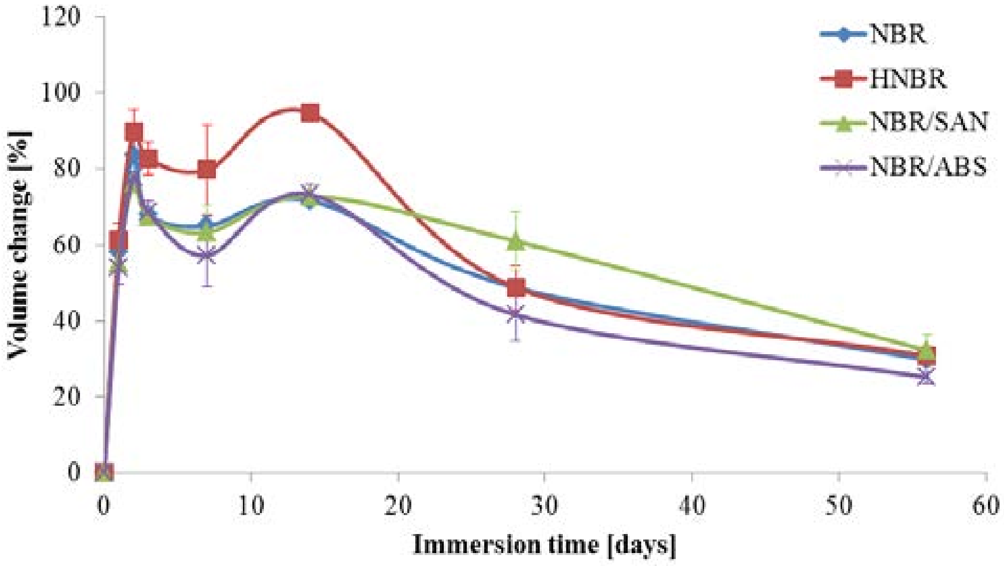

Figure 5.57 Volume change of samples immersed in acidic E20 (Error bar is one standard deviation)

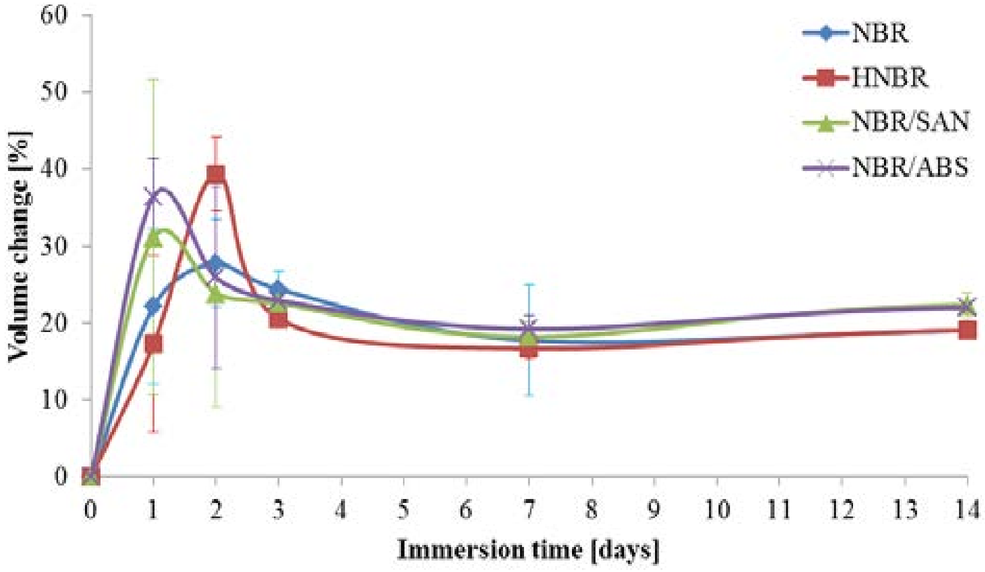

Figure 5.58 Volume change of samples immersed in E85 (Error bar is one standard deviation)

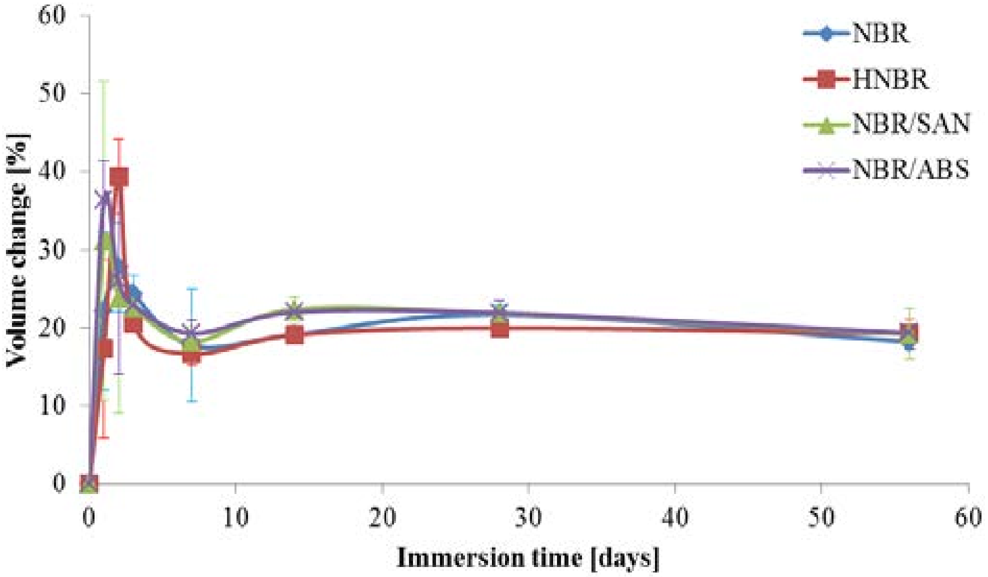

Figure 5.59 Volume change of samples immersed in E85 (Error bar is one standard deviation)

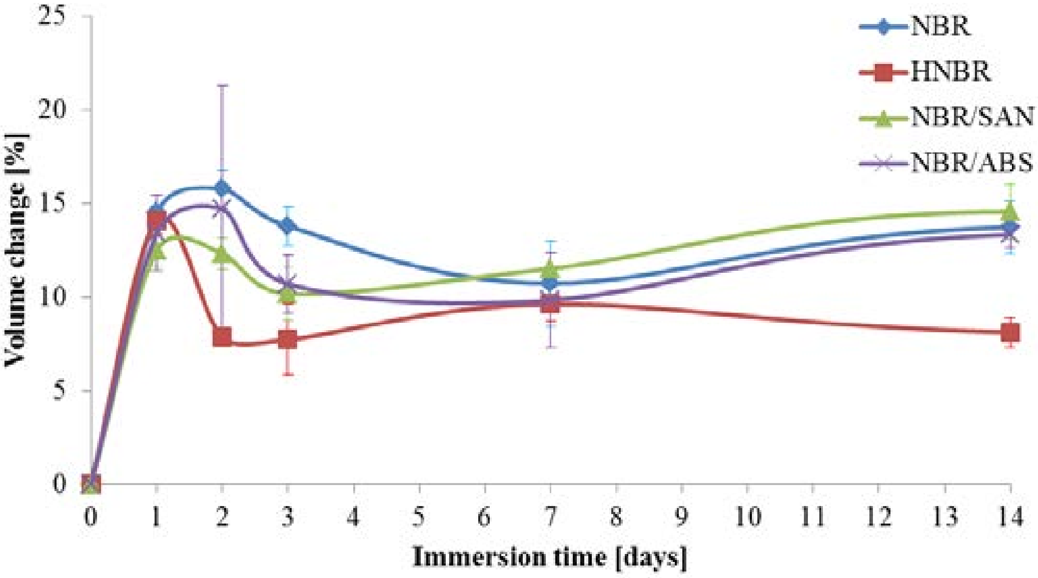

Figure 5.60 Volume change of samples immersed in ethanol (Error bar is one standard deviation)

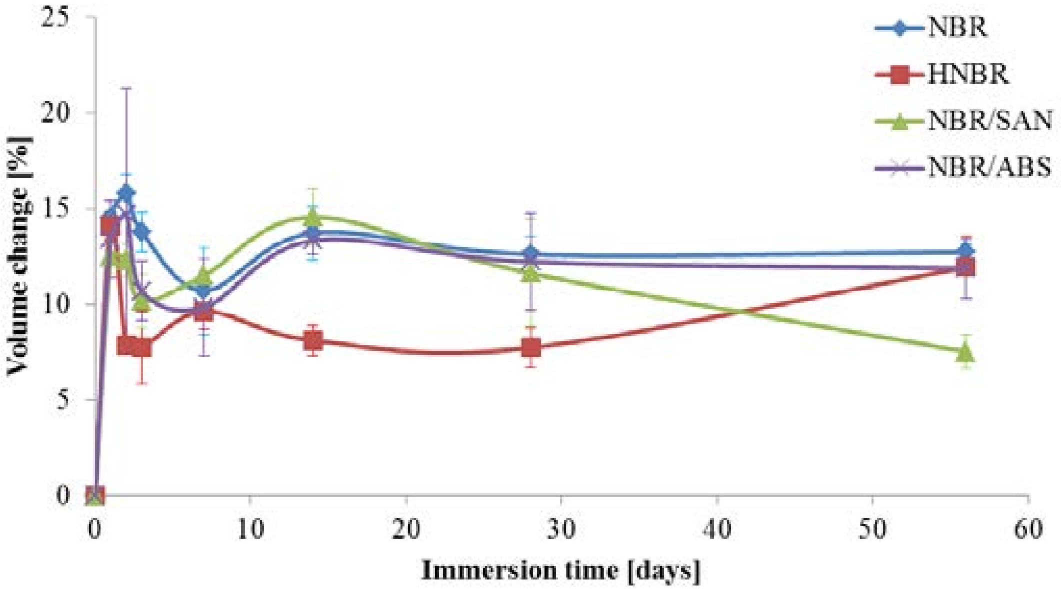

Figure 5.61 Volume change of samples immersed in ethanol (Error bar is one standard deviation)

Compared the result swelling to dimension change, the difference of them were the thickness of samples. The sample of dimension change test had more thickness than swelling samples around 6 times. It could be assume that swelling sample was the future trend of dimension change sample.

$$J = - D\frac{dC}{dX}$$

Where ;
J = molar flux (kgmol/s*m^2)
D = molecular diffusivity (m^2/s)
C = concentration of chemical solution (kgmol/m^3)
X = distance or thickness (m)

Because swelling sample had less thickness for 6 times, so the diffusion coefficient of swelling sample could be lower than dimension sample that lead to the different of immersion time which means that one day of swelling sample test was equal to around six days of dimension sample immersed. So, if this study has extended to the immersion time of dimension test, the trend line could be similar to volume change. For this hypothesis dimension change graph might be explain about the primary region of volume change graph in details.

CHAPTER VI

CONCLUSIONS & RECOMMENDATIONS

6.1 Conclusions

In this research, there were many ways of conclude depended on different source of data, the most possible general conclusion was summarized as the followings.

1. From SEM, DSC, and TGA, it indicated SAN and ABS were partially compatible with NBR.

2. From mechanical properties, with the increasing of SAN or ABS content, tensile strength and modulus were increased. Elongation at break increased when increasing NBR content.

3. HNBR could be better resisted to ethanol rich than NBR, NBR/SAN, and NBR/ABS but had worse results when immersed in gasoline 95 rich.

4. NBR/SAN and NBR/ABS had quite closed results of volume change and dimension change.

5. Compared NBR and polymer blends, the most susceptible for dissolve in solvents were cure-NBR, NBR and ABS, respectively regardless of HNBR.

6.2 Recommendations

To investigate further the effects of chemical solutions on NBR, NBR/SAN, and NBR/ABS blends, the following recommendations are suggested.

1. There should be adjusted the formulation of rubber chemicals for better mechanical properties.

2. The more conclusions of the difference between NBR/SAN and NBR/ABS blends should be composed.

3. The immersion test should be take longer time and control condition such as temperature and humidity.

4. After immersion the sample should be analyze by elemental analysis.

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APPENDICES

APPENDIX A

THE EXPERIMENTAL DATA OF MECHANICAL PROPERTIES

Appendix A 1. Mechanical properties of NBR, NBR/PVC, NBR/SAN, and NBR/ABS without carbon black

Table A1-1 Tensile strength

Materials	Mixing time [min]	Tensile strength [kg_f/cm^2]			Average [kg_f/cm^2]
		1	2	3	
NBR	-	21	21	22	22
NBR/PVC [70/30 w/w]	-	63	64	63	63
NBR/SAN [80/20 w/w]	3	103	72	58	78
NBR/SAN [80/20 w/w]	4	56	54	66	59
NBR/SAN [70/30 w/w]	3	145	104	114	121
NBR/SAN [70/30 w/w]	4	96	129	153	126
NBR/SAN [60/40 w/w]	3	94	101	100	98
NBR/SAN [60/40 w/w]	4	139	102	75	105
NBR/ABS [80/20 w/w]	3	37	95	74	69
NBR/ABS [80/20 w/w]	4	51	65	50	55
NBR/ABS [70/30 w/w]	3	77	75	102	85
NBR/ABS [70/30 w/w]	4	41	88	67	65
NBR/ABS [60/40 w/w]	3	104	77	122	101
NBR/ABS [60/40 w/w]	4	64	90	107	87

Table A1-2 Elongation at break

Materials	Mixing time [min]	Elongation at break [%]			Average [%]
		1	2	3	
NBR	-	450	323	478	417
NBR/PVC [70/30 w/w]	-	398	378	412	396
NBR/SAN [80/20 w/w]	3	423	300	276	333
NBR/SAN [80/20 w/w]	4	272	255	273	267
NBR/SAN [70/30 w/w]	3	366	335	332	344
NBR/SAN [70/30 w/w]	4	208	273	302	261
NBR/SAN [60/40 w/w]	3	122	133	132	129
NBR/SAN [60/40 w/w]	4	184	135	179	166
NBR/ABS [80/20 w/w]	3	243	457	328	343
NBR/ABS [80/20 w/w]	4	205	309	231	248
NBR/ABS [70/30 w/w]	3	216	210	233	220
NBR/ABS [70/30 w/w]	4	95	158	127	127
NBR/ABS [60/40 w/w]	3	153	116	178	149
NBR/ABS [60/40 w/w]	4	84	155	205	148

Table A1-3 100% Modulus

Materials	Mixing time [min]	100% Modulus [kg_f/cm^2]			Average [kg_f/cm^2]
		1	2	3	
NBR	-	12.9	13.1	13.7	13.2
NBR/PVC [70/30 w/w]	-	15.7	16.9	16.9	16.5
NBR/SAN [80/20 w/w]	3	22.3	25.4	24.3	24.0
NBR/SAN [80/20 w/w]	4	24.1	23.6	25.0	24.2
NBR/SAN [70/30 w/w]	3	36.4	34.3	33.1	34.6
NBR/SAN [70/30 w/w]	4	45.8	41.9	41.3	43.0
NBR/SAN [60/40 w/w]	3	83.1	80.8	84.8	82.9
NBR/SAN [60/40 w/w]	4	87.7	82.9	78.1	82.9
NBR/ABS [80/20 w/w]	3	22.0	21.5	23.7	22.4
NBR/ABS [80/20 w/w]	4	29.5	24.8	25.3	26.5
NBR/ABS [70/30 w/w]	3	37.5	36.9	41.3	38.6
NBR/ABS [70/30 w/w]	4	50.9	57.3	54.1	54.1
NBR/ABS [60/40 w/w]	3	75.5	69.3	79.9	74.9
NBR/ABS [60/40 w/w]	4	65.7	61.2	50.4	59.1

Appendix A 2. Mechanical properties of NBR, HNBR, NBR/SAN, and NBR/ABS

Table A2-1 Tensile strength of samples when immersed in gasoline 95

Materials	Immersion time [days]	Tensile strength [kg_f/cm^2]			Average [kg_f/cm^2]	SD [kg_f/cm^2]
		1	2	3		
NBR	0	141.0	108.3	106.3	118.53	19.48
	1	30.9	29.2	34.9	31.67	2.93
	2	29.4	32.4	29.9	30.57	1.61
	3	42.6	40.2	33.9	38.90	4.49
	7	51.9	38.5	20.7	37.03	15.65
	14	66.0	35.9	42.0	47.97	15.91
	28	42.8	37.4	42.2	40.80	2.96
	56	33.1	37.5	30.6	33.73	3.49
HNBR	0	265.0	245.7	272.1	260.93	13.66
	1	42.3	45.9	51.0	46.40	4.37
	2	57.8	46.3	36.7	46.93	10.56
	3	48.3	40.4	45.0	44.57	3.97
	7	71.2	58.5	64.0	64.57	6.37
	14	54.5	54.4	46.4	51.77	4.65
	28	63.8	52.6	61.2	59.20	5.86
	56	49.9	38.6	40.6	43.03	6.03
NBR/SAN [80/20 w/w] at mixing time 3 min	0	173.5	177.0	161.8	170.77	7.96
	1	38.2	39.9	43.4	40.50	2.65
	2	42.6	35.4	36.1	38.03	3.97
	3	52.0	45.9	45.1	47.67	3.77
	7	57.9	61.8	58.7	59.47	2.06
	14	41.5	41.4	42.4	41.77	0.55
	28	61.8	59.5	57.1	59.47	2.35
	56	39.3	47.0	51.0	45.77	5.95
NBR/ABS [80/20 w/w] at mixing time 3 min	0	147.9	143.4	110.4	133.90	20.48
	1	35.5	40.2	31.0	35.57	4.60
	2	37.8	35.8	36.2	36.60	1.06
	3	42.7	53.0	48.0	47.90	5.15
	7	61.5	64.2	60.2	61.97	2.04
	14	52.1	44.3	47.8	48.07	3.91
	28	58.5	70.7	78.0	69.07	9.85
	56	55.9	56.1	57.7	56.57	0.99

Table A2-2 Tensile strength of samples when immersed in acidic E20

Materials	Immersion time [days]	Tensile strength [kg_f/cm^2]			Average [kg_f/cm^2]	SD [kg_f/cm^2]
		1	2	3		
NBR	0	141.0	108.3	106.3	118.53	19.48
	1	20.9	20.7	21.3	20.97	0.31
	2	16.8	17.9	20.5	18.40	1.90
	3	17.5	19.2	20.1	18.93	1.32
	7	30.0	27.5	27.1	28.20	1.57
	14	20.5	19.5	20.5	20.17	0.58
	28	30.8	26.1	32.0	29.63	3.12
	56	26.8	28.7	29.2	28.23	1.27
HNBR	0	265.0	245.7	272.1	260.93	13.66
	1	36.7	35.4	47.0	39.70	6.36
	2	36.6	34.2	34.2	35.00	1.39
	3	32.0	40.3	37.4	36.57	4.21
	7	38.7	28.1	42.6	36.47	7.50
	14	38.9	28.6	35.5	34.33	5.25
	28	36.1	46.9	31.1	38.03	8.08
	56	21.2	21.8	21.0	21.33	0.42
NBR/SAN [80/20 w/w] at mixing time 3 min	0	173.5	177.0	161.8	170.77	7.96
	1	20.2	18.6	19.8	19.53	0.83
	2	19.0	18.7	17.8	18.50	0.62
	3	20.2	22.4	19.8	20.80	1.40
	7	26.2	27.3	25.2	26.23	1.05
	14	21.1	22.1	21.8	21.67	0.51
	28	26.3	27.3	27.3	26.97	0.58
	56	28.3	28.3	18.5	25.03	5.66
NBR/ABS [80/20 w/w] at mixing time 3 min	0	147.9	143.4	110.4	133.90	20.48
	1	38.1	30.0	26.8	31.63	5.82
	2	18.0	17.8	17.0	17.60	0.53
	3	26.0	41.4	25.7	31.03	8.98
	7	28.5	27.0	29.8	28.43	1.40
	14	30.0	26.9	26.9	27.93	1.79
	28	50.0	53.2	55.8	53.00	2.91
	56	20.0	20.4	21.0	20.47	0.50

Table A2-3 Tensile strength of samples when immersed in E85

Materials	Immersion time [days]	Tensile strength [kg_f/cm^2]			Average [kg_f/cm^2]	SD [kg_f/cm^2]
		1	2	3		
NBR	0	141.0	108.3	106.3	118.53	19.48
	1	47.1	54.4	50.0	50.50	3.68
	2	44.1	43.8	48.3	45.40	2.52
	3	44.8	47.3	46.8	46.30	1.32
	7	58.0	57.2	65.6	60.27	4.64
	14	46.5	48.3	49.2	48.00	1.37
	28	53.4	49.6	55.7	52.90	3.08
	56	31.9	33.4	27.4	30.90	3.12
HNBR	0	265.0	245.7	272.1	260.93	13.66
	1	79.2	78.3	80.2	79.23	0.95
	2	81.9	63.2	80.1	75.07	10.32
	3	99.5	83.8	67.0	83.43	16.25
	7	131.7	123.4	114.8	123.30	8.45
	14	91.0	83.0	79.4	84.47	5.94
	28	85.7	72.5	85.1	81.10	7.45
	56	47.3	46.8	48.7	47.60	0.98
NBR/SAN [80/20 w/w] at mixing time 3 min	0	173.5	177.0	161.8	170.77	7.96
	1	72.2	70.9	64.8	69.30	3.95
	2	60.7	65.6	58.2	61.50	3.76
	3	59.7	58.6	62.6	60.30	2.07
	7	88.1	80.1	88.4	85.53	4.71
	14	67.0	62.6	63.4	64.33	2.34
	28	70.9	73.0	80.3	74.73	4.93
	56	32.8	32.0	30.0	31.60	1.44
NBR/ABS [80/20 w/w] at mixing time 3 min	0	147.9	143.4	110.4	133.90	20.48
	1	73.5	66.0	66.3	68.60	4.25
	2	62.6	58.6	63.2	61.47	2.50
	3	49.2	65.9	63.4	59.50	9.01
	7	93.2	76.1	93.6	87.63	9.99
	14	68.6	70.1	72.1	70.27	1.76
	28	81.2	68.5	77.2	75.63	6.49
	56	28.4	29.7	28.5	28.87	0.72

Table A2-4 Tensile strength of samples when immersed in ethanol

Materials	Immersion time [days]	Tensile strength [kg$_f$/cm^2]			Average [kg$_f$/cm^2]	SD [kg$_f$/cm^2]
		1	2	3		
NBR	0	141.0	108.3	106.3	118.53	19.48
	1	46.6	52.3	48.8	49.23	2.87
	2	31.2	47.0	54.7	44.30	11.98
	3	72.3	38.4	71.4	60.70	19.32
	7	72.5	76.1	70.1	72.90	3.02
	14	68.9	67.0	59.7	65.20	4.86
	28	86.3	75.1	84.7	82.03	6.06
	56	40.5	44.9	45.4	43.60	2.70
HNBR	0	265.0	245.7	272.1	260.93	13.66
	1	76.5	79.0	67.7	74.40	5.94
	2	128.9	150.3	131.1	136.77	11.77
	3	157.7	151.7	148.7	152.70	4.58
	7	133.4	162.1	108.3	134.60	26.92
	14	162.2	126.2	147.8	145.40	18.12
	28	145.6	138.6	178.1	154.10	21.08
	56	56.3	62.6	57.7	58.87	3.31
NBR/SAN [80/20 w/w] at mixing time 3 min	0	173.5	177.0	161.8	170.77	7.96
	1	77.8	83.4	79.0	80.07	2.95
	2	85.5	73.2	76.0	78.23	6.45
	3	89.8	90.5	86.1	88.80	2.36
	7	102.6	113.2	89.6	101.80	11.82
	14	89.3	90.3	83.9	87.83	3.44
	28	92.0	100.2	105.9	99.37	6.99
	56	42.6	62.3	53.3	52.73	9.86
NBR/ABS [80/20 w/w] at mixing time 3 min	0	147.9	143.4	110.4	133.90	20.48
	1	81.1	80.0	82.7	81.27	1.36
	2	79.2	77.4	75.9	77.50	1.65
	3	99.5	106.1	96.0	100.53	5.13
	7	105.8	91.6	88.2	95.20	9.34
	14	78.3	90.9	97.2	88.80	9.62
	28	88.4	96.3	112.6	99.10	12.34
	56	55.7	73.7	85.9	71.77	15.19

Table A2-5 Elongation at break of samples when immersed in gasoline 95

Materials	Immersion time [days]	Elongation at break [%]			Average [%]	SD [%]
		1	2	3		
NBR	0	616	509	508	544	62.07
	1	248	276	315	280	33.65
	2	279	281	283	281	2.00
	3	317	287	304	303	15.04
	7	322	298	200	273	64.63
	14	267	303	289	286	18.15
	28	321	320	365	335	25.70
	56	466	286	257	336	113.23
HNBR	0	590	588	620	599	17.93
	1	321	246	272	280	38.08
	2	290	252	209	250	40.53
	3	275	315	298	296	20.07
	7	357	314	327	333	22.05
	14	300	315	283	299	16.01
	28	430	364	480	425	58.18
	56	396	257	248	300	82.97
NBR/SAN [80/20 w/w] at mixing time 3 min	0	427	450	412	430	19.14
	1	266	251	299	272	24.56
	2	362	327	335	341	18.34
	3	384	340	384	369	25.40
	7	375	418	399	397	21.55
	14	279	286	351	305	39.70
	28	365	325	352	347	20.40
	56	312	373	343	343	30.50
NBR/ABS [80/20 w/w] at mixing time 3 min	0	416	404	338	386	42.00
	1	246	245	203	231	24.54
	2	268	270	261	266	4.73
	3	287	332	281	300	27.87
	7	322	343	336	334	10.69
	14	313	245	269	276	34.49
	28	345	402	420	389	39.15
	56	318	342	388	349	35.57

Table A2-6 Elongation at break of samples when immersed in acidic E20

Materials	Immersion time [days]	Elongation at break [%]			Average [%]	SD [%]
		1	2	3		
NBR	0	616	509	508	544	62.07
	1	250	240	235	242	7.64
	2	180	190	220	197	20.82
	3	190	220	198	203	15.53
	7	210	187	242	213	27.62
	14	230	252	261	248	15.95
	28	252	254	271	259	10.44
	56	227	200	230	219	16.52
HNBR	0	590	588	620	599	17.93
	1	228	282	239	250	28.54
	2	240	212	300	251	44.96
	3	250	210	392	284	95.65
	7	217	261	212	230	26.96
	14	235	231	255	240	12.86
	28	279	410	332	340	65.90
	56	255	258	305	273	28.04
NBR/SAN [80/20 w/w] at mixing time 3 min	0	427	450	412	430	19.14
	1	220	222	176	206	26.00
	2	250	255	262	256	6.03
	3	245	250	252	249	3.61
	7	210	212	250	224	22.54
	14	196	180	180	185	9.24
	28	218	226	214	219	6.11
	56	340	294	261	298	39.68
NBR/ABS [80/20 w/w] at mixing time 3 min	0	416	404	338	386	42.00
	1	269	231	216	239	27.32
	2	155	198	180	178	21.59
	3	220	249	271	247	25.58
	7	242	220	239	234	11.93
	14	217	220	218	218	1.53
	28	276	320	398	331	61.78
	56	205	230	235	223	16.07

Table A2-7 Elongation at break of samples when immersed in E85

Materials	Immersion time [days]	Elongation at break [%]			Average [%]	SD [%]
		1	2	3		
NBR	0	616	509	508	544	62.07
	1	339	371	356	355	16.01
	2	332	329	367	343	21.13
	3	328	342	340	337	7.57
	7	403	393	440	412	24.76
	14	351	347	340	346	5.57
	28	358	362	384	368	14.00
	56	322	297	260	293	31.19
HNBR	0	590	588	620	599	17.93
	1	347	398	380	375	25.87
	2	372	335	350	352	18.61
	3	386	344	319	350	33.86
	7	480	472	456	469	12.22
	14	432	368	395	398	32.13
	28	330	302	363	332	30.53
	56	441	319	338	366	65.64
NBR/SAN [80/20 w/w] at mixing time 3 min	0	427	450	412	430	19.14
	1	438	430	435	434	4.04
	2	371	408	350	376	29.37
	3	369	348	384	367	18.08
	7	404	458	418	427	28.02
	14	367	348	401	372	26.85
	28	366	367	484	406	67.84
	56	402	314	350	355	44.24
NBR/ABS [80/20 w/w] at mixing time 3 min	0	416	404	338	386	42.00
	1	401	442	659	501	138.64
	2	370	320	439	376	59.75
	3	279	384	387	350	61.51
	7	433	333	455	407	65.02
	14	411	382	397	397	14.50
	28	460	410	413	428	28.04
	56	235	274	248	252	19.86

Table A2-8 Elongation at break of samples when immersed in ethanol

Materials	Immersion time [days]	Elongation at break [%]			Average [%]	SD [%]
		1	2	3		
NBR	0	616	509	508	544	62.07
	1	317	390	379	362	39.36
	2	262	367	392	340	68.98
	3	454	248	443	382	115.89
	7	434	466	452	451	16.04
	14	433	438	395	422	23.52
	28	499	486	485	490	7.81
	56	363	327	346	345	18.01
HNBR	0	590	588	620	599	17.93
	1	407	399	370	392	19.47
	2	488	546	478	504	36.72
	3	497	416	472	462	41.48
	7	540	519	504	521	18.08
	14	534	494	500	509	21.57
	28	478	552	550	527	42.16
	56	545	384	367	432	98.23
NBR/SAN [80/20 w/w] at mixing time 3 min	0	427	450	412	430	19.14
	1	362	470	366	399	61.23
	2	477	433	477	462	25.40
	3	376	397	372	382	13.43
	7	399	477	439	438	39.00
	14	387	383	372	381	7.77
	28	340	390	408	379	35.23
	56	248	439	318	335	96.63
NBR/ABS [80/20 w/w] at mixing time 3 min	0	416	404	338	386	42.00
	1	428	357	381	389	36.12
	2	376	368	375	373	4.36
	3	438	430	510	459	44.06
	7	459	379	391	410	43.14
	14	376	421	440	412	32.87
	28	334	337	435	369	57.47
	56	362	441	332	378	56.31

Table A2-9 100% Modulus of samples when immersed in gasoline 95

Materials	Immersion time [days]	100% Modulus [kg$_f$/cm^2]			Average [kg$_f$/cm^2]	SD [kg$_f$/cm^2]
		1	2	3		
NBR	0	16.2	18.3	17.2	17.23	1.05
	1	10.2	8.4	7.6	8.73	1.33
	2	7.6	8.5	7.5	7.87	0.55
	3	10.1	11.4	8.2	9.90	1.61
	7	13.7	10.3	10.7	11.57	1.86
	14	10.5	9.0	8.5	9.33	1.04
	28	10.1	9.2	8.2	9.17	0.95
	56	9.5	9.9	9.5	9.63	0.23
HNBR	0	19.1	21.0	19.4	19.83	1.02
	1	9.7	12.3	11.6	11.20	1.35
	2	15.4	12.9	13.1	13.80	1.39
	3	12.9	10.3	11.3	11.50	1.31
	7	15.4	14.4	14.6	14.80	0.53
	14	13.7	10.8	11.5	12.00	1.51
	28	10.7	10.1	8.3	9.70	1.25
	56	10.3	11.7	12.8	11.60	1.25
NBR/SAN [80/20 w/w] at mixing time 3 min	0	35.4	32.6	32.8	33.60	1.56
	1	12.9	9.0	11.9	11.27	2.03
	2	9.7	8.7	9.1	9.17	0.50
	3	11.0	12.2	10.7	11.30	0.79
	7	14.2	12.8	12.5	13.17	0.91
	14	14.4	11.8	9.3	11.83	2.55
	28	14.7	17.0	13.6	15.10	1.73
	56	11.4	10.3	13.0	11.57	1.36
NBR/ABS [80/20 w/w] at mixing time 3 min	0	35.7	33.6	29.1	32.80	3.37
	1	12.4	15.2	14.6	14.07	1.47
	2	12.8	11.7	11.9	12.13	0.59
	3	12.5	12.9	14.2	13.20	0.89
	7	18.2	16.9	15.7	16.93	1.25
	14	14.9	18.8	17.2	16.97	1.96
	28	15.2	14.6	15.6	15.13	0.50
	56	16.5	14.6	11.8	14.30	2.36

Table A2-10 100% Modulus of samples when immersed in acidic E20

Materials	Immersion time [days]	100% Modulus [kg$_f$/cm^2]			Average [kg$_f$/cm^2]	SD [kg$_f$/cm^2]
		1	2	3		
NBR	0	16.2	18.3	17.2	17.23	1.05
	1	7.4	8.1	7.4	7.63	0.40
	2	9.0	9.8	6.9	8.57	1.50
	3	9.9	8.9	11.1	9.97	1.10
	7	9.1	7.6	8.5	8.40	0.75
	14	7.4	6.7	6.6	6.90	0.44
	28	8.4	8.4	10.0	8.93	0.92
	56	10.1	8.4	7.4	8.63	1.37
HNBR	0	19.1	21.0	19.4	19.83	1.02
	1	14.1	9.3	16.5	13.30	3.67
	2	12.4	13.5	9.1	11.67	2.29
	3	9.8	15.9	6.2	10.63	4.90
	7	13.6	8.6	15.4	12.53	3.52
	14	14.1	8.7	8.7	10.50	3.12
	28	9.8	7.3	7.2	8.10	1.47
	56	8.1	7.2	4.9	6.73	1.65
NBR/SAN [80/20 w/w] at mixing time 3 min	0	35.4	32.6	32.8	33.60	1.56
	1	8.9	9.1	9.0	9.00	0.10
	2	7.3	6.0	6.1	6.47	0.72
	3	8.7	7.0	6.6	7.43	1.12
	7	8.1	8.6	7.0	7.90	0.82
	14	9.1	8.5	7.8	8.47	0.65
	28	9.4	10.8	8.7	9.63	1.07
	56	8.3	7.6	6.5	7.47	0.91
NBR/ABS [80/20 w/w] at mixing time 3 min	0	35.7	33.6	29.1	32.80	3.37
	1	14.3	11.7	9.9	11.97	2.21
	2	12.5	8.3	8.3	9.70	2.42
	3	11.5	16.3	8.6	12.13	3.89
	7	9.8	9.1	10.2	9.70	0.56
	14	9.1	9.3	10.7	9.70	0.87
	28	17.2	15.3	11.2	14.57	3.07
	56	7.3	6.3	7.3	6.97	0.58

Table A2-11 100% Modulus of samples when immersed in E85

Materials	Immersion time [days]	100% Modulus [kg_f/cm^2]			Average [kg_f/cm^2]	SD [kg_f/cm^2]
		1	2	3		
NBR	0	16.2	18.3	17.2	17.23	1.05
	1	11.0	12.1	11.8	11.63	0.57
	2	10.2	10.0	9.6	9.93	0.31
	3	10.5	10.4	11.3	10.73	0.49
	7	11.1	11.3	11.2	11.20	0.10
	14	9.8	10.5	12.1	10.80	1.18
	28	11.7	10.4	10.3	10.80	0.78
	56	8.0	8.0	8.2	8.07	0.12
HNBR	0	19.1	21.0	19.4	19.83	1.02
	1	17.7	14.7	14.5	15.63	1.79
	2	17.3	15.4	15.8	16.17	1.00
	3	17.6	17.0	14.0	16.20	1.93
	7	14.5	14.5	13.5	14.17	0.58
	14	14.5	15.8	12.9	14.40	1.45
	28	18.6	16.8	17.7	17.70	0.90
	56	8.9	9.3	8.1	8.77	0.61
NBR/SAN [80/20 w/w] at mixing time 3 min	0	35.4	32.6	32.8	33.60	1.56
	1	14.7	15.1	14.9	14.90	0.20
	2	15.9	14.3	14.0	14.73	1.02
	3	13.1	13.8	12.7	13.20	0.56
	7	19.1	14.4	18.7	17.40	2.61
	14	16.3	14.8	12.9	14.67	1.70
	28	17.9	17.7	12.6	16.07	3.00
	56	9.2	7.8	5.7	7.57	1.76
NBR/ABS [80/20 w/w] at mixing time 3 min	0	35.7	33.6	29.1	32.80	3.37
	1	17.1	12.4	10.9	13.47	3.23
	2	16.7	17.2	11.1	15.00	3.39
	3	17.4	17.3	15.5	16.73	1.07
	7	19.7	23.8	16.9	20.13	3.47
	14	16.2	15.4	14.7	15.43	0.75
	28	14.7	13.3	16.4	14.80	1.55
	56	10.1	8.8	8.9	9.27	0.72

Table A2-12 100% Modulus of samples when immersed in ethanol

Materials	Immersion time [days]	100% Modulus [kg_f/cm^2]			Average [kg_f/cm^2]	SD [kg_f/cm^2]
		1	2	3		
NBR	0	16.2	18.3	17.2	17.23	1.05
	1	13.3	10.9	10.6	11.60	1.48
	2	10.1	10.2	9.7	10.00	0.26
	3	11.8	16.3	11.3	13.13	2.75
	7	14.3	12.1	11.2	12.53	1.59
	14	12.5	11.2	10.8	11.50	0.89
	28	13.0	11.5	12.6	12.37	0.78
	56	9.6	10.2	9.2	9.67	0.50
HNBR	0	19.1	21.0	19.4	19.83	1.02
	1	13.7	14.7	13.5	13.97	0.64
	2	15.4	13.7	17.0	15.37	1.65
	3	19.3	23.6	17.9	20.27	2.97
	7	16.6	18.8	15.1	16.83	1.86
	14	14.9	15.9	18.0	16.27	1.58
	28	20.0	15.5	16.0	17.17	2.47
	56	13.4	13.7	13.4	13.50	0.17
NBR/SAN [80/20 w/w] at mixing time 3 min	0	35.4	32.6	32.8	33.60	1.56
	1	19.5	16.2	18.5	18.07	1.69
	2	15.9	15.8	13.7	15.13	1.24
	3	21.1	19.7	19.5	20.10	0.87
	7	23.5	20.9	17.5	20.63	3.01
	14	20.7	20.5	18.9	20.03	0.99
	28	26.4	22.3	21.4	23.37	2.67
	56	16.8	10.9	14.5	14.07	2.97
NBR/ABS [80/20 w/w] at mixing time 3 min	0	35.7	33.6	29.1	32.80	3.37
	1	18.3	24.5	19.6	20.80	3.27
	2	21.0	19.3	19.1	19.80	1.04
	3	19.7	23.4	16.2	19.77	3.60
	7	20.6	23.3	20.8	21.57	1.50
	14	19.9	19.8	18.3	19.33	0.90
	28	27.3	29.7	23.7	26.90	3.02
	56	13.1	12.3	19.6	15.00	4.00

Table A2-13 Hardness shore A of samples when immersed in gasoline 95

Materials	Immersion time [days]	Hardness shore A			Average	SD
		1	2	3		
NBR	0	59.2	59.3	59.3	59.27	0.06
	1	42.7	42.9	41.1	42.23	0.99
	2	40.2	41.9	42.1	41.40	1.04
	3	42.0	42.1	44.4	42.83	1.36
	7	34.1	34.6	33.9	34.20	0.36
	14	37.0	37.4	36.0	36.80	0.72
	28	37.2	37.6	36.8	37.20	0.40
	56	39.1	38.2	40.5	39.27	1.16
HNBR	0	62.9	63.1	63.3	63.10	0.20
	1	46.4	45.8	45.9	46.03	0.32
	2	48.4	47.9	49.9	48.73	1.04
	3	49.0	49.1	49.1	49.07	0.06
	7	44.4	46.2	46.0	45.53	0.99
	14	47.5	46.8	46.0	46.77	0.75
	28	45.3	44.5	45.7	45.17	0.61
	56	49.8	49.8	49.5	49.70	0.17
NBR/SAN [80/20 w/w] at mixing time 3 min	0	73.2	73.8	73.2	73.40	0.35
	1	52.6	52.2	51.3	52.03	0.67
	2	54.8	56.5	65.1	58.80	5.52
	3	52.4	52.1	53.2	52.57	0.57
	7	43.1	40.7	43.6	42.47	1.55
	14	49.8	47.8	46.8	48.13	1.53
	28	44.4	42.4	44.0	43.60	1.06
	56	46.8	47.3	45.6	46.57	0.87
NBR/ABS [80/20 w/w] at mixing time 3 min	0	70.6	70.5	70.9	70.67	0.21
	1	51.4	51.2	50.1	50.90	0.70
	2	52.1	50.9	52.5	51.83	0.83
	3	51.5	50.9	51.5	51.30	0.35
	7	41.0	41.9	42.1	41.67	0.59
	14	46.9	45.0	48.9	46.93	1.95
	28	42.6	43.7	44.6	43.63	1.00
	56	47.2	46.0	48.0	47.07	1.01

Table A2-14 Hardness shore A of samples when immersed in acidic E20

Materials	Immersion time [days]	Hardness shore A			Average	SD
		1	2	3		
NBR	0	59.2	59.3	59.3	59.27	0.06
	1	29.2	29.1	30.4	29.57	0.72
	2	28.0	28.0	28.1	28.03	0.06
	3	25.8	25.8	27.5	26.37	0.98
	7	22.6	24.6	25.5	24.23	1.48
	14	28.0	28.2	28.9	28.37	0.47
	28	26.1	27.9	26.2	26.73	1.01
	56	37.0	36.5	36.2	36.57	0.40
HNBR	0	62.9	63.1	63.3	63.10	0.20
	1	60.3	59.6	60.0	59.97	0.35
	2	34.9	35.5	35.0	35.13	0.32
	3	34.7	34.7	37.7	35.70	1.73
	7	39.4	38.5	38.9	38.93	0.45
	14	40.5	40.4	41.1	40.67	0.38
	28	37.8	35.0	34.8	35.87	1.68
	56	45.0	45.2	45.9	45.37	0.47
NBR/SAN [80/20 w/w] at mixing time 3 min	0	73.2	73.8	73.2	73.40	0.35
	1	32.6	32.0	32.9	32.50	0.46
	2	26.8	25.5	26.5	26.27	0.68
	3	27.0	29.0	28.1	28.03	1.00
	7	20.4	23.4	20.5	21.43	1.70
	14	20.5	21.0	21.0	20.83	0.29
	28	22.3	24.2	22.9	23.13	0.97
	56	33.2	34.2	32.2	33.20	1.00
NBR/ABS [80/20 w/w] at mixing time 3 min	0	70.6	70.5	70.9	70.67	0.21
	1	35.1	33.6	36.1	34.93	1.26
	2	28.4	28.2	27.5	28.03	0.47
	3	28.0	29.0	29.2	28.73	0.64
	7	23.6	23.1	22.5	23.07	0.55
	14	20.0	22.5	22.1	21.53	1.34
	28	26.3	26.8	25.0	26.03	0.93
	56	37.5	38.5	35.8	37.27	1.37

Table A2-15 Hardness shore A of samples when immersed in E85

Materials	Immersion time [days]	Hardness shore A			Average	SD
		1	2	3		
NBR	0	59.2	59.3	59.3	59.27	0.06
	1	36.1	36.5	38.9	37.17	1.51
	2	43.0	43.0	40.0	42.00	1.73
	3	47.6	46.5	47.6	47.23	0.64
	7	42.9	42.1	45.5	43.50	1.78
	14	42.2	43.2	44.5	43.30	1.15
	28	40.3	40.5	40.5	40.43	0.12
	56	43.3	45.8	44.2	44.43	1.27
HNBR	0	62.9	63.1	63.3	63.10	0.20
	1	52.7	49.8	50.5	51.00	1.51
	2	51.1	49.5	52.0	50.87	1.27
	3	58.7	56.8	57.3	57.60	0.98
	7	53.7	54.5	54.2	54.13	0.40
	14	55.4	57.6	56.2	56.40	1.11
	28	50.6	50.9	50.7	50.73	0.15
	56	49.0	51.0	51.1	50.37	1.18
NBR/SAN [80/20 w/w] at mixing time 3 min	0	73.2	73.8	73.2	73.40	0.35
	1	53.1	55.2	56.0	54.77	1.50
	2	52.0	51.0	54.6	52.53	1.86
	3	59.8	59.1	59.4	59.43	0.35
	7	57.3	57.7	57.0	57.33	0.35
	14	55.4	57.6	56.2	56.40	1.11
	28	49.6	49.6	48.9	49.37	0.40
	56	45.6	49.8	48.0	47.80	2.11
NBR/ABS [80/20 w/w] at mixing time 3 min	0	70.6	70.5	70.9	70.67	0.21
	1	49.0	52.1	49.9	50.33	1.59
	2	53.5	54.1	53.0	53.53	0.55
	3	55.7	55.5	54.2	55.13	0.81
	7	53.8	53.3	54.3	53.80	0.50
	14	52.8	51.9	50.4	51.70	1.21
	28	48.2	47.5	48.9	48.20	0.70
	56	46.3	46.5	48.0	46.93	0.93

Table A2-16 Hardness shore A of samples when immersed in ethanol

Materials	Immersion time [days]	Hardness shore A			Average	SD
		1	2	3		
NBR	0	59.2	59.3	59.3	59.27	0.06
	1	48.5	48.5	50.1	49.03	0.92
	2	54.9	55.1	53.8	54.60	0.70
	3	53.8	53.1	52.5	53.13	0.65
	7	47.9	48.4	48.1	48.13	0.25
	14	47.0	49.6	49.9	48.83	1.59
	28	45.1	46.1	46.2	45.80	0.61
	56	48.6	48.2	51.0	49.27	1.51
HNBR	0	62.9	63.1	63.3	63.10	0.20
	1	62.9	63.1	63.3	63.10	0.20
	2	68.2	65.4	65.0	66.20	1.74
	3	58.1	53.1	61.1	57.43	4.04
	7	57.9	56.8	57.3	57.33	0.55
	14	61.2	61.8	59.7	60.90	1.08
	28	57.8	58.1	57.8	57.90	0.17
	56	54.4	54.2	56.0	54.87	0.99
NBR/SAN [80/20 w/w] at mixing time 3 min	0	73.2	73.8	73.2	73.40	0.35
	1	62.0	63.6	62.5	62.70	0.82
	2	67.0	68.1	66.1	67.07	1.00
	3	67.8	65.2	68.0	67.00	1.56
	7	62.5	62.5	62.7	62.57	0.12
	14	62.2	60.9	62.3	61.80	0.78
	28	58.5	58.3	58.4	58.40	0.10
	56	57.3	56.7	56.9	56.97	0.31
NBR/ABS [80/20 w/w] at mixing time 3 min	0	70.6	70.5	70.9	70.67	0.21
	1	62.1	61.3	62.8	62.07	0.75
	2	65.9	64.9	64.5	65.10	0.72
	3	64.8	60.8	61.8	62.47	2.08
	7	56.9	57.5	57.0	57.13	0.32
	14	61.7	59.0	61.5	60.73	1.50
	28	54.8	55.4	55.8	55.33	0.50
	56	58.0	59.2	60.8	59.33	1.40

Table A2-17 Compression set of samples when immersed in gasoline 95

Materials	Immersion time [days]	Compression set [%]			Average [%]	SD [%]
		1	2	3		
NBR	0	22.26	23.35	20.59	22.07	1.39
	1	24.54	22.35	21.13	22.67	1.73
	2	23.46	21.99	24.38	23.28	1.21
	3	23.25	23.05	25.83	24.04	1.55
	7	19.92	20.79	19.39	20.03	0.71
	14	14.62	13.38	14.41	14.14	0.66
	28	5.28	8.14	9.57	7.66	2.18
	56	7.80	7.89	6.76	7.48	0.63
HNBR	0	40.92	48.37	52.26	47.18	5.76
	1	46.99	48.61	49.59	48.40	1.31
	2	49.58	48.96	52.14	50.23	1.69
	3	54.62	50.27	52.27	52.39	2.18
	7	43.30	40.60	41.58	41.83	1.37
	14	35.58	33.46	33.41	34.15	1.24
	28	26.61	29.58	27.98	28.06	1.49
	56	24.66	29.72	22.93	25.77	3.53
NBR/SAN [80/20 w/w] at mixing time 3 min	0	28.30	35.25	39.72	34.42	5.75
	1	40.17	42.90	42.99	42.02	1.60
	2	45.21	44.96	45.67	45.28	0.36
	3	52.75	51.75	51.00	51.83	0.88
	7	50.87	47.25	49.72	49.28	1.85
	14	37.76	38.82	37.16	37.91	0.84
	28	24.96	28.53	27.66	27.05	1.86
	56	18.83	23.46	20.34	20.88	2.36
NBR/ABS [80/20 w/w] at mixing time 3 min	0	25.29	31.50	30.88	29.22	3.42
	1	41.17	39.62	40.00	40.26	0.81
	2	47.14	44.88	46.80	46.27	1.22
	3	53.45	51.23	54.15	52.94	1.52
	7	46.28	44.96	41.69	44.31	2.36
	14	34.78	35.66	35.43	35.29	0.46
	28	24.42	26.89	27.64	26.32	1.68
	56	26.75	22.98	23.88	24.54	1.97

Table A2-18 Compression set of samples when immersed in acidic E20

Materials	Immersion time [days]	Compression set [%]			Average [%]	SD[%]
		1	2	3		
NBR	0	22.26	23.35	20.59	22.07	1.39
	1	25.22	26.17	24.65	25.35	0.77
	2	24.19	23.45	21.71	23.12	1.27
	3	15.37	11.63	14.52	13.84	1.96
	7	7.38	7.78	6.22	7.13	0.81
	14	5.79	5.78	6.40	5.99	0.36
	28	5.19	5.00	5.57	5.25	0.29
	56	5.58	4.94	4.44	4.99	0.57
HNBR	0	40.92	48.37	52.26	47.18	5.76
	1	61.23	62.31	69.92	64.49	4.74
	2	56.03	55.45	53.78	55.09	1.17
	3	48.17	59.15	53.28	53.53	5.49
	7	13.63	11.46	11.35	12.15	1.29
	14	10.64	9.46	10.11	10.07	0.59
	28	7.56	10.68	8.66	8.97	1.58
	56	8.38	8.03	9.05	8.49	0.52
NBR/SAN [80/20 w/w] at mixing time 3 min	0	28.30	35.25	39.72	34.42	5.75
	1	62.92	61.56	63.00	62.49	0.81
	2	50.05	49.78	50.16	50.00	0.20
	3	33.06	29.79	34.37	32.41	2.36
	7	10.79	12.31	13.15	12.08	1.20
	14	10.44	9.16	10.88	10.16	0.89
	28	6.46	8.56	9.14	8.05	1.41
	56	7.86	5.98	8.64	7.49	1.37
NBR/ABS [80/20 w/w] at mixing time 3 min	0	25.29	31.50	30.88	29.22	3.42
	1	54.12	56.53	62.60	57.75	4.37
	2	40.76	41.02	38.96	40.25	1.12
	3	28.24	20.67	26.09	25.00	3.90
	7	7.49	8.10	7.55	7.71	0.34
	14	7.08	8.04	8.14	7.75	0.59
	28	7.02	8.63	7.88	7.84	0.81
	56	10.69	5.80	6.65	7.71	2.61

Table A2-19 Compression set of samples when immersed in E85

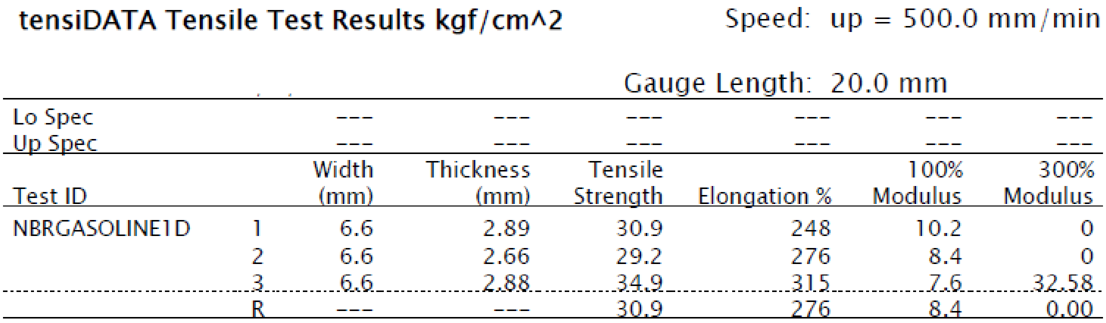
Materials	Immersion time [days]	Compression set [%]			Average [%]	SD[%]
		1	2	3		
NBR	0	22.26	23.35	20.59	22.07	1.39
	1	20.62	16.41	22.44	19.82	3.09
	2	21.64	19.32	20.56	20.51	1.16
	3	27.45	23.51	23.80	24.92	2.20
	7	15.37	18.05	15.67	16.36	1.47
	14	11.46	11.97	12.67	12.03	0.61
	28	7.49	6.44	7.80	7.24	0.71
	56	6.16	9.21	7.09	7.49	1.56
HNBR	0	40.92	48.37	52.26	47.18	5.76
	1	49.03	47.80	61.42	52.75	7.53
	2	47.11	49.08	48.21	48.13	0.99
	3	45.51	48.43	47.95	47.30	1.57
	7	46.53	47.76	45.86	46.72	0.96
	14	29.67	30.46	30.14	30.09	0.40
	28	21.36	18.47	19.45	19.76	1.47
	56	19.74	16.16	17.48	17.79	1.81
NBR/SAN [80/20 w/w] at mixing time 3 min	0	28.30	35.25	39.72	34.42	5.75
	1	42.97	36.56	45.93	41.82	4.79
	2	42.50	41.37	43.79	42.55	1.21
	3	44.41	45.51	45.19	45.04	0.57
	7	51.36	54.60	53.62	53.19	1.66
	14	37.78	35.97	34.46	36.07	1.66
	28	22.41	27.89	24.93	25.08	2.74
	56	17.05	29.41	25.53	24.00	6.32
NBR/ABS [80/20 w/w] at mixing time 3 min	0	25.29	31.50	30.88	29.22	3.42
	1	35.47	33.90	35.07	34.81	0.82
	2	37.68	38.69	37.41	37.93	0.67
	3	42.25	40.63	37.14	40.01	2.61
	7	49.44	53.04	51.12	51.20	1.80
	14	31.03	29.78	30.21	30.34	0.64
	28	17.46	19.30	18.75	18.50	0.94
	56	14.12	11.81	12.40	12.78	1.20

Table A2-20 Compression set of samples when immersed in ethanol

Materials	Immersion time [days]	Compression set [%]			Average [%]	SD[%]
		1	2	3		
NBR	0	22.26	23.35	20.59	22.07	1.39
	1	21.05	23.81	26.32	23.73	2.64
	2	22.06	21.33	22.78	22.06	0.73
	3	18.52	20.88	22.69	20.70	2.09
	7	14.14	10.37	16.62	13.71	3.15
	14	11.97	12.46	14.43	12.95	1.30
	28	19.77	16.43	18.05	18.08	1.67
	56	13.11	15.45	12.07	13.54	1.73
HNBR	0	40.92	48.37	52.26	47.18	5.76
	1	43.74	45.07	46.24	45.02	1.25
	2	47.04	45.23	46.25	46.17	0.91
	3	49.20	44.65	51.21	48.35	3.36
	7	46.90	44.06	35.16	42.04	6.13
	14	42.66	41.13	42.44	42.08	0.83
	28	39.44	40.02	42.89	40.78	1.85
	56	38.65	38.96	37.36	38.32	0.85
NBR/SAN [80/20 w/w] at mixing time 3 min	0	28.30	35.25	39.72	34.42	5.75
	1	32.45	37.20	37.09	35.58	2.71
	2	34.74	36.28	35.78	35.60	0.79
	3	35.29	32.25	39.51	35.68	3.65
	7	47.54	40.54	42.17	43.42	3.66
	14	42.47	42.64	40.96	42.02	0.92
	28	43.02	42.00	38.91	41.31	2.14
	56	42.28	37.77	37.50	39.18	2.69
NBR/ABS [80/20 w/w] at mixing time 3 min	0	25.29	31.50	30.88	29.22	3.42
	1	31.10	34.20	37.67	34.32	3.29
	2	34.67	35.86	36.04	35.52	0.74
	3	38.74	37.25	38.92	38.30	0.92
	7	34.93	39.67	39.03	37.88	2.57
	14	37.46	39.01	38.41	38.29	0.78
	28	40.50	39.47	42.57	40.85	1.58
	56	42.76	42.60	32.50	39.29	5.88

Appendix A 3. Raw data of NBR, HNBR, NBR/SAN, and NBR/ABS in Gasoline 95 immersed for 1 day

Table A3-1 Raw tensile data of NBR



tensiDATA Tensile Test Results kgf/cm^2 Speed: up = 500.0 mm/min

Gauge Length: 20.0 mm

Test ID		Width (mm)	Thickness (mm)	Tensile Strength	Elongation %	100% Modulus	300% Modulus
Lo Spec		---	---	---	---	---	---
Up Spec		---	---	---	---	---	---
NBRGASOLINE1D	1	6.6	2.89	30.9	248	10.2	0
	2	6.6	2.66	29.2	276	8.4	0
	3	6.6	2.88	34.9	315	7.6	32.58
	R	---	---	30.9	276	8.4	0.00

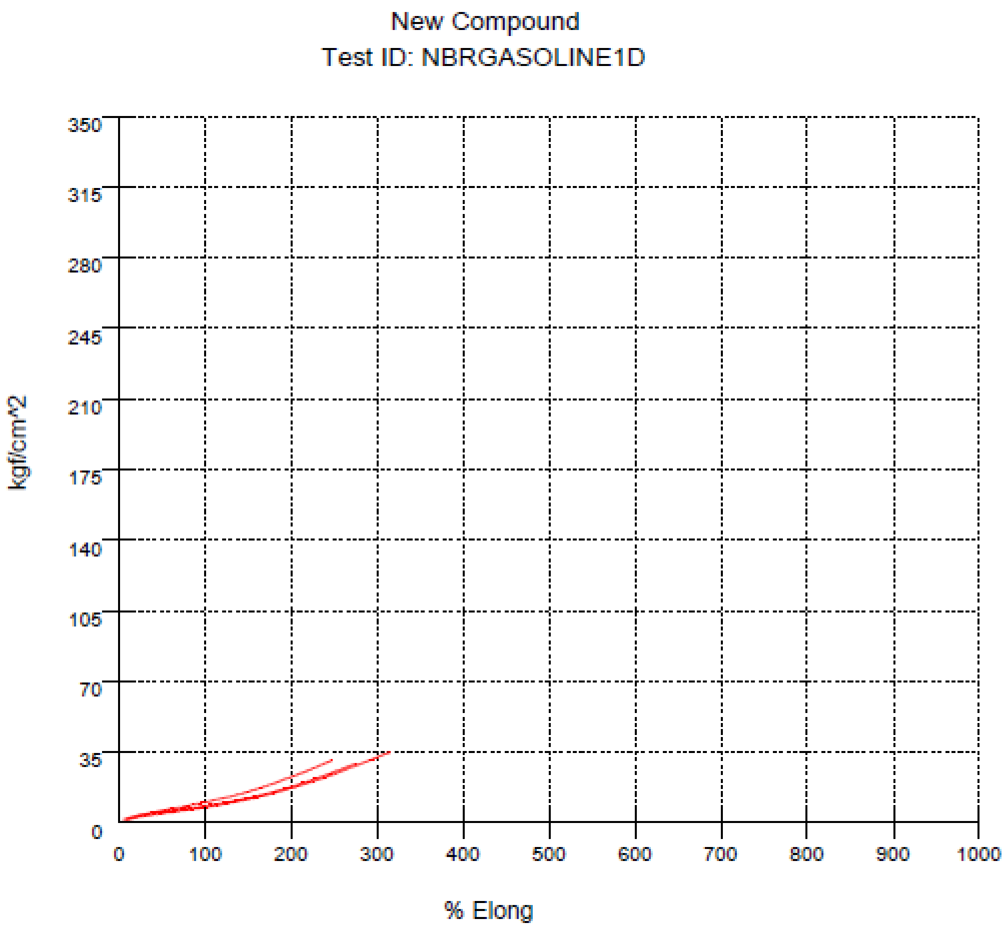


Figure A3-1 Stress-Strain curve of NBR after immersed in Gasoline 95 for 1 day

Table A3-2 Raw tensile data of HNBR

tensiDATA Tensile Test Results kgf/cm^2

Speed: up = 500.0 mm/min

Gauge Length: 20.0 mm

EDE Item	RESULT	Lower:	Upper:	Pass/Fail
dispersion				
Hardness				
Specific Gravity				
Shift				

Test ID		Width (mm)	Thickness (mm)	Tensile Strength	Elongation %	100% Modulus	300% Modulus
Lo Spec		---	---	---	---	---	---
Up Spec		---	---	---	---	---	---
HNBRGASOLINE1D	1	6.6	3.22	42.3	321	9.7	38.25
	2	6.6	2.94	45.9	246	12.3	0
	3	6.6	3.03	51.0	272	11.6	0
	R	---	---	45.9	272	11.6	0.00
JIS_MED				49.1	304	11.9	26.78

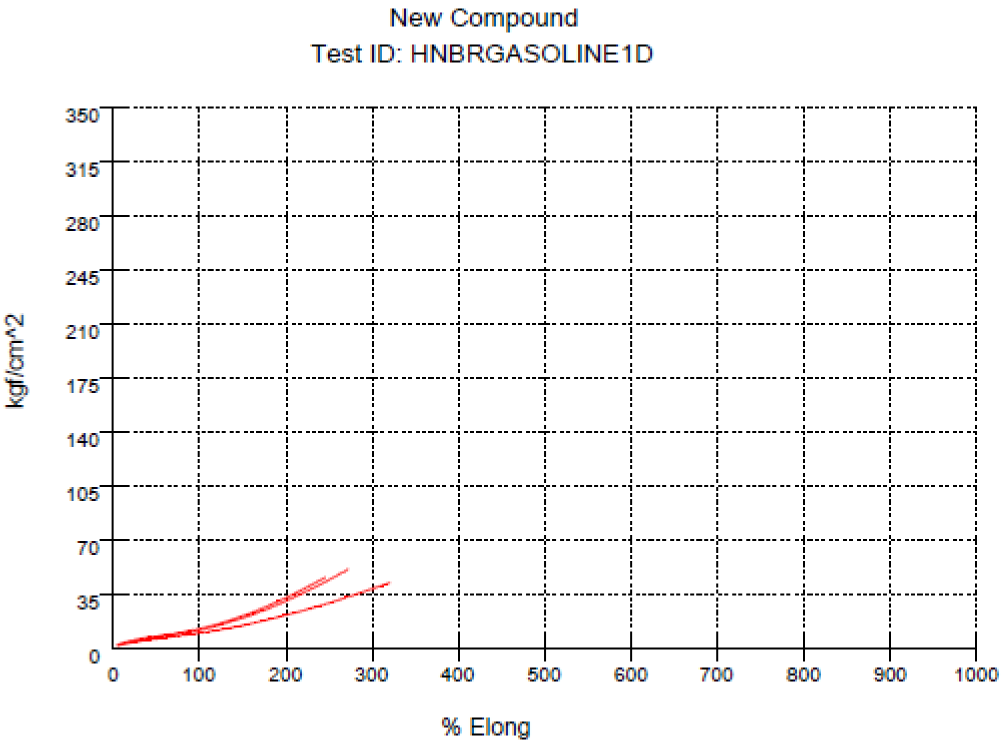
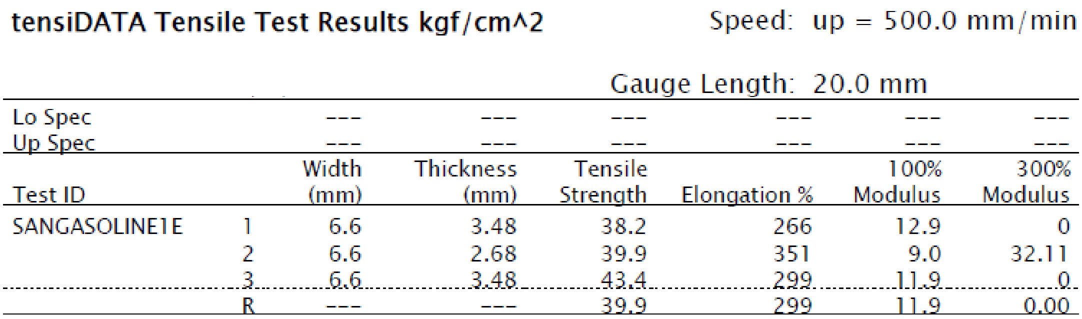


Figure A3-2 Stress-Strain curve of HNBR after immersed in Gasoline 95 for 1 day

Table A3-3 Raw tensile data of NBR/SAN [80/20 w/w] blended



tensiDATA Tensile Test Results kgf/cm^2 Speed: up = 500.0 mm/min

Gauge Length: 20.0 mm

Test ID		Width (mm)	Thickness (mm)	Tensile Strength	Elongation %	100% Modulus	300% Modulus
Lo Spec		---	---	---	---	---	---
Up Spec		---	---	---	---	---	---
SANGASOLINE1E	1	6.6	3.48	38.2	266	12.9	0
	2	6.6	2.68	39.9	351	9.0	32.11
	3	6.6	3.48	43.4	299	11.9	0
	R	---	---	39.9	299	11.9	0.00

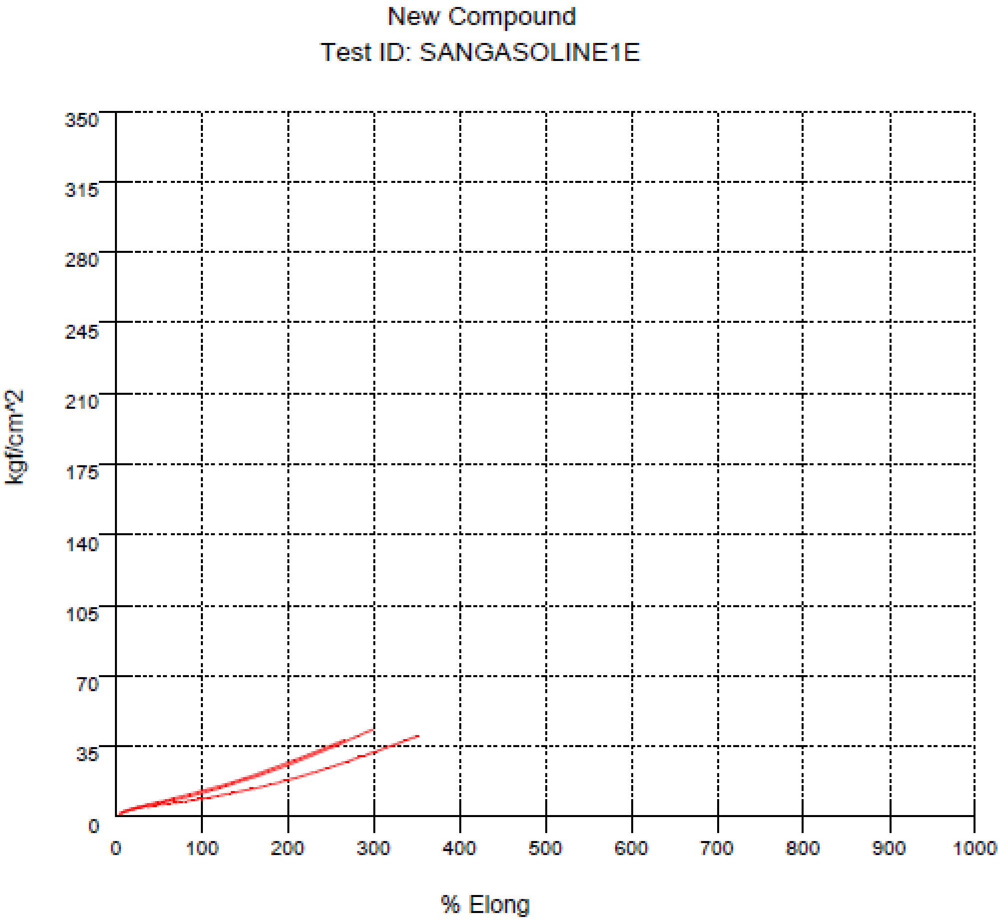


Figure A3-3 Stress-Strain curve of NBR/SAN [80/20 w/w] after immersed in Gasoline 95 for 1 day

APPENDIX B

THE EXPERIMENTAL DATA OF PHYSICAL PROPERTIES

Appendix B. Dimension change of NBR, HNBR, NBR/SAN, and NBR/ABS

Table B-1 Percent thickness change of samples when immersed in gasoline 95

Materials	Immersion time [days]	Thickness change [%]			Average [%]	SD [%]
		1	2	3		
NBR	0	-	-	-	-	-
	1	4.51	4.28	4.01	4.27	0.25
	2	5.64	4.96	5.47	5.36	0.35
	3	5.41	6.80	6.42	6.21	0.72
	7	11.66	10.26	11.76	11.23	0.84
	14	11.58	11.46	11.36	11.47	0.11
	28	9.72	12.86	13.08	11.89	1.88
	56	12.51	12.18	10.99	11.89	0.80
HNBR	0	-	-	-	-	-
	1	5.09	6.06	5.47	5.54	0.49
	2	5.98	6.94	6.48	6.47	0.48
	3	9.95	9.50	10.09	9.85	0.31
	7	12.73	12.40	12.96	12.70	0.28
	14	13.26	12.14	13.00	12.80	0.59
	28	13.50	11.50	12.34	12.45	1.00
	56	12.38	13.30	13.46	13.05	0.58
NBR/SAN [80/20 w/w] at mixing time 3 min	0	-	-	-	-	-
	1	4.06	3.89	4.69	4.21	0.42
	2	3.76	3.55	2.47	3.26	0.69
	3	6.83	3.40	6.66	5.63	1.93
	7	9.29	9.25	10.11	9.55	0.49
	14	10.26	10.78	9.96	10.33	0.41
	28	11.96	10.89	11.76	11.54	0.57
	56	12.69	12.73	14.95	13.46	1.29
NBR/ABS [80/20 w/w] at mixing time 3 min	0	-	-	-	-	-
	1	2.84	2.87	3.24	2.98	0.22
	2	4.13	2.99	3.23	3.45	0.60
	3	7.11	8.56	4.00	6.56	2.33
	7	10.76	9.58	10.78	10.37	0.69
	14	11.78	11.66	12.06	11.83	0.21
	28	14.06	12.22	13.81	13.36	1.00
	56	13.10	16.62	14.45	14.72	1.78

Table B-2 Percent thickness change of samples when immersed in acidic E20

Materials	Immersion time [days]	Thickness change [%]			Average [%]	SD [%]
		1	2	3		
NBR	0	-	-	-	-	-
	1	10.46	9.95	10.14	10.18	0.26
	2	9.77	11.25	11.36	10.79	0.89
	3	16.31	15.39	16.54	16.08	0.61
	7	20.19	22.32	21.59	21.37	1.08
	14	21.03	19.47	20.01	20.17	0.79
	28	24.27	23.87	23.31	23.82	0.48
	56	21.32	22.05	24.33	22.57	1.57
HNBR	0	-	-	-	-	-
	1	10.28	8.68	9.68	9.55	0.81
	2	12.33	13.50	13.97	13.27	0.84
	3	17.82	20.14	17.94	18.63	1.31
	7	25.92	25.16	25.53	25.54	0.38
	14	27.17	28.28	27.33	27.59	0.60
	28	29.37	29.45	30.46	29.76	0.61
	56	34.20	31.04	28.22	31.15	2.99
NBR/SAN [80/20 w/w] at mixing time 3 min	0	-	-	-	-	-
	1	7.58	8.78	8.99	8.45	0.76
	2	12.46	12.70	12.86	12.67	0.20
	3	15.21	16.81	17.02	16.35	0.99
	7	14.88	19.22	17.65	17.25	2.20
	14	19.63	18.99	19.78	19.47	0.42
	28	20.03	19.78	20.66	20.16	0.45
	56	24.75	21.67	24.10	23.51	1.62
NBR/ABS [80/20 w/w] at mixing time 3 min	0	-	-	-	-	-
	1	10.55	10.93	9.36	10.28	0.82
	2	12.28	12.15	13.22	12.55	0.58
	3	17.71	16.40	16.25	16.79	0.80
	7	22.33	20.43	22.05	21.60	1.03
	14	21.98	22.06	22.13	22.06	0.08
	28	25.40	24.03	24.55	24.66	0.69
	56	21.60	17.53	21.60	20.24	2.35

Table B-3 Percent thickness change of samples when immersed in E85

Materials	Immersion time [days]	Thickness change [%]			Average [%]	SD [%]
		1	2	3		
NBR	0	-	-	-	-	-
	1	2.05	2.30	2.14	2.16	0.13
	2	2.44	1.68	3.16	2.43	0.74
	3	3.96	3.23	3.70	3.63	0.37
	7	2.54	2.15	3.99	2.89	0.97
	14	4.60	4.77	3.74	4.37	0.55
	28	7.34	4.89	6.35	6.19	1.23
	56	7.08	6.93	6.95	6.99	0.08
HNBR	0	-	-	-	-	-
	1	1.80	1.95	1.54	1.76	0.21
	2	2.27	2.37	2.46	2.37	0.10
	3	2.21	2.90	1.38	2.16	0.76
	7	1.84	3.54	3.77	3.05	1.05
	14	3.51	3.78	2.98	3.42	0.41
	28	3.78	3.84	3.41	3.68	0.23
	56	5.40	2.71	3.40	3.84	1.40
NBR/SAN [80/20 w/w] at mixing time 3 min	0	-	-	-	-	-
	1	1.66	1.48	1.72	1.62	0.12
	2	2.48	2.12	4.44	3.01	1.25
	3	3.00	4.45	3.31	3.59	0.76
	7	5.02	5.87	4.37	5.09	0.75
	14	6.06	6.96	5.89	6.30	0.58
	28	7.29	6.96	6.99	7.08	0.18
	56	7.74	7.71	8.48	7.98	0.44
NBR/ABS [80/20 w/w] at mixing time 3 min	0	-	-	-	-	-
	1	1.66	1.33	1.46	1.48	0.17
	2	1.58	3.15	2.63	2.45	0.80
	3	2.46	3.21	2.91	2.86	0.38
	7	3.82	5.64	4.04	4.50	0.99
	14	4.98	5.06	5.72	5.25	0.41
	28	6.39	6.49	4.73	5.87	0.99
	56	5.84	6.29	7.88	6.67	1.07

Table B-4 Percent thickness change of samples when immersed in ethanol

Materials	Immersion time [days]	Thickness change [%]			Average [%]	SD [%]
		1	2	3		
NBR	0	-	-	-	-	-
	1	1.97	1.43	3.40	2.27	1.02
	2	1.19	1.28	1.31	1.26	0.06
	3	1.36	1.98	1.83	1.72	0.32
	7	0.83	1.65	0.44	0.97	0.62
	14	2.65	2.99	2.87	2.84	0.17
	28	3.66	3.75	3.30	3.57	0.24
	56	2.95	4.42	3.79	3.72	0.74
HNBR	0	-	-	-	-	-
	1	0.51	0.52	0.51	0.51	0.01
	2	0.78	1.05	0.84	0.89	0.14
	3	1.40	1.33	1.40	1.38	0.04
	7	0.88	1.04	1.29	1.07	0.21
	14	1.50	1.80	1.70	1.67	0.15
	28	2.99	3.06	2.78	2.94	0.15
	56	2.78	2.96	3.46	3.07	0.35
NBR/SAN [80/20 w/w] at mixing time 3 min	0	-	-	-	-	-
	1	0.78	0.27	0.47	0.51	0.26
	2	1.54	1.50	1.57	1.54	0.04
	3	2.74	0.00	1.97	1.57	1.41
	7	1.18	1.96	2.27	1.80	0.56
	14	2.63	2.96	2.41	2.67	0.28
	28	3.52	3.38	3.78	3.56	0.20
	56	4.48	5.64	4.67	4.93	0.62
NBR/ABS [80/20 w/w] at mixing time 3 min	0	-	-	-	-	-
	1	1.05	0.90	0.71	0.89	0.17
	2	0.45	1.79	2.14	1.46	0.89
	3	1.62	0.74	2.28	1.55	0.77
	7	1.58	1.90	2.07	1.85	0.25
	14	2.61	1.98	2.66	2.42	0.38
	28	3.38	3.37	4.04	3.60	0.38
	56	4.57	4.95	4.36	4.63	0.30

Table B-5 Percent diameter change of samples when immersed in gasoline 95

Materials	Immersion time [days]	Diameter change [%]			Average [%]	SD [%]
		1	2	3		
NBR	0	-	-	-	-	-
	1	2.75	2.57	2.68	2.67	0.09
	2	3.54	4.11	3.94	3.86	0.29
	3	5.48	4.82	5.29	5.20	0.34
	7	9.24	8.46	8.85	8.85	0.39
	14	9.35	8.77	8.93	9.02	0.30
	28	10.4	9.14	9.74	9.76	0.63
	56	10.44	10.48	11.35	10.76	0.51
HNBR	0	-	-	-	-	-
	1	4.7	4.41	4.84	4.65	0.22
	2	5.56	5.71	6.06	5.78	0.26
	3	7.51	7.6	7.13	7.41	0.25
	7	13.45	12.47	12.54	12.82	0.55
	14	12.61	12.55	13.23	12.80	0.38
	28	11.97	12.95	12.44	12.45	0.49
	56	11.72	12.56	11.6	11.96	0.52
NBR/SAN [80/20 w/w] at mixing time 3 min	0	-	-	-	-	-
	1	2.3	2.14	2.4	2.28	0.13
	2	3.42	3.36	3.04	3.27	0.20
	3	3.6	3.66	3.86	3.71	0.14
	7	5.57	5.55	5.95	5.69	0.23
	14	7.46	8.23	7.86	7.85	0.39
	28	9.45	8.72	9.01	9.06	0.37
	56	10.03	10.16	10.21	10.13	0.09
NBR/ABS [80/20 w/w] at mixing time 3 min	0	-	-	-	-	-
	1	2.04	2.77	3.06	2.62	0.53
	2	3.65	3.13	3.56	3.45	0.28
	3	3.56	4.43	4.03	4.01	0.44
	7	7.05	6.33	6.77	6.72	0.36
	14	8.76	9.33	8.95	9.01	0.29
	28	11.52	11.75	11.61	11.63	0.12
	56	9.65	9.66	10.73	10.01	0.62

Table B-6 Percent diameter change of samples when immersed in acidic E20

Materials	Immersion time [days]	Diameter change [%]			Average [%]	SD [%]
		1	2	3		
NBR	0	-	-	-	-	-
	1	6.74	6.82	6.45	6.67	0.19
	2	10.01	9.69	10.84	10.18	0.59
	3	15.48	15.32	17.4	16.07	1.16
	7	21.65	21.62	20.77	21.35	0.50
	14	20.16	20.29	20.02	20.16	0.14
	28	20.52	20.03	19.22	19.92	0.66
	56	19.9	22.22	21.05	21.06	1.16
HNBR	0	-	-	-	-	-
	1	9.07	9.01	9.93	9.34	0.51
	2	10.00	9.23	9.42	9.55	0.40
	3	21.8	20.11	20.46	20.79	0.89
	7	22.32	22.73	26.63	23.89	2.38
	14	25.63	25.23	24.88	25.25	0.38
	28	25.36	24.78	25.30	25.15	0.32
	56	23.71	25.28	24.3	24.43	0.79
NBR/SAN [80/20 w/w] at mixing time 3 min	0	-	-	-	-	-
	1	5.69	5.43	5.02	5.38	0.34
	2	8.91	8.46	7.98	8.45	0.47
	3	12.54	13.37	13.2	13.04	0.44
	7	18.75	18.06	16.93	17.91	0.92
	14	17.67	18.49	18.02	18.06	0.41
	28	18.03	18.00	17.69	17.91	0.19
	56	15.3	18.35	17.61	17.09	1.59
NBR/ABS [80/20 w/w] at mixing time 3 min	0	-	-	-	-	-
	1	7.16	4.97	6.07	6.07	1.10
	2	11.46	9.50	9.89	10.28	1.04
	3	15.18	14.09	12.83	14.03	1.18
	7	17.72	17.45	15.82	17.00	1.03
	14	19.02	19.11	18.08	18.74	0.57
	28	16.56	20.28	20.63	19.16	2.26
	56	16.81	17.13	18.17	17.37	0.71

Table B-7 Percent diameter change of samples when immersed in E85

Materials	Immersion time [days]	Diameter change [%]			Average [%]	SD [%]
		1	2	3		
NBR	0	-	-	-	-	-
	1	2.1	1.28	2.34	1.91	0.56
	2	2.01	1.98	2.50	2.16	0.29
	3	2.86	2.59	1.82	2.42	0.54
	7	3.08	3.76	3.98	3.61	0.47
	14	4.85	4.04	4.21	4.37	0.43
	28	5.97	6.47	4.82	5.75	0.85
	56	8.18	7.83	8.24	8.08	0.22
HNBR	0	-	-	-	-	-
	1	0.65	0.59	0.63	0.62	0.03
	2	1.95	1.83	1.51	1.76	0.23
	3	2.31	2.39	2.29	2.33	0.05
	7	3.25	2.31	3.07	2.88	0.50
	14	3.96	3.12	3.19	3.42	0.47
	28	4.41	4.62	4.80	4.61	0.20
	56	5.51	5.14	6.34	5.66	0.61
NBR/SAN [80/20 w/w] at mixing time 3 min	0	-	-	-	-	-
	1	1.04	1.77	0.93	1.25	0.46
	2	1.64	1.76	1.45	1.62	0.16
	3	1.97	1.81	1.8	1.86	0.10
	7	3.5	2.65	3.34	3.16	0.45
	14	4.94	6.14	5.84	5.64	0.62
	28	7.65	6.53	7.01	7.06	0.56
	56	9.59	9.64	9.3	9.51	0.18
NBR/ABS [80/20 w/w] at mixing time 3 min	0	-	-	-	-	-
	1	1.52	2.25	1.18	1.65	0.55
	2	1.46	1.75	1.24	1.48	0.26
	3	2.15	1.06	2.05	1.75	0.60
	7	3.1	2.65	2.91	2.89	0.23
	14	4.44	3.96	3.54	3.98	0.45
	28	5.67	5.59	5.37	5.54	0.16
	56	9.52	9.91	9.42	9.62	0.26

Table B-8 Percent diameter change of samples when immersed in ethanol

Materials	Immersion time [days]	Diameter change [%]			Average [%]	SD [%]
		1	2	3		
NBR	0	-	-	-	-	-
	1	1.37	0.88	0.59	0.95	0.39
	2	1.45	1.11	1.21	1.26	0.17
	3	1.53	1.93	1.64	1.70	0.21
	7	1.01	1.29	1.5	1.27	0.25
	14	1.75	1.84	1.42	1.67	0.22
	28	2.49	2.97	2.26	2.57	0.36
	56	5.49	5.15	6.22	5.62	0.55
HNBR	0	-	-	-	-	-
	1	1.41	0.31	0.28	0.67	0.64
	2	0.71	1.01	0.94	0.89	0.16
	3	1.01	1.44	1.37	1.27	0.23
	7	1.33	1.55	1.96	1.61	0.32
	14	3.03	2.61	2.89	2.84	0.21
	28	3.44	3.78	3.63	3.62	0.17
	56	3.81	4.91	4.76	4.49	0.60
NBR/SAN [80/20 w/w] at mixing time 3 min	0	-	-	-	-	-
	1	0.17	0.73	0.17	0.36	0.32
	2	0.41	0.62	0.51	0.51	0.11
	3	0.73	0.98	0.88	0.86	0.13
	7	1.11	1.78	1.29	1.39	0.35
	14	2.02	2.08	1.86	1.99	0.11
	28	2.49	2.56	2.09	2.38	0.25
	56	2.04	3.88	3.18	3.03	0.93
NBR/ABS [80/20 w/w] at mixing time 3 min	0	-	-	-	-	-
	1	0.94	0.94	2	1.29	0.61
	2	0.76	1.06	0.84	0.89	0.16
	3	1.3	0.14	0.17	0.54	0.66
	7	1	1.43	2.06	1.50	0.53
	14	1.94	2.34	1.98	2.09	0.22
	28	3.4	3.14	1.36	2.63	1.11
	56	8.78	5	3.08	5.62	2.90

Table B-9 Percent volume change of samples when immersed in gasoline 95

Materials	Immersion time [days]	Volume change [%]			Average [%]	SD [%]
		1	2	3		
NBR	0	-	-	-	-	-
	1	40.49	38.22	39.54	39.42	1.14
	2	45.32	44.86	39.27	43.15	3.37
	3	39.20	39.14	37.31	38.55	1.07
	7	32.26	23.31	32.32	29.30	5.18
	14	36.62	35.22	37.22	36.35	1.03
	28	32.60	32.10	28.03	30.91	2.51
	56	17.77	23.90	20.89	20.85	3.07
HNBR	0	-	-	-	-	-
	1	49.05	45.60	47.19	47.28	1.73
	2	50.73	49.70	36.35	45.59	8.02
	3	47.75	50.07	44.61	47.48	2.74
	7	36.11	35.83	36.42	36.12	0.30
	14	45.20	47.31	45.48	46.00	1.15
	28	35.64	35.04	34.77	35.15	0.45
	56	20.01	27.46	22.93	23.47	3.75
NBR/SAN [80/20 w/w] at mixing time 3 min	0	-	-	-	-	-
	1	32.37	35.77	31.35	33.16	2.31
	2	41.49	41.28	40.47	41.08	0.54
	3	33.78	36.94	36.64	35.79	1.74
	7	35.29	32.16	30.85	32.77	2.28
	14	34.32	32.91	36.43	34.55	1.77
	28	25.26	25.26	28.57	26.36	1.91
	56	18.32	21.98	20.36	20.22	1.83
NBR/ABS [80/20 w/w] at mixing time 3 min	0	-	-	-	-	-
	1	33.58	37.92	38.87	36.79	2.82
	2	35.31	44.20	38.04	39.18	4.55
	3	33.54	39.96	35.15	36.22	3.34
	7	36.27	34.77	35.16	35.40	0.78
	14	36.70	41.72	35.93	38.12	3.14
	28	25.91	25.09	22.92	24.64	1.54
	56	20.18	22.84	21.99	21.67	1.36

Table B-10 Percent volume change of samples when immersed in acidic E20

Materials	Immersion time [days]	Volume change [%]			Average [%]	SD [%]
		1	2	3		
NBR	0	-	-	-	-	-
	1	62.84	56.67	54.49	58.00	4.33
	2	88.28	82.68	79.62	83.53	4.39
	3	68.15	69.51	66.91	68.19	1.30
	7	62.97	67.80	64.32	65.03	2.49
	14	72.28	72.64	70.06	71.66	1.40
	28	46.97	51.42	47.96	48.78	2.34
	56	30.05	29.78	29.60	29.81	0.23
HNBR	0	-	-	-	-	-
	1	66.24	59.57	58.43	61.41	4.22
	2	89.78	83.98	95.45	89.74	5.74
	3	80.57	79.70	87.70	82.66	4.39
	7	68.13	91.93	79.00	79.69	11.91
	14	95.87	95.22	92.81	94.63	1.61
	28	42.19	51.38	52.78	48.78	5.75
	56	28.15	32.19	32.17	30.84	2.33
NBR/SAN [80/20 w/w] at mixing time 3 min	0	-	-	-	-	-
	1	54.56	53.23	57.35	55.05	2.10
	2	79.04	75.56	74.06	76.22	2.55
	3	68.67	67.45	66.45	67.52	1.11
	7	66.62	68.10	55.34	63.35	6.98
	14	73.57	73.62	71.23	72.81	1.37
	28	59.71	54.11	69.23	61.02	7.64
	56	27.50	35.27	33.95	32.24	4.16
NBR/ABS [80/20 w/w] at mixing time 3 min	0	-	-	-	-	-
	1	54.93	57.90	49.21	54.01	4.42
	2	76.80	79.41	76.94	77.72	1.47
	3	71.72	68.38	65.89	68.66	2.93
	7	55.22	50.17	66.41	57.27	8.31
	14	70.19	74.38	75.22	73.26	2.69
	28	48.93	41.06	34.90	41.63	7.03
	56	23.42	26.41	25.78	25.20	1.58

Table B-11 Percent volume change of samples when immersed in E85

Materials	Immersion time [days]	Volume change [%]			Average [%]	SD [%]
		1	2	3		
NBR	0	-	-	-	-	-
	1	21.98	32.40	12.16	22.18	10.12
	2	34.37	24.87	23.95	27.73	5.77
	3	21.91	24.95	26.35	24.40	2.27
	7	14.68	25.95	12.58	17.74	7.19
	14	19.48	18.86	18.93	19.09	0.34
	28	23.10	20.81	21.22	21.71	1.22
	56	19.15	18.43	17.16	18.25	1.01
HNBR	0	-	-	-	-	-
	1	29.93	7.58	14.48	17.33	11.44
	2	44.63	38.11	35.35	39.36	4.77
	3	19.87	20.25	21.59	20.57	0.90
	7	18.27	16.41	15.38	16.69	1.46
	14	19.48	18.86	18.93	19.09	0.34
	28	20.14	20.75	19.03	19.97	0.87
	56	21.36	18.93	17.53	19.27	1.94
NBR/SAN [80/20 w/w] at mixing time 3 min	0	-	-	-	-	-
	1	8.18	37.96	47.34	31.16	20.45
	2	31.23	33.28	6.99	23.83	14.62
	3	23.01	22.48	22.17	22.55	0.42
	7	16.11	19.01	19.58	18.23	1.86
	14	20.56	23.30	23.28	22.38	1.58
	28	21.46	22.29	21.89	21.88	0.42
	56	15.58	21.67	20.37	19.21	3.21
NBR/ABS [80/20 w/w] at mixing time 3 min	0	-	-	-	-	-
	1	41.61	31.79	35.89	36.43	4.93
	2	39.56	18.72	19.49	25.92	11.82
	3	23.55	23.32	22.00	22.96	0.84
	7	21.07	19.20	17.51	19.26	1.78
	14	22.04	21.48	22.53	22.02	0.53
	28	20.17	22.24	23.36	21.92	1.62
	56	19.89	20.02	18.07	19.33	1.09

Table B-12 Percent volume change of samples when immersed in ethanol

Materials	Immersion time [days]	Volume change [%]			Average [%]	SD [%]
		1	2	3		
NBR	0	-	-	-	-	-
	1	14.84	14.47	14.10	14.47	0.37
	2	15.79	16.75	14.73	15.76	1.01
	3	12.88	13.49	14.91	13.76	1.04
	7	8.52	13.07	10.50	10.70	2.28
	14	12.17	14.10	14.85	13.71	1.38
	28	11.67	13.54	12.56	12.59	0.94
	56	13.07	12.32	12.69	12.69	0.38
HNBR	0	-	-	-	-	-
	1	13.47	13.83	14.88	14.06	0.73
	2	11.92	11.54		7.82	0.27
	3	5.61	9.27	8.21	7.70	1.88
	7	10.20	10.04	8.55	9.60	0.91
	14	8.72	8.34	7.21	8.09	0.79
	28	7.13	7.08	8.90	7.70	1.04
	56	10.17	12.18	13.37	11.91	1.62
NBR/SAN [80/20 w/w] at mixing time 3 min	0	-	-	-	-	-
	1	12.09	11.83	13.55	12.49	0.93
	2	12.33	11.44	13.16	12.31	0.86
	3	8.65	10.39	11.41	10.15	1.40
	7	12.40	10.75	11.32	11.49	0.84
	14	13.46	16.20	13.92	14.53	1.47
	28	12.97	8.37	13.47	11.60	2.81
	56	6.67	8.45	7.35	7.49	0.90
NBR/ABS [80/20 w/w] at mixing time 3 min	0	-	-	-	-	-
	1	12.44	12.01	15.69	13.38	2.01
	2	18.10	18.85	7.04	14.66	6.61
	3	8.90	11.79	11.33	10.67	1.55
	7	6.98	10.72	11.75	9.82	2.51
	14	12.50	13.92	13.52	13.31	0.73
	28	15.10	10.28	11.25	12.21	2.55
	56	10.10	13.16	12.28	11.85	1.58

Table B-13 Percent weight change of samples when immersed in gasoline 95

Materials	Immersion time [days]	Weight change [%]			Average [%]	SD [%]
		1	2	3		
NBR	0	-	-	-	-	-
	1	26.06	30.05	31.71	29.27	2.90
	2	35.10	35.26	32.58	34.31	1.50
	3	31.18	30.64	30.19	30.67	0.50
	7	28.96	20.86	26.44	25.42	4.15
	14	28.74	30.67	29.82	29.74	0.97
	28	26.23	26.47	23.81	25.50	1.47
	56	16.25	12.28	18.13	15.55	2.99
HNBR	0	-	-	-	-	-
	1	39.73	36.68	36.41	37.61	1.84
	2	40.50	40.44	38.83	39.92	0.95
	3	38.67	41.09	36.46	38.74	2.32
	7	32.02	31.19	32.11	31.77	0.51
	14	37.91	38.25	36.27	37.48	1.06
	28	30.16	30.17	29.41	29.91	0.44
	56	19.23	19.78	20.20	19.74	0.49
NBR/SAN [80/20 w/w] at mixing time 3 min	0	-	-	-	-	-
	1	25.13	25.57	25.29	25.33	0.22
	2	32.97	32.89	31.94	32.60	0.57
	3	28.14	29.70	28.79	28.88	0.78
	7	25.45	26.99	28.03	26.82	1.30
	14	28.24	28.18	28.98	28.47	0.45
	28	22.05	20.40	24.74	22.40	2.19
	56	17.26	18.59	18.28	18.04	0.70
NBR/ABS [80/20 w/w] at mixing time 3 min	0	-	-	-	-	-
	1	26.94	29.68	28.66	28.43	1.38
	2	32.14	34.30	30.57	32.34	1.87
	3	29.41	30.91	30.34	30.22	0.76
	7	31.10	29.56	29.52	30.06	0.90
	14	29.93	32.12	29.73	30.59	1.33
	28	21.69	25.00	20.96	22.55	2.15
	56	18.40	19.27	19.25	18.97	0.50

Table B-14 Percent weight change of samples when immersed in acidic E20

Materials	Immersion time [days]	Weight change [%]			Average [%]	SD [%]
		1	2	3		
NBR	0	-	-	-	-	-
	1	46.20	45.29	41.32	44.27	2.59
	2	64.77	65.19	61.42	63.79	2.07
	3	53.76	54.49	51.65	53.30	1.47
	7	49.69	53.75	52.11	51.85	2.04
	14	55.28	58.29	53.94	55.84	2.23
	28	46.78	36.55	38.45	40.59	5.44
	56	26.04	24.10	25.44	25.19	0.99
HNBR	0	-	-	-	-	-
	1	48.35	45.98	45.36	46.56	1.58
	2	72.16	68.18	63.68	68.01	4.24
	3	63.83	62.05	70.68	65.52	4.56
	7	58.04	72.28	64.63	64.98	7.13
	14	74.88	74.86	72.97	74.24	1.10
	28	34.90	43.23	43.23	40.45	4.81
	56	23.08	25.51	26.20	24.93	1.64
NBR/SAN [80/20 w/w] at mixing time 3 min	0	-	-	-	-	-
	1	45.25	40.74	42.93	42.97	2.26
	2	58.60	56.73	56.10	57.14	1.30
	3	52.87	52.07	51.19	52.04	0.84
	7	52.00	52.78	44.83	49.87	4.38
	14	55.93	56.52	55.56	56.00	0.48
	28	46.20	42.05	52.60	46.95	5.31
	56	22.56	30.17	28.18	26.97	3.95
NBR/ABS [80/20 w/w] at mixing time 3 min	0	-	-	-	-	-
	1	41.29	42.69	38.92	40.97	1.91
	2	57.40	58.52	56.60	57.51	0.96
	3	55.92	54.29	51.59	53.93	2.19
	7	43.72	41.24	54.19	46.38	6.87
	14	54.07	57.30	59.22	56.86	2.60
	28	41.50	35.19	32.43	36.37	4.65
	56	19.51	22.10	22.11	21.24	1.50

Table B-15 Percent weight change of samples when immersed in E85

Materials	Immersion time [days]	Weight change [%]			Average [%]	SD [%]
		1	2	3		
NBR	0	-	-	-	-	-
	1	38.24	38.10	37.85	38.06	0.20
	2	44.38	45.56	44.85	44.93	0.59
	3	20.26	20.00	21.02	20.43	0.53
	7	15.63	22.89	10.92	16.48	6.03
	14	19.32	20.11	19.16	19.53	0.51
	28	19.32	18.60	18.13	18.68	0.60
	56	16.32	15.38	16.17	15.96	0.51
HNBR	0	-	-	-	-	-
	1	41.81	42.86	43.84	42.84	1.02
	2	50.90	49.66	51.85	50.80	1.10
	3	17.59	18.28	18.36	18.08	0.42
	7	14.89	16.75	15.71	15.78	0.93
	14	16.83	16.95	16.41	16.73	0.28
	28	18.18	18.52	17.01	17.90	0.79
	56	19.15	16.57	15.47	17.06	1.89
NBR/SAN [80/20 w/w] at mixing time 3 min	0	-	-	-	-	-
	1	36.68	37.13	33.13	35.65	2.19
	2	44.32	44.12	43.32	43.92	0.53
	3	18.79	19.23	19.05	19.02	0.22
	7	15.57	17.65	16.87	16.70	1.05
	14	18.78	18.29	19.47	18.85	0.59
	28	17.71	18.78	19.14	18.54	0.74
	56	15.53	18.18	17.74	17.15	1.42
NBR/ABS [80/20 w/w] at mixing time 3 min	0	-	-	-	-	-
	1	36.93	37.01	40.66	38.20	2.13
	2	43.20	43.50	42.35	43.02	0.60
	3	18.71	18.95	18.75	18.80	0.13
	7	16.76	15.79	17.37	16.64	0.80
	14	19.10	18.45	18.28	18.61	0.43
	28	18.79	19.87	19.17	19.28	0.55
	56	17.24	17.16	15.94	16.78	0.73

Table B-16 Percent weight change of samples when immersed in ethanol

Materials	Immersion time [days]	Weight change [%]			Average [%]	SD [%]
		1	2	3		
NBR	0	-	-	-	-	-
	1	11.41	11.04	12.80	11.75	0.93
	2	12.79	5.98	26.54	15.10	10.47
	3	10.78	11.39	11.24	11.14	0.32
	7	9.43	11.56	11.11	10.70	1.12
	14	12.96	12.07	12.12	12.38	0.50
	28	10.59	10.50	10.37	10.49	0.11
	56	12.00	11.48	12.57	12.02	0.55
HNBR	0	-	-	-	-	-
	1	11.70	10.00	11.17	10.96	0.87
	2	12.63	9.60	9.79	10.67	1.70
	3	6.37	7.94	7.65	7.32	0.84
	7	9.39	8.54	9.60	9.18	0.56
	14	8.02	8.21	7.98	8.07	0.12
	28	7.14	7.02	8.67	7.61	0.92
	56	9.20	12.37	10.81	10.79	1.59
NBR/SAN [80/20 w/w] at mixing time 3 min	0	-	-	-	-	-
	1	8.02	9.09	8.93	8.68	0.58
	2	9.41	9.64	10.10	9.72	0.35
	3	7.95	9.39	10.40	9.25	1.23
	7	12.42	10.00	10.73	11.05	1.24
	14	11.86	12.36	11.43	11.88	0.47
	28	10.40	10.00	11.58	10.66	0.82
	56	8.24	8.44	8.38	8.35	0.10
NBR/ABS [80/20 w/w] at mixing time 3 min	0	-	-	-	-	-
	1	9.94	9.64	10.69	10.09	0.54
	2	14.20	23.78	2.81	13.60	10.50
	3	8.56	9.36	8.74	8.89	0.42
	7	9.68	11.66	11.80	11.05	1.19
	14	11.18	11.85	11.03	11.35	0.44
	28	11.31	9.59	9.94	10.28	0.91
	56	11.19	12.23	10.98	11.47	0.67

APPENDIX C

IR CHARACTERIZATION

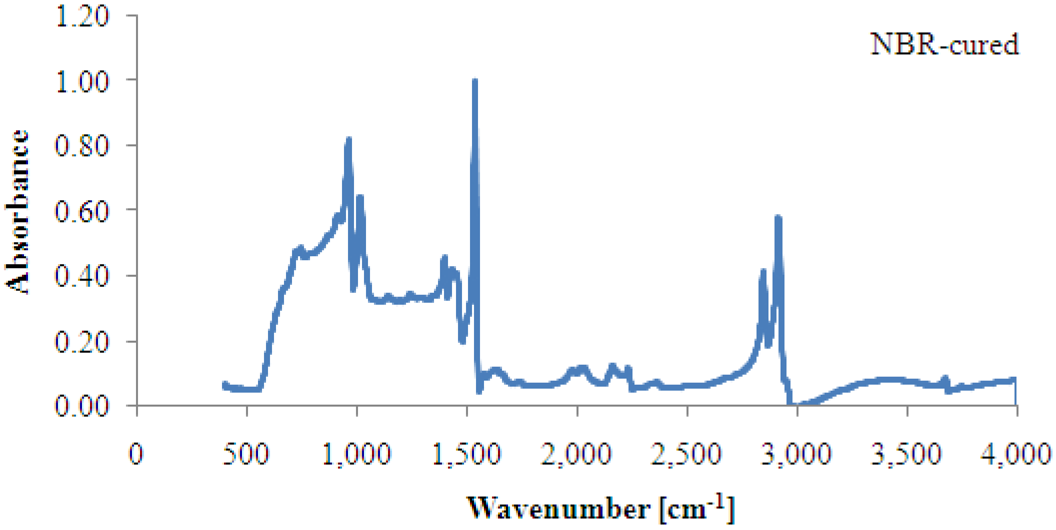


Figure C-1 IR spectra of NBR-cured

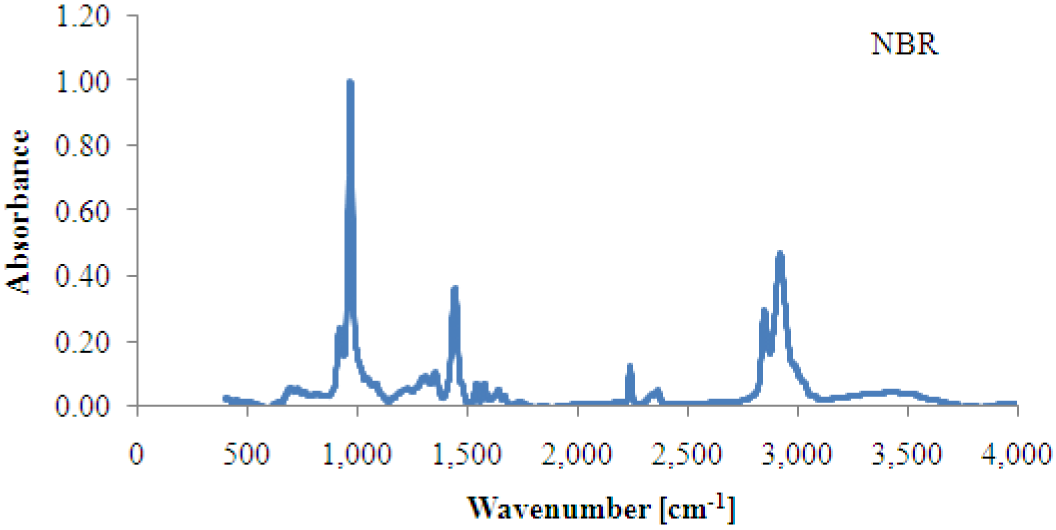


Figure C-2 IR spectra of NBR

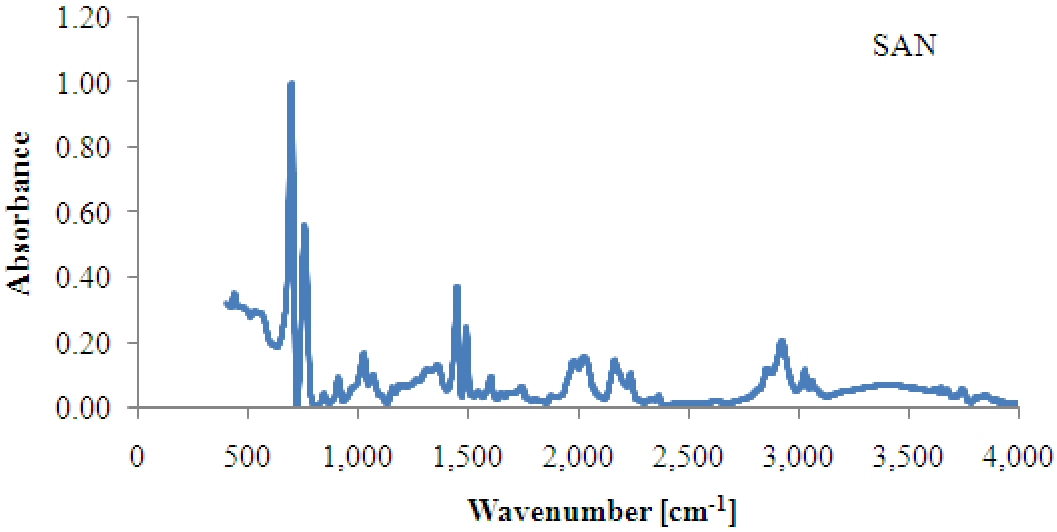


Figure C-3 IR spectra of SAN

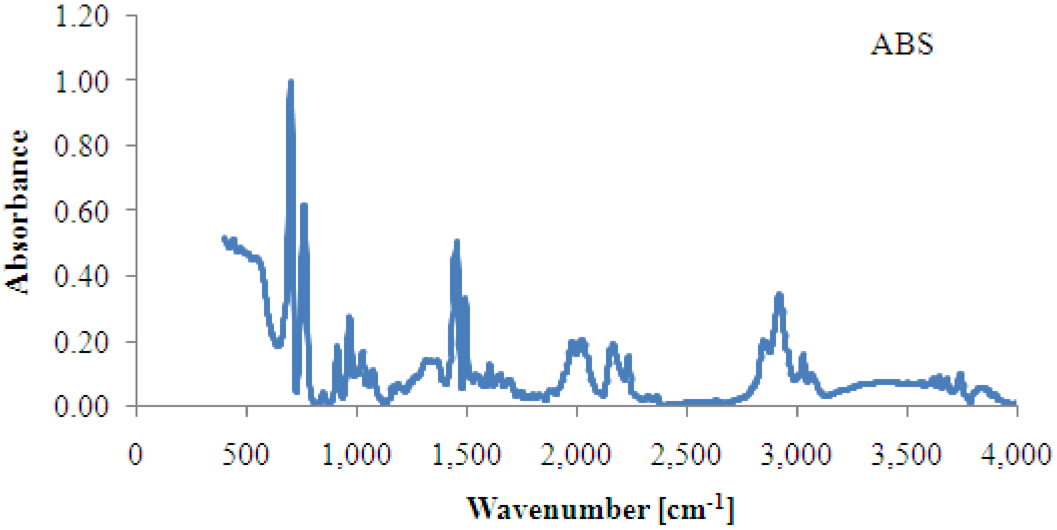


Figure C-4 IR spectra of ABS

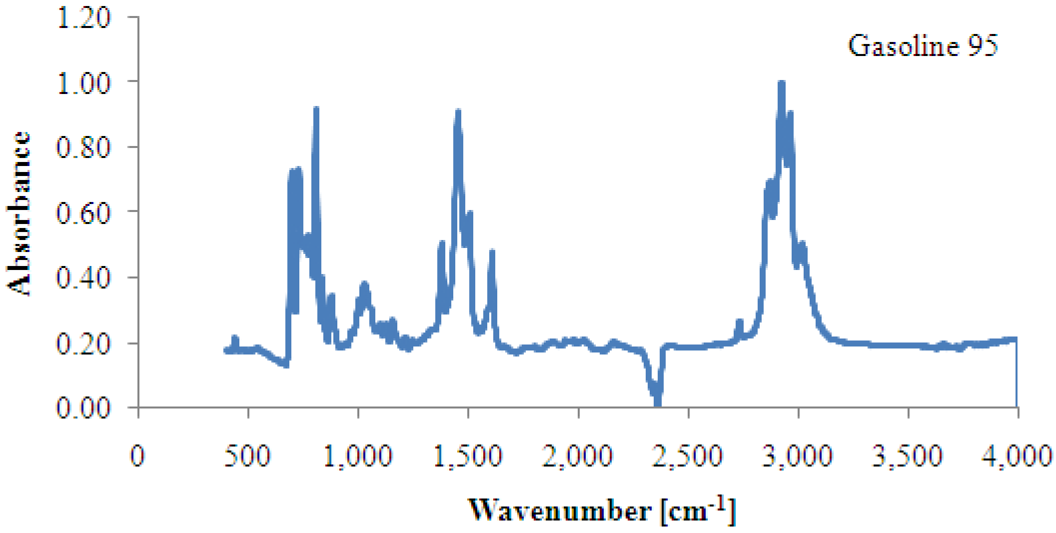


Figure C-5 IR spectra of precipitated gasoline 95

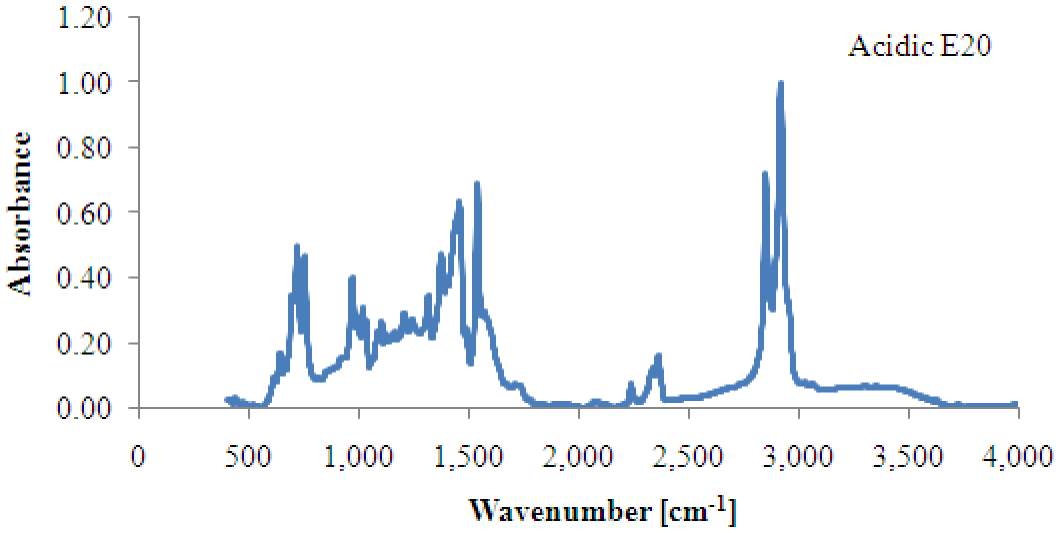


Figure C-6 IR spectra of precipitated acidic E20

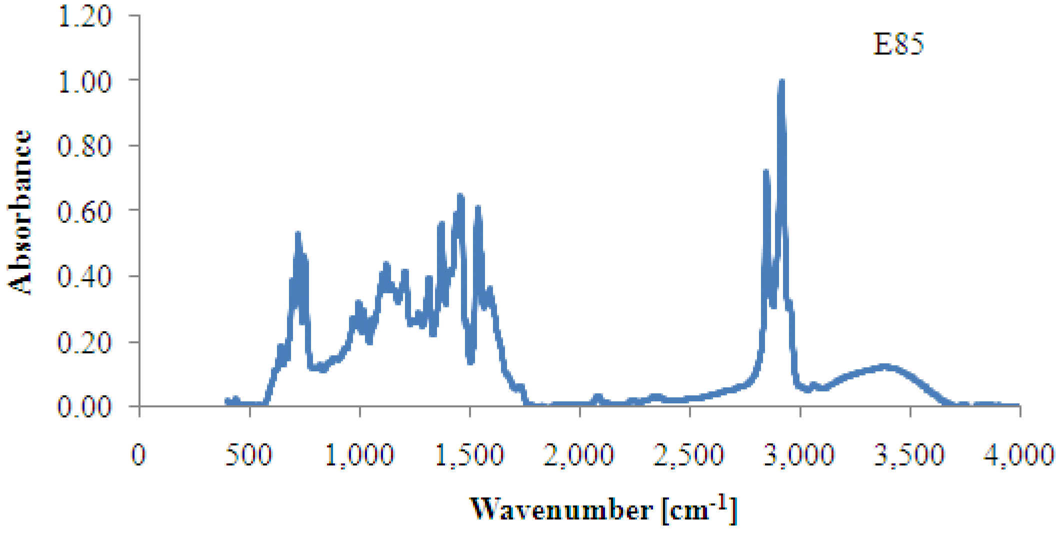


Figure C-7 IR spectra of precipitated E85

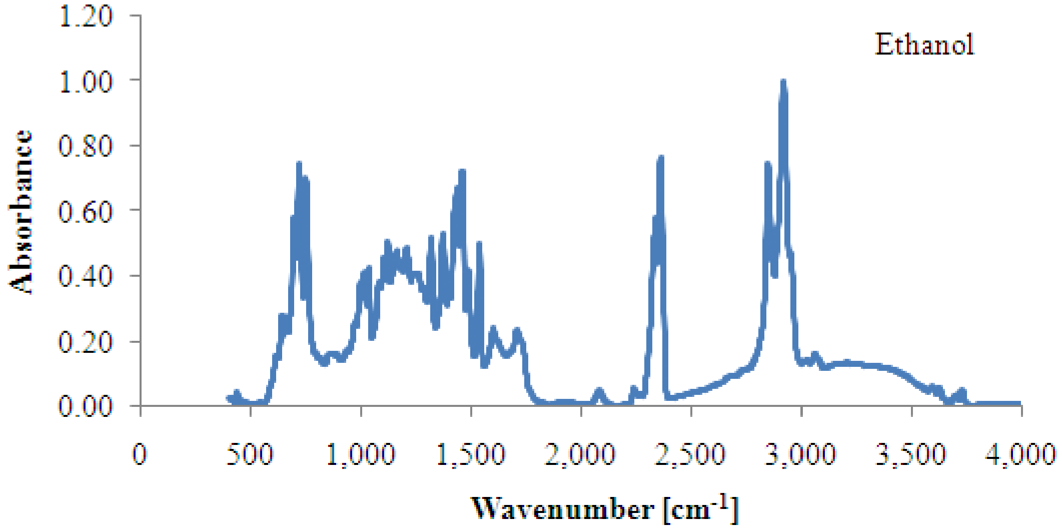


Figure C-8 IR spectra of precipitated ethanol

VITA

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