

**CHARACTERIZATION AND PROPERTIES OF
NATURAL RUBBER/RECYCLED
ACRYLONITRILE-BUTADIENE RUBBER
BLENDS**

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**CHARACTERIZATION AND PROPERTIES OF NATURAL
RUBBER/RECYCLED ACRYLONITRILE-BUTADIENE RUBBER BLENDS**

by

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LIST OF ABBREVIATIONS

NR	Natural rubber
SMR L	Standard Malaysian Rubber (Light colour)
NBRr	Recycled acrylonitrile-butadiene rubber
NBRv	Virgin acrylonitrile-butadiene rubber
ENR-50	Epoxidized natural rubber
EVA	Ethylene vinyl acetate
NRL	Natural rubber latex
RRP	Recycled rubber powder
ZnO	Zinc oxide
DCP	Dicumyl peroxide
N330	Carbon black (High abrasion furnace)
CBS	N-Cyclohexyl-2-benzothiazole sulfonamide
IPPD	N-(1-methylethyl)-N'-phenyl (IPPD)
FTIR	Fourier transform infrared
SEM	Scanning electron microscopy
TGA	Thermogravimetric analysis
ASTM	American Society for Testing and Materials
t_{s2}	Scorch time
t_{90}	Cure time
M_L	Minimum torque
M_H	Maximum torque
M100	Modulus at 100% elongation
M300	Modulus at 300% elongation

PENCIRIAN DAN SIFAT ADUNAN-ADUNAN GETAH ASLI/ GETAH AKRILONITRIL-BUTADIENA KITAR SEMULA

ABSTRAK

Dalam kajian ini, lima siri formulasi telah digunakan untuk mengkaji kesan pengadunan sarung tangan getah kitar semula akrilonitril-butadiena (NBRr) dengan getah asli (NR). Ujian sifat pematangan, ujian tensil, ujian kekerasan dan resilien, ujian ketumpatan sambung silang, ujian fatig, analisis haba, dan analisis *Fourier transform infrared* (FTIR) telah dijalankan ke atas kelima-lima siri ini. Kajian morfologi permukaan kegagalan telah dianalisis menggunakan Mikroskop electron imbasan (SEM). Pada siri pertama, adunan getah asli/getah dara akrilonitril-butadiene (NR/NBRv) menunjukkan sifat-sifat pematangan dan mekanikal yang lebih baik berbanding dengan adunan getah NR/NBRr. Walaubagaimanapun, adunan getah NR/NBRr menunjukkan keputusan yang lebih baik ke atas beberapa sifat seperti peningkatan modulus dan kekerasan, dan pengurangan penyerapan pelarut. ENR-50 dan EVA telah ditambah ke dalam adunan getah NR/NBRr sebagai agen pengserasi pada siri kedua dan ketiga. Keputusan menunjukkan sifat-sifat pematangan dan mekanikal adunan getah NR/NBRr dengan agen pengserasi didapati meningkat berbanding adunan getah NR/NBRr tanpa agen pengserasi. Walaubagaimanapun, penambahan ENR-50 ke dalam adunan getah NR/NBRr menunjukkan sifat-sifat pematangan dan mekanikal yang lebih baik dari segi masa skorj, kekuatan tensil, modulus, kekerasan, dan pengurangan penyerapan pelarut berbanding adunan getah NR/NBRr yang telah diserasikan dengan EVA. Ini telah dibuktikan dengan mikrograf SEM ke atas permukaan kegagalan dimana penambahan agen pengserasi telah meningkatkan keserasian adunan getah

NR/NBRr. Kajian selanjutnya mengenai adunan getah ENR-50/NBRr telah dijalankan pada siri ke empat. Keputusan menunjukkan sifat-sifat pematangan dan mekanikal adalah lebih baik berbanding adunan getah NR/NBRr. Pengadunan ENR-50 dengan NBRr menghasilkan keserasian dan pelekatan antara-muka yang lebih baik antara ENR-50 dengan NBRr. Pada siri ke lima, kesan-kesan perbezaan sistem penyambungsilang iaitu sulfur (S), dikumul peroksida (DCP), sistem campuran (S+DCP) ke atas adunan getah NR/NBRr telah dijalankan. Sistem sulfur menunjukkan sifat-sifat pematangan yang lebih baik berbanding dengan peroksida dan sistem campuran. Sementara itu sistem campuran menunjukkan sifat-sifat mekanikal dan fizikal yang lebih baik berbanding dengan sistem sulfur dan peroksida pada semua nisbah adunan getah.

CHARACTERIZATION AND PROPERTIES OF NATURAL RUBBER/RECYCLED ACRYLONITRILE-BUTADIENE RUBBER BLENDS

ABSTRACT

In this study, five series of formulations have been used to study the effects of recycled acrylonitrile-butadiene rubber glove (NBRr) blending together with natural rubber (NR). Cure characteristics, tensile test, hardness and resilience tests, crosslink density test, fatigue test, thermal analysis, and Fourier transform infrared (FTIR) analysis were carried out on these five series. Morphology of failure surface was analyzed using Scanning electron microscopy (SEM). In the first series, natural rubber/virgin acrylonitrile-butadiene rubber (NR/NBRv) blends showed better cure characteristics and mechanical properties compared with NR/NBRr blends. However, NR/NBRr blends showed a better result on some properties such as higher modulus and hardness, and less solvent uptake. ENR-50 and EVA was added into the NR/NBRr blends as compatibilizers in the second and third series. Result indicated cure characteristics and mechanical properties of compatibilized NR/NBRr blends were improved compared with uncompatibilized NR/NBRr blends. However, addition of ENR-50 into NR/NBRr blends showed better cure characteristics and mechanical properties in terms of scorch time, tensile strength, modulus, hardness, and solvent uptake compared with NR/NBRr blends with EVA. It had been proven by SEM micrograph of failure surface which shown addition of compatibilizer enhanced the compatibility of NR/NBRr blends. Further study of ENR-50/NBRr blends was carried out in the fourth series. Results show that cure characteristics and mechanical properties improved for all blends compared with NR/NBRr blends. Blending ENR-50 with NBRr gives better compatibility and strong interfacial

adhesion between ENR-50 and NBRr. On the fifth series the effects of different crosslinking system which are sulphur (S), dicumyl peroxide (DCP), and mixed system (S+DCP) on NR/NBRr blends were carried out. The sulphur system show the best cure characteristics compared to peroxide and mixed systems, while the mixed system show the best mechanical and physical properties compared to sulphur and peroxide systems at all blend ratios.

CHAPTER ONE

INTRODUCTION

1.1 Recycling rubber waste

1.1.1 Introduction

Nowadays, one of the various problems which mankind faces is the problem of waste disposal management. Since polymeric do not decompose easily, disposal of waste polymers is a serious environmental problems (Adhikari et al., 2000). But in recent years there has been a growing concern about the disposal of waste or scrap rubber especially scrap tires and gloves. The discarded scrap rubbers do not degrade rapidly enough due to the crosslinked structure of rubber and presence of stabilizers and other additives (Noriman et al, 2010).

Scrap rubbers are made up of rubber that does not meet the processing and product specifications, scrap rubber from manufacturing activities and also old and defective rubber products. The scrap rubbers are considered as waste and usually discharged. Considering the economic and environmental advantages, recycling is one of the best options to solve the scraps disposal problems (Ismail et al., 2001; Ismail et al., 2002a; Ismail et al., 2002b; Ismail et al., 2003). A number of possible applications of various forms of waste rubber in broad disciplines have been studied and reported. Recycled rubber can be generalized as any rubber waste that has been converted to an economically useful form, such as reclaimed rubber, ground rubber or reprocessed synthetic rubber (Noriman et al., 2010).

The annual consumption of natural rubber is more than 15 million tons and the output of rubber products is more than 31 million tons worldwide. With the

development of rubber industry, a lot of waste rubber is produced in the world every year. These materials cannot return to the ecological environment through natural biological degradation because they cannot degrade by themselves. They belong to the class of non-environmental materials. The environmental materials refer to the material which can maintain ecological balance, have superior properties and best environmental compatibility. The main source of waste rubber is from discarded rubber products such as discarded tires, rubber belts, rubber shoes, and waste products which are produced during rubber process (Ismail and Hairunezam, 2001; Ismail et al., 2001; Ismail et al., 2002a; Ismail et al., 2002b; Ismail et al., 2003).

The latex industry has expanded over the years to meet the world demand for examination gloves, condoms, latex thread, etc. The products might be rejected up to 15% due to the strict specifications for latex products. The largest numbers of defects come from latex dipping which are pinholes, craters, and blisters. These defects were caused by air bubbles entrapped in the latex compound, particles of dirt in the latex compound and on the former, and greasy areas of the former. Therefore, these rejects create a major disposal problem for the rubber industry because the latex product waste represents a source of high quality rubber hydrocarbon which it is potential feedstock for superior quality of reclaimed rubber (Hassan et al., 2000; Maridass and Gupta, 2006; Noriman et al., 2010; Rajan et al., 2006; Sreeja and Kutty, 2000).

Over the past 43 years, the world consumption of natural rubber latex (NRL) had grown at an average of 4.2% per year and increase to 925 000 tons in 2003. Gloves were the main reason for the demand of NRL over the past 20 years and it was still playing the leading role in the latex world. The product range of NRL is

wide and varied which is ranging from industrial to household over medical applications. The main area of latex consumption was Asia from 1984 to 2003 with the average growth rate was 9.2% per year. Its annual consumption was increase from 144 000 to 692 000 tons. In 2003, the annual consumption levels of the other five regions are North America is 101 000 tons, Latin America is 33 000 tons, European Union is 78 000 tons, other European countries is 14 000, and Africa is 4000 tons (Noriman et al., 2010).

Generally, the blending of two or more types of polymers is a useful technique for the preparation and development of materials with properties superior to those of individual constituents. The purpose of blending the rubber is to improve the physical and mechanical properties, improved service life, easier processing, and reduce the cost of the final product. The blending together of polymer is intended to produce a vulcanizate with the best properties from each component. Polymer blends are frequently used in the rubber industry to obtain the best compromise in compound physical properties, processability and cost (Adhikari et al., 2000; Awang et al., 2007; Fang et al., 2001; Ismail and Hairunezam, 2001; Ismail et al., 2001; Ismail et al., 2002a; Ismail et al., 2002b; Ismail et al., 2003; Habeeb Rahiman et al., 2005; Hassan et al., 2000; Maridass and Gupta, 2006; Noriman et al., 2010; Rajan et al., 2006; Sreeja and Kutty, 2000).

1.1.2 Recycling and reclamation of waste rubber

The first method of reclaiming waste rubber is to grind it as fine as possible and blend it with new rubber as elastomeric filler. This method is a patent was granted to Charles Goodyear himself for this technique. Manufacturing powdered

rubber is the main recycling route for waste rubber. The first step in the recycling process is a preliminary treatment such as cutting and milling. Then, the waste rubber is cured by mechanical methods, chemical methods, and freezing or crushing. Finally, the waste rubber is made into rubber chips or powdered rubber. The rubber Research Institute of India (RRII) had reported a method of reclaiming latex products by using waste condoms. The waste condoms were powdered by passing through a two-roll mill with size about 40 mesh. The reclaimed rubber obtained was found to form a smooth band on the mill and contained about 82% of rubber hydrocarbon. Then, this reclaimed rubber was added to raw rubber. However, only a small amount of reclaimed rubber could be added to raw rubber without affecting the mechanical properties. The addition of 25% reclaimed rubber to filled natural rubber (NR) can cause a decrease in tensile strength, elongation at break, resilience, tear strength, and abrasion resistance, but it shows better processing characteristics. Reclaimed rubber was added only in a very small percentage of the raw rubber in high quality products or in high percentage in low quality products. This was due to the degradation of the rubber hydrocarbon during the reclaiming process (Adhikari et al., 2000; Fang et al., 2001; Rajan et al., 2006).

1.2 Research background

The increased use of acrylonitrile butadiene rubber (NBR) latex in glove manufacture has been seen over the last couple of years all over the world. The reason is its excellent resistance to punctures and tears as well as the non-existence of leachable allergenic proteins, unlike in natural rubber latex. Similarly, nitrile gloves can be used to offer superior resistance to many types of chemical. Nitrile gloves are currently used in many areas such as the medical field and, to a greater

extent, the food industry, automotive industry, etc. As a result, significant quantities of discarded gloves are generated worldwide daily. In Malaysia, the output of nitrile rubber gloves was found to be abundant. Most of this material originates from medical, industrial, and research activities. After a certain period of time these polymeric materials are not serviceable and are mostly discarded. To solve this environmental issue, recycled NBR gloves (waste) were used in an effort to create value added materials. Therefore, the recycled NBR gloves (waste) will blend together with natural rubber to produce a vulcanizate with the best properties from each component. NBR gloves have excellent resistance to punctures, tears, and many types of chemicals. Natural rubber has good strength will give better physical and mechanical properties on the vulcanizate (Ismail et al., 2009b; Noriman et al., 2010; Rajan et al., 2006).

1.3 Problem statement

It is well known that direct material recycling and reshaping is difficult because of the irreversible three-dimensional crosslinking of rubber. It means that they cannot be re-melted or dissolved in organic solvents. Many attempts have been made to reuse waste rubbers by reclamation, devulcanization, high pressure and high temperature sintering, fuel recovery and other. Most processes are based on mechanical shear, heat, and energy input together with a combination of chemicals such as oils, accelerators, amines, or disulfides to reduce the concentration of sulfur crosslinks in the vulcanized rubber. Grinding is the basic step for recycling scrap rubber, and ground rubber (GR) has been used as the raw material not only for the production of reclaimed rubber but also for various applications, such as fillers for rubber, fillers for thermoplastic compounds, and modifiers for asphalt concrete. From

economic and environmental points of view, the use of GR as a filler for rubber compounds has more merit than other methods because it does not need additional processing, reactions, or treatments, and the chemical nature of the various ingredients in GR can be maintained. Every year large numbers of papers are published on the recycling of vulcanized rubber products where the rubber powder is used as filler or blended with virgin rubber or the modified rubber powder is incorporated in different composite materials. However, to our knowledge, no investigations have been carried out on the characterization and properties of natural rubber/recycled acrylonitrile-butadiene rubber (NR/NBRr) blend. Therefore, the present study was to investigate the characteristics and properties of NR/NBRr blends by using various testing and measurement such as cure characteristics, physical and mechanical measurement and thermal analysis.

1.4 Research objective

The main aims of these studies were to study the possibility of using recycled NBR glove (NBRr) as a part in natural rubber blends (NR/NBRr). Subsequently, the principle objectives of this research were follows:

- To compare the cure characteristics and mechanical properties of natural rubber/virgin acrylonitrile-butadiene rubber (NR/NBRv) and natural rubber/recycled acrylonitrile-butadiene rubber (NR/NBRr) blends.
- To examine the effects of epoxidized natural rubber (ENR-50) and poly(ethylene-*co*-vinyl acetate) (EVA) as compatibilizers on cure characteristics and mechanical properties of natural rubber/recycled acrylonitrile-butadiene rubber (NR/NBRr) blends.

- To compare the cure characteristics and mechanical properties of natural rubber/recycled acrylonitrile-butadiene rubber (NR/NBRr) and epoxidized natural rubber/recycled acrylonitrile-butadiene rubber (ENR-50/NBRr) blends.
- To study the effect of natural rubber/recycled acrylonitrile-butadiene rubber (NR/NBRr) blends with three different crosslinking systems which are sulphur system (S), peroxide system (DCP), and mixed system (S+DCP).

1.5 Scope of thesis

This dissertation was organized in nine chapters consecutively and can be summarized as follow;

First chapter (Chapter 1) relates with the introduction of the research work, problem statement, objective and research outline of the thesis.

Second chapter (Chapter 2) reviews the development of recycling rubber waste, characterization of recycled NBR glove, compatibilization of rubber blends, vulcanization system in rubber blends and application of recycled rubber products.

Third chapter (Chapter 3) describes the materials, equipments, procedures of experimental works and characterization technique performed in this research.

Fourth chapter (Chapter 4) reports the results and discussion on the properties of virgin NBR and recycled NBR blend with NR.

Fifth chapter (Chapter 5) reports the results and discussion of ENR-50 and EVA as compatibilizer on the NR/NBRr blends.

Sixth chapter (Chapter 6) reports the comparison of NR/NBRr blends and ENR-50/NBRr blends.

Seventh chapter (Chapter 7) reports the results and discussion on different crosslinking system of NR/NBRr blends.

Eighth chapter (Chapter 8) presents the conclusion of the findings and the recommendations for the future work.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

In recent years, the environmental problems caused by waste rubber have become an important issue in the rubber industry. Utilization of waste rubbers either the powdered rubber or reclaimed rubber into raw rubber is the most effective way to reduce disposal problem and environmental pollution (Rattanasom et al., 2005). Blending is an easy and cost effective way to produce new combination properties of recycled rubber waste (Noriman et al., 2008). This technique can be implemented more rapidly and economically. It has helped to develop many new materials which are good quality and cheaper in the market (De et al., 2013; George et al., 2000; Habeeb Rahiman et al., 2005).

The blending of two or more types of rubber is a useful technique for preparing materials with superior properties which are absent in the individual component rubbers. Rubber-rubber blends are used in the rubber industry to obtain the desired physical properties, improved service life, processability, and reduced product cost (Ismail et al., 2001; Ismail et al., 2003). The purpose of blending the rubber is to improve the physical and mechanical properties which give it the potential of entering application areas (Ismail and Leong, 2001; Ismail et al., 2003). The characteristics of rubber blend depend on the type of rubber, formulations, and cure conditions (Noriman et al., 2008). Also, the rubber blend depends on the miscibility between two rubbers either heterogeneous or homogeneous blends (George et al., 2000).

2.2 Recycling Rubber Waste

Nowadays, one of the various problems which mankind faces is the problem of waste disposal management. Disposal of waste polymer is a serious environmental problem because the polymeric materials do not decompose easily. The rubber industry faces a major challenge in finding a way to deal with the increasing quantities of rubber goods such as tires, rubber hoses, belts, shoes, and flash. Large amount of rubbers are used to form a useful product, but after a long run, this product is not serviceable and discarded. It needs very long time for natural degradation due to the crosslinked structure of rubbers and presence of stabilizers and other additives. Two major approaches to solve this problem which is recycled and reuse of used and waste rubber, and reclaim of rubber raw materials (Adhikari et al., 2000; Fang et al., 2001; Manuel and Dierkes, 1997; Rajan et al., 2006). Table 2.1 presents the different methods of rubber recycling.

Table 2.1: The different methods of rubber recycling (Manuel and Dierkes, 1997).

Repeat use	Reuse
	Retreading
Physical recycling	Reclaiming
	Grinding
	Surface activation
Recovery of base chemicals	Pyrolysis
	Gasification
	Hydrogenation
Energy recycling	Incineration

Therefore, recycling of waste rubber has important implication as shown in Figure 2.1.

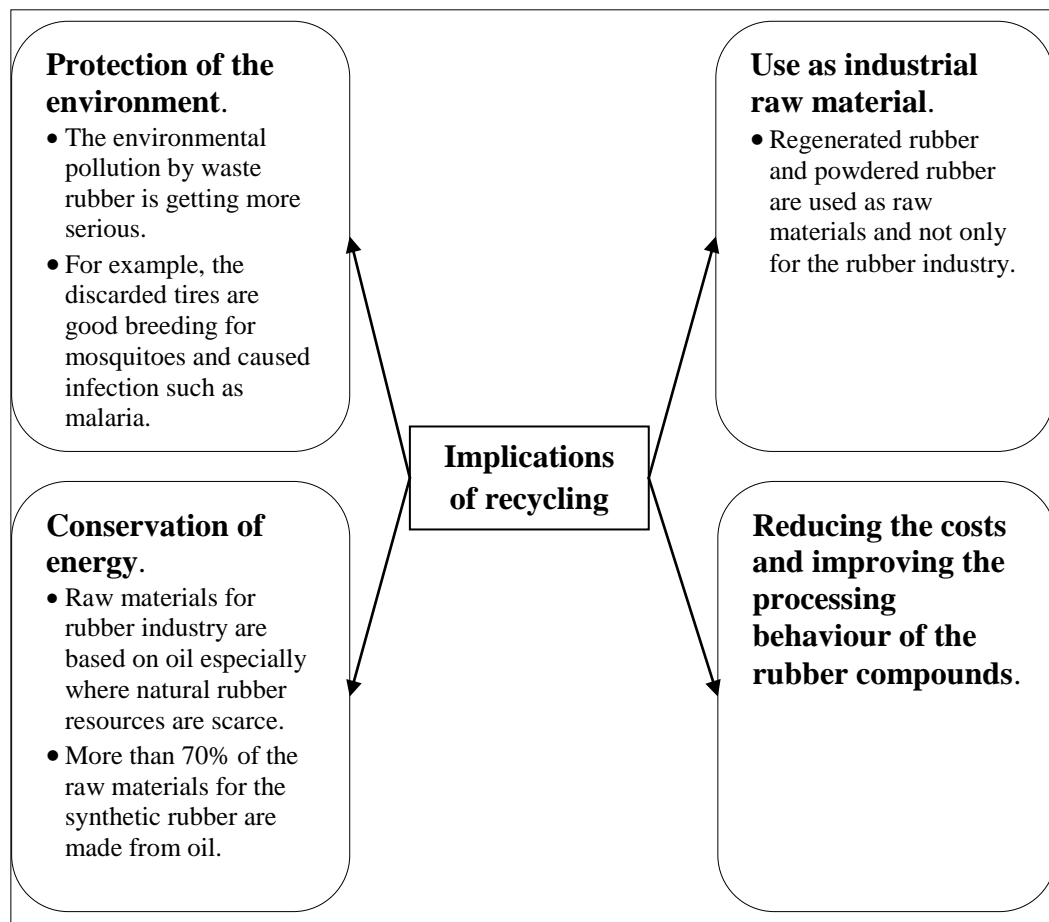


Figure 2.1: Implications of recycling waste rubber (Fang et al., 2001; Rajan et al., 2006).

2.2.1 Recycled and reuse of waste rubber products.

Polymers can be divided into two main groups which are thermoplastics and thermosetting materials. Thermoplastics can be repeated either by direct reheating or preferably after grinding into granules of scrap products. Thermosetting materials like rubbers are crosslinked and cannot be softened or remolding by heating again. Thus, thermoplastics are more readily and easily recyclable than thermoset polymers and rubbers. In principle, recycling of thermoplastics involve a reversible physical

change by heating the resin above its processing temperature for shaping it and then cooling it to room temperature to obtain the desired recycled product. However, in the case of thermosetting materials is not easy. The three dimensional network of the thermoset polymer system must be broken down either through the cleavage of crosslinks or the carbon-carbon linkage of the backbone chain. This is more severe process and the fragmented products obtained are different from the starting thermoset materials. There are two major used of waste rubber products which are waste rubber as landfills and scrap rubber as fuel source.

2.2.2 Reclaiming from rubber products

The reclaiming of scrap rubber is the most desirable approach to solve the disposal problem. Recovery and recycle of rubber from used and scrap rubber products can save some petroleum resources and solve scrap or waste rubber disposal problems. The definition of reclaimed rubber was adopted in 1981 by the Rubber Recycling Division of the National Association of Recycling Industries, Inc. Reclaimed rubber is the product when waste vulcanized scrap rubber is treated to produce a material which can be easily processed, compounded, and vulcanized with or without the addition of either natural or synthetic rubbers. Regeneration can occur by breaking the existing crosslinks in the vulcanized polymer or by promoting scission of the main chain of the polymer or a combination of both processes. The reclaiming process can be classified into two groups which are physical reclaiming processes and chemical reclaiming processes.

2.2.2 (a) Latex products reclaiming

The latex industry has expanded over the years to meet the world demand for examination gloves and so on. Up to 15% of the products might be rejected due to the strict specifications for latex products (Rajan et. al, 2006). These reject products create a major disposal problem for the rubber industry. The largest numbers of defects encountered in articles produced by latex products are pinholes, craters, and blisters. These defects are caused by air bubbles entrapped in the latex compound, particles of dirt in the latex compound and on the former, and greasy areas of the former. Since waste latex products represent a source of high quality rubber, it is a potential feedstock for reclaimed rubber of superior quality. However, addition of reclaimed rubber into raw rubber affects the mechanical properties of the final product. Incorporation of 25% reclaimed rubber to filled natural rubber will cause a decrease in tensile strength, elongation at break, resilience, tear strength, and abrasion resistance. The compression set was not much affected, but heat buildup and hardness increased. The compound containing the reclaimed rubber showed better processing characteristics. Only in a very small percentage of reclaimed rubber was added into raw rubber in high quality products or in high percentage in low quality products. This was due to the degradation of the rubber hydrocarbon during the reclaiming process.

The first method of reclaiming waste rubber is to grind it as fine as possible and blend it with new rubber as elastomeric filler. This method is a patent was granted to Charles Goodyear himself for this technique. Manufacturing powdered rubber is the main recycling route for waste rubber. The first step in the recycling process is a preliminary treatment such as cutting and milling. Then, the waste rubber

is cured by mechanical methods, chemical methods, and freezing or crushing. Finally, the waste rubber is made into rubber chips or powdered rubber.

2.2.2 (b) Advantages of reclaimed rubber

Although reclaimed rubber reduced the mechanical properties like tensile strength, modulus, resilience, tear resistance, etc with increasing amount of reclaimed rubber in the raw rubber, but it provides many advantages of incorporated in raw rubber. Figure 2.2 shows the advantages by using reclaimed rubber into raw rubber.

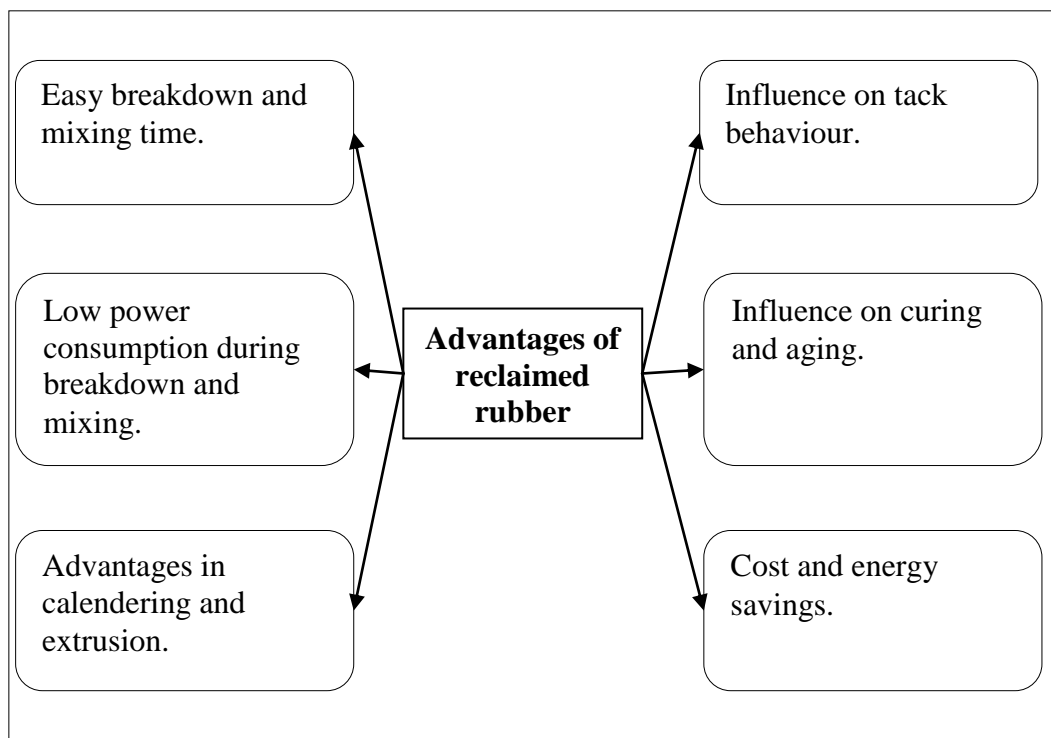


Figure 2.2: Advantages of reclaimed rubber.

2.2.3 Properties of recycled rubber blend based on study case

2.2.3 (a) Influence on cure characteristic

Addition of recycled rubber affects the scorch time, optimum cure time, cure rate and state of cure of the rubber compound, depending on the nature of the rubber in the matrix and the characteristics of the rubber powder (Gibala et al., 1996). Ismail et al. (2003) studied the effects of recycled rubber powder (RRP) content and various vulcanization systems on curing characteristics of natural rubber/RRP blends. It was reported that the cure time (t_{90}) decreased as recycled rubber powder (RRP) increased in NR/RRP blends for all vulcanization systems. This was due to the sulphur migration from the rubber powder into the rubber matrix. Increasing in RRP content, the accelerator concentration in the blend increases and this accounts for decreases in cure time.

Increment in recycled rubber content reduces the scorch time and cure time. This is because of the presence of crosslinked precursor and unreacted accelerator in recycled rubber powder. Furthermore, reducing in scorch time and cure time due to the lower concentration of sulphur migration in the rubber matrix. The cure enhancement can be related with some parameters such as particle size, surface area, moisture content, surface reactivity, and metal oxide content. The longer scorch time and cure time in the rubber compound due to the other chemical composites in recycled rubber such as stabilizer, heat sensitive agent, and colorant which might interact with curatives and delay the total curing process (Ismail et al., 2002; Noriman et al., 2008; Zulkepli et al., 2009).

Many researchers reported that increasing recycled rubber in the blends will increase the minimum torque due to the presence of crosslinked rubber particle and reduction of rubber matrix in the blends. This indicates that the processability of the compounds becomes more difficult. However, maximum torque shows the opposite trend as recycled rubber content increased. This was due to the poor interaction in the rubber blends (Ismail et al., 2002; Ismail et al., 2003; Noriman et al., 2008; Zulkepli et al., 2009).

2.2.3 (b) Influence on mechanical properties

There are several reports on mechanical properties of recycled rubber blend with rubber matrix. The factors affecting the performance of a vulcanizate containing recycled rubber are the particle size, hardness, and aging condition of the precursor rubber article; filler content in the particle; and the particle-matrix rubber interaction. Sombatsompop and Kumnuantip (2003) studied the rheology, cure characteristics, physical and mechanical properties of tire tread reclaimed rubber/natural rubber compounds. They discussed that the modulus at 100% elongation of the rubber blend increased with reclaimed rubber content increased but opposite trend for tensile strength and elongation at break. Modulus increased due to the increase in crosslink density and restrictions of molecular mobility of the compounds. Opposite trends for tensile strength and elongation at breaks due to the less homogeneity with presence of reclaimed rubber. The carbon black in the reclaimed rubber may restrict the molecular orientation and mobility of the rubber blends. The hardness and heat build-up properties of the blends increased with reclaimed rubber content whereas the tear strength was independent of the reclaimed rubber.

In other study, the effect of different particle sizes of recycled acrylonitrile-butadiene rubber and its blend ratios on mechanical and morphological properties and curing characteristics of SBR/NBRr blends was investigated by Zulkepli et al. (2009). Results indicate that the tensile strength decreased with increasing recycled rubber content due to the incompatibility in rubber blends. The deterioration of tensile strength at higher recycled rubber content was due to weak interaction between recycled rubber and rubber matrix. In fatigue life shows decreasing effect as recycled rubber content increased due to the filler particles and aggregates are not dispersed and wetted efficiently by the rubber matrix and stress concentration factor can cause fatigue failure. However, the modulus, M100 and hardness increased as recycled rubber content increased due to the increasing in crosslink density. Increasing in crosslink density contributes to the decrease in elongation at break and resilience with increasing recycled rubber content.

Rattanasom et al. (2005) were studied the effect of curing system on the mechanical properties and heat aging resistance of natural rubber/tire tread reclaimed rubber blends. They found that the modulus, M100 and hardness increase with increasing reclaimed rubber content due to the presence of carbon black and active crosslink sites in the reclaimed rubber. The increase in carbon black content and crosslink density can reduce elongation at break as reclaimed rubber content increased. However, the tensile strength decreases as the reclaimed rubber content increased. Also, the tensile strength was not dependent on the curing system when a high amount of reclaimed rubber was added.

2.3 Acrylonitrile-Butadiene Rubber (NBRr) Glove

There are several types of gloves made from natural rubber latex, nitrile rubber, chloroprene rubber, vinyl, and etc. Currently, Malaysia is the world's largest exporter and producer of both nitrile and natural rubber gloves. Latex gloves are natural material which made from natural rubber latex and a processed plant product. They are most trusted material and first choice of protective glove for medical or industrial use. Even with the advent of synthetic materials, latex still remains the most elastic, resilient, and consistent fitting material on the market today. They are great barrier protection against infection and contamination. The drawbacks to natural rubber latex are some individuals are highly allergic to latex gloves. Latex allergies are more likely to develop with the use of latex glove and form of a skin irritation, if the gloves are not properly washed and processed. Normally, latex allergy will develop slowly as itching, burning, peeling, and dry or cracked skin. When allergy is not a concern, latex does have slight advantage with comfort and dexterity over nitrile gloves. Another drawback of latex is subjected to cost fluctuation similar to other natural resources. Lastly, latex gloves are not chemical resistant as nitrile gloves.

In this research, we used nitrile gloves because after a certain period of time, these polymeric materials are not serviceable and mostly discarded. As a result, significant quantities of discarded gloves are generated. Nitrile gloves are a type of disposable gloves made from a synthetic rubber copolymer called nitrile butadiene rubber. This butadiene rubber is a durable, synthetic material consist of acrylonitrile, butadiene and carboxylic acid which is provide specific advantages for manufacturing disposable gloves. The acrylonitrile content in this rubber enhances

the chemical resistance, while butadiene increases the flexibility and tear resistant. Nitrile gloves are more puncture resistance compared to many other types of rubber gloves and can be used to offer superior resistance to many type of chemicals. These advantages make the nitrile gloves are the best choice when it comes to chemical and puncture resistance. Nitrile gloves are three times more puncture resistance than vinyl and latex gloves.

Nitrile gloves are considered to be one of the strongest types of disposable glove and safe for people who are allergic to latex. When latex allergies are of concern, nitrile gloves are the best choice because it provide a synthetic rubber compared to latex gloves which are made from natural rubber. Latex allergies happen due to the proteins in the natural rubber latex that remain in the finished gloves. This proteins act as stabilizers. Contrast this to nitrile which contains no proteins because it is stabilized with anionic surfactants. Furthermore, nitrile gloves have low resistance to friction and very easy to slide on. It has high degree flexibility and superior solvent resistance. Nitrile gloves have been chosen for many manufacturing environment due to superior resistance to many oils and some acids. However, nitrile gloves cannot be stored under excessive light or heat because it can make the rubber disintegrate more rapidly.

2.4 Rubber

Originally, the term rubber means that the material obtained from the tree *Hevea Brasiliensis*. The word elastomer and rubber are often used by the industry to mean the same thing to describe the raw polymer. Another definition of rubber is usually indicates substances such as natural rubber (NR), acrylonitrile-butadiene

rubber (NBR), styrene butadiene rubber (SBR), and so on, but this not leads to the definition of rubber. Actually, the word rubber based on very simple experience which is a rubber material allows a large deformation without break. It will stretch easily several times and even more than fifteen times in some cases. The deformation recovers almost 100% instantly. So, the word rubber is used in two different ways. One is refer to specific substances such as NR, NBR, and SBR. The other one is an expression of mechanical behaviour for material at specific temperature range (Andrew, 1999).

2.4.1 Natural rubber (NR)

Natural rubber (NR) is a material that was harvested from bushes and trees and fabricated into products by the indigenous natives of Central and South America far in the past. Natural rubber has been known since the year 1493 when Christopher Columbus found the natives of Haiti playing with balls made from the exudates of a tree called “cau-uchu” or weeping wood. Natural rubber is present as latex in a large variety of plants in many region of the world. Currently, Malaysia is one of the leading producers of rubber. Rubber is harvested mainly in the form of latex from the Para rubber tree or others. The most important source is the tree *Hevea brasiliensis*. This tree is the most widely commercial source of natural rubber and was introduced into Asia in 1876 by Sir Henry Wickham.

Natural rubber latex is the polymer cis-1,4-polyisoprene with high molecular weight polymeric substance with viscoelastic properties. A small percentage up to 5% of dry mass of other materials such as proteins, fatty acids, resins, and inorganic materials are found in natural rubber. Figure 2.3 shows the structure of natural

rubber. Isoprene is a diene and 1, 4 addition leaves a double bond in each of the isoprene unit in the polymer. Table 2.2 shows the characteristics of natural rubber. Table 2.3 show the properties of SMR grades since 1979. ASTM D 2227 also has standard specification for technical grades (Mathew, 2009).

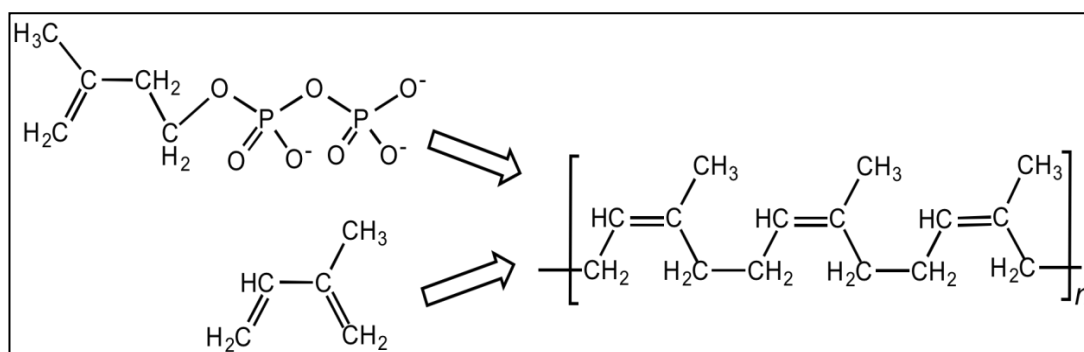


Figure 2.3: The structure of natural rubber (NR).

Table 2.2: Typical characteristics of natural rubber.

Molecular weight	68.12 g/mol
Specific gravity	0.92
Glass transition temperature (T _g)	-70°C
Refractive index	1.52
Coefficient of cubical expansion	0.00062/°C
Cohesive energy density	63.7 Cal/cc.
Heat of combustion	10547.084 Cal/g
Thermal conductivity	0.00032 Cal/sec/cm/°C
Dielectric constant	2.37
Power factor (at 1000 cycles)	0.15-0.2
Volume resistivity	1015 ohm.cm
Dielectric strength	3937 V/mm

Table 2.3: The properties of SMR grades since 1979 (Mathew, 2009).

	SMR-L	SMR-5	SMR-10	SMR-20	SMR-50
Dirt retained, %	0.03	0.05	0.10	0.20	0.50
Ash content, %	0.50	0.60	0.75	1.00	1.50
Plastic Retention Index	60	60	50	40	30

Vulcanized products from natural rubber have high mechanical strength and can be compounded to have excellent elasticity. Natural rubber has very good abrasion resistance and dynamic mechanical properties. It also has very good low temperature resistance around -57°C which its stiffness shows a considerable increase. The temperature for heat aging resistance is limit in the region 75°C . It has poor UV light and ozone resistance. Addition of carbon black filler to a rubber compound gives resistance to UV, while waxes help with ozone resistance. It has good electrical insulation. In addition, resistance to petroleum oils is poor, but resistance to alcohols (ethanol and methanol) and ketones (methyl ethyl ketone and acetone) is good (Mathew, 2009; Nakajima, 2000).

2.4.2 Acrylonitrile-butadiene rubber

Acrylonitrile-butadiene rubber (NBR) was commercialized by I.G. Farbindustry, Germany in 1937 with trade name of Buna N. NBR is a synthetic rubber copolymer of acrylonitrile (ACN) and butadiene. The butadiene unit in NBR imparts electricity, crosslinking site, low temperature flexibility, and all the rubbery properties like other diene rubber. The ACN unit offer oil and fuel resistance and high strength which is makes NBR a special elastomer. NBR is also known as Buna-N, Perbunan, acrylonitrile-butadiene rubber, and NBR. The trade names for NBR

include Nipol, Krynac and Europrene (Bhattacharjee et al., 1997; Seil and Wolf, 1987). Figure 2.4 shows the structure of NBR.

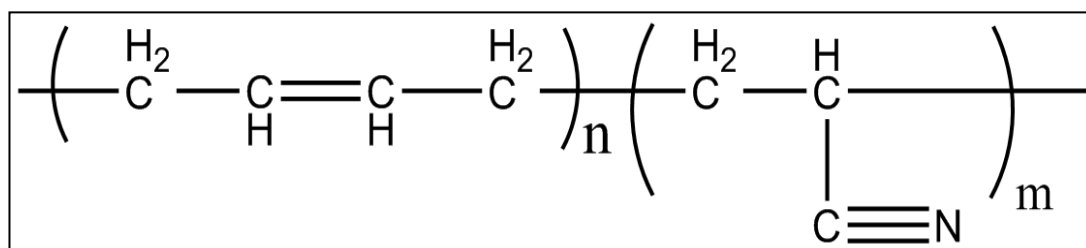


Figure 2.4: Structure of Acrylonitrile-Butadiene Rubber (NBR).

The important characteristics which can affect the properties of NBR are Mooney, plasticity and gel content. Typical Mooney viscosity for NBR is 30 to 95, while the gel content ranges from 0% to over 80%. NBR is able to withstand a range of temperature from -40°C to 108°C and makes it used to create moulded goods, footwear, adhesives, sealants, sponges, expanded foams, and floor mats. Its resilience makes NBR is useful for disposable lab, cleaning, and examination gloves. NBR is more resistant than NR to oils and acids, and has superior strength, but has inferior flexibility. Nitrile glove is more puncture resistant and less to cause an allergic reaction than NR (Bhattacharjee et al., 1997; Seil and Wolf, 1987).

Many attempts have been made to modify the NBR by chemical and physical methods to improve its properties. Chemical modifications include structural changes of the polymer chain, while physical modifications involve the mechanical blending of NBR with other polymers or chemical ingredients to achieved desired properties. Major application of NBR include disposable non-latex gloves, automotive transmission belts, hoses, O-rings, gaskets, oil seals, V belts, synthetic leather, printer's form rollers, and cable jacketing (Bhattacharjee et al., 1997).

2.4.3 Epoxidized natural rubber (ENR-50)

Epoxidized natural rubber (ENR) had been introduced to the elastomeric world as a modified form of natural rubber. ENR is a chemically modified form of the cis-1,4-polyisoprene. The isoprene and epoxidized isoprene act as monomer units that are randomly distributed along the polymer chain. Various degree of epoxidation of NR is 25%, 50%, and 75% epoxidized in ENR-25, ENR-50, and ENR-75 respectively. Figure 2.5 shows the structure of ENR (Hamzah et al., 2012; Ismail and Chia, 1998; Mahmood and Azarian, 2015; Noriman et al., 2010).

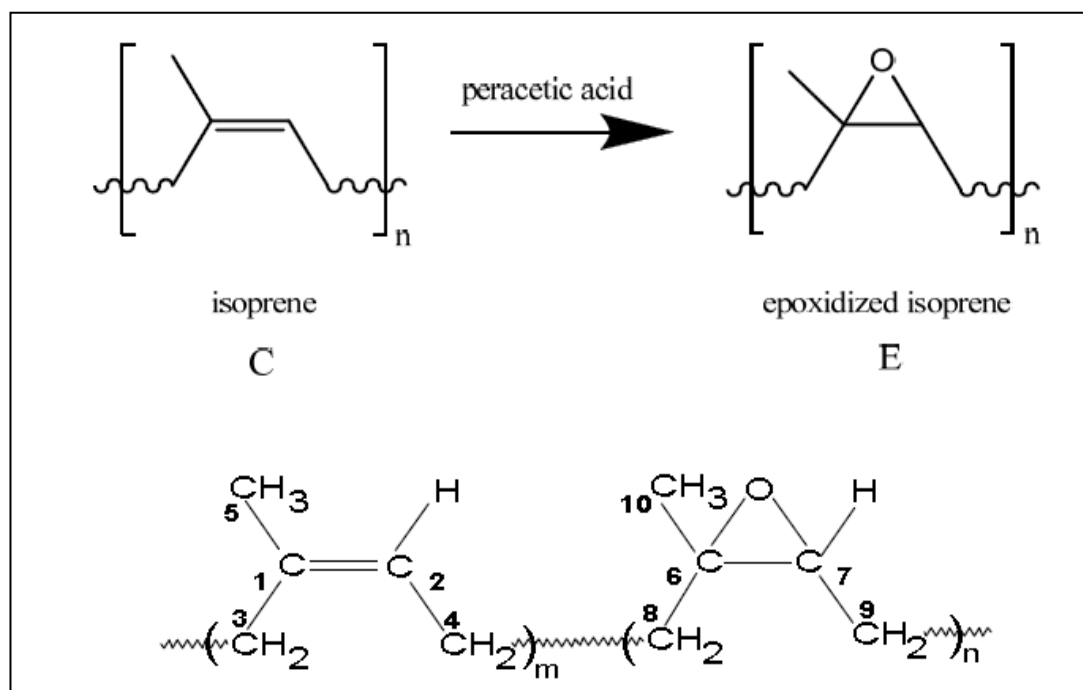


Figure 2.5: The structure of epoxidized natural rubber (ENR).

The carbon-carbon double bonds on the natural rubber being converted into the polar epoxy group to obtain ENR. The free volumes of chain phases are decreased and the density and polarity are increased. When prepared the ENR, the epoxidation reaction is always accompanied with the further ring-opening reaction of epoxy group. The main factors in the formation of ring-opening product are acidity