UNIVERSITI TEKNIKAL MALAYSIA MELAKA

CHARACTERIZATION AND MECHANICAL TESTING OF ELASTOMER MODIFIED BITUMEN

Submitted in accordance with the requirement of the University Teknikal Malaysia Melaka (UTeM) for Bachelor Degree of Manufacturing Engineering (Hons.)

by

ZATY ZHAFARINA BINTI NADZRI

B051520003

950620-10-5700

FACULTY OF MANUFACTURING ENGINEERING

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Cop Rasmi:

SAIKO RUBBER (M) SDN. BHD
(Company No: 205991-V)
Lot 49-51, Senawang Industrial Estate
70450 Seremban, N.S.D.K.
Tel: 06-6771711 Fax: 06-6793560
Web Page http://www.suntex.com.my

Nama Pegawai: Mrs. Nurzallia Binti Mohd Saad

Jawatan: QC Chemist

Tarikh: 02/11/2018

Tandatangan Pelajar:

Nama Pelajar: Zaty Zhafarina Binti Nadzri

No Matriks: B051520003

Tarikh: 30/10/2018

Tandatangan Penyelia:

Cop Rasmi:

DR. CHANG SIANG YEE
Senior Lecturer
Faculty of Manufacturing Engineering
Universiti Teknikal Malaysia Melaka
Hang Tuah Jaya
76100 Durian Tunggal

Nama Penyelia: Dr. Chang Siang Yee

Jawatan: Pensyarah Kanan

Tarikh: 30/10/2018

DECLARATION

I hereby, declared this report entitled "Characterization and Mechanical Testing of Elastomer Modified Bitumen" is the results of my own research except as cited in reference.

Signature : ………………………………………..
Author's Name : ZATY ZHAFARINA BINTI NADZRI
Date : 2019

APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of Universiti Teknikal Malaysia Melaka as a partial fulfillment of the requirements for the degree of Bachelor of Manufacturing Engineering (Hons.). The member of the supervisory committee is as follow:

……………………………………

DR. CHANG SIANG YEE

ABSTRAK

Projek ini bertujuan untuk mengkaji sifat-sifat mekanik sejenis bahan viskoelastik, iaitu bitumen diubahsuai dengan elastomer untuk aplikasi helaian redaman. Bitumen diubahsuai elastomer biasanya digunakan sebagai pangkalan untuk menghasilkan lembaran redaman disebabkan oleh keupayaan redamannya kerana kelakuan viscoelasticnya. Kebanyakan pengeluar menggunakan bahan sintetik sebagai pengikat bitumen. Walau bagaimanapun, dunia menghadapi pencemaran suasana yang hebat disebabkan oleh bahan yang tidak biodegradasi seperti tayar kenderaan. Oleh itu, perlunya untuk melakukan proses mengitar semula bahan-bahan. Objektifprojek ini adalah untuk memasukkan serbuk tayar ke bitumen untuk menilai potensinya sebagai lembaran redaman. Kerja ini mengkaji kesan pencampuran suhu dan kuantiti serbuk tayar pada sifat fizikal dan sifat mekanik bitumen diubahsuai elastomer. Debu tayar dalam bentuk zarah berukuran mikro bercampur dengan bitumen pada pemuatan pengisi yang bervariasi (0-25 wt.%) Dan suhu pencampuran (140-180 °C). Campuran kemudiannya dimampatkan ke dalam bentuk lembaran menggunakan mesin mampatan panas. Sekurang-kurangnya lima sampel dipotong dari lembaran dan kemudiannya diuji bagi menentukan ketumpatan, suhu peralihan kaca dan sifat redaman. Hasil uji kaji menejukkanpeningkatan serbuk tayar meningkatkan ketumpatan kerana ketumpatan serbuk tayar lebih besar daripada bitumen. Bagi kesan suhu pencampuran, tiada perubahan dalam suhu peralihan kaca campuran bituminus apabila suhu pencampuran telah ditetapkan pada 140°C; Walau bagaimanapun, peningkatan suhu pencampuran menyebabkan suhu peralihan kaca jatuh dengan peningkatan beban debu tayar. Ini disebabkan oleh tindak balas kimia yang mungkin terjadi di antara bitumen dan serbuk tayar pada suhu pencampuran yang lebih tinggi. Sementara itu, semua komposisi mempamerkan sifat redaman substansial. Kesan redaman bertambah baik dengan peningkatan beban debu tayar untuk campuran bitumen bercampur pada 140 °C. Hasil redaman tidak konsisten untuk campuran bituminous bercampur pada suhu yang lebih tinggi yang memerlukan kajian lebih lanjut untuk penjelasan.

ABSTRACT

This project aimed to characterize and study the mechanical properties of a type of viscoelastic materials, i.e. elastomer modified bitumen for damping sheet application. Elastomer modified bitumen is commonly used as the base to manufacture damping sheet due to its damping ability owing to its superior viscoelastic behavior. Most of the manufacturers use synthetic rubbers to be incorporated into bitumen binder. However, the world faces great atmosphere pollution partly due to non-biodegradable materials such as used tires. Hence, there is a need to recycle materials instead. The motivation of this work was motivated to incorporate waste tire dust into bitumen to evaluate its potential as damping sheet. This work studied the effect of mixing temperature and tire dust filler loading on the physical properties and mechanical properties of the elastomer modified bitumen. Tire dust in the form of micro-sized particles were mixed with bitumen at varying filler loading (0-25 wt.%) and mixing temperatures (140-180 °C). The mixture was then pressed into sheet form using hot compression machine. A minimum of five samples were cut from the sheets and later subjected to determination of density, glass transition temperature and damping properties. It was observed that increase of tire dust increased density due to greater density of tire dust than that of bitumen. As for the effect of mixing temperature, there was no change in the glass transition temperature of the bituminous mixture when mixing temperature was fixed at 140 °C; however, increase of mixing temperature caused glass transition temperature to drop with increase of tire dust loading. It was due to probable chemical reaction occurring between bitumen and tire dust at higher mixing temperatures. Meanwhile, all compositions exhibited substantial damping properties. Damping effect improved with increase of tire dust loading for bituminous mixture mixed at 140 °C. The damping result was inconsistent for bituminous mixture mixed at higher temperatures which requires further studies for clarification.

DEDICATION

Only

my beloved father, Nadzri bin Ismail

my appreciated mother, Siti Rozanah binti Md sidek

my adored sisters and brother, Zaty Awanis, Zaty Syazwani and Nur Zhafri Irfan

for giving me moral support, money, cooperation, encouragement and also understandings

Thank You So Much & Love You All Forever

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LIST OF ABBREVIATIONS

ASTM	-	American Society for Testing and Materials
BIS	-	Bureau of Indian Standards
BIT	-	Bitumen
C	-	Carbon ion
$CaCO_3$	-	Calcium Carbonate
CH	-	Carbon hydrogen
Cis	-	Trans isomerism
DMC	-	Differential Scanning Calorimetry
EBA	-	Ethylene Butyl Acrylate
et al.	-	and others
EVA	-	Ethylene Vinyl Acetate
FRF	-	Frequency respond function
Inc.	-	Incorporation
NR	-	Natural Rubber
NVH	-	Noise, vibration and harshness
OBM	-	Oberst Beam Method
PE	-	Ethylene Vinyl Acetate
PP	-	Polypropylene
RILEM	-	International Union of Laboratories and Experts in Construction Materials, Systems and Structures
SBR	-	Styrene Butadiene Rubber
SBS	-	Styrene Butadiene Styrene
Sdn. Bhd.	-	Incorporated
SEBS	-	Styrene Ethylene Butylene Styrene
SEM	-	Scanning Electron Microscopy
SiO_4	-	Silica group
-SiOH	-	Saline

SIS	-	Styrene Isoprene Styrene
tan δ	-	Tan delta (lost factor)
T_d	-	Thermal decomposition temperature
T_g	-	Glass transition temperature
TGA	-	Thermogravimetric Analyzer
UTeM	-	Universiti Teknikal Malaysia Melaka
PSA	-	Particle Size Analyzer

LIST OF SYMBOLS

%	-	Percentage
a	-	Parallel axis displacement
b	-	Specimen width
℃	-	Celsius
E’	-	Storage modulus
E”	-	Lost modulus
G*	-	Complex modulus
g/l	-	Gram per liter
GPa	-	Giga Pascal
kg	-	Kilogram
kg/m3	-	Kilogram per cubic meter
L	-	Specimen length
mm	-	Millimeter
MPa	-	Mega Pascal
N	-	Axial force
pH	-	Potential Hydrogen
t	-	Specimen depth
ton/year	-	Ton per year
USD/kg	-	United State Dollar per kilogram
wt.%	-	Weight percent
δ	-	Phase angle
E	-	Young’s modulus of beam material, Pa
ρ	-	Density of beam, kg/m^3
H_l	-	Thickness of damping material, m,
Hz	-	Hertz
Pa	-	Pascal

CHAPTER 1

INTRODUCTION

This chapter introduces the subject matter and problems being studied, and indicates its importance and validity. The chapter comprised of research background, problem statement, objectives, and research scope of the work entitled “Characterization and mechanical testing of elastomer modified bitumen”.

1.1 Research Background

Damping sheets is made to minimize the noise, vibration and harshness (NVH) in automotive. It soaks up the shaking movement and sound created by the automobile. The vibration can be ceased with the use of damping sheet, through dissipation of mechanical energy associated with vibration as heat due to the internal friction of the molecular chains. (Christensen, 1982; Ferry, 1980; Ward & Sweeney, 2013). It can remarkably reduce noise if it is used on a thin metal structure that is excited by vibration or airborne sound. It is usually used in vehicle body parts, chutes, metal equipment cabinets, panels, hoppers, sheet metal ducts, bulkheads, cabs, equipment housings, bins and many more (Sound Technology, 2018).

Many existing manufacturers like H&H Acoustic Technologies, Hudgson & Hodgson Group Ltd., Sound Control Services Ltd. and many more use bitumen as the base of the damping sheet with addition of mineral fillers and rubber to form a highly viscoelastic material. Viscoelastic material has behavior which falls between viscous and elastic extremes. When the loads are removed, some energy is recovered; while some gone in the form of heat (Hujare & Sahasrabudhe, 2014). After the applied stress is being removed, the material returns to its initial shape, but it can compete against the next cycle of vibration because deform the material slowly (Rao, 2003). This is the reason why viscoelastic material is used in damping sheet.

Bitumen or also known as asphalt is a viscous solid that contains essentially of hydrocarbons and their derivatives. This material is not resistant to low and high temperature. It melts in high temperature and cracks in the low temperature. In order to enhance the properties of bitumen as damping sheet, elastomeric materials such as rubber is typically incorporated into the bitumen blend. Rubber added in bitumen changes its extensibility and elasticity at low temperatures because rubber has wide operating temperature range (Pyshyev *et al*.,2016). Rubber is also a material that can undergo greater amount of elastic deformation under stress and still retains to its initial size without any deformation than most of the materials that exist (ScienceStruck.com, 2018). Because rubber structure is like coil, when stretched it expands and attains to its original state when the stress is released (Khan & Poh, 2011).

According to Wardlaw & Shuler (1992), in order to increase the performance of bitumen, several additives are being used such as mica, calcium carbonate, asbestos and many more. Additives increase impact resistance, shear, softening point and compressive strength. It also decreases brittleness of the bitumen. By adding additive to bitumen, it can control the deformation and sag (Mehmet Dogan, 2006). As the asbestos has been banded from use, mica is used as the substitute. It is used in brake linings and gaskets, as mold lubricant and release agent in the manufacture of tires. Due to crystalline structure, mica is resistant to high temperature service conditions, as it contains aluminum silicate. Therefore, the thermal properties of the bitumen can be improved by using mica. Meanwhile, according to Xanthos M (2005), the main function of calcium carbonate is to reduce cost, but still having average effects on mechanical properties. According to Tanzadeh & Kianfar (2016), adding calcium carbonate to bitumen has enhanced bitumen resistance against temperature drop.

1.2 Problem Statement

To reduce the noise, vibration and harshness (NVH) in automotive by soaking up the shaking movement and noise of automobile, damping sheet is being used in automobile (Lembaga Minyak Sawit Malaysia., 2007). Typical material used in damping sheet is elastomer modified bitumen. This is because elastomer is a material that have a wide working temperature range and the modification of bitumen with elastomer will produce desirable properties required in a damping sheet.

Despite the lack of plastic properties of bitumen after incorporating elastomer, the new rheological state will provide composition deformation at low temperatures. In other words, this elastomer added in bitumen improves its durability, extensibility and elasticity at low temperatures. It also can improve the thermal properties by making it resistant to crack, deformation, water, frost and aging (Pyshyev *et al*., 2016). The damping ratio of the mixture increases with the increase of rubber composition in the binder (Zeng *et al*., 2001).

Synthetic rubber is common type of elastomer used in the modification with bitumen. The examples are styrene-butadiene-rubber (SBR), styrene-butadiene styrene (SBS), and styrene-isoprene-styrene (SIS) (Yildirim, 2007). SBS could increase the properties of bitumen in terms of ductility at low temperature, viscosity and recovery of elastic. King *et al*. (1999) thought that styrene-butadiene-rubber (SBR) imparted bitumen with better ductility. Even though these elastomers have enhanced the bitumen properties, the use of synthetic rubbers comes at the expense of environment as it resulted in a generation of huge carbon footprint.

Besides, the world faces great problem due to undisposed of tire wastes. Tire waste was dumped into landfills, where a tire takes hundreds of years to decompose(Roy Berendsohn, 2018). These scenarios lead to pollution in the atmosphere due to it was non-biodegradable material. Hence, there is a need to go for recycle material instead. More importantly, the use of recycle material helps to preserve the natural sources whilst providing comparable properties. So is the factor, why tire dust was used in this project.

1.3 Objectives

The objectives of the research project are as follows:

a) To study the effect of mixing temperature and tire dust filler loading on the physical properties of the elastomer modified bitumen, in terms of density and glass transition temperature.
b) To study the effect of mixing temperature and tire dust filler loading on the mechanical properties of the elastomer modified bitumen, in terms of damping properties.

1.4 Research Scope

The scope of study focused on the preparation and characterization of tire dust modified bitumen. The weight percent of tire dust used varied between 0 to 25 wt.%. with mica being added in the mixture at a fixed 10 wt.%, same goes to calcium carbonate. During the sample fabrication, the bituminous blend mixing temperature varied at 140℃, 160℃, and 180℃ while the duration to stir the mixture was fixed at 15 minutes. The mixing temperature was being varied in order to determine the temperature at which the mixtures become homogeneous. The density of compounded material was measured using Top Loading Balances according to dry density method.

Meanwhile, the glass transition temperature of the blend was also studied using Differential Scanning Calorimetry (DSC) technique, in accordance to ASTM D3418 - 15. Additionally, using the Oberst Beam Method, the damping properties of the materials were tested to determine the material loss factor and percentage of reduction percentage in peak in accordance to the ASTM E 756-05. In the all experiments, the bitumen without modification by tire dust was used as the control specimen and a minimum of three specimens were used for each test to obtain an average value.

CHAPTER 2

LITERATURE REVIEW

This chapter is mainly describing the theory and research related to this project, which have been defined and done by various researcher years ago.

2.1 Damping Sheet

According to Silva *et al*. (2006), damping is a conversion of mechanical vibration energy and dissipation in a dynamic system, while Rodriguez (2006) stated that damping is an energy dissipation of a system or material under cyclic stress. Numbers of means that minimize the noise and vibration in a dynamic system can be generally grouped into three methods that are passive, semi- active and active. Method that includes the use of certain active elements such as speakers, actuators, and microprocessors to produce an ‘‘out of phase’’ signal to electronically cancel the disturbance is called active control methods.

Traditional passive control methods for air borne noise consist of absorber, barrier, muffler, silencer and many more. For decreasing the structure borne vibration and noise, several methods are existing. Sometimes by simply changing the system’s stiffness or mass to modify the resonance frequencies can decrease the undesirable vibration as long as there is no modification at the excitation frequencies. On the other hand, in most cases, the vibrations need to be insulated or dissipated by using isolator or damping materials (Rao, 2003).

The complete scale application of active and semi-active control technology in automobiles and commercial airplanes has been reducing in numbers because of high costs and the difficulty of sound field control in the cabin interior. While, passive damping via viscoelastic materials is simpler to implement and more cost effective than active and semi-active techniques. The conversion of mechanical energy produced by vibrating system into heat is referred to damping. Damping is used to control the steady state resonant response and attenuate traveling waves in the structure (Rao, 2003).

Damping sheet is used for controlling noise in thin metal parts in commercial and industrial environments. It is also used in vehicle body parts, chutes, metal equipment cabinets, panels, hoppers, sheet metal ducts, bulkheads, cabs, equipment housings, and bins (Sound Technology, 2018). Damping sheets are normally placed in certain parts of the vehicle such as on the floor and in the doors and trunk, fussed permanently in place by heat as shown below (Lembaga Minyak Sawit Malaysia, 2007). Figure 2.1 shows place where damping sheet normally placed (Sound Technology, 2018) while, Table 2.1 shows the percentage contribution of sources of the total noise (Radhakrishna *et. al.*, 2012).

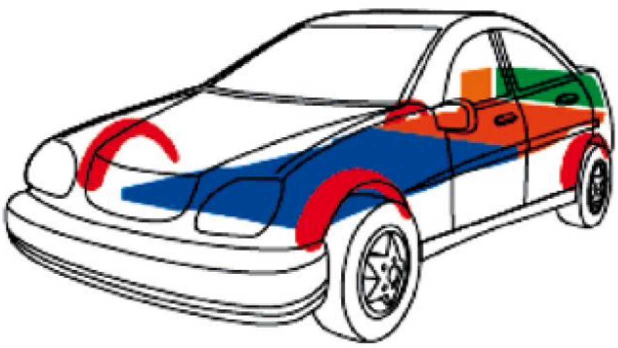

Figure 0.1: Place where damping sheet normally placed (Sound Technology, 2018)

Table 0.1: The percentage contribution of sources of the total noise (Radhakrishna *et al*., 2012).

No	Source	Percent of contribution (%)
i.	Engine	22 to 30
ii.	Exhaust system	25 to 35
iii.	Intake system	5 to 15
iv.	Fan and cooling system	7 to 15
v.	Transmission	12 to 15
vi.	Tires	9 to 15

Damping sheets are normally made by melting one or more binders, such as natural rubber, synthetic rubber and with or without various synthetic resins. Fillers such as asbestos and calcium carbonate are mixed with the binder before rolling the mixture into sheets which are then cut into the desired shapes (Ramli *et al.*, 2007). More than 500 000 passenger cars were sold annually in Malaysia. This is because Malaysia is an attractive market for that types of automobiles. It is estimated that minimum 10 kg damping sheets are used for a car. Many current manufactures are using bitumen as the base of the damping sheet with added mineral fillers and rubber to form a highly viscoelastic material. (Acoustical Surfaces, 2018; Sound Technology, 2018; Soundown, 2011; Sound Control Services Ltd, 2018)

2.2 Bitumen

The Oxford English Reference Dictionary defines bitumen as a tar-like mixture of hydrocarbons produced by the distillation of crude oil during petroleum refining and exist in numerous forms and types; whilst British Standard 3690, Part 1: 1989 states that bitumen is a viscous liquid or solid that contain essentially of hydrocarbons and their derivatives. Bitumen is soluble in trichloroethylene and substantially non-volatile. Bitumen softens gradually when heat is applied (Hosein, Maharaj, Maharaj, & Singh-Ackbarali, 2013). It is black or brown in color, sticky and composed primarily of highly condensed polycyclic aromatic hydrocarbons (Fagbote & Olanipekun, 2010). Bitumen possesses waterproofing and adhesive properties. Bitumen can be obtained by refinery processes from petroleum or also found as a natural deposit or as component of naturally-occurred asphalt (Suryakanta, 2015).

According to the Bureau of Indian Standards (BIS), bitumen is a thermoplastic material and its stiffness is dependent on temperature. The temperature verses stiffness relationship of bitumen is dependent on the source of crude oil and the method of refining (Suryakanta, 2015). Bitumen shows a high level of chemical complexity, containing diverse types of molecular class which are classified in term of solubility in *n*-heptane into two main fractions, maltenes and asphaltenes (Domínguez & García-Morales, 2011).

The International Union of Laboratories and Experts in Construction Materials, Systems and Structures (RILEM) Technical Committees states that bitumen is the heaviest fraction of petroleum. It can be artificial bitumen or natural bitumen. Atherton et. al. (1987) stated that most of bitumen contains carbon 82–85%, hydrogen 8–11%, sulphur 0–6%, oxygen 0–1.5% and nitrogen 0–1%. Figure 2.2 shows the molecular structure of bitumen.