# CHARACTERIZATION AND MECHANICAL TESTING OF WASTE TIRE DUST MODIFIED BITUMEN

This report is submitted in accordance with the requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor Degree of Manufacturing Engineering (Hons.)

by

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Tajuk PSM: Characterization and Mechanical Testing of Natural Rubber Modified Bitumen

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# DECLARATION

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

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# APPROVAL

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

……………………………………

(Dr. Chang Siang Yee)

# ABSTRAK

Pada masa kini, lembaran redaman berasaskan bitumen digunakan untuk mengurangkan getaran yang dijanakan oleh enjin kereta. Dalam pasaran komersial, kebanyakan industri menggunakan getah sintetik sebagai penguat dalam lembaran redaman. Walaubagaimanapun, habuk tayar sisa yang dijana semasa proses buffing tayar boleh digunakan sebagai alternatif untuk mengurangkan penggunaan getah sintetik dalam lembaran redaman. Oleh itu, kajian ini memberi tumpuan kepada habuk tayar sisa sebagai bahan mentah untuk mengubah sifat redaman untuk lembaran redaman berasaskan bitumen disebabkan oleh habuk tayar sisa boleh digunakan semula dan mesra alam. Objektif kajian ini adalah untuk mengkaji kesan kandungan habuk tayar sisa sebagai pengisi dan masa campuran untuk bahan mentah yang digunnakan dalam kajian ini pada sifat redaman terhadap bitumen yang telah diubahsuaikan oleh habuk tayar sisa. Dalam kajian ini, terdapat tiga komposisi habuk tayar sisa yang digunakan iaitu 10, 15, dan 20 wt. % dan masa campuran untuk bahan mentah adalah 15, 30, dan 45 minutes. Selain itu, 10 wt. % mika dan 10 wt. % kalsium karbonat telah digunakan semasa fabrikasi sample untuk menguatkan bitumen. Selepas itu, sample dipotong ke dalam size berdasarkan ASTM E756 untuk Oberst beam Method test untuk mengkaji sifat redamannya. Melalui ujian ini telah menunjukkan bahawa nisbah redaman habuk tayar sisa diubahsuai bitumen akan meningkat oleh sebab dengan kandungan pengisi habuk tayar sisa dan masa campuran bahan mentah meningkat. Pada akhir kajian ini, sifat rendaman untuk kandungan habuk tayar sisa dengan 20 wt. % sebagai pengisi dalam bitumen adalah paling baik, dan masa pencampuran yang optimum untuk bahan mentah adalah 45 minutes. Oleh sebab, semasa kandungan habuk tayar sisa meningkat, kehilangan tenaga oleh sample meningkat. Selain itu, masa pencampuran yang lebih lama membawa kepada peningkatan homogeniti untuk sample, oleh itu, sifat mekanikal campuran meningkat. Jadi, kandungan habuk tayar sisa yang lebih tinggi dan masa campuran yang lebih panjang mengakibatkan prestasi rendaman yang baik.

# ABSTRACT

Nowadays, the bitumen-based damping sheet is applied on the body panel of the car body to reduce the vibration generated from the car engine. In the commercial market, most of the industry used synthetic rubber as reinforcement in the bitumen-based damping sheet. However, waste tire dust generated during tire buffing process could serve as an alternative to reduce the used of synthetic rubbers in damping sheets Thus, this research focuses on the waste tire dust as the raw material to modify the damping properties of the bitumen-based damping sheet due to its reusability and ecologically friendly characteristic. The objectives of this research were to investigate the effect of the waste tire dust filler content and mixing time of the raw materials on the damping properties of the waste tire dust modified bitumen. In this research, there were three different loading of waste tire dust being incorporated into bitumen-based damping sheet which were 10, 15, and 20 wt. %. Meanwhile, the mixing time during the sample fabrication process was varied at 15, 30, and 45 minutes. Besides that, 10 wt. % of mica and 10 wt. % of calcium carbonate were employed during sample fabrication to improve the strength of bitumen. After that, the waste tire dust modified bitumen samples were cut based on the ASTM E756 for Oberst beam Method test in order to study its damping properties. Through this testing, the damping performance of the waste tire dust modified bitumen was found to increase as the waste tire dust filler content and mixing time of the raw materials increased. At the end of this research, the damping properties of the waste tire dust filler content with 20 wt. % was found to be the highest and the optimum mixing time of the raw materials was 45 minutes. As the filler loading increased, loss of energy by the sample increased, thus more energy has dissipated. Besides that, the longer mixing time lead to the increased homogeneity of the sample and it will definitely enhance the mechanical properties of the mixture. Hence, the higher the waste tire dust filler content and longer mixing time of the raw materials have shown to result in the high damping performance of the waste tire dust modified bitumen.

# DEDICATION

Dedicated to

My beloved mother, Cheah Meei Ling

my appreciate siblings, Lim Hong Zhao, Lim Qin Rou, Lim Hong Wei

my supervisor, Dr. Chang Siang Yee for giving me moral support, understanding, and encouragement.

my examiners Dr. Zaleha binti Mustafa, Dr. Muhammad Zaimi bin Zainal Abidin, and Dr. Toibah binti Abd Rahim for examining and giving suggestions for this work.

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| | | |
|---|---|---|
| ASTM | - | American Society for Testing and Materials |
| $CaCO_3$ | - | Calcium Carbonate |
| CLD | - | Constrained Layer Damping |
| CRM | - | Crumb Rubber Modifier |
| EDPM | - | Ethylene Propylene Diene |
| EVA | - | Ethlyene Vinyl Acetates |
| FLD | - | Free Layer Damping |
| OBM | - | Oberst Beam Method |
| PE | - | Polyethylene |
| SBR | - | Styrene Butadiene Rubber |
| SBS | - | Styrene Butadiene Styrene |
| TVD | - | Turned Viscoelastic Damper |

# LIST OF SYMBOLS

| | | |
|---|---|---|
| cm | - | Centimeter |
| ° C | - | Degree Celsius |
| $g/cm^3$ | - | Density |
| mg | - | Milligram |
| mm | - | Millimeter |
| % | - | Percentage |
| r.p.m. | - | Revolutions Per Minute |
| g/l | - | Solubility |
| wt.% | - | Weight Percentage |

# CHAPTER 1

# INTRODUCTION

## 1.1 Background of Study

Nowadays, there are numerous of ways to reduce the vibration and noise in an automotive system. The ways that can be used to decrease the vibration and noise of a dynamic system can be classified into three categories, which are, active, passive, and semi-active methods. However, passive damping using viscoelastic damping materials is easy to apply and more cost effective than active, and semi-active techniques. Passive damping treatment by using viscoelastic materials can be added to the body of an automotive system by a number of means, which are, free-layer damping treatment (FLD), constrained-layer or sandwich-layer damping treatment (CLD), and tuned viscoelastic damper (TVD). These three methods have been widely used in the automotive industry, especially CLD is the most common method that used to reduce the vibration and sound of an automotive system because it is more effective since it can consume and dissipate more energy into heat (Rao, 2003).

Zhou *et al.* (2016) reported that bitumen-based viscoelastic damping material is the most commonly used in automotive industry due to it is relatively low cost, possess highest damping ratio, and ease of implementation as compared with others type of damping materials. It is normally applied on the body of vehicles, ship vessels, and aircrafts. Bitumen-based viscoelastic damping material is a highly viscoelastic material that made of bitumen with added synthetic rubber and mineral fillers. It is able to reduce vibration and is generally used for FLD and CLD. The operating temperature of bitumen-based viscoelastic damping material are at continuous temperatures between 20–90 °C and 20– 110 °C respectively. Asphalt melt is usually used on the surface damping treatment on the vehicle body panels due to its low cost. However, the damping performance of these asphaltic materials is relatively low as compared to others materials. Hence, it is poor to reduce the floorpan vibration levels on vehicles (Policarpo *et al.*, 2013).

In order to improve the quality of bitumen, bitumen modification has been received increasing attention from industries. Polymer modification is one of the most familiar method that has been used to modified and enhance the quality of bitumen. Polymer modification of bitumen is often the incorporation of polymers in bitumen and the process usually done by high shear mixing. There are various types of polymers have been incorporated in bitumen, the artificial synthesis polymer included plastomer and thermoplastic elastomers are the most widely used polymers for the bitumen modification. These polymers were reported can lead to higher stiffness at high temperature, higher cracking resistance at low temperatures, better moisture resistance or longer fatigue life of bitumen. Thermoplastic is widely used as bitumen modifier compared to plastomer due to it is soften on heating and harden on cooling which resulting in the high resistance of permanent deformation and elastically recovering. However, the combination of the oxidation of bitumen and the degradation of polymer was reported to cause the ageing propensity of polymer modified bitumen (Zhu *et al*, 2014).

In polymer modification of bitumen, styrene butadiene styrene (SBS) which is a synthetic thermoplastic elastomer is the most widely used modifier to improve the properties of bitumen. This is because SBS possess relatively good solubility in bitumen as well as the cost of the SBS polymer modified bitumen is reasonable and acceptable. It was reported that SBS polymer modified bitumen exhibit relatively high temperature flow resistance and low temperature flexibility as compared to the unmodified bitumen (G.D. Airey *et al*., 2002). Due to the thermoplastic nature of SBS copolymers at elevated temperature and their ability to provide the continuous network on cooling, SBS has been chosen as the great bitumen modifiers (Isacsson and Lu, 1995). Besides that, due to the presence of the 3D network physical cross-linking in the polymer blocks, the SBS polymer modified bitumen able to maintain high elasticity and strength at the elevated service temperature. The cross-links formed due to the incompatible between styrene and butadiene copolymers, each of them tend to form links within their own polymer group. From the SBS, the styrene as referred to the end-block contributes strength of the material, while the butadiene as referred to the middle block provides the elasticity of the material. Hence, it can be said that the incorporation of SBS modifier in the bitumen will result in the increased stiffness, reduced temperature sensitivity, and improved elastic response of polymer modified bitumen (Read and Whiteoak, 2003).

In most studies, researchers used synthetic rubber instead of waste tire dust as modifier to improve the damping properties of the polymer modified bitumen. This is because synthetic counterparts are made to meet some specific requirements such as for high temperature application since the waste tire dust is highly sensitive to heat. However, these synthetic rubbers are mostly manufactured from non-renewable oil-based resource (Kalkornsurapranee *et al*., 2009). Thus, this research is going to study more on the incorporated waste tire dust as a modifier into bitumen instead of using synthetic rubber. This research helps us understand more about the effect of waste tire dust on the damping performance of bitumen-based damping materials. At the end of this research, the optimum waste tire dust filler and mixing time that would result in enhanced damping performance of the bitumen-based materials are proposed.

## 1.2 Problem statement

In recent years, waste tire dust are becoming an alternative for synthetic materials as it provide good health to the greener environment. Instead of using synthetic rubber, waste tire dust is one of the other examples that can be used as modifier in bitumen modification (Airey, 2003). As waste tire dust is reuseable, the usage of the valuable resource can be reduced since reusing of waste material is one of the best way to find and add value to waste material in order to prevent wastage. Besides that, the utilization of waste material can prevent pollution caused by the landfill and incineration of waste material. Hence, it is sustainable material to be used in the developement of economic and environment.

Other than that, the price of the waste tire dust is relatively low as compared to the synthetic rubber. The price of waste tire dust is around 1.40 USD/kg while the synthetic rubber costs 3.26 – 3.59 USD/kg. It can be seen that the price of the synthetic rubber is twice as expensive as waste tire dust. Therefore, the cost of producing the product also can be reduced significantly by using waste tire dust instead of using synthetic rubber.

Besides that, waste tire dust also has the comparable density as compared to synthetic rubber. The density of the waste tire dust is 0.937 $g/cm^3$ and the density of the synthetic rubber for example styrene-butadiene styrene is lies between 0.93-0.94 $g/cm^3$. Therefore, there is not much difference since the density of the waste tire dust is very close to that of the synthetic rubber.

As our mother earth is facing great challenge due to non-degradable waste materials, there is a vital need to go for recycling or reusing waste materials in order to prevent further pollution as well as to preserve natural resource. Therefore, this work is carried out to explore the utilization of waste tire dust as an alternative material for damping sheet with comparable damping properties. In particular, this research is carried out to explore and study on the effect of waste tire dust filler content and mixing time of the raw materials on the damping properties of waste tire dust modified bitumen.

## 1.3 Objective

The objectives of this research as follows:

a) To investigate the effect of waste tire dust content on the damping properties of waste tire dust modified bitumen.

b) To evaluate the effect of mixing time of the raw materials on the damping properties of the waste tire dust modified bitumen.

## 1.4 Scope

The scope of this study is focused on the characterization and mechanical testing of waste tire dust modified bitumen. Waste tire dust, bitumen, calcium carbonate, and mica powder were the raw materials that used in the mixing process of sample fabrication. The process flow of this research can be separated into four stages which are raw material preparation, sample fabrication, test specimen preparation, and testing of specimen. The temperature of mixing process was fixed at 140 °C while the duration to stir the mixture were 15, 30, and 45 minutes respectively.

Besides that, the scope of this study also focused on the effect of waste tire dust filler loading and mixing time of raw materials in the bitumen modification. The weight percent of waste tire dust used were 0, 10, 15, and 20 wt.%. The calcium carbonate and mica powder that were added in the mixture was fixed at 10 wt.% respectively. Optimum filler loading which will be resulting in the highest damping performance of the waste tire dust modified bitumen was proposed at the end of this research. Meanwhile, the mixing time of raw materials were 15, 30, and 45 minutes. The mixing time were varied in order to determine the optimum mixing time of the raw materials which can resulting in the enhanced damping properties of the waste tire dust modified bitumen.

The damping properties of the blend was studied using Oberst Beam Method (OBM). Before testing, the fabricated samples were prepared into test specimen with differences geometries in accordance to ASTM E756. Through OBM testing, the damping properties of the test specimens in term of reduction in peak and loss factor were determined from the analysis of frequency response function (FRF) obtained from the OBM test. In experiment, the bitumen without modification of waste tire dust was used as the control specimen. To obtain average result, minimum of three test specimens were evaluated during the OBM testing.

# CHAPTER 2

## LITERATURE REVIEW

### 2.0 Introduction

This chapter mainly review about elastomer as the potential modifier to be used in the modification of bitumen. Due to the limited literature available on elastomer modified bitumen, the following discussion was also take into account of modification of bitumen with other polymers like thermoplastics.

### 2.1 Damping sheet

Traditionally, in the industry of automotive, a vibration damping sheet has been invented to adhere on the body panel of the car body. It has been widely used in order to improve the insulation of vibration and reduce the noise level that are generated from the moving vehicle. Generally, damping sheet is made of viscoelastic damping materials that exhibit both of the elastic and viscous characteristics and it is usually available into sheet form and bonded to the body panels of vehicle by using adhesive.

The application of damping materials has been widely used as the damping treatment to reduce the vibration and sound within the railway vehicles. Damping materials can be categorized into few types. However, bitumen-based damping materials is the most excellent damping materials due the highest transmission loss at low frequency. Hence, it can reduce much more wide frequency range of vibration as compared to others types of damping material. Traditionally, the bitumen-based damping materials are pasted partially on the outside sheeting of the car body (Fan *et al*., 2009).

For a vehicle, since the interior sound field depends on the body panels, the damping materials are conventionally applied on the door, floor, back panels, roof, and dash to reduce the vibration level of the vehicle. Usually, asphalt melt sheets which is an asphaltic-based compound materials used on the surface damping treatment on the vehicle body panels due to its relatively low cost as compared to others. Figure 2.1 shows the application of asphalt melt sheet in the floor pan of an automobile (Policarpo *et al.*, 2013).

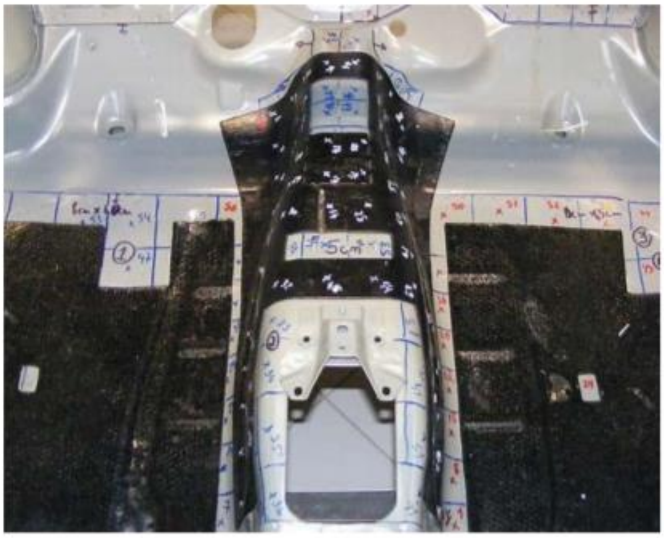

Figure 2.1: Asphalt melt sheet applied on floor pan of an automobile (Policarpo *et al.*, 2013).

## 2.2 Viscoelastic materials in damping sheet

Damping materials are also known as viscoelastic sheet materials, they are able to store and absorb the mechanical and acoustical energy from a vibrating system, the energy absorbed is then convert into the heat. Generally, there are there types of damping materials which are bitumen-based damping materials, butyl rubber damping materials, and water-based damping materials. Bitumen-based material is the most widely used damping materials due to its low cost and ease of implementation (Fan *et al.*, 2009).

Material that exhibit both characteristic of elastic solid and viscous fluid is commonly called as viscoelastic material. After being stressed, viscoelastic material tends to returns to its original shape, but does it slowly enough to oppose the next cycle of vibration. Various polymeric materials such as rubbers, plastics, vinyl, and adhesives exhibit viscoelastic behaviour due to the presence of long-chain molecules. The material properties of viscoelastic material can be influenced by the environmental condition such as environment temperature, vibration frequency and so on (Rao, 2003).

The viscoelastic material has been widely used to inhibit the vibration and sound level in the automotive industry. The high damping of the viscoelastic material plays an important role in the inhibition of vibration and noise in a relatively wide band (He *et al.*, 2014).

### 2.2.1 Bitumen

Bitumen is a black adhesive material that can be obtained as a residue of the distillation of crude oil (Redelius and Soenen, 2015). Bitumen which is manufactured from crude oil can be also known as refined bitumen. Besides that, bitumen can also occur in nature as "natural asphalt" which can be found as a natural deposit of naturally occurring asphalt such as at the bottom of ancient lakes (Morgan and Mulder, 1995).

#### 2.2.1.1 Physical properties of bitumen

Bitumen behaves as a viscoelastic material at usual in-service temperatures (Navarro *et al.*, 2009). It is black or dark brown material which is possessing adhesive and waterproofing qualities. Bitumen is soluble in trichloroethylene and is substantially non-volatile and softens gradually when heated (McNally, 2011). The density of bitumen is depends on the paving grade and crude source and it is normally lies between 1.01 and 1.04 g/cm$^3$ at room temperature (Read and Whiteoak, 2003).

The glass transition temperature of bitumen is varying in a very wide range which is ranging from -40 °C to +5 °C. However, the glass transition temperature of bitumen is generally around -20 °C and it is depending on the origin of the crude oil. Besides that, the transition range which is corresponds to the value of the midpoint typically spans -20 ºC and 30 °C to 45 ºC. Therefore, from the viewpoint of thermodynamical, bitumen exhibit as a very viscous liquid at room temperature (Lesueur, 2009).