UNIVERSITI TEKNIKAL MALAYSIA MELAKA

EFFECT OF HARD AND SOFT SEGMENT RATIO TO VIBRATION DAMPING PROPERTIES OF POLYURETHANE

This report is submitted in accordance with the requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor of Mechanical Engineering Technology (Maintenance Technology) with Honours.

by

LIEW CHIN CHIN
B071410748
940412-08-6008

FACULTY OF ENGINEERING TECHNOLOGY
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DECLARATION

I hereby, declared this report entitled "Effect of Hard and Soft Segment Ratio to Vibration Damping Properties of Polyurethane" is the results of my own research except as cited in references.

Signature	:	……………………………………….
Author's Name	:	………………………………………
Date	:	………………………………………

APPROVAL

This report is submitted to the Faculty of Engineering Technology of UTeM as a partial fulfillment of the requirements for the degree of Bachelor of Mechanical Engineering Technology (Maintenance Technology) with Honours. The member of the supervisory is as follow:

………………………………

(DR ABDUL MUNIR HIDAYAT SYAH LUBIS)

ABSTRAK

Getaran terjadi pada mesin, sistem mekanikal boleh menjurus kepada kerosakan komponen dan sistem. Retak dan tidak penjajaran adalah contoh kerosakan daripada getaran. Polyurethane (PU) boleh digunakan sebagai bahan redaman dengan menukar tenaga getaran kepada tenaga lain untuk pengurang getaran. *PU* boleh digunakan untuk membaiki kedap kebocoran dan retak dalam konkrit, sebagai pengasingan terma, tapak dalam kasut dan gasket produk. Project ini bertujuan (i) membangunkan rumusan busa *PU* yang tegar, (ii) menuntukan nisbah segmen keras and lembut untuk getaran *PU* dan (iii) menyiasat kesan nuih *PU* yang ubal dengan getaran keluli. "*Isocyanate*" (MDI) sebagai segmen keras, "*polyol*" sebagai segmen lembut dan "amine" sebagai pemangkin. Lima sampel disediakan dengan campur perbezaan nisbah segmen keras dan lembut tetapi kandungan pemangkin adalah tetap. Analisis *FTIR* digunakan untuk mengkaji perumusan *PU* punya kumpulan fungsi. Pengujian getaran rujuk ASTM E756 dalam rasuk cantilever merangsang pada frekuensi tetap dan rawak. Hasil ketumpahan menunjukkan kelebihan "*polyol*" menguranْkan ketumpatan. Daripada analisis *FTIR*, kepentingan spektrum rujuk pada 3323 1/cm, 2938 1/cm dan 2895 1/cm. Frekuensi tetap di 10 Hz, PU 1 (27.5 *vol%* polyol dan 52.5 *vol% MDI*) dan *PU* 3 (32.5 *vol%* polyol dan 47.5 *vol% MDI*) mempunyai paling kurang magnitud getaran 0.67g dan 0.69g masing-masing. Tambahan pula, *PU* 3 mengurangkan getaran keluli di 10 Hz dari 0.11g kepada 0.09g. Frekuensi rawak pada keluli menunjukkan paling tinggi magnitude getaran di 570 Hz dan *PU* 3 mengurangkan magnitud dari 0.29g kepada 0.011g. Oleh itu, rumusan busa *PU* yang keras berjaya didapat, tiada kesan penting bagi nisbah segmen keras dan lembu kepada getran *PU* dan keluli.

Kata Kunci: Getarn; Polyurethane foam; Getaran lembap; Rasuk cantilever

ABSTRACT

Vibration occur in machines, mechanical system which can lead to component or system failure. Crack and misalignment are common effect of vibration. Polyurethane (PU) can be used as damping material by convert vibration energy to other energy in vibration reduction. *PU* can be used to repair and seal crack of concrete, also as thermal isolation, insole of shoes, gasket, coating etc. This project aimed to : (i) develop a formulation of rigid polyurethane foam, (ii) to determine the effect hard and soft segments ratio to vibration response of rigid polyurethane foam and (iii) to investigate the effect of formulated polyurethane foam to vibration of steel. Isocyanate (MDI) was used as hard segment, polyol as soft segment and amine used as catalyst. Five samples were prepared by difference ratio of hard and soft segment while the catalyst content was fixed. *FTIR* analysis was performed to study formulation of *PU*'s functional group. Vibration testing was performed according to ASTM E756 where cantilever beam specimen excited by constant and random frequency respectively. Density measurement show that more polyol reduce the density. From the *FTIR* septrum, the important septrum of *PU* were observed at 3323 1/cm, 2938 1/cm and 2859 1/cm. By constant frequency at 10 Hz, *PU* 1 (27.5% polyol and 52.5% *MDI*) and *PU* 3 (32.5% polyol and 47.5% *MDI*) were found to have the lowest vibration magnitude of 0.67g and 0.69g respectively. In addition, *PU* 3 reduce vibration of steel at 10 Hz from 0.11g to 0.09g. Random vibration testing of steel show the highest magnitude of vibration at frequency 570 Hz and *PU* 3 reduce the magnitude from 0.29g to 0.011g. Therefore, the formulation of PU were succeessfully obtain, no significant effect of hard and soft segment ratio to vibration of *PU* and steel.

Keywords: Vibration; Polyurethane foam; Damped vibration; Cantilever beam

DEDICATION

To my beloved parents

ACKNOWLEDGEMENT

Firstly, I would like to thanks to my beloved university, Universiti Teknikal Malaysia Melaka (UTeM) giving me this opportunity to explore myself in new thing. I would like to thanks God for blessings to allow me complete my Final Year Project smoothly although there are some problems faced during my research.

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LIST OF ABBREVIATIONS, SYMBOLS AND NOMENCLATURE

ASTM	-	American Society for Testing and Materials
C	-	Carbon
CPS	-	Cycle Per Second
DMCHA	-	Dimethylcyclonexylamide
F	-	Fibre
FFT	-	Fast Fourier Transform
FIV	-	Flow Induced Vibration
FTIR	-	Fourier Transform Infrared Spectrum
HAV	-	Hand-arm Vibration
IPDI	-	Isophorone Diisocyanate
IT	-	Information Technology
MEKP	-	Methyl Ethyl Ketone Peroxide
MDI	-	Diphenyl Methane Diisocyanate
N	-	Nitrogen
O	-	Oxygen
OBM	-	Observed Beam Method
OH	-	Hydroxyl Group
PU	-	Polyurethane
PESP	-	Polyester Polyol
PETP	-	Polyether Polyol
P	-	Recycled Tires
R-value	-	R-Resistance To Heat Flow
SDOF	-	Single-Degree-Of-Freedom
SEM	-	Scanning Electron Microscopy
SERDP	-	Strategic Environmental Research Development Program
TDI	-	Toluene Diisocyanate
UTM	-	Universal Testing Machine
WBV	-	Whole Body Vibration

CHAPTER 1
INTRODUCTION

1.1 Introduction

Polyurethane, usually referred as *PU*; it is usually name of the family of chemicals known as the thermoset polyurethane which compose raw materials isocyanate and polyol. Polyurethane much used in everything in daily life example likes baby toys, airplane wings, industry application and others. Vibration is common phenomena exist in everything. Albert Einstein say that ‘Everything in Life is Vibration’. Excessive vibration can bring problems to human, things and environment. In automotive mechanical system, unbalance in the engine, looseness of bolts and misalignment of shaft are examples of basic of vibrational problems. In industry plants, vibration problems may be occurs due to fluid flow known as Flow Induced Vibration (FIV) (Kaneko, et al., 2008). The problem of coupling vibration between shaft causes misalignment and non-symmetrical occur which affects the issue of component life and lead to fatigue failure. For this reason, property of coupling material is focused and some new material are analysis for replace or as alternative the existing products (Meagher, 2013). The selection of coupling very important because it is accommodating misalignment between shafts, vibration from one machine to another, maintain precise alignment between connected shaft and others. There are rigid coupling, flexible coupling, mechanically flexible couplings, material-flexible coupling, metallic flexile material coupling, elastomer material flexible coupling and magnetic coupling. Each coupling has them own advantage and limitation (Budris, 2017).

In case of house appliances, washing machine, robot vacuum cleaner, fans also can generate vibration when they are working. Workers have high potential of injury risk of hand-arm vibration (HAV) and whole-body vibration (WBV) when in contact with grinding or cutting operations (Brauch, 2015). However, *HAV* and *WBV* at certain vibration level are useful for fitness machine purpose (Guy, 2015).

Excessive vibration can be eliminate by using vibration damping and vibration isolator. Polyurethane can be used to protect the generator engine from harm particles and reduce vibration because it provides a two-part foam filter (Kino, et al., 2012). Polyurethane gaskets ensure a proper seal to prevent leakage due to vibration (Hoffman, 2002). Such as basement crack can be repaired by polyurethane foam injection concrete crack effectively and low cost required (Eastern, 2012).

1.2 Problem Statement

As mention earlier, vibration can give problem to automotive plan structure and machinery. Therefore, vibration need to be controlled or eliminated if possible. One of the method to control vibration is using vibration damper or vibration isolator. Vibration damper is an energy dissipating device by convert kinetic energy to mostly heat in vibratory motion. While vibration isolator is an element with stiffness only or combination of stiffness and damping which use to eliminate the transmission of vibration by placed between vibrating body and support body (Dharankar, 2017). Polyurethane has been used as vibration damper and isolator. And the damping or isolating properties refer to mechanical properties. However, the mechanical properties of polyurethane itself much affected by composition and manufacturing method of polyurethane. In this project, focused on the study of composition relationship to vibration damping or isolating properties of polyurethane.

1.3 Objective

This project is meant to obtain preliminary results on the development vibration reduction material for automotive and industrial application. The objectives of this project are:

1. Develop a formulation of rigid polyurethane foam.
2. To determine the effect hard and soft segments ratio to vibration response of rigid polyurethane foam.
3. To investigate the effect of formulated polyurethane foam to vibration of steel.

1.4 Scope

Scope of this project are:

1. Formulate the rigid polyurethane by combination of hard and soft segments ratio including the catalyst contents.
2. Fabricate/mould the polyurethane foam sample based on the formulation.
3. Determining the vibration damping or isolating properties by using vibration shaker according to ASTM E756 Measuring Vibration-Damping Properties of Materials.

CHAPTER 2

LITERATURE REVIEW

2.1 Polymer

Polymer are large molecules consisting of at least five small molecules, called monomers joined together and some may contain hundreds or thousands of monomers in each chain called macromolecules. The term “polymer” first introduced by Swedish chemist Jons Jakob Berzelius, in year 1833. For word “poly” mean many and “meros” mean part. Polymer consist of long and flexible chains with a string of *C* atoms as a backbone. Polymer epically undergo polymerization. Polymerization may occur if monomers involves in the reaction have proper functionality. Polymerization is taken place when the monomers bond with other molecules through addition or condensation (Chanda, 2013). Addition polymerization is taken place of several the stages from initial to propagation and finally with termination stage. While the condensation polymerization formed by additional-elimination reactions; in this case water or another compound are eliminated (Ramsden, 2000).

Polymers can be natural polymer or synthesis polymer. Natural polymer such as cellulose, rubber and wood. While synthetic polymer has spaghetti-like conformations and range of molar masses. Synthetic polymer can be made by addition polymerization or condensation polymerization (Stephen, 2017). Examples of paints, coatings, plastic and nylon are type of material made of polymers. Long time ago, synthetic polymer such as polyethylene and polystyrene used to produce plastic products before they discover polyurethane and that it can be transform or modify in different ways.

2.2 Type of polymer

In general, polymers can be categorized as thermoplastic and thermoset polymer. Thermoplastic polymer is a type of polymer when heated will become soften and when cool down, it will become harden No matter how many time repeat heating and cooling, it does not degrade the polymer. Example of thermoplastic polymers are acrylic, nylon, Teflon, polypropylene, polyethylene, polystyrene, polyvinyl chloride and others. Nylon be use as mechanical and automotive parts, clothing, packing and heat resistant composite manufacture. While Teflon can be use as flange spacers, gaskets, machine parts, wires and others. Thermoplastic such as expanded polystyrene foam can be drawn into films, fibres or packaging material used to cushion fragile products. In electronic devices, thermoplastic such as polyvinyl chloride is useful for coats and electrical insulation because it can convert to flexible form with addition of plasticizers (Stephen, 2017).

Characteristic of thermoplastic polymers are low density, low melting temperature, low thermal and high ductility. This characteristic has relation with thermoplastic polymer's structure. Thermoplastic polymers have branched or linear structure or both are mixing (Figure 2.1). Thermoplastic polymer can be stronger in solid state and more viscous at certain temperature in liquid state due to the branched structure. Besides that, branched structure can increase dissension among of polymer chains. Polymer chains bond each other together by secondary bonds in thermoplastic.

Figure 2.1 : Thermoplastic cross linking (Chavan, 2016)

Thermoset polymers are cross- linked polymers. Crosslinking affect the reaction. So, it cannot be reversed hence the polymer become chemically set (Figure

2.2). When thermoset polymer melted and cool down, the polymer degrades. Behavior and characteristic of thermoset polymer are possess a high degree of cross- linking, hard and brittle, less soluble in common solvent thus result in cannot be recycled. Example of thermoset polymers are phenolic, amino resin, epoxy and others. Epoxy resins are famous materials used in glues and adhesives because their setting does not depend on evaporation. Phenolic resins or bakelite used in electrical insulating properties, adhesive in plywood manufacture and making paint (Stephen, 2017). But disadvantage of cured epoxy thermoset is highly brittle due to restrict chain mobility restrain deformation process.

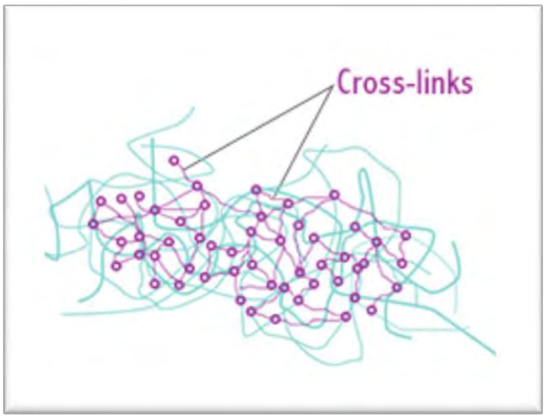

Figure 2.2 : Thermoset cross linking (Chavan, 2016)

Crosslinking of thermoset polymers can be processed into three ways. The three ways are (i) temperature- activated system, (ii) catalyst- activated system and (iii) mixing- activated system. The temperature- activated cross linking system is performed by heating the polymer. Catalyst- activated system performed such as adding little amount of catalysts to the polymer to form cross- linking. Mixing-activated system is prepared by two chemicals in a reaction and solid polymer cross-linking will be formed.

Curing or setting is an important and familiar chemical reaction related with cross- linking. Chemical reaction can be due to heat, light or addition of chemical catalyst as mention above. Curing also called thermal curing when the process of chemical reaction with temperature-induced in material. A transfer molding process was done by (Frel, 2016) to modeling thermal curing in *COMSOL* Multiphysics software. Material was loaded inside mould and heated. During heating and curing, the material does not flow inside cavity. Moreover, fiber reinforced thermoset start with uncured at room temperature. But when it placed inside a heated mould, the material become cures and solidifies (Theriault & Osswald, 2000). Curing or setting is a complicated process and it causes thermoset polymers are using widely.

2.3 Polyurethane

Polyurethane, *PU* or urethane polymer is one member of the polymer family. Polyurethane discovers by German scientist called Otto Bayer and his co-workers. Therefore, Otto Bayer was famous well-known "father" of polyurethane. Polyurethane exhibit good property of stiffness or desired polymer which depends on the ratio of mixing hard and soft segment raw materials polyurethane. Thermosetting polyurethane forms when undergoes crosslinking between the diisocyanate such as methylene diphenyl diisocyanate (MDI) or toluene diisocyanate (TDI) reacts with three hydroxyl groups. The mixing process called addition polymerization by hard segment called isocyanate while soft segment called polyol. Thermoplastic polyurethane almost similar with thermosetting polyurethane. Thermoplastic polyurethane can be made by extrusion as well as injection, blow and compression molding equipment. It is linear segmented block copolymer composed of hard segment (aromatic or aliphatic based isocyanates) and soft segments (polyether or polyester) (Source: <https://polyurethane.americanchemistry.com> 18/10/2017). The difference between thermoset polyurethane and thermoplastic polyurethane is abrasion resistance. Thermoset polyurethane good in abrasive application because of its high resistance to abrasion compared to thermoset polyurethane which will tear with abrasive application. Thermoset polyurethane can withstand temperature up to 250ºC while thermoplastic polyurethane will become soften, deform in temperature above 250 ºC (Source: <https://psiurethanes.com> 12/01/2017).

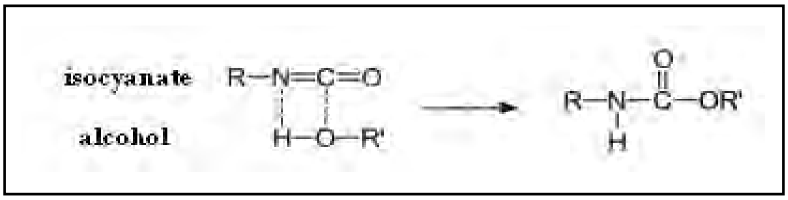

Figure 2.3 : Urethane group (Source: <http://www.whatischemistry.unina.it> 26/12/2013)

2.4 Application of Polyurethane

In general, polyurethane with different properties as well as chemical structure can apply in various application. Polyurethane can directly make into the final product compare to other such as polyethene and polypropene are product in chemical plants (Source: <http://www.essentialchemicalindustry.org> 24/04/2017). Products are subsequently make from polyethene and polypropene by heating the polymer, shaping it under pressure and cooling it. Finally, the end of the product almost complete depend by original polymer. Polyurethane often produced in the large blocks of foam, cushion or thermal insulation. Figure 2.4 below show the percentage uses of polyurethane.

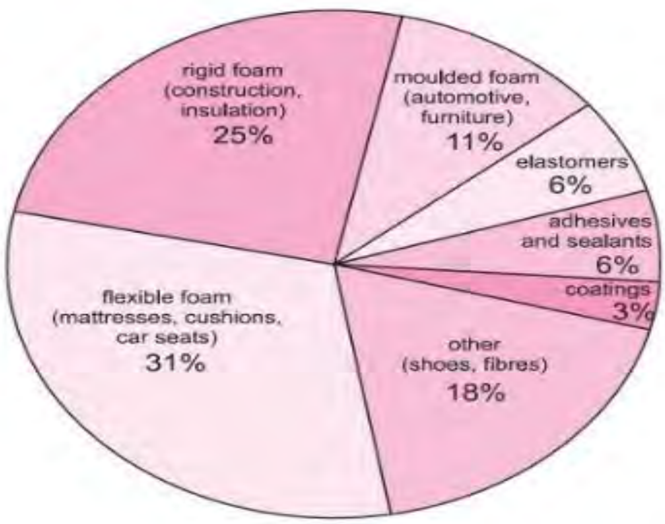

Figure 2.4 : Uses of polyurethane (Clements, et al., 2013)

Polyurethane foam can help to stop concrete basement crack leaks is polyurethane foam injected into the crack to stop the crack happen. After injected the polyurethane foam into the crack, the foam will begin expand and expansion can fill any voids. Treatment of the foam will seal out any water and it is perform from the inside of the basement since the foundation does not need to be grub on the outside as shown in Figure 2.5 (Eastern, 2012).

Figure 2.5 : Step of injecting polyurethane foam (Eastern, 2012)

Beside basement injection, polyurethane can be implement in road maintenance. Application of polyurethane in expressways is a big and important insfrastruture that require mainenance and rehibilitation to maintain its quality to met the safety requirement and succefully comply to the operation requirement. Fakhar and Asmaniza discuss two approach as road rehabilitation which are polyurethane (PU) foam injection system and geocrete soil stabilization (Fakhar & Asmaniza, 2016). Polyurethane foam injection system (Figure 2.6) uses chemical grout which are isocyanate and polyol that mix together within soil structure through injection. The chemical grout able to uplift, realign, underseal, fill voids and strengthening ground soil structure within soil around 15 minutes. The process of injection start with drilling a hole, install the packer with tube and filling up the voids with *PU* grout between the ground soil. After that, *PU* grout within soil will polymerized with volume expansion. The expansion of *PU* grout cause significant compression and compacting of the surrounding soil. The benefits of this approach are improve the ground property which the lightweight characteristics of *PU* allow a reduction of settlemnt rate and expansion characterixtics of *PU* able to lift up the ground soil. In addition, it also can improve the characteristics soil such as stiffness and shear strength which make the soil almost rigid yet flexible. In geocrete soil stabilization merge with in-situ soil materials,cement, white powder/ alkaline additive and water to produce hard yet flexible solid and durable ground layer which act as solid foundation (Fakhar & Asmaniza, 2016).

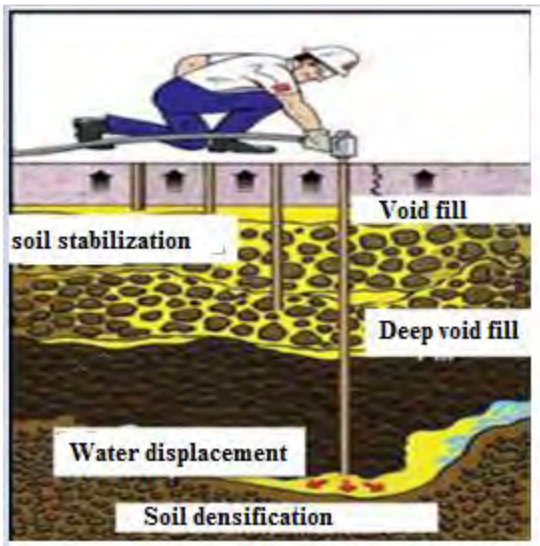

Figure 2.6 : Polyurethane injection system (Fakhar & Asmaniza, 2016)

Besides that, polyurethane also provide application in automotive nowadays. Uses of polyurethane include seating, interior padding such as steering wheels and dashboads, accessories such as mirror surround. Besides that, door panels, parcel shelves, components mounted in the engie space are made from polyurethane. The reason of apply polyurethane in automotive application because the shock absorbing qualities and high resilience of polyurethane foam can ensure safety of car user. Polyurethane foam characteristic lightweight thus lowinging fuel consumption and CO_2 emission (Basf, et al., 2016). However, versatilie of polyuethane material which can perfom in difference range of foam can make ideal in car from seat fillings to bumpers and steering wheels.

Study by Justine (2013) on apply 100% solid polyurethane as coating in oil and gas ppelines. He or she state that polyurethane material was harmless, more adjustment than anti corrsion traditional coatings with environment. Beides that, the other good properties of 100% solid polyurethane were without caves, suitable flexibility, high resistance to corrosion and in high temperature, high adhesion, application in external and internal coating of different pipe (Justine, 2013). Cast polyurethane had been use