CHARACTERISTICS OF DEVELOPED FLEXIBLE POLYURETHANE FOAMS
REINFORCED WITH COCONUT COIR FIBRES AND
RECYCLED TYRES

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Flexible Polyurethane (PU) foam is generally used in seat cushions of automotive seating for comfort and supporting the occupants. However, due to the demand for more comfortable compartment; seat cushions are now designed for better riding comfort and acoustic absorption which linked to the damping of foam. Incorporated treated coir fibres (F) and tyre particles (P) into polymeric material had improved the damping and strength of the material. In this research, flexible PU foams were reinforced with two fillers for the purpose of higher damping property and improve the mechanical strength. Five samples with 2.5wt% of filler loading were developed. The damping of samples was measured on sound absorption and vibration transmissibility test that generated at 1mm, 1.5mm, 0.1g, and 0.15g base excitation while their mechanical properties were examined through compression, tear resistance, and compression set. The morphology of samples was also observed by SEM in this research. The results showed that the foam composites produced have smaller cell size, in which the smallest was 840μm compared to 1290μm obtained in pure PU foam. The mechanical properties revealed that the strength of flexible PU foam increased with added treated coir fibres and recycled tyres. The best properties were shown in PU+2.5wt%(50F50P) which increased by 10.78% on the compressive modulus, 9.33% on the compressive strength, 14.49% on the static energy absorption, and 3.76% on the tear strength compared to pure PU foam. The sound absorption and vibration damping of the developed foams showed that more energy were absorbed and dissipated by these foams after fillers added. The PU+2.5wt%(80P20F) and PU+2.5wt%F presented an excellent sound absorption characteristics at 20mm and 40mm thickness, respectively, whereas PU+2.5wt%P, PU+2.5wt%(80P20F), and PU+2.5wt%(80F20P) showed higher vibration damping from the transmissibility test.
ABSTRAK

Pada amnya, *Flexible Polyurethane (PU)* berbusa diguna dalam kusyen tempat duduk kenderaan untuk memberi keselesaan dan menanggung penggunanya. Namun, atas permintaan pengguna supaya bahagian dalaman menjadi lebih selesa, kusyen tempat duduk kenderaan kini di rekabentuk untuk keselesaan dan penyerapan akustik yang lebih baik, dimana ianya berhubung kait dengan penyerapan pada bahan yang berbusa. Campuran sabut kelapa dirawat (F) dan serbuk tayar (P) ke dalam bahan polimer meningkatkan penyerapan dan kekuatan bahan. Dalam kajian ini, *flexible PU* berbusa diperkukuh dengan dua pengisian bagi tujuan meningkatkan penyerapan dan kekuatan mekanikal bahan. Lima sampel kajian dengan 2.5wt% pengisian telah dihasilkan. Penyerapan bahan komposit diukur dengan ujian penyerapan bunyi dan ujian kebolehpindahan getaran yang dilakukan pada 1mm, 1.5mm, 0.1g, dan 0.15g yang diuji pada tapak, manakala sifat-sifat mekanikal pula diperolehi melalui ujian seperti mampatan, rintangan koyak, dan set mampatan. Morfologi komposit pula diperolehi dari *SEM* dalam kajian ini. Keputusan ujian menunjukkan bahawa komposit berbusa yang dihasilkan mempunyai sel bersaiz lebih kecil, di mana yang paling kecil adalah 840μm berbanding dengan 1290μm yang diperolehi dari *PU* berbusa yang tulen. Sifat-sifat mekanikal menunjukkan bahawa kekuatan *flexible PU* berbusa meningkat dengan campuran sabut kelapa dirawat dan serbuk tayar kitar semula. Sifat-sifat yang terbaik ditunjukkan pada PU+2.5wt%(50F50P) dan ianya meningkat sebanyak 10.78% pada modulus mampatan, 9.33% pada kekuatan mampatan, 14.49% pada penyerapan tenaga statik, dan 3.76% pada kekuatan koyak berbanding dengan *PU* berbusa yang tulen. Penyerapan bunyi dan serapan getaran bahan yang dihasilkan menunjukkan bahawa ianya meningkat apabila bahan berbusa dicampur dengan pengisian, iaitu PU+2.5wt%(80P20F) dan PU+2.5wt%F dimana ianya boleh menyerap bunyi dengan baik pada ketebalan 20mm dan 40mm, manakala PU+2.5wt%P, PU+2.5wt%(80P20F), dan PU+2.5wt%(80F20P) pula boleh menyerap getaran dengan baik dalam ujian kebolehpindahan.
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CHAPTER 1

INTRODUCTION

1.1 Background of research

Flexible polyurethane (PU) foam is one of the major productions from urethane material (Zhang, 2008). It is widely used as cushioning material in applications of furnishing, transportation and in packaging systems (Figure 1.1). This is because it shows excellence in being lightweight; strength to weight ratio performance, and most importantly, it offers a degree of comfort, protection, and utility not matched by other single material (Klempner & Sendijarevic, 2004). By proper choice of raw materials, additive and manufacturing technology, the properties of flexible PU foam can be changed to satisfy desired application.

![Figure 1.1: Major applications of flexible PU foam (Polyurethane Foam Association, 1992, 1996 & 1997)](image)

It is common that flexible PU foam is used in automotive seating for the purpose of load bearing. However, in recent years, users demand a more comfortable compartment experience; seat cushions are now designed for better...
ing comfort, sound absorption, and longer service life (Broos et al., 2000). With respect to the improvement of riding comfort, it is desirable to improve the vibration characteristic of flexible PU foam whereas with respect to sound absorption, noises such as from engine, road, as well as wind should be absorbed and reduced by using foam (Broos et al., 2000, Koshute et al, 2001 and Murakami et al., 2001).

Generally, the characteristic of flexible PU foam can be changed via adjusting the chemical composition of raw materials, in particular polyol and isocyanate. During the formation of flexible PU foam, polyol and isocyanate are reacted to form polyurethane linkage (Klemper & Sendjarevic, 2004). It was reported that development of novel polyether-polyol or novel methylene diphenyl diisocyanate (MDI) is for increasing the strength of PU foam used in automotive seat (Murakami et al., 2001 and Sasaki et al., 2003). However, due to the fluctuation of oil price, these petro-chemical feed stocks would rise in price and this in fact could influence the production cost of automotive seats (Latinwo et al., 2010b). Thus, it became one of the factors that affected the attempt of adjusting properties of foam via the chemical modification method.

Substitution of fillers into flexible PU foams have been recently grow due to the advance in composite technology and the fluctuation of oil price. It was observed that fined fillers such as montmorillonite, post-consumer PET particle, carbon nanotube, calcite (CaCO₃), dolomite (CaMg(CO₃)₂), calcium carbonate, and fumed silica are added to flexible PU foams for the purpose of recycling, cost reduction, mechanical as well as acoustic properties enhancement (Sung et al., 2007, Mello et al., 2009, Verdejo et al., 2009, Latinwo et al., 2010a & 2010b, Sant'Anna et al., 2008 and Ting et al., 2011). These studies confirmed the possibility of incorporating fillers into flexible PU foam for composite formation although it is not as popular as rigid polyurethane foam composite formed.

The addition of coconut coir fibres or rubber particles in pure polymer has been proved that it could enhance the damping performance of material, according to the studies of Geethamma et al. (2005), Bujang et al. (2009), and Sankar et al. (2010). Figure 1.2 illustrates the image of coconut coir fibres and waste rubber. Damping plays an important role for kinetic energies absorption. It helps to convert the vibration and sound energies to other energies such as thermal, via its dissipative mechanism in composite (Chandra et al., 1999, Balachandran & Magrab, 2004 and Strong & Rotz, 1999). For an automotive seat cushions, a superior damping is
it is applied for the demand for more comfortable seats (Broos et al., 2000). Besides, it is reported that adding treated coir fibres in pure polymer would obtain a better mechanical strength as compare with those added untreated coir fibres (Geethamma et al., 2005 and Gu, 2009). This finding was good for the improvement the load bearing capacity of flexible PU foam since it was mainly used for support the human weight in seating. Furthermore, presence of waste rubber particles in the foam composite could develop a cellular-structure which is good in damping performance also (Xin et al., 2010).

![Image](image.png)

Figure 1.2: Image of (a) coconut coir fibres and (b) waste rubbers from tyre

Hence, it is desirable to incorporate treated coir fibres and rubber particles into flexible polyurethane foam for seating foam production since a wide variety of mechanical and damping properties are provided as composite material. In this research, rubber particles are selected from recycled tyres. The innovative use of coconut coir fibres and tyre particles in the foam composite formation provides an alternative method for these materials to be reused and recycled. It helps to solve the problem related to the disposal of huge production found on coir fibres and recycled tyres (Monteiro et al., 2008 and Shulman, 2004).

Similar invention that is mixing of natural fibres and or waste rubber into flexible PU foam had been previously presented by McClellan & Viejo (1995) and Clausi & Dilogeto (2009) in US patent number of 5385953 and 20090053490. However, there was not any research related to the combination of natural fibres and waste rubber added to flexible PU foam for properties enhancement. Besides, the invention presented in such US patents do not investigate the physical, mechanical, and dynamic properties of foamed materials.
Therefore, the purpose of the research is to develop a flexible PU foam composite using coconut coir fibres and recycled tyres for automotive seat cushions. The characteristics of fillers and the properties of foamed composite are investigated and analyzed in detail. The foamed composite shall provides superior damping to absorb vibration and sound in particular, better mechanical strength to support human weight, longer service time, as well as offer benefits of recycling and cost reduction as a composite material to seat cushion.

1.2 Problem statement

During a journey, driver and passengers are subjected to the both mental and physical stresses when exposed to irregular road vibrations, dense traffic, noise and different weather conditions. If these stresses cannot be eliminated, it could cause irritation and impatience to the driver or cause him to be queasy and cause car sickness to the passengers. A car accident could happen due to the emotional state of the driver. Thus, it is important to have some instruments for at least, reducing the vibration and sound transmitted to the driver and passengers, when dense traffic and weather are not under control. Seat cushions which are generally made of flexible PU foam in this case could become one of the mediums to eliminate the unwanted vibration and sound transmitted to occupants from the vehicle.

In this research, it is believed that flexible PU foam composite develops can provide a superior vibration and sound damping compared to pure PU foam. As mentioned, incorporated coconut coir fibres and recycled tyres in pure polymer could offer a better damping property for energy absorption, via its dissipative mechanism. Hence, with a proper percentage of short coir fibres and tyre particles inserted to flexible PU foam, the new developed foam composite may deliver a significant improvement on the vibration and sound absorption to the occupants/seating system.

1.3 Hypothesis of research

The hypotheses consider in this research are:

i The treated coir fibres added to the flexible polyurethane foams will improve the mechanical properties of the foams.
The recycled tyres added to the flexible polyurethane foams will improve the
dynamic properties of the foams.
The proper weight percentage (wt%) of treated coir fibres and recycled tyres
added may offer the develop foam composite a better mechanical as well as
dynamic properties than the pure foam.

Objective of research

The objective of the research are:

i To develop the flexible PU foam composites using treated coconut coir fibres
and recycled tyres as reinforcement.

ii To determine the physical and mechanical properties of flexible PU foam
composites.

iii To determine the sound absorption coefficient of flexible PU foam
composites at variable frequencies.

iv To identify the vibration and damping characteristics of flexible PU foam
composites.

1.5 Scope of research

The scopes of the research include:

i The molded density of flexible PU foam composites is decided to be 60kg/m³.

ii Short coir fibres with length in the range of 0.1-5mm and recycled tyre with
80 mesh particles size are used as fillers.

iii The characteristics of fillers are analyzed by Scanning Electron Microscopy
(SEM), X-Ray Fluorescence (XRF), and Thermogravimetric Analysis (TGA).

iv The physical property of foams composites is examined through density test
according to ASTM D3574-08.

v The mechanical properties of foam composites are examined through testing
of force deflection (compression), tear resistance, and compression set
according to ASTM D3574-08.

vi The acoustic absorption of foam composites are tested according to ASTM
E1050.
A foam-block system is designed and developed based on modification from previous studies for vibration transmissibility test. A constant base excitation is applied to the foam-block system during the transmissibility testing. Besides, the testing is carried out in frequency range of 2-20 Hz. Nonlinear model with nonlinear damping properties is used to characterize the flexible PU foam composites.

**Significant of research**

The significances of the research include:

i. The foam composites developed may increase the comfortableness of seats for the driver and passengers. The emotional disturbance on the driver and passengers due to environmental or mechanical effects are decreased since the vibration and sounds are dissipated by foam composite before being transmitted to the driver and passengers.

ii. An alternative reusing and recycling method for coir fibres and tyre particles is generated in this research. It is especially true for tyre particles since the methods on managing them are not as much as coir fibres.

iii. Incorporated fillers on cushioning material make the production cost reduce because the use of petro-chemical based feed stocks that is polyol and isocyanate are decrease.

1.7 **Expected outcome**

It is expected that the flexible PU foams reinforced with treated coir fibres and recycled tyre particles can be developed and foamed uniformly as pure PU foam in this research. Besides, the mechanical properties of foam composites are expected to be at least retain as pure PU foam by some treated coir fibres added, though part of the PU derivative are replaced by fillers in composite formation. Furthermore, the most important part in this research; the vibration and sound absorption of developed foams are expected to be improved favorably with the tyre particles as well as treated coir fibres inclusion. Moreover, compared to the foams reinforced with single filler (either treated coir or recycled tyre), foams reinforced with the combination of
Compressed coir fibres and recycled tyres added are expected to obtain favorable vibration damping, excellent sound absorption, and better mechanical strength.

### Thesis organization

This chapter has highlighted the research background, problem statement, hypothesis, objective, scope as well as its significance. It stresses the purpose of research aimed at developing foam composites which can provide superior damping for vibration and sound absorption.

The entire ideas of following chapters are illustrated in Table 1.1. In CHAPTER 2, a review of literatures pertaining to flexible PU foam, automotive seat cushions, and foam composite are presented. The reviews mainly point out some useful information such as: flexible PU foam formation and its morphology, foam properties, foam as cushioning material in automotive seat, energy absorption of foam, nonlinear and viscoelastic behavior of foam, foam modeling, and also foam in composite. Besides, it also list out the strength of organic and inorganic fillers reinforced with polymer for properties improvement.

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**CHAPTER 3** covers the methodology that will be used to conduct the whole research. The technique of samples preparation, the physical and mechanical tests for samples analysis, the constitutive model for characterizing the foam, and also the foam-block system which designed according to the previous studies are described in detail.
CHAPTER 4 until CHAPTER 7 shows the results and discussion for all of the testing carried out in this research. The structure, chemical composition and thermal profiles of fillers are discussed in CHAPTER 4. The effect of fillers to production and the morphologies of foam composites are analyze and described in this chapter also. Furthermore, the results of density and mechanical testing on the composites such as force deflection (compression), tear resistance, and compression set are investigated and discussed in CHAPTER 5. CHAPTER 6 deals with the acoustic absorption of foam composites developed. They are tested at various foam’s thickness and from low to high frequency that is 0-6000Hz. In CHAPTER 7, the results of vibration transmissibility of foam inserted in a foam-sled system are described and discussed. The vibration damping of foams in this chapter, are determine by calculation based on the measurement data from vibration transmissibility test.

Last but not least, CHAPTER 8 summarises the results and discussion for all testing. The summaries may answer the hypothesis which conducted at the beginning of the research. At the end, a conclusion is drawn from this research and recommendations are list out for future study.
CHAPTER 2

LITERATURE REVIEW

The literature pertaining to flexible PU foam, foam composites, as well as automotive seat cushion were reviewed in this chapter. It helps to point out some useful information regarding the research topic such as the development and characteristics of flexible PU foam, the development of flexible PU foam composite, and the testing methods used for evaluating the cushioning material for automotive seat cushions.

2.1 Flexible polyurethane foam

Polyurethane (PU) is an important commercial polymer which possesses a wide range of physical and chemical properties based on different combination of the starting material. It can exist in numerous forms ranging from light weight rigid foams to dense solid compositions and from soft flexible foams to tough elastomeric moldings through different combination of starting materials which are polyol and isocyanate. Figure 2.1 shows the formation of polyurethane pre-polymers based on polyol and isocyanate with their final formed. In this figure, the TDI and MDI is the abbreviation of toluene diisocyanate and methylene diphenyl diisocyanate, which are the most common isocyanate used to produce PU polymer (Klempern & Sendijarevic, 2004). Among all the forms, flexible PU foam is the largest product of the family by quantity. It constitutes more than 40% of all PU productions (Zhang, 2008).
Figure 2.1: Polyurethane Pre-polymers (Indian Rubber Institute, 2000)

Flexible PU foam is widely found in many applications. It is used as cushioning material in automotive seats, mattresses, furniture, and packaging systems. Besides, it is also used as clothing or diapers in our daily lives. All of these can be seen in Figure 2.2 which illustrates the major applications of flexible PU foam in the market. It was reported that due to its versatile in applications, flexible PU foam has found grown in sale volume to occupy the sixth position in the global market among all of the plastics sold (Klempner & Sendijarevic, 2004). The total sales volume was growing over 11 billion pounds in year 2000 compared to only 400 million pound in year 1960 (Klempner & Sendijarevic, 2004).

According to the previous work, flexible PU foam has become such a widely used material (Figure 2.2) because it provides a unique combination of form and function. It is light, quiet, resists mildew, and will not aggravate allergies during in use (Polyurethane Foam Association, 1991). Foam can easily be cut or molded to almost any shape (Polyurethane Foam Association, 1991). At the same time, by a proper choice of raw materials and manufacturing technologies, foam can made to offer broad range of load bearing capacities and other physical properties which make it offer degree of comfort, protection and utility not matched by other single material (Klempner & Sendijarevic, 2004).
Flexible PU foam also found some negative defects when used in applications. It is unable to withstand many in-use temperature and humidity conditions, and it is often failed by simply crumbling always (Klempner & Sendijarevic, 2004). However, these defects were shown improved by the introduction of polyether-based polylol (Klempner & Sendijarevic, 2004). It was noted that foams with ethers polylol are better than esters polylol in terms of hysteresis heat buildup (Indian Rubber Institute, 2000). Basically, foams with ethers based polylol were less affected by hydrolysis, were more comfortable, and considered more durable (Klempner & Sendijarevic, 2004). In contrast, esters based polylol have the advantage over the ethers based polylol in tensile strength, tear strength, oil resistance, and heat aging properties (Indian Rubber Institute, 2000).

2.1.1 Foam formula and generation

Basically, flexible PU foam is made from a formula that contains a host of ingredients selected to aim in achieving the desired grade of foam. These
Components included polyol, isocyanate, water, catalysts, surfactants, cross-linkage, auxiliary blowing agent, and additives such as colorant, flame retardant, antioxidant, bacteriostat or UV stabilizer. Among all, polyol and isocyanate are main components used to forms polyurethane linkage (Figure 2.3).

\[
\text{R-N=O} + \text{R'-CH}_2\text{-OH} \rightarrow \text{R-N-C-N-R'} \\
\text{Isocyanate} \quad \text{Alcohol} \quad \text{Urethane}
\]

Figure 2.3: Gelation reaction or PU cross-linking reaction (Kaushiva, 1999)

The reaction between polyol and isocyanate is called gelation reaction (Kaushiva, 1999). It is an exothermic process for which heat of reaction had been reported approximately 24 kcal/mol of urethane (Klempner & Sendjarevic, 2004). There is another reaction occurred during foam generation. It is called blow reaction (Kaushiva, 1999). Figure 2.4 illustrates the blow reaction generation. In this reaction, water reacts with isocyanate to produce carbon dioxide (CO₂) which diffuses to the existing gas bubbles in the polyol and so expands the foam. Heat would generate in this mixture and it plays a large role on expanding the gas into the liquid to form a desired cellular-structure. It was reported that the internal temperature of foam bun/rise would build up on the order of 140°C during foam generation (Klempner & Sendjarevic, 2004).

\[
\text{R-N=O} + \text{H}_2\text{O} \rightarrow \text{R-N-C-OH} \rightarrow \text{CO}_2 + \text{R-NH}_2 + \text{Heat} \\
\text{Isocyanate} \quad \text{Water} \quad \text{Carbon} \quad \text{Amine} \\
\quad \text{Di} \quad \text{O} \quad \text{Acid}
\]

Figure 2.4: Blow reaction between isocyanate and water (Kaushiva, 1999)

Other components in formula are working as: Surfactants are necessary components in foam formation in order to produce a well open-celled morphology. They perform to reduce surface tension in polyurethane, emulsifying incompatible
promoting bubble nucleation, stabilizing the rising foam, thus reducing
formation effect and the most important is to stabilise the cell wall. As
by Klempner & Sendijarevic (2004), surfactant prevents the coalescence of
growing cells until those cells have attained sufficient strength through
gelation to become self supporting. Without this, cell coalescence would lead
to foam collapse. Catalysts are generally used in foam formulation for
reaching a balance between the chain propagation in of gelation reaction and
reaction (Klempner & Sendijarevic, 2004). Besides, it is also for assuring
completeness of reaction or “cure” in finished foam (Klempner & Sendijarevic,

1.2 Foam development and its morphology

There are three basic stages found in foam foaming process. They are bubble
initiation, bubble growth, and cell opening (Klempner & Sendijarevic, 2004). Figure
2.5 illustrates the development and formation of a flexible PU foam in an open-
mold. According to the figure, the first stage which is bubble initiation of foam was
initially introduced by physically blending air into the mixture. This could be done
by using a high shear mixing machine or a stirring device that works in a certain
rotational speed for entrance of enough bubbles to account for all of the cells present
in the PU foam (Latinwo et al., 2010b and Zhang et al., 2011).

The second stage is called bubble growth. This occurs when the gas diffuses
and expands the gas phase due to the increase in foaming temperature. The gas may
originate from sources such as gas evolved by water reaction, as the gas dissolves in
the liquid reactant, auxiliary blowing agents vaporizes and gas evolves by thermal
decomposition of additives or components (Kaushiva, 1999). According to the
Figure 2.5, the gas diffuses to bubbles which is carbon dioxide (CO₂). The heat
generated during the reactions (exothermic process) play an important role in
expansion for example CO₂ to form a cellular structure.

It was noted that as bubbles continued to grow, it will begin to impede with
each other in the foam system (Kaushiva, 1999). At this time, the solid phase of
matrix is forced to distribute itself around and form as lamellae and plateau borders
in between the cells. This solid phase can be referred to the Figure 2.6 which
illustrates the morphology of cured flexible PJ foam. From this figure, there is a
Polyhedrons development inside foam (Kaushiva, 1999). It was reported that the bubbles packaging during foam rising is very uncontrollable (Kaushiva, 1999). Hence, the cellular-structure of foam may shows anisotropic. Gibson & Ashby (1997) mentioned that almost all man-made foams are anisotropic.

![Diagram of foam development stages and timeline](image)

**Figure 2.5: Development of flexible PU foam (Klempner & Sendijarevic, 2004)**

![Image showing closed and open window structures in PU foam](image)

**Figure 2.6: Morphology of flexible PU foam (Klempner & Sendijarevic, 2004)**
In the third stage which is the cell opening, closed cells started to open when
more bubbles rupture. These ruptures are actually caused by excessive
opening of lamellae which could not withstand the pressure in the cell. Struts are
formed once the lamellae of closed cell rupture. At the end, the open-celled flexible
foam is obtained once the foam finish is cured. However, it is not easy to obtain
all open-celled foam due to problems like blowing agents escape in close cells,
which may result in the cells remaining closed at all the time (Kaushiva, 1999).

In order to produce well open-celled foams, there are two critical elements to
which are adjustment of (i) the rate of foaming, and (ii) the rate of stabilization.
This is to make sure that during the peak of foam rise, the cell membranes (lamellae)
are thin and rupture, but the ribs or struts of the cells are strong enough to withstand
rupture (Klempner & Sendijarevic, 2004). If the struts cannot stop the rupture, a
large void would occur and it could damage and cause the foam to collapse easily.
The rate of foaming and rate of stabilization can be affected by the foaming
temperature during processing (Klempner & Sendijarevic, 2004).

2.1.3 Foam production

Flexible PU foam is produced by one-shot and free rise method (Klempner &
Sendijarevic, 2004 and Sung et al., 2007). The one shot and free rise means that the
isocyanate, polyol, water and other ingredients are rapidly and intensively mixed and
immediately poured to carry out the foaming. The method indicates that once the
process is started, the formation of foam is exothermic until completion such as those
illustrated in Figure 2.5.

Generally, flexible PU foams are made via two types of fabrication process
which are molded and slab-stock foaming (Zhang, 2008). Molded foams are largely
used in transportation application such as automotive seating whereas slab-stock
foams are used in furnishing industry such as mattress and carpet backing (Zhang,
2008). For molded foams, the process begins by mixing all of the reactants together
and transferring the foaming mixture to a closed mold (Klempner & Sendijarevic,
2004). The foams are then raised to take on the shape of the mold. However, for
slab-stock foams, the process is performed in an open environment (Klempner &
Sendijarevic, 2004). That is, the well-mixed reactants are spread onto a conveyor
and as the conveyor belt moves forward, the foaming mixture expands and rises

For the small or laboratory scale production, the flexible PU foams could be produced using simple hand or cup-foam mixes to techniques of box-foaming mixes leading to Klempner & Sendijarevic (2004). In this process, the foam is prepared to rise and form a composite bun. It was noted that the production routes from many laboratory scale composite fabrication are actually similar (Table 2.1). The differences between the previous works were the time decided for components mixing and for curing. Table 2.1 lists the time consumed at each stage for flexible PU foam composites production.

### Table 2.1: Time consumed at each stage for flexible PU foam composites production

<table>
<thead>
<tr>
<th>Year</th>
<th>Author</th>
<th>Time Consumed in Production Stage</th>
<th>Foam Cured</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>Sant'Anna et al.</td>
<td>i. Polyol and fillers were stirred until completed homogenization.</td>
<td>The foams were left for cured for three days.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ii. Amine, surfactant, and water were added to mixtures and mechanical stirred for 1 minute.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>iii. Catalysts was added and stirred for 30 seconds.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>iv. Isocyanate was introduced to mixtures and stirred for 6 seconds.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>The foams were produced at room temperature.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>i. Mechanical stirred the polyol and PET particles for 15 seconds.</td>
<td>After the foam development, the foam was demould</td>
</tr>
<tr>
<td>2009</td>
<td>Mello et al.</td>
<td>ii. Polyol with PET particles, water, silicone, catalysts, and stannous octate at 850rpm were</td>
<td>and left to rest for 24 hours.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>again stirred for 1 minute.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>iii. Addition of isocyanate and methylene chloride to mixtures and stirred for 5 seconds.</td>
<td></td>
</tr>
<tr>
<td>2009</td>
<td>Verdejo et al.</td>
<td>i. A fixed weight of carbon nanotube was mixed with polyol at 2000rpm for 10 minutes using an</td>
<td>The foam in mould was transferred into oven at</td>
</tr>
<tr>
<td></td>
<td></td>
<td>overhead stirrer equipped with dispersion disc.</td>
<td>50°C overnight and demould.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ii. The surfactant, catalyst, distilled water were added to mixtures and mixed at 2000rpm for 1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>minute.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>iii. Isocyanate was added and stirred for 15 seconds before foaming occurred.</td>
<td></td>
</tr>
</tbody>
</table>
Table 2.1 (Continued)

<table>
<thead>
<tr>
<th>Author</th>
<th>Components Mixing</th>
<th>Foam Cured</th>
</tr>
</thead>
</table>
| Ting et al. | i. The desired fumed silica was mixed with isocyanate using a magnetic stirrer for 30 minutes.  
                   ii. Polyol with catalyst, surfactant and blowing agent container were added into mixture and stirred at 500 r/min for 15 seconds. | The foams were transferred into an oven at 50°C for 3 hours and demould. |
| Mar Bernal et al. | i. The polyol and carbon nanofillers were stirred using overhead stirrer equipped with dispersion disc for 6 hours and 2400rpm.  
                   ii. The surfactant, catalysts, and distilled water were added to mixtures and stirred at 2400rpm for 3 minutes.  
                   iii. Finally, isocyanate was added and mixed again for 20 seconds. | -                                              |

2.2 Composite material

Composite can be defined as a structural unit which consists of two or more materials differing in form or composition on a macro scale (Klemppner & Sendijarevic, 2004 and Gibson, 2007). The materials basically include a matrix or binder, and a filler or reinforcement. In most composite formation, the matrix will hold the reinforced fillers on a structural unit and protect them from external damage (Gibson, 2007). Besides, it is required to transfer and distribute the applied loads to fillers at very short interval in composite (Klempner & Sendijarevic, 2004 and Gibson, 2007). Furthermore, it would contribute to some of the needed properties such as ductility, toughness, or electric insulation to the structural unit (Gibson, 2007). For filler or reinforcement, it can be either solid particulate or fibrous material. It is usually much stronger and stiffer than the matrix material (Gay, 2003, Klempner & Sendijarevic, 2004 and Gibson, 2007).

It was reported that composite formed would retain the materials identity; i.e. they do not dissolve or merge completely into one another, although they act in unison, so that the desirable properties of each material is incorporated into one structural unit, thereby giving rise to a better material (Klempner & Sendijarevic, 2004). Normally, the matrix and filler can be physically identified and exhibit an interface between one another.
In this research, the composites developed are desired to have a superior damping of vibration and sound absorption. Thus, the damping elements found in a composite were focused to review. Damping in general, defined as any means of dissipation of some fraction of each increment of energy which is otherwise added to or removed from a system by excitation, by the exciting forces during each cycle of response (Jones, 1961). The exciting forces may come from mechanical vibration and or acoustic excitation (Strong & Rotz, 1999). It was reported that the existing forces or energies were dissipated as heat and sound via the damping in composite (Balachandran & Swain, 2004).

For a composite material, the damping is usually controlled by few elements in the composite itself. According to Strong & Rotz (1999), most of the damping in a composite was come from the matrix material itself. Elastomer and most of the modern composites, which having viscoelastic characteristic may offer a good damping property compared to those with high cross-linked material such as thermoset. However, by itself also provides some damping to the composite material. However, as reported by Strong & Rotz (1999), the damping property (shows by energy losses, $\tan \delta$ of fibers is quite small thus it is usually not considered to give any contribution to the damping composite. Nevertheless, Chandra et al. (1999) has mentioned that the fiber damping must be included if its origin is from carbon and kevlar fibers. These fibers are proved to have high damping as compared to others (Chandra et al., 1999).

Other than the matrix and filler itself, the damping elements occurred in composite include interaction between fibers and matrix, and damping due to matrix damage. In an article written by Strong & Rotz (1999), the researchers mentioned that the damping arising from the interaction between fibres and matrix can be very large and are quite complicated because many different aspects of composites affect the interaction. The aspects include: (i) fibers length, (ii) orientation of fibers and, (iii) fiber-matrix interphase region. It was reported that short fibers give slightly better damping because there are more ends and therefore more interaction between matrix (Strong & Rotz, 1999). The random orientation of fibers in matrix will result in higher damping than those with aligned fibers (Strong & Rotz, 1999). Lastly, the fiber-matrix interphase is an area where energy can be converted into heat, thus, it is a region of potential high damping (Strong & Rotz, 1999). Generally, the factors tend to increase the damping in the interphase area.
poor fiber-matrix adhesion, (ii) low modulus of the interphase itself, (iii) cellular motion with the interphase and, (iv) high total volume associated interface and interphase (Chandra et al., 1999 and Strong & Rotz, 1999).

Flexible PU foam composite

Use of fillers to achieve polymeric foam composite formation is not a new idea due to the advance in composite technology. Many studies have showed the formation of fibres or particles such as woven jute, flax yarn, polyamide shortaramid fiber, glass fiber, carbon black, and multi-wall nanotube with varies i.e. rigid PU foam, epoxy foam, natural rubber foam) for mechanical properties improvement (Bledzki et al., 2001, Lin et al., 2004, Alonso et al., 2006, et al., 2006, Lee & Choi, 2007 and Zhang et al., 2011). For flexible PU foam, though it is rarely found, there are also few studies involved the addition of fillers flexible PU foam for composite formation in recent time.

Sung et al. (2007) integrated various kinds of montmorillonite that is bentonite, organophilic clay, and sodium montmorillonite (NA-MMT) into flexible foam to examine its sound dampening, its cellular-structure characteristic, as well as its mechanical properties. The designed composites were fabricated by one-shot free-rising method using a mould. The montmorillonite were added to PU in accordance to weight ratio that is 2.2, 4.3, and 6.3. Besides, all of the designed samples were controlled to have a density of 85 kg/m³.

Based on the experimental results obtained by Sung et al. (2007), the sound dampening of developed foams was increased as the content of fillers inserted increase. Figure 2.7 illustrates the sound absorption ratio of foam composite with bentonite inclusion. According to the researchers, this is because of the sound energy was dissipated as heat through hysteresis when the fillers were dispersed in wall of foam. The dissipation occurred as the wall of foam is move together with the massive inorganic when it is recovers its deformation caused by sound wave (Sung et al., 2007). It was reported that the sound damping by reflection would be increased when stiffness of wall is increased or, when the inorganic or plastic filled act as another wall for sound blocking (Sung et al., 2007). Besides, based on Figure 2.7 as well as other sound absorption results shown in Sung et al. (2007), the sound
of foam composites were advantageously at high frequency but not at low

![Graph](b)

Figure 2.7: Sound absorption ratio of foam composites with fillers increase from 2.2, 4.3, and 6.3 weight ratio (Sung et al., 2007)

For the cellular-structure and mechanical properties examined in Sung et al. (2007), the cell sizes of developed foams were reduced as compared to the reference sample that is without montmorillonite included. The researchers explained that it is usually because of the nucleating effect from montmorillonite to foams. Besides, due to the improved of stiffness of foam composite through filler added, the tear strength of foams with montmorillonite inclusion was increased also.

Sant’Anna et al. (2008) carried out a study to analyze the morphologies and mechanical properties of flexible PU foams containing calcium carbonate (CaCO₃). The weight percentage (wt%) of CaCO₃ incorporated to flexible PU foam are 1%, 3%, 15%, 21%, and 30%. Based on the researchers’ study, the foams reinforced with 21% of CaCO₃ showed that the fillers is agglomerated in some points at polymer matrix and it is not-evenly distributed in foams. The results revealed that incorporated excessive quantities of fillers may destroy the characteristic of foam in polyhedral morphology, though it may enrich the properties of foam. In the compression-decompressed cycle test analysis, the measurement data of hysteresis showed that adding and increasing the quantity of CaCO₃ in matrix would also increase the hysteresis value. It signifies that the foams would lose its ability to
its original shape (Sant'Anna et al., 2008). Thus, the researchers concluded that the addition of fillers to foams may reduce the foam quality since it increased the energy during testing and led to deformation.

Nevertheless, according to the compression force deflection (CFD) value of 40% compressed, the obtained results showed that incorporated CaCO$_3$ would increase the hardness of foams. Thus it may obtain a greater dimensional stability (Sant'Anna et al., 2008). Figure 2.8 illustrates the CFD 40 at a function of the concentration of CaCO$_3$. Therefore, combine with the results of hysteresis and CFD observed in the study of Sant'Anna et al. (2008), a balancing of foam characteristics must be taken in order to have a foam composite with good dimensional quality but less hysteresis. Both characteristics are increase as fillers are added to flexible PU foams (Sant'Anna et al., 2008).

![Figure 2.8: CFD 40 for flexible PU foam containing commercial CaCO$_3$.](image)

Sant'Anna et al. (2008)

Mello et al. (2009) conducted a research on the use of milled post-consumer plastic bottle waste as filler for flexible PU foam for cushion and cleaning applications. The objective of their research was to find an alternative way for the recycling material; reduce the cost of material, and of course getting a better mechanical properties from the new composite developed. According to the researchers’ work, the fillers were prepared as a particulate shape in size of < 297µm and it is added to PU at a concentration of 1.5 part by hundred parts of polyol (php). Figure 2.9 shows the resulting foam block and layers in the study by Mello et al. (2009). With this PET-PU foam production, the researches conducted some
tests such as tensile resistance, tear resistance, and strain at break (%) for mechanical strength. The results obtained by such testing showed that the performance of PET-PU foams surpassed than the standard foam for all mid-top, mid-bottom and bottom).

![Image](image_url)

Figure 2.9: (a) Foam block and (b) Layer cuts from foam block (Mello et al., 2009)

Besides, the PET filled foams are also used to conduct the wear, compression strength and compression set tests. The results obtained show a filled foam yield: (i) better wear which has less mass losses during the wear test, (ii) a better compressive strength which indicated that PET particles can effectively absorb the compression energy; it may because of the good adhesion found in between the PU matrix and PET particles, and (iii) a lower compression set value which means that PET filled-foam could reduced the overall deformation of foam in the standpoint of static fatigue. Table 2.2 lists the compression results of PET filled foam and standard foam in various layers.

Table 2.2: The compression results of PET filled foam and standard foam in various layers (Mello et al., 2009)

<table>
<thead>
<tr>
<th>Foam type (layer)</th>
<th>Compression strength (kPa)</th>
<th>Compression set (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard (T)</td>
<td>3.67</td>
<td>10.71</td>
</tr>
<tr>
<td>Standard (B)</td>
<td>4.30</td>
<td>9.97</td>
</tr>
<tr>
<td>PET-PU (T)</td>
<td>3.82</td>
<td>8.09</td>
</tr>
<tr>
<td>PET-PU (B)</td>
<td>5.04</td>
<td>8.65</td>
</tr>
</tbody>
</table>

Note: T: Top, B: Bottom layer.
Verdejo et al. (2009) developed the composite of flexible polyurethane foams with carbon nanotubes (CNT) for acoustic damping enhancement. In their study, the carbon nanotubes were prepared in diameter of 40-60nm with around 5nm in length. The carbon nanotube went through a chemical treatment before it was incorporated to PU matrix. It was reported that the foam composites were produced with loading fraction up to 0.2 wt% only in study of Verdejo et al. (2009). Because addition of fillers more than 0.2 wt% to PU was found to cause the foam system no longer to foam properly (Verdejo et al., 2009). According to researchers, this problem is affected by the viscosity; which is increased when fillers are added to the foams. The researchers explained that the higher the quantities of fillers added to foams, the higher the viscosity would creates; hence, would effect the expansion of the expanding structure.

The study of Verdejo et al. (2009) revealed that the mean cell size of cellular-structure of flexible PU foam was initially increased, when increasing the CNT inclusion, as compared to pure foam. However, it is subsequently decreased in foam loaded with 0.2wt% CNT. As mentioned in paragraph before, this phenomena is likely linked to viscosity according to researchers. The quantities of CNT loading can be attributed to higher viscosity which will limit the expansion of foam and thus, limit the cell growth (Verdejo et al., 2009).

Besides, the acoustic damping measured in study of Verdejo et al. (2009) revealed that the sound absorption of foam system was increased over the entire frequency range due to the added CNT. According to the Figure 2.10, the results indicated that increasing the CNT loading from 0.01 wt% to 0.1 wt% would make the foam composite become more sufficient to increase the peak of sound absorption. These results showed that added and increased CNT within PU polymer would help to absorb and dissipates the sound energy. According to researchers, the sound damping effect from CNT is attributed to the large surface area at the polymer-CNT interface, where energy can be dissipated by interfacial sliding and stick slip behaviour. It was reported that sound waves can be absorbed by two mechanisms that are: conversion to mechanical friction at sample boundaries and direct dissipation the thermal energy (Verdejo et al., 2009).
Acoustic performance of CNT-flexible PU foams (Verdejo et al., 2009)

However, although there are a lot of increased on sound damping, the results compressive response from study of Verdejo et al. (2009) shown that there was no improvement given from CNT to the PU foam, if compare to the result obtained pure foam. The compressive modulus and strength were reduced when the CNT adding in foam composite was increased. The researchers explained that this negative impact may due to the CNT itself and the changes in foams cellular-structure when incorporated fillers.

Latinwo et al. (2010a) conducted a study which entitle as effects of different filler treatment on morphology and mechanical properties of flexible polyurethane foam composite. The purpose of their study was to find a suitable inorganic substance to reinforce the flexible PU for better mechanical properties. It was noted that two types of filler that are calcite and dolomite with particles size of 6nm, 3.5μm, and 0.84mm were prepared in this work. The fillers loading from 0% to 40% were incorporated to the PU matrix for investigation.

According to the results obtained in study of Latinwo et al. (2010a), it was observed that incorporated particles fillers could improve the hardness and compression set of flexible PU foam but, in contrast, it would reduce the elastic properties such as tensile strength and elongation at break of foam. It was also observed that the influence of hardness in foam composite strongly depend on the filler content and particles sizes. The higher hardness data was found in foam
REFERENCES


