

**STRUCTURE-PROPERTIES RELATIONSHIP OF  
OPEN CELL ETHYLENE VINYL ACETATE  
FOAM FOR SOUND INSULATION APPLICATION**

**MOHD NIDZAM ADHA BIN ATAN**

**UNIVERSITI SAINS MALAYSIA**

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**SCHOOL OF MATERIALS AND MINERAL RESOURCES ENGINEERING**  
**UNIVERSITI SAINS MALAYSIA**

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VINYL ACETATE FOAM FOR SOUND INSULATION APPLICATION**

By

**MOHD NIDZAM ADHA BIN ATAN**

**Supervisor: Prof. Dr. Zulkilfi Mohamad Ariff**

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## DECLARATION

I hereby declare that I have conducted, completed the research work and written the dissertation entitled: "Structure-Properties Relationship of Open Cell Ethylene Vinyl Acetate Foam for Sound Insulation Application". I also declare that it has not been previously submitted for the award of any degree or diploma or another similar title of this for any other examining body or university.

Name of Student: Mohd Nidzam Adha bin Atan

Signature:

Date:

Witness by

Supervisor: Prof. Dr. Zulkifli Mohamad Ariff

Signature:

Date:

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## LIST OF SYMBOLS

%	Percentage
$\Delta F$	System free energy
$\gamma$	Surface tension
$\Gamma$	Excess surface of the absorbent component
$\mu$	Chemical ability of the absorbent material
$^{\circ}\text{C}$	Degree Celsius
$\alpha$	Sound absorption coefficient

## LIST OF ABBREVIATIONS

ADC	Azodicarbonamide
CBS	N-cyclohexyl-2-benzothiazolesulfenamide
DCP	Dicumyl peroxide
EVA	Ethylene-vinyl acetate
SEM	Scanning electron microscopy
PU	Polyurethane
N <sub>2</sub>	Nitrogen gas
CO <sub>2</sub>	Carbon dioxide
NaHCO <sub>3</sub>	Sodium bicarbonate
LDPE	Low-density polyethylene
PE	Polyethylene
NR	Natural rubber
EPDM	Propylene diene monomer
ENR	Epoxidized NR
CBS	N-cyclohexyl-2-benzothiazolesulfenamide
TMTD	Tetramethyl thiuram disulfide
ZnO	Zinc oxide
TL	Transmission loss
ASTM	American society for testing and materials
ISO	International origination for standardization

# **STRUCTURE-PROPERTIES RELATIONSHIP OF OPEN CELL ETHYLENE VINYL ACETATE FOAM FOR SOUND INSULATION APPLICATION**

## **ABSTRAK**

Kesan hubungan struktur-sifat busa etilena vinil asetat (EVA) sel terbuka untuk aplikasi penebat bunyi telah dikaji. Matlamat projek ini adalah untuk menyediakan busa EVA sel terbuka dengan memanipulasi agen peniupan, azodicarbonamide (ADC) yang digunakan untuk setiap sampel. Terdapat lima formulasi berbeza yang digunakan untuk mendapatkan pelbagai jenis EVA busa bersel terbuka. Untuk menghasilkan busa, proses mastikasi dan penyebatian dilakukan untuk mendapatkan sebatian campuran bahan-bahan busa tersebut. Seterusnya, proses pembusaan dilakukan dengan proses pemanasan dua-langkah. Proses pembusaan dilakukan dua kali untuk mendapatkan dua set sampel yang terdiri daripada kelima-lima ADC yang berbeza dengan dua strategi pemprosesan yang berbeza. Perbezaan bagi setiap set adalah semasa langkah kedua proses pemanasan. Langkah pertama pemanasan dilakukan pada suhu yang lebih rendah daripada langkah kedua iaitu 140°C selama 30 minit, manakala bagi peringkat kedua pemanasan suhu pada 180°C selama 6 minit 50 saat bagi set Sampel 1 dan 6 minit 30 kedua untuk set Sampel 2. Sampel kemudiannya dicirikan dengan menjalani beberapa ujian termasuk ujian pekali penyerapan bunyi dan ujian kehilangan penghantaran untuk menilai sifat akustik busa. Selepas pencirian dilakukan didapati bahawa pengaruh utama kepada prestasi akustik busa EVA sel terbuka adalah oleh masa pembusaan semasa proses pemanasan peringkat kedua. Lebih lama masa pembusaan, lebih baik sifat akustik yang dimiliki oleh busa. Oleh itu, Sampel 1 mempunyai sifat yang lebih lebih baik bagi aplikasi penebatan bunyi berbanding Sampel 2.

# **STRUCTURE-PROPERTIES RELATIONSHIP OF OPEN CELL ETHYLENE VINYL ACETATE FOAM FOR SOUND INSULATION APPLICATION**

## **ABSTRACT**

The effect of structure-properties relationship of open cell ethylene vinyl acetate (EVA) foam for sound insulation applications has been studied. This project aimed to prepare open-cell EVA foam by manipulating the blowing agent, azodicarbonamide (ADC) used for each sample. There were five different formulations used in order to obtain different types of open cell EVA foam. To produce the foam, mastication and compounding process was done to obtain a compound of mixture the foam ingredients. Next, foaming process was done by two-step of heating process. The foaming process was done twice to obtain two sets of samples consists of all five of different ADC loadings with different processing strategies. The difference for each set was during the second step of heating process. The first step of heating was done at lower temperature than the second step which was 140°C for 30 minutes, while for the second stage of heating the temperature was at 180°C for 6 minutes 50 second for Sample 1 and 6 minutes 30 second for Sample 2. The samples were then characterized by undergoes a few testings including sound absorption coefficient test and transmission loss test to evaluate the foam acoustic properties. After the characterization was done it was found that the main influence on open cell EVA foam acoustic performance was by the foaming time during the second stage of heating process. The longer the foaming time, the better the acoustic properties the foam had. Thus, sample 1 had better properties for sound insulation application compared to sample 2.



# CHAPTER 1

## INTRODUCTION

### 1.1 Background study

As the progress, there are more and more significant environmental noise that led to several problems that affect the communication, health and living quality, mainly caused by industrial noise which account for 27%, traffic noise (33%) and live noise (40%). For this reason, efficient sound absorption will works as a “quick capsule” (Gong *et al.*, 2019).

Open-cell polymeric foams are good for sound insulation application compared to the closed-cell foams. This is because, cellular such as the cell size of the foams have significant impact to properties such as sound insulation ability of open cell polymeric foam. The aim of this study is to investigate the structure properties relationship of open-cell ethylene vinyl acetate (EVA) foam for sound insulation application. The open-cell EVA foam was produced using compression moulding. The method involves two stages of heating, the first stage of heating was to allow the crosslink inside the foam to happen at about 130 °C, the second stage of heating was to decompose the blowing agent at about 180°C to obtain an open-cell foam. To obtain different size of cell, the manipulated parameter was the blowing agent which was azodicarbonamide (ADC). To measure the cell size, optical microscopy was used at a fix magnification. Density test according to ASTM D 1056-00 was also conducted to evaluate which cell structure has better properties for sound insulation either the denser or less dense cell structure. To evaluate the sound insulation performance, sound impedance tube was used. It is expected that the addition of more ADC will increase the formation of the open-cell structures and cell size. The high amount of ADC which is acting as the blowing agent can more porosity inside the foam. Thus, creating an

open cell EVA foam. The knowledge gained from this project is highly beneficial to the sound insulation application.

## **1.2 Problem statement**

Various investigations on acoustic properties have been conducted because undesired and potentially dangerous noise is regarded to be major environmental contamination. Adachi *et al.*, (1997) investigated the influence of two-dimensional and three-dimensional cell distribution on the sound absorption characteristics of flexible polyurethane foams, and the focus of that work was on the influence of cell features. Meanwhile, Jaouen *et al.*, (2008) suggested that the elastic and damping properties of acoustical porous materials (such as polymer foam or mineral wool) could affect their acoustic efficiency. Several research, on the other hand, focused on the method and/or approach of the experimental procedures rather than the materials' acoustic properties. Chevillotte and Panneton, (2007) for example, established an approach based on absorption of sound measures for determining the bulk characteristics of a substance foam with a closed cell structure. Other researchers have done similar work.

Open cell foams exhibit excellent sound insulation compared to the closed cell foam. This is due to the ability of the open cell foam to absorb the sound wave. However, the ability of the sound absorption is varying depends on the cell structure of the foam i.e., the cell size, cell thickness. The different in the structure is mainly because of the blowing agent and crosslink agent used. Not so many investigations have been done regarding different weight percent of both chemical agents in the production of ethylene vinyl acetate (EVA) foam.

Generally, the most common experiments studied were related to the polyurethane (PU) foam. This is because PU foam is a typical polymer used for sound insulation application because of the properties the polymer.

Therefore, the aim of this research is to study the structure relationship of the open cell ethylene vinyl acetate (EVA) foam for sound insulation application in which the evaluation will be based on the weight percent of blowing agent and crosslink agent used.

### **1.3 Research objectives**

The objectives for this research are to prepare the open cell ethylene vinyl acetate (EVA) foam based on different blowing agent loading, parameters and to investigate the effect of the cell structure to the sound absorption coefficient.

The main goal of this research is to study the cell structure relationship of open cell EVA foam for sound insulation application. The specific research objectives are as follow:

- i. To prepare the open cell EVA foam with different blowing agent, Azodicarbonamide (ADC) loadings.
- ii. To investigate the effect different ADC loading on the tortuosity and acoustic properties of open cell EVA foam.

## **1.4 Thesis outline**

**Chapter 1:** This chapter is about the introduction of the thesis which covers the background story, problem statement, research objectives and thesis outline of all chapter.

**Chapter 2:** This chapter is about literature review which contains of extensive review of the polymer used, ingredients used as well as the sound adsorption coefficient which was important to evaluate the sound insulation properties of the foam.

**Chapter 3:** Chapter 3 explains the material and experimental works of this research. These includes material, equipment, formulation used in this project, sample preparation methods, characterization methods and parameters and standards involved in this study. Generally, this chapter describes everything that is essential for carrying out this research work.

**Chapter 4:** This chapter encloses result and discussions of the research project which consists of research data, results and discussions related to the research objectives. This is where all the explanations will be described in detail.

**Chapter 5:** This chapter summarize the whole thesis research project and give recommendation for future works.

## **CHAPTER 2**

### **LITERATURE REVIEW**

#### **2.1 Basic principle of foam formation**

Polymer foam preparation involves formation of bubbles nuclei when the polymer is in fluid state (liquid or melt), followed by formation of gas bubbles and bubbles stabilization which is associated with an increase in viscosity of the polymer melt during solidification process of the polymer resin in a certain processing technique.

##### **2.1.1 Formation of gas bubble nuclei**

The first step in foam production is the formation of gas bubble nuclei in a fluid system. There are three techniques for formation of gas bubble nuclei in the liquid phase:

1. Gas distribution technique – gas like air or nitrogen ( $N_2$ ) to the liquid phase to form colloidal system in which the gas acts as a dispersed phase.
2. Gas formation technique – formation of gas in liquid phase and this gas formed bubbles that is separated in the liquid phase. The gas formation is produced by the reaction of polymerization. For example, reaction between isocyanate with water released carbon dioxide ( $CO_2$ ) and heating of sodium bicarbonate ( $NaHCO_3$ ) also capable of releasing  $CO_2$ .
3. Solvent evaporation technique – gas production through the evaporation of solvent which has low boiling point that acts as a dispersed phase, and it occurs when an exothermic reaction occurs. For example, the use of trichlorofluoromethane, Freon-11 or methylene chloride (Landrock, 1995).

In homogeneous bubble formation, additives such as wetting agents, emulsifiers, and some oils are used aimed at lowering the surface tension and in turn facilitating the formation of bubbles. This can be explained by equation 2.1 below which relates the surface tension to the number of interface areas in influencing the free energy of an emulsion system:

$$\Delta F = \gamma A \text{ ----- Equation 2.1}$$

Where,

$\Delta F = \text{system free energy}$

$\gamma = \text{surface tension}$

$A = \text{total interface area}$

If the additives used or the heat applied can lower the surface tension, the free energy will increase with the help of gas diffusion. This condition in turn will promote the formation of small cells in a high number of interface areas. However, if bubbles are formed heterogeneously in the presence of an existing second phase (nucleating agent), bubbles easily form at the solid-liquid interface. This is because the added nucleation can reduce the surface tension at the solid-liquid interface which then creates voids (Klempner and Frisch, 1991).

### **2.1.2 Gas bubble growth**

This process occurs through the technique of diffusion of gas from the liquid phase (solution or melt) into the air bubble. In the early stages, the size of the bubble cells formed is small and spherical in shape. An increase in the volume of gas in the bubble causes the fluid phase of the bubble to undergo stretching and eventually unable to maintain the shape of the sphere. this happens because the spheres of these gas bubbles will collide with each other and undergo distortion, in turn giving the shape of the bubble of various shapes, for example the shape of a polyhedron. Vigorously

expanding bubbles will produce a thin membrane or cell thus producing a low-density foam.

In addition, there are also other factors that influence bubble growth, among which are system balance and gas pressure. The gas pressure inside the spherical bubble is greater than the pressure around the fluid (Klempner and Frisch, 1991).

### 2.1.3 Gas bubble stabilization

The gas bubble stabilization process is the last stage in the basic principle of foam formation. bubble stabilization is closely related to the factors influencing the stability of the liquid that forms the foam. Logically, a foam structure is a thermodynamically unstable structure. In addition, the presence of gravitational forces also contributes to the collapse of foam cells in the liquid phase. Pure liquid will not form a stable foam without the aid of surface tension. To stabilize these bubbles, at least two other components in the liquid medium must exist with one of those components capable of being absorbed on the surface of the liquid. the surface tension of the bubble can be controlled by changing the type of concentration and this can be explained according to Gibbs theory (Landrock, 1995) through Equation 2.2 below:

$$d\gamma = -\sum \Gamma d\mu \text{ ----- Equation 2.2}$$

Where,  $\Gamma = \text{excess surface of the absorbent component}$   
 $\mu = \text{the chemical ability of the absorbent material}$

If only a limited amount of solvent is present, an increase in surface area will lower the excess surface area of the absorbent component, causing an increase in surface tension and acting against any surface expansion. This effect reduces excessive thinning of cell membranes and can also act as a bubble stabilizing factor. For thermoplastic foams, bubble stabilization can be produced by cooling the polymer

melt. While for vulcanized rubber foam and thermoset foam, it can be prepared through continuous chemical reaction (cross linking) and a complete melting process. These techniques can increase the viscosity of the polymer involved and can prevent the collapse of the foam cell structure. In both thermoplastic and thermoset polymers, temperature factors play an important role in influencing the degree of stabilization of a bubble. For thermoplastic polymer foams, an increase in the processing temperature will subsequently lower the viscosity and surface tension, causing the foam expansion to be easier. While a decrease in temperature, will help stabilize the bubbles because of the increase in viscosity of the polymer involved. However, for thermoset foams, a reverse pattern of temperature change is required to stabilize the bubble from collapsing.

## **2.2 Polymeric foam**

Foam is a material, and foaming is a phenomenon. Both involve the presence of a gas phase encapsulated by a spherical shell dense phase. Foam contains porous structures perceived as gaseous voids surrounded by a dense phase or as a gas–solid composite. The drastic differences in nature between gases and solids make foams unique combinations that have special properties for applications. For instance, the presence of a cellular structure can regulate flow velocity, dissipate disturbance, and enlarge mass transfer area. Metal foam, polymeric foam, paper foam, and ceramic foam have been developed for unique applications to enrich our lives or to explore the mysterious universe.

Polymers, especially thermoplastic polymers, are characterized by their viscoelastic nature, which possesses processing and material uniqueness. When fit into processing and foaming criteria, their expanded cellular structure shows interesting



properties. However, not every polymer is a good candidate for foam. Considering compatibility with gas, processing window, capability to hold dynamic foaming, and stability during gas replacement by air, few polymers are left on the list. Surprisingly, these polymeric foams developed solid and strong applications due to their unique properties. Polymeric foam can be viewed from different practical perspectives, such as products, technology, and components. Products can be categorized by dimension, density, cell size, cell density, morphology, and property, for instance, block versus film, high density versus low density, microcellular versus cellular, open cell versus closed cell, and rigid versus soft. As for technology, it is basically classified as soluble foaming and reactive foaming, or physical foaming and chemical foaming. Foam can also be classified in accordance with polymer materials such as thermoplastic and thermoset foam (Ramesh, 2004).

### **2.2.1 Polyolefins foam**

Polyolefin foam are the most used and produced foam in the world. There are many techniques used to produce this type of foam such as molding, bead, and autoclave. Polyethylene and polypropylene are the type of polyolefin polymer foamed. Their properties are also same with others types of foams in which it depends on the base polymer, degree of foam expansion and degree of crosslinking (Eaves, 2004).

In term of the structure of the foam, almost all the polyolefin foams have closed cell structure that allow them to be used for buoyancy applications and providing resiliency for packaging applications. They are also mostly be used in building and construction, automobiles, insulation, sports and leisure and agriculture. (Eaves, 2001).

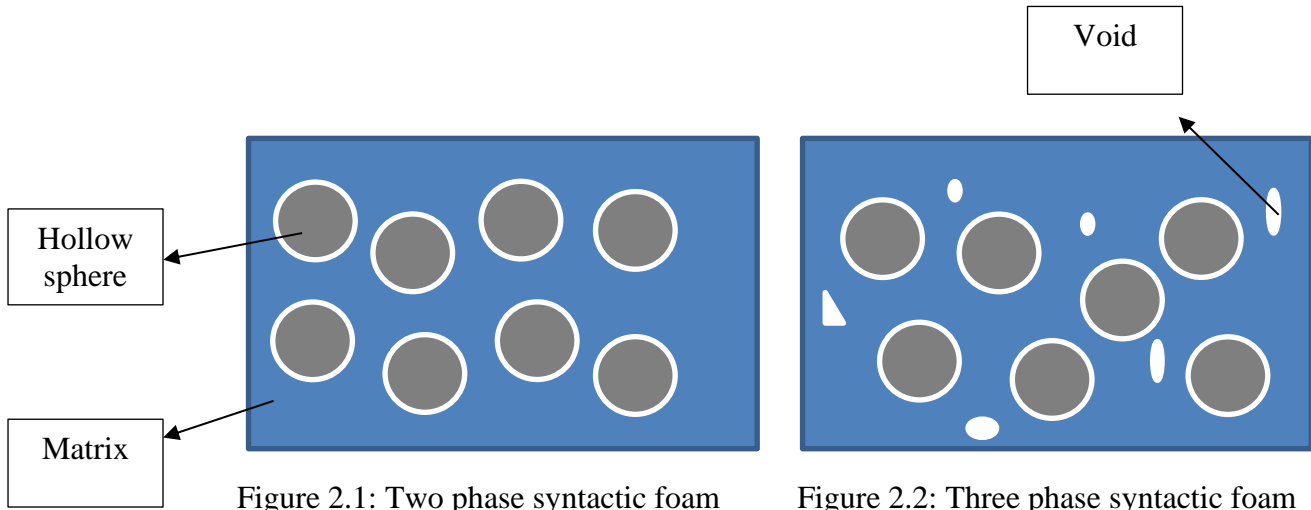
### **2.2.2 Polyethylene (PE) foam**

The main polymer used for polyolefin foam production is low density polyethylene (LDPE) which has been produced by high pressure polymerization. LDPE has sufficient melt strength to allow foam production using blowing agents. It has semi rigid properties with processing temperature within range of 90-100 °C. (Sharin, 2019).

Polyethylene (PE) foam is a durable, lightweight, and resilient. It is often used for packaging fragile goods due to its excellent vibration dampening and insulation properties. It also offers high resistance to chemicals and moisture. PE foam is easy to process and fabricate. It has high load bearing characteristics that help manufacturers reduce packaging cost as they can use thinner and smaller amount of foam yet still meet the requirements to protect their products (Eaves, 2001).

### **2.2.3 Syntactic foam**

Figure 2.1 and Figure 2.2 shows the two-phase syntactic foam and three phase syntactic foam respectively. Syntactic foam is a type of foam that differs from normal foam and getting a lot attention since recently. This is because it is usually used as a core material in sandwich composite for aerospace component, automotive, structural, high-pressure furnace and for marine ship component. Syntactic foam can be described as a composite material that contained hollow sphere (as filler) or hollow small particles that is distributed randomly in the matrix as a binder inside the matrix. It is also known as composite foam because the hollow sphere acts as an amplifier (Karthikeyan *et al.*, 2001). Generally, syntactic foam divided into two types, which are two phase syntactic foam and three phase syntactic foam.



Two phase syntactic foam is a foam that has hollow sphere that is randomly distributed in the matrix of the polymer either it is loose structure or fully compact structure (John and Nair, 2010). While three phase syntactic foam has hollow sphere in the matrix along with the hollow filled gas (Landrock, 1985). During the processing of syntactic foam, the probability for the air to be trap inside the matrix is high due to the processing which usually extensive and will create a void in the foam structure. The resulting void is one of the porosities in syntactic foam other than the hollow sphere.

Syntactic foam has good characteristics which are low density, corrosion resistance, high specific strength, low moisture absorption and low thermal coefficient (John and Nair, 2010). One of the advantages of this foam is it is easy to be adapted and has characteristics that is needed for certain products. This foam was used in a robotic field for seabed diving and components for sonar insulator. The closed cell structure that is controlled in terms of size, gives good structure strength, and can withstand high hydrostatic pressure during seabed diving. Such structure provides sound insulation capabilities that is required in use as a sonar insulator.

#### 2.2.4 Elastomeric foam

Elastomeric foam had been widely used around since 1950 through the product of natural rubber (NR) latex mattress. There are two types of NR that can be used to produce NR elastomeric foam which are dry rubber and rubber latex. Other than NR, synthetic rubber like Ethylene Vinyl Acetate (EVA) and Ethylene Propylene Diene Monomer (EPDM) was also used, however the physical and mechanical properties of synthetic rubber was different compared to NR.

Figure 2.3 shows the general overview of rubber foam preparation. Generally, the principle of the initial step of preparation elastomeric foam is almost the same as thermoplastic foam but a little different during the stabilization of the cell structure because the processing technique of NR compound used usually produced a thermoset polymer.

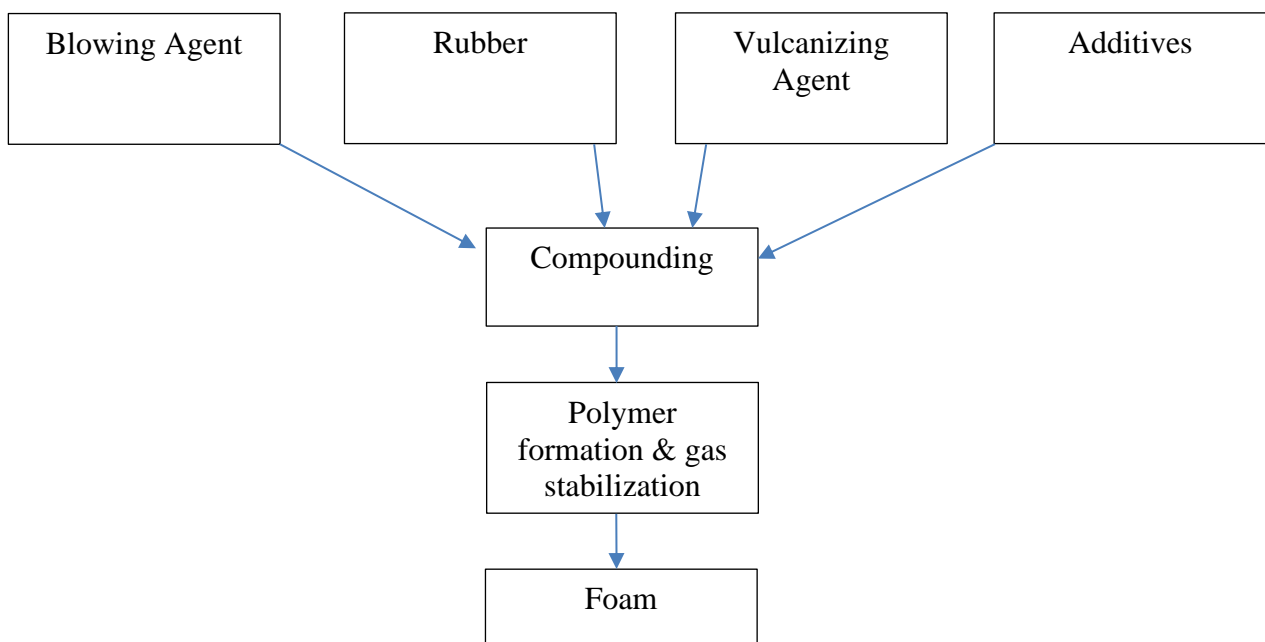
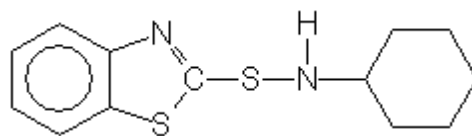


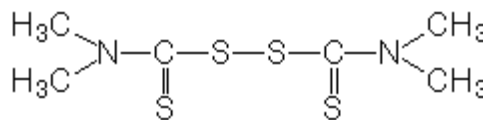
Figure 2.3: General overview of rubber foam preparation

Rubber foam produced by adding blowing agent to the rubber during mastication process and foaming process, or gas production occurs during or simultaneously with vulcanization process. Other ingredients such as vulcanizing agent, accelerators and activators also needed to produce rubber foam. NR, Epoxidized NR (ENR), and EPDM are the examples of rubber foam. The structure of the rubber foam either it is open cell or closed cell depends on the blowing agent, type of rubber and foaming system used. These factors also affect the cell size and cell thickness formed.

Normally accelerator was used to reduce the maturation of rubber vulcanize. Therefore, accelerator will only be used to produce rubber foam. There are several types of accelerators that can be use in rubber vulcanize like N-cyclohexyl-2-benzothiazolesulfenamide (CBS) and tetramethyl thiuram disulfide (TMTD). TMTD is primary accelerator and CBS is secondary accelerator and both types of accelerators were organic accelerator. Figure 2.4 shows the chemical structure of CBS and TMTD.



a) N-cyclohexyl-2-benzothiazolesulfenamide (CBS)



b) Tetramethyl thiuram disulfide (TMTD)

Figure 2.4: Chemical structure of CBS and TMTD (Whitby and Simmons, 1925)

### **2.2.5 Ethylene Vinyl Acetate (EVA) foams**

Ethylene vinyl acetate (EVA) foam is widely used for many purposes especially for energy absorption. For example, it is used in the midsole of running shoes (Kim *et al.*, 2004). The reason for the selection of EVA foams for sport shoes midsole application are related to the durability and the ability to absorb tens of thousands of impact, in which compressive stress reaches about 500 Pa and compressive strain can 60% (Mills, 2003).

EVA foam sheet is a resilient and closed cell foam with high levels of cross linkage. EVA foam has greater recovery characteristics after compression. Due to great level of resilience, this closed cell foam was used as an excellent material in production of sport goods which is effective for protection. Ideally suited as packaging material for protection of fragile goods (Sharin, 2019).

## **2.3 Cell structure of foam**

### **2.3.1 Closed cell foam**

Closed cell foam is a foam that contain cell that is not joined or connected to the neighboring cell. Figure 2.5 shows the closed cell polymer foam structure.

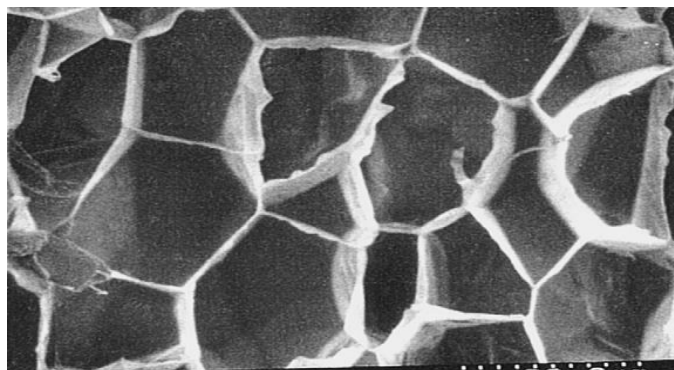


Figure 2.5: Closed cell in polystyrene (Ramsteiner *et al.*, 2001)

Most of the closed cell polymer has rigid and semi rigid properties and is suitable for load bearing structural application that is used in construction. This type of cell also used in thermal insulation application because the gas trapped inside the cell can increase the resistance towards heat exchange. Closed cell foam mostly produced used blowing agent that released nitrogen gas ( $N_2$ ). This is because the molecule structure of  $N_2$  gas is relatively big compared to other gas such as carbon dioxide ( $CO_2$ ). Because of these big molecules, it is difficult to penetrate to the polymer interstices and finally it will grow locally without colliding (Sombatsompop, N. & Lertkamolsin., 2000). These rigid cellular foams are extensively used as a structural core in load carrying sandwich structures. The usage stretches over applications in aerospace, automotive, marine, transportation, and infrastructure. There are numerous examples of applications and a few worth noticing here are the new Swedish Navy Corvette Visby, wind-mill blades, and novel train car structures (Zenkert and Burman, 2009). This is because closed cell foam has other properties such as high rigidity, good buoyancy, fair compression set and insulation, because of that it is suitable in such application.

### 2.3.2 Open cell foam

Open cell foam structure has connected structure. Figure 2.6 shows the open cell structure for polyurethane (PU) foam.

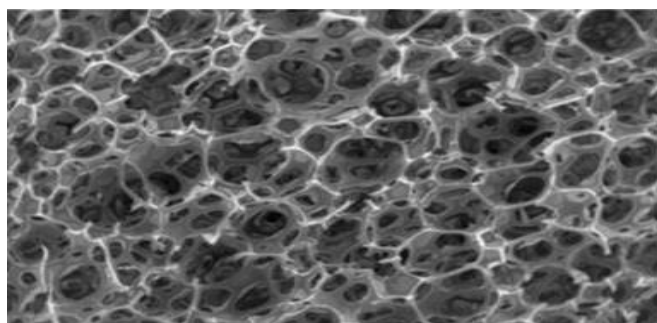


Figure 2.6: Open cell polyurethane foam (Ramsteiner *et al.*, 2001)

Air bubbles in this foam has a continuous gas phase. Most of the foams has soft and good flexible characteristics compared to closed cell foam. Usually, open cell structure was produced by blowing agent that released carbon dioxide ( $\text{CO}_2$ ) during foaming process, for example azo compound and sodium bicarbonate ( $\text{NaHCO}_3$ ). This is because  $\text{CO}_2$  gas has low relative molecular structure and permeable to polymer molecules (Sombatsompop and Lertkamolsin, 2000).

The infinite diffusion rate of  $\text{CO}_2$  allows the cell to be uniformly distributed with low density and high degree of diffusion formed. To increase the open structured cell production rate, plasticizer was usually used to decrease the polymer matrix viscosity. Low viscosity will increase the rate of gas diffusion. In addition, the use of  $\text{CO}_2$  itself can naturally reduce the viscosity of the polymer matrix. Factors that play important roles to produce open cell structure foam was depend on the amount of blowing agent, type of matrix, plasticizers, stabilizer, and activators used.(Landrock, 1995).

The production of open cell foam was done at normal air pressure or a bit more than atmospheric pressure and this is the opposite from the production of closed cell foam (Rahim, 2007). Common properties that can found from open cell foam are good durability, good acoustic absorption, and good permeability. This characteristics allows these type of foam to be used as car seat pads, furniture pads, mattress, acoustic insulation and others (Klempner and Sendijarevic, 2004).



## 2.4 EVA foam formulation

### 2.4.1 Ethylene vinyl acetate (EVA)

Ethylene Vinyl Acetate (EVA) is the copolymer of ethylene and vinyl acetate, which the weight percent of vinyl acetate (VA) usually varies from 10 to 40%, with the remainder being ethylene. The EVA copolymer, which is based on the proportion of VA (approximately 4 to 30%), is referred to thermoplastic ethylene vinyl acetate. Meanwhile, the EVA copolymer, which is based on the high proportion of VA (greater than 40%), is referred to as ethylene vinyl acetate rubber. The chemical structure of EVA is illustrated in Figure 2.7 (Salyer and Kenyon, 1971).

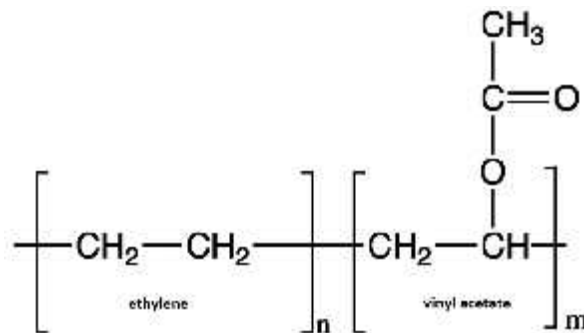


Figure 2.7: Chemical structure of Ethylene Vinyl Acetate (EVA)

Hot melt glue accounts for a significant portion of the EVA copolymer market. They're employed as a substitute for vulcanised rubber and plasticized PVC. Turntable mats, base pads for small things such as office supplies, equipment, and power tools, buttons, automobile door protection strips, and other elements that require a soft product with a good appearance are among the applications. In shoe parts, cellular cross-linked EVA is used. Furthermore, EVA is a zero-halogen material that might be used to replace PVC in many present applications, particularly in the cable industry. The fully saturated backbone is resistant to heat, ozone, and weather, while the vinyl

acetate groups are resistant to oil. EVA is also tear resistant and can be cross-linked (Ratnam et al., 2006).

#### **2.4.2 Crosslink agent**

Usually crosslink agent was added to form a crosslink to the polymer chain. Theoretically, crosslink agent was not needed to form a thermoplastic foam. This is because the amount of crosslink agent used is just about 0.2-0.4 phr to increase the melting ability of the thermoplastic which is important to stabilize bubble during foaming process. For rubber foam, crosslink agent was usually known as vulcanization agent. Crosslink agent was used to increase the resistance of the foam upon breakage of the foam cell. There are several techniques of crosslinking, which are: high energy radiation (for example, electron radiation), peroxide based chemical agent, and versatile azide compound or organosilanol functional group (Sipaut, 2005). However, most of the commercial polymeric foam used peroxide system as the crosslink agent. Dicumyl peroxide (DCP) was the most popular crosslinking agent and was used widely in modification of behavior of the polymeric foam. Generally, peroxide was chosen due to the decomposition temperature that was relative to the melting point of polymer, decomposition rate and efficiency to form crosslink. Increment of peroxide concentration in a polymeric foam will increase the mechanical strength of the polymer. DCP was used to increased mechanical properties, thermal resistance, and chemical resistance. However, not all polymer foam can be produced using peroxide. For example, polypropylene (PP) can't be produced by using peroxide because instead of creating a crosslink network, the peroxide will destroy the polymer chain due to the presence of allylic unit which was reactive to the peroxide. This in turn will decrease the polymer viscosity during the foaming process and lead to collapsing of the cell (Mohamad Ariff *et al.*, 2020).

### 2.4.3 Blowing agent

Blowing agent is important ingredients in producing polymer foam. Generally, it is used to produce air bubbles or gas inside the polymer matrix. Many research had been made to improvise the usage of existing blowing agent beside giving the required properties and characteristics of the polymer foam. Various types of blowing agent were used to produce gas to form cellular and hollow structure in polymers. Types and amount of blowing agent used will influence the characteristics of the foam either it will be rigid or flexible. In general, there are two types of blowing agent which are chemical blowing agent (CBA) and physical blowing agent (PBA).

CBA is a single or mixed compounds that releases gas during decomposition. Usually, CBA is in a solid form and can be categorized into 2 types, which are organic and inorganic. Chemical reaction of CBA can happen from thermal or interaction between the blowing agent and other ingredients base on the formulation used. From the reaction, gas will be release in a specific temperature range called decomposition temperature. Sodium bicarbonate ( $\text{NaHCO}_3$ ) and azodicarbonamide (ADC) are among the examples of chemical blowing agents that is often used.

ADC is an organic chemical that is usually exist in a form of solid at atmospheric conditions, orange in color and does not exhibit any smells. It often used in plastic foam industry. This kind of blowing agent has high decomposition rate. It undergoes exothermic reaction upon decomposition and release gases such as nitrogen gas ( $\text{N}_2$ ) and carbon dioxide ( $\text{CO}_2$ ). The thermal decomposition happens at temperature between  $190^\circ\text{C}$  to  $230^\circ\text{C}$ . ADC usually used along with activator such as zinc oxide ( $\text{ZnO}$ ) and zinc stearate to reduce the decomposition temperature. The addition of activator can reduce the decomposition temperature up to  $50^\circ\text{C}$  which make ADC

suitable for production of several plastic foam like polyethylene (PE) and polypropylene (PP) (Zakaria, 2007).

#### **2.4.4 Activator**

Zinc oxide (ZnO) and steric acid were among the ingredients of rubber vulcanization which act as an activator and used only in small amount. It was also used to increase the efficiency of the accelerator through a formation of chemical complexes. The chemical complexes will increase the rate of vulcanization and in some cases, it will give better physical characteristic to the product (Ismail & Hashim, 1998). ZnO and steric acid were the most common activator used in preparation of rubber compound.

ZnO was often used to prepare plastic foam and acting as nucleation agent. In plastic foam application ZnO can produce a more uniform foam and used to produce polyethylene (PE) foam. Other than that, ZnO also can reduce the decomposition temperature of blowing agent such as azodicarbonamide (ADC) (Zakaria, Ariff & Sipaut, 2009). The decomposition temperature of ADC can be reduced up to 80°C. However, the decomposition temperature of the blowing agent needs to be above the melting point of the base polymer to allow the mixing process occurs without any foaming process.

#### **2.5 Foaming techniques**

Generally, foaming technique that can be used to produce polymer foam can be divided into three techniques which are single stage foaming, two stage foaming and three stage foaming. These techniques are used to produce different type of polymer foam.

### 2.5.1 Single stage foaming

The single -stage foaming process involves the heating process of a polymer compound containing a cross -linking agent and a blowing agent under pressure for a specified period. The foaming process occurs immediately as soon as the pressure is released. Usually, this process is used to produce plastic foam because the cross - linking process can take place before the foaming process is completed because the degree of cross-linking obtained is not so extensive than that required for rubber foam. Therefore, the compound is capable of being developed even if a network of crosslinks has been present in the developed polymer.

This technique is less suitable to produce rubber foam due to several factors. First, the degree of network cross-linking in rubber vulcanizates is usually quite extensive and if the foaming process is carried out after the vulcanization process has been complete, it is highly likely that the foam cells will not be able to grow or stagnate. In addition, the barrier to cell expansion will be more serious if a blowing agent with a moderate expansion capacity such as sodium bicarbonate ( $\text{NaHCO}_3$ ) is used. Second, if foaming occurs before vulcanization, when the foaming process occurs, the air bubbles formed will expand easily and may eventually be released out of the rubber compound before the rubber compound reaches maturity. Third, heat transfer in rubber compounds can be considered relatively slow and this is especially critical if the compound to be expanded is relatively thick. Since the vulcanization and foaming processes have to take place simultaneously, the rubber compound has to undergo a preheating process so that the whole part can reach the appropriate temperature range for the two processes to take place in a balanced way (Mohamad Ariff *et al.*, 2020).

### **2.5.2 Two stage foaming**

Heat transfer foaming is a continuation to the single -stage foaming process. This type of foaming is widely used in the production of rubber foam. In the first stage, the rubber foam compound only goes through a pre-vulcanization process at a lower temperature and no or only part of the rubber foam is expected to develop. For the heat transfer stage, the high temperature in this process promotes the foam expansion process perfectly.

After the rubber foam compound undergoes the required pre-vulcanization process, the compound will be removed from the mold. Then, it is put into a hot air flow oven at an instantaneous rate. The hot air flow oven temperature is set for a certain period of time. The set temperature is usually the vulcanization temperature for the rubber foam compound. The process of complete vulcanization and blowing takes place simultaneously in the oven. The heat transfer process becomes an option as it can reduce their surface problems and the resulting cells are more controlled (Lee *et al.*, 2007).

### **2.5.3 Three stage foaming**

Another foaming technique is three -stage foaming which is very similar to the heat transfer foaming technique. A significant difference in this technique is that the compound to be expanded is not heated to a higher temperature in the second stage, instead it will be cooled to room temperature under pressure with the help of a flow of cooling medium (water) in the cooling duct of the compression mold heating plate. The compression mold plate will only be opened after the compound reaches room temperature so the compound can be stored or used directly for the foaming process which is the third stage of this technique. During this foaming process, a hot air flow oven can be used, and the set temperature is a temperature capable of activating the

decomposition of the blowing agent to complete the desired foaming process. Just like heat transfer foaming, a more controlled foaming process can be carried out and uniform cell formation can be obtained. The difference is that this foaming technique is more widely used to produce thermoplastic foam.

## **2.6 Acoustic properties of foam**

### **2.6.1 Sound absorption coefficient**

Measuring the sound absorption coefficient of an acoustic material can be divided into two main methods, namely, the normal incidence method and the diffuse field method. In the first method, the material is excited by sound energy at angle normal to the surface of the material. For this purpose, the wavelength of the sound incident must be much greater to the diameter of the test material. Thus, only relatively small size of material is required (usually circular shape with less than 100 mm in diameter) and sound energy is contained inside a circular tube, known as impedance tube. Meanwhile in the diffuse field method, the sound excites the material from any possible angles of incidence and thus closely resembles the situation in practice. However, a special, large room is required to enable the sound energy to be diffuse in the room to the lowest frequency possible, known as reverberation chamber. According to BS EN ISO-354, a chamber with volume of at least 150 m and test material with surface area of 10 m are required to have an accurate result above 100 Hz (Putra *et al.*, 2021).

Sound absorption can be evaluated through sound absorption coefficient and can be described by using two mechanisms. The first mechanism involves the reduction of the viscosity due to the friction between the air and the solid phases. Both phases coupled elastically and relative movement between these phases exist. The

second mechanism involves the loss of the sound as heat because of the transfer by the matrix. The best sound absorption performance must consist of low sound reflection and high sound dissipation. When the sound wave touches the surface of the foam, air constituents will be forced out or into the foam cells due to the pressure generated by the sound. The sound pressure will also be forcing the cell wall to stretch and bend. This change in form happens when the sound energy is converted to the dynamic energy (Mohamad Ariff *et al.*, 2020).

According to Gong *et al.*, (2019) foam cell size has a significant influence on sound absorption coefficient and noise reduction coefficient of the different EVA foam materials. The sound absorption coefficient decreased with increase in the foam cell size at low frequencies. However, it increased at higher frequencies. It was reported that when the foam cell size was 71.3  $\mu\text{m}$ , the sound absorption coefficient at the low frequency of 1000 Hz was maximum, at 0.487. However, it was less than 0.45 at high frequency area, where the noise reduction coefficient was as large as 0.358. When the foam cell size was increased to 426.8  $\mu\text{m}$ , the sound absorption coefficient at low frequency was significantly decreased, but increased at high frequency, to 0.357 at the maximum. The noise reduction coefficient was small, i.e., 0.203, which was 43.3 % lower than that for 71.3  $\mu\text{m}$  cells.

#### **2.6.1(a) Acoustic properties of natural rubber (NR) foam**

In the study of correlation between the acoustic and dynamic mechanical properties of natural rubber foam: Effect of foaming temperature by Najib *et al.*, (2011), the result of the study was shown in Figure 2.8. The NR foams with a similar amount of blowing agent were foamed at three different temperatures, 140 °C, 150 °C and 160 °C. The sample with the lowest foaming temperature, NR 140, recorded the highest sound absorption peak. As the foaming temperature increased, the peak shifted