



**EFFECT OF CROSS HEAD SPEED ON  
PROPERTIES AND ENERGY ABSORPTION OF  
SANDWICH AL/PU-PTFE FOAM COMPOSITE**

by

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## LIST OF ABBREVIATIONS

Al	Aluminium
DSC	Differential Scanning Calorimeter
FTIR	Fourier-transform Infrared Spectroscopy
GPa	GigaPascal
MDI	4, 4-diphenylmethane diisocyanate
MPa	MegaPascal
N=C=O	Isocyanate group
OH	Hydroxyl groups
PMC	Polymer-Matrix Composite
PTFE	Polytetrafluoroethylene
PU	Polyurethane
TGA	Thermogravimetry Analysis
XRD	X-Ray Diffraction

## LIST OF SYMBOLS

%	Percentage
wt%	Weight percentage
$\theta$	Theta
$^{\circ}\text{C}$	Degree Celsius
$^{\circ}$	Degree
$T_c$	Crystallization temperature
$T_g$	Glass transition temperature
$T_{\max}$	Temperature maximum degradation
$T_m$	Melting temperature
$\text{cm}^{-1}$	Inverse centimetres
$\text{Pa. s}^{-1}$	Pascal per second
$\mu\text{m}$	Micrometer
g	Gram
ml	Milliliter
mm	Millimeter
min	Minute
mg	Milligram

# **Kesan Kelajuan Kepala Silang ke atas Sifat-Sifat dan Penyerapan Tenaga bagi Al/PU-PTFE Komposit Busa Terapit**

## **ABSTRAK**

Kajian ini mengkaji hubungan antara kelajuan kepala silang dan penyerapan tenaga bagi komposit busa terapit Al/PU/PTFE. PU busa disediakan dengan menggunakan polioliol yang berasaskan minyak kelapa sawit dan isosianat (MDI) dengan nisbah 1:1.1. Tujuan penambahan pengisi 2% PTFE adalah untuk memperbaiki sifat-sifat busa seperti rintangan apabila beban dikenakan ke atas struktur komposit mengikut kekukuhan, kekuatan, kestabilan haba dan sifat-sifat struktur lain. Bagi komposit busa PU/PTFE dan komposit busa terapit, ciri lenturan dan tenaga penyerapan dikaji dengan menggunakan kelajuan kepala silang yang berbeza (5, 10, 15 dan 20 mm/min). Selain itu, penggunaan PTFE dalam PU komposit busa dapat dilihat melalui X-Ray, DSC, TGA dan FTIR. PU/PTFE telah menunjukkan indeks penghabluran yang lebih rendah berbanding busa PU kerana PTFE mempunyai susunan molekul yang sangat lemah. Keputusan DSC menunjukkan bahawa penambahan PTFE menunjukkan kestabilan haba yang paling tinggi walaupun dipanaskan melebihi takat lebur kristal pada 327 °C manakala PTFE juga menunjukkan keputusan rintangan haba yang lebih tinggi bagi TGA. Ini bermaksud, PU/PTFE busa komposit mengambil masa yang lebih lama untuk penguraian sepenuhnya berbanding PU busa. Tambahan pula, pada kelajuan sederhana bagi kepala silang (10 dan 15 mm/min) menunjukkan kekuatan lenturan dan modulus lenturan yang lebih tinggi bagi PU busa dan PU/PTFE samaada dalam keadaan busa komposit atau busa terapit. Sementara itu, peningkatan penyerapan tenaga bagi busa PU dan PU/PTFE komposit busa adalah disebabkan oleh kepala silang yang lebih rendah dan hal ini yang boleh melambatkan retakkan berlaku. Dalam busa terapit, Al yang bersifat kemuluran digunakan adalah untuk meningkatkan penyerapan tenaga dan kekuatan busa terapit.

# **Effect of Cross Head Speed on Properties and Energy Absorption of Sandwich Al/PU-PTFE Foam Composite**

## **ABSTRACT**

This study to investigate the relations between cross head speed and the energy absorption of sandwich Al/PU/PTFE foam composite. The PU foam was prepared using the palm oil based polyol and isocyanate (MDI) with ratio of 1:1.1. The purpose addition of 2% PTFE filler for improve the properties of the foam such as resistance when load applied on composite structure according to stiffness, strength, thermal stability and other structural properties. The flexural properties and energy absorption was study by using different cross head speed (5, 10, 15 and 20 mm/min) on PU/PTFE foam composite and sandwich foam composite. Moreover, the effect of PTFE on X-Ray diffraction, DSC, TGA and FTIR in PU foam composite were also investigated. It was found that PU/PTFE showed the lower crystallinity index as compared to PU foam due to the poor arrangement of PTFE. The DSC results indicate that adding of PTFE gives the higher heat stability even heated above its crystalline melting temperature of 327 °C while PTFE also shows better thermal resistance than PU foam for TGA result. That means, PU/PTFE foam composite takes longer time to fully degrade than PU foam. Furthermore, the medium crosshead speed (10 and 15 mm/min) shows the higher flexural strength and flexural modulus for PU foam and PU/PTFE either in composite or sandwich foam. Meanwhile, the energy absorption of PU and PU/PTFE was increases due the lower cross head speed and this can delay the crack failure. In sandwich foam, the ductility of Al sheet used to increase the energy absorption and improved the strength of sandwich foam.

depend on low apparent density, cheap and flexibility design which is can be easily molded in complex geometric parts. His research also proved that, PU foams also can reduce the sound absorption efficiently.

The preparation of PU foam consists of two reactions such as isocyanate-polyol (or known as the gelling one which forms the backbone urethane group) and isocyanate-water reaction (or known as the blowing). The isocyanate-polyol reaction leads to the formation of a crosslinked polymer, since polyols with several hydroxyl groups are used either by reaction of urethane group with an isocyanate group. The other one reaction is isocyanate-water reaction that forms amine and carbon dioxide gas in the form of bubbles from decomposition of carbamic acid (Dworakowska et al., 2014). The advantages of rigid PU foam such as better dimensional stability, good adhesion to facing materials and mechanical strength at low densities and low thermal conductivity due to blowing agent and fine closed cell structure (Randall & Lee, 2002).

According by Avalle et al., (2001) have described the polymeric foams undergo large compressive deformations and absorb considerable amounts of specific energy. Energy is dissipated through the cell bending, buckling or fractures but the stress is generally limited by the long and flat plateau of the stress-strain curve. For impact testing, the rigid polyurethane foam as core material in sandwich structure can absorb higher energy in closed cell morphology compared to open cell morphology (Saha at al., 2008).

Based on the research study, the flexural testing of PU foam with different cross head speed is to identify the interaction of flexural stiffness and absorbing energy

without weight penalty. Loading speed is experimental parameter which can be altered to study the energy absorption effect from the different cross head speed to the composite foam. The loading speed refers to the cross-head velocity which has direct proportionality with strain rate. The composite foam that is shows the increases of cross head speed which bring about a resulting decreases in energy absorption (Dash et al., 2014).

The function of filler is to enhance performance and reduce manufacturing costs compared to a reinforcement that gives much stiffer and stronger than the polymer by increasing modulus and strength of material (Ajayan et al., 2003). The PTFE was chosen in this research study because PTFE can improve the properties of foam materials such as foam density and modulus properties. PTFE also possesses many outstanding properties such as high melting point, marked solvent resistance, low yield stress, and low surface tension. Other properties of PTFE are non-aging, chemical inertness, exceptional dielectric properties, heat resistance, non-stick and weather-resistance properties (Mark, 1999). PTFE is usually used in application such as a coating for cookware, gaskets, seals and hoses.

## **1.2 Problem Statement**

From the previous study, the effect of impact velocity and geometry on the deformation and energy absorbed has been discussed by Shim et al., 2000. This studied focus on the impact response of crushable polyurethane foam, particularly with regard to the deformation induced and the energy dissipation characteristics. This result shows the increase in energy absorbed with volume of material crushed, generally increases

slightly with impact velocity, signifying a strain-rate effect. However, the effect of different cross head speed on the properties and energy absorption of PU foam composite foam with PTFE by using flexural testing has not yet been studied. The sandwich foam is normally high stiffness but low in weight to withstand the shear loading (cross head speed). The addition of PTFE filler is to reduce the subsurface deformation and interrupt crack propagation. However, PTFE is high energy impact for energy absorption capability that can reduce the force transmitted through in porous polymeric foams or other materials. PTFE may recover some or all of its ability to absorb another high energy impact because of its high strength and stiffness (Tanaka & Kawakami, 1982).

The sandwich panel is influenced by the face sheet strength. This results in failure structure such as face sheet indentation, core crushing, visible penetration or perforation and invisible internal delamination and debonding (Das et al., 2009). All these types of damages will result in strength and stiffness reduction of the structure. On the other hand, adhesive failures occur between the adhesive (such as epoxy and hardener) that applied between core and skin that considered as weakest point of the joint. The failure such as delamination will be happened because too weak adhesively bonded between PU foam and aluminium (Al) sheet that are manually applied. The solution of delamination failure is by trying to control the thickness of adhesive produce the stronger bonding of sandwich foam with high shear strength (Vivek et al., 2010).



### **1.3 Objectives**

The objectives of this study are:

1. To study the effect of cross head speed on the flexural properties of PU/PTFE foam composite.
2. To study the effect of cross head speed on the energy absorption of Al/PU/PTFE foam composite.
3. To compare energy absorption between PU/PTFE foam composite and Al/PU with PTFE composite.

### **1.4 Scope of Study**

The simple formulation to produce rigid PU was using the polyol and isocyanates (MDI) according 1:1:1 ratio by weight that using close cell system in the open mould technique. The 2% PTFE powder was added as filler in mixture of polyoyl and isocynate to withstand the shear stresses set up by the external forces. PTFE also make the foam composite become stiff, strong and lightweight structures. Furthermore, the aluminium sheet was used as skin while epoxy-hardener mixture that are used as adhesive to bond between rigid PU foam and aluminum sheet in order produce the sandwich foam.

The scope of this study involve several testings such as flexural testing (ASTM D790) with the effect of different cross head speed which is 5, 10, 15 and 20 mm/minute on the energy absorption of PU foam and PU/PTFE with or without Al sheet. This composite foam can be analyzed by using Fourier transform infrared

spectroscopy (FTIR). FTIR is represents the infrared spectrum of absorption and emission to identify the functional group of material. The thermal property of composites was studied by using Differential Scanning Calorimetry (DSC) and Thermaogravimetric Analysis (TGA) testing instrument. The glass transition temperature (T<sub>g</sub>), crystalline temperature (T<sub>c</sub>) and melting temperature of the material can be define by using DSC testing. DSC is measure the amount of heat absorbed and release during transition with observe the physical change. X-ray diffraction (XRD) was used to to study the crsytallinity of PU foam and PU/PTFE foam composite.

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## CHAPTER 2

### LITERATURE REVIEW

#### 2.1 Introduction

Polytetrafluoroethylene (PTFE) is a remarkably versatile polymer. It was patented in 1937 by DuPont as Teflon; however, it was in the late 1960s that Gore discovered that rapidly stretching PTFE under the right conditions created a strong and microporous material the expanded of PTFE (Tanaka & Kawakami, 1982).

Previously research was studied about the relationship between the different percentage of filler loading and energy absorption of composite foam by using compression test. The nanoclay was used as filler with different percentage of filler were varied from 0 to 5 percents of weight to produce of nanocomposite polyurethane (PU) foam. The water was used as the blowing agent, besides the catalyst and surfactant were used to enhance better properties of foam. The energy absorption is evaluated by area under stress-strain graph from compression set and the result showed the addition of nanoclay filler will be increases the value of energy absorption at 5000 rpm speed (Zainuddin et al., 1990).

The nanoclay such as montmorillonite (MMT) a quickly popular nanofiller in many polymeric systems as it imparts characteristics such as light weight, improved thermal stability, flame retardant and high compressive strength (Chuayjuljit et al.,

2010; Song et al., 2005). However, hydrophilic nature of MMT causes a weak interfacial adhesion with the polymer matrix which is hydrophobic (El-Sabbagh, 2014). The purpose of applied PTFE filler in this researched study according to high molecular weight and hydrophobic neither water nor water-containing substances wet PTFE as fluorocarbons demonstrate mitigated London dispersion forces due to the high electronegativity of fluorine that produce stronger interaction bonding between PU foam and PTFE (Ellis et al., 2001).

Furthermore, from other previous studies from Apostol & Constantinescu, (2011) that are studied about energy absorption of rigid PU foam effected on different cross head speed The largest comparison speed of loading that are applied from 2 mm/min up to 1000 mm/min. The result shows increasing the crosshead speed will decreases the energy absorption according the decreasing of modulus of elasticity. The failure was happened when the cell walls tend to collapse when the compression force/strain reaches a critical value. This critical value is noted as the compression failure stress/strain (Apostol & Constantinescu, 2011).

## **2.2 Composite**

A composite consisting of different materials is known as laminar composites. Composite materials are combination of two elements with very different characteristics to provide a material with good structural capability. Wood is one of natural composite material consisting cellulose fibers with good strength and stiffness properties. The composite can be classified into three categories according to the matrix material such

as polymer (or plastic), metal or ceramic. Figure 2.1 shows a certain familiar materials which can be described as composites (Szycher, 1999).

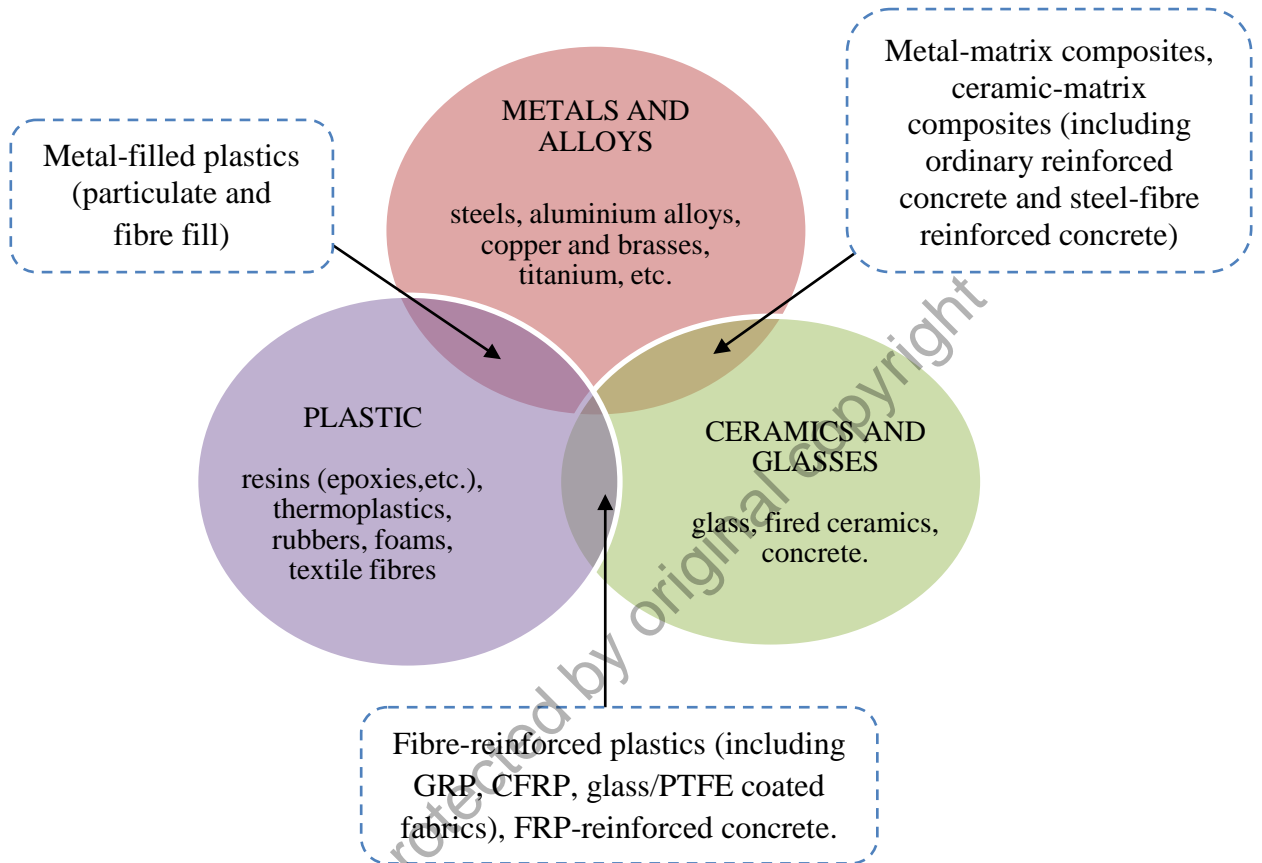


Figure 2.1: Relationships between classes of engineering materials showing the evolution of composites (Szycher, 1999)

### 2.2.1 Polymer-Matrix Composites

Polymer matrix composites (PMC) is the combination of plastic (or known as the matrix) and fibers orientation (eg., reinforcement). PMC can be group into two sections or categories namely, reinforced plastics and advanced composites. Reinforced plastics are related to low manufacture cost, commonly consist of polyester resins reinforced with low-stiffness glass fibers (E-glass). Advanced composites primarily used in the aerospace field, exhibit exceptional strength and stiffness and are

comparatively pricey. Advanced composites that currently used are graphite, high-stiffness glass (S-glass), aramid, or other organic fibers (Reginald & Stoops, 1985).

The matrix phase of commercial PMC can be classified as either thermoset or thermoplastic. The thermoset resins undergo the curing process whereby the chemical reactions will crosslink the polymer chains. Hence, these phenomena connect or join the entire matrix together in a three-dimensional network. The three-dimensional crosslinked structure tends to have high-temperature resistance, high or steep dimensional stability, great resistance to solvents, improving the toughness and maximum operating temperatures especially for thermosets (Matthews & Rawlings, 1999). But nowadays, a thermoplastic is commonly used in manufacturing compared to thermoset especially in high volume industries such as the automotive industry. This is because thermoplastic is stronger, easily reprocessed and faster to heat and cool a material than thermoset that need longer cure time (Akovali, 2001).

The reinforcement PMC provides high strength and stiffness compared to ceramic matrix composite (CMC) where the reinforcement is used to enhance the fracture toughness. The interphase of PMC is the section in which loads are transported between the reinforcement and the matrix. The interaction or relationship between the reinforcement and the matrix are depending on strong and firm chemical bonding to weak frictional forces. Generally, a strong interfacial bonding between the strong PMC will become more rigid but brittle. Furthermore, the polymeric foams can be flexible, semi-flexible (or semi-rigid) and rigid. These different forms depend on the chemical constitution and also the rigidity of the resin used as a matrix and the type of crosslinking that exists between the molecules (Akovali, 2005).

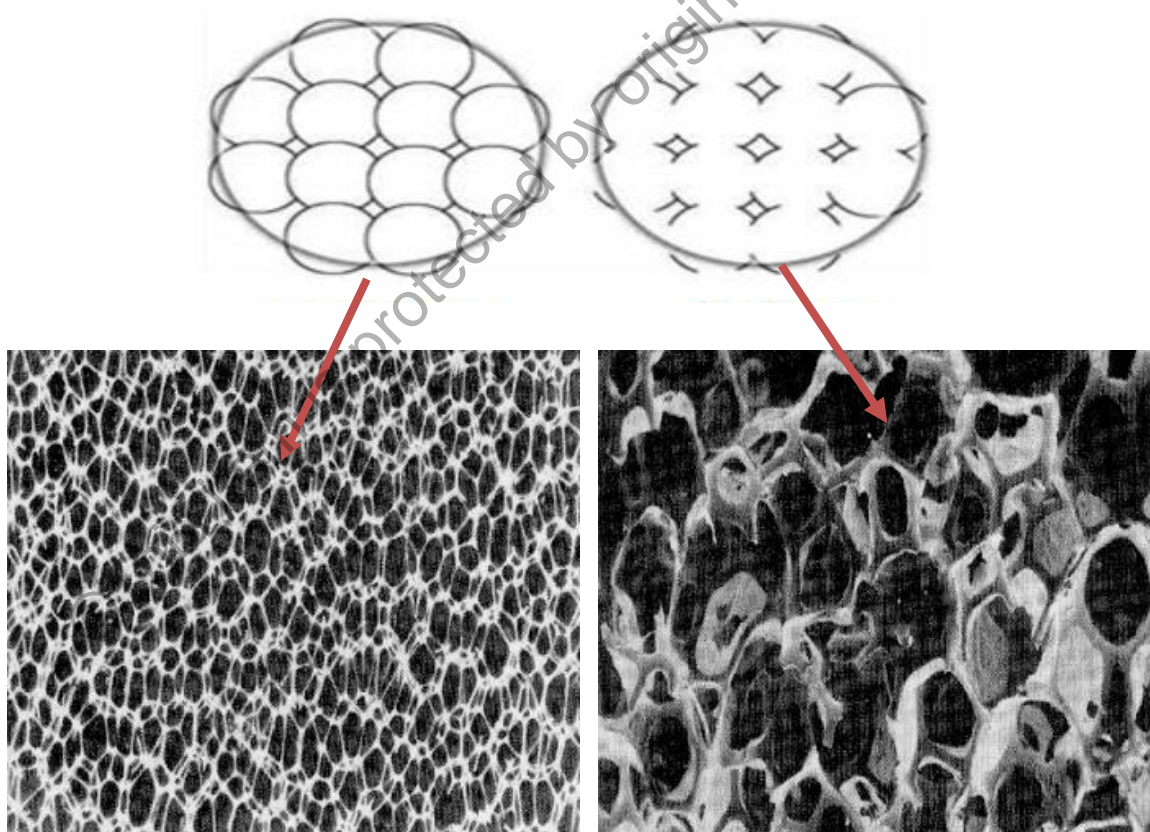
## 2.3 Foam

Polymer foams are made of thermoplastics or thermosets. Thermoset foam are generally stronger than thermoplastic foam due to this three-dimensional network of bonds (cross-linking) and are also better suited to high-temperature applications up to the decomposition temperature. However, they are more brittle and their shape is permanent which is tend not to be recyclable as a source for newly made plastic The foams that dominate the market are made of polystyrene (PS), polyurethane (PU) and polyvinyl chloride (PVC). Phenolic foams are also used in a significant volume. Table 1.1 shows some examples of thermoplastic and thermosetting foams (Japon et al., 2000)

Table 1.1: Some thermoplastic and thermosetting foams (Japon et al., 2000)

Type of polymer	Mode of synthesis	Mechanical properties
PVC	Polymerisation	Flexible and rigid
PS	Polymerisation	Rigid
PU	Polyaddition	Flexible and rigid
Polyisocyanurate	Cyclotrimerisation	Rigid
Polyamide	Polycondensation	Flexible and rigid
Poyimide	Polycondensation	Semi rigid
Phenolics (PF)	Polycondensation	Rigid
Amino plasts (UF)	Polycondensation	Rigid
Polyurea	Polyaddition	Flexible and rigid
Epoxy ring	Ring-opening polymerisation	Rigid

The foams can be classified either in open cell foam and closed cell foam that based on their core structure. The closed-cell foams are generally rigid while open-cell foams are more flexible. Figure 2.2 shows that the closed cell produces most of the original bubbles or cells remain intact compared to open cell where the bubbles have broken and allow air to flow through but the edges of the bubbles are stiff enough to retain their shape. The open cell foams is suitable to be used in seat cushions or mattresses while closed cell rigid foams are usually used as thermal insulation, for example in refrigerators. Self-skinning foams or known as structural or syntactic got a dense surface skin that is made by foaming in a cold mold (Tankara, 2011).



a) Rigid PU foam (close-cell)

b) Flexible PU foam (open-cell)

Figure 2.2: Closed and open cell structure of PU foams. a) Rigid PU foam (close-cell), b) Flexible PU foam (open-cell) ( Tankara , 2011)