MEASUREMENT ON STRAIN RATE SENSITIVITY PROPERTIES OF RICE HUSK/LINEAR LOW DENSITY POLYETHYLENE (LLDPE) COMPOSITES UNDER VARIOUS LOADING RATES

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by

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LIST OF ABBREVIATIONS

ASTM	American Society For Testing Materials
FTIR	Fourier Transform Infrared Spectroscopy
LLDPE	Linear Low Density Polyethylene
PMCS	Polymer Matrix Reinforced Composites
RH	Rice Husk
SEM	Scanning Electron Microscopy
SHPB	Split Hopkinson Pressure Bar Apparatus
UCS	Ultimate Compressive Strength
UTM	Universal Testing Machine

LIST OF SYMBOLS

$\dot{\varepsilon}$	Strain rate
V^*	Thermal Activation Volume
A_b	Cross-Sectional Area of Bar
A_s	Cross-Sectional Area of Specimen
C_o	Wave velocity
ρ	Density
E	Bridge Voltage
e_o	Voltage Change In The Bridge
s_g	Strain Gauge Factor
E	Young Modulus
k	Boltzmann Constant
l_o	Initial Length of The Specimen
T	Absolute Temperature
β	Strain Rate Sensitivity Parameter
G	Amplifier Gain Factor
ε	Strain Pulse
ε_i	Incident Strain Pulse
ε_r	Reflected Strain Pulse
ε_t	Transmitted Strain Pulse
σ	Stress

Pengukuran pada Ciri-ciri Kepekaan Kadar Terikan Komposit Sekam Padi/Polietilena Berketumpatan Rendah Linear (LLDPE) di Bawah Pelbagai Kadar Beban

ABSTRAK

Dalam kajian ini, ujian mampatan dinamik dan ujian mampatan statik telah dijalankan dengan menggunakan alatan pecahan Hopkinson tekanan bar (SHPB) dan mesin ujian konvensional (UTM). Kedua-dua teknik ini digunakan untuk mengkaji kesan kadar terikan terhadap sifat-sifat mampatan komposit sekam padi diperkukuh dengan polietilena berketumpatan rendah linear. Keputusan SHPB pada awalnya telah disahkan dan ditentukurkan. Hasil kajian menunjukkan bahawa semua komposit sekam padi/polietilena berketumpatan rendah linear yang diuji mempunyai pergantungan besar terhadap kadar terikan yang dikenakan, dimana tegasan alah, modulus mampatan dan kekuatan mampatan, kesemuanya meningkat dengan peningkatan kadar terikan. Selain itu, kesan kandungan pengisi, agen gandingan silana dan saiz partikel komposit sekam padi/polietilena berketumpatan rendah linear di bawah pelbagai kadar terikan yang dikenakan juga dikaji. Ia boleh dilihat secara jelas bahawa penggunaan pengisi sekam padi ke dalam matrik polietilena berketumpatan rendah linear meningkatkan sifat-sifat mampatan komposit, termasuklah tegasan alah, modulus mampatan dan kekuatan mampatan. Ia juga didapati bahawa kandungan pengisi menunjukkan hubungan yang tidak ketara dengan kepekaan kadar terikan dan isipadu pengaktifan haba. Bagi kesan agen gandingan silana, keputusan menunjukkan bahawa kekuatan mampatan, ciri-ciri kekakuan dan tegasan alah telah bertambah baik bagi komposit sekam padi/polietilena berketumpatan rendah linear yang diuji. Sementara itu, agen gandingan silana mempamerkan hubungan yang ketara dengan kepekaan kadar terikan dan isipadu pengaktifan haba. Bagi kesan saiz partikel pula, ianya didapati bahawa saiz sekam padi memberi kesan yang ketara terhadap ciri-ciri mampatan komposit sekam padi/polietilena berketumpatan rendah linear. Komposit yang mempunyai saiz partikel yang lebih kecil merekodkan ciri-ciri mampatan yang tinggi dari segi kekuatan alah, kekuatan dan kekakuan jika dibandingkan dengan komposit yang mempunyai partikel saiz yang lebih besar. Untuk analisis pasca-kerosakan, keputusan menunjukkan kadar terikan yang dikenakan mempengaruhi kelakuan ubahbentuk komposit sekam padi/polietilena berketumpatan rendah linear yang diuji manakala pada beban dinamik, analisis kerosakan permukaan komposit diperiksa. Keseluruhannya, ia dapat disimpulkan bahawa penemuan kajian ini boleh meluaskan skop dalam bidang kajian yang berkaitan dengan kadar terikan di bawah beban dinamik untuk pengisi semula jadi diperkukuh komposit, dan komposit sekam padi/polietilena berketumpatan rendah linear ini juga mempunyai potensi yang lebih tinggi untuk digunakan dalam aplikasi industri.

Measurement On Strain Rate Sensitivity Properties Of Rice Husk/Linear Low Density Polyethylene (LLDPE) Composites Under Various Loading Rates

ABSTRACT

In this study, the dynamic compression testing and static compression testing were performed using Split Hopkinson Pressure Bar (SHPB) apparatus and a conventional Universal Testing Machine (UTM), respectively. These two techniques were used to investigate the effect of strain rates towards the compressive properties of rice husk (RH) reinforced with linear low density polyethylene (LLDPE) composites. The SHPB results were initially verified and calibrated. The results show that all tested RH/LLDPE composites have a greater dependency towards the strain rate applied, where the yield stress, compression modulus, and compressive strength, were all proportionally increased as the strain rate increased. Besides, the effect of filler content, silane coupling agents and particle sizes of RH/LLDPE composites under a wide range of strain rates also investigated. It can be clearly seen that the introduction of rice husk filler into LLDPE matrix increased the composite's compressive properties, including yield stress, compression modulus and compressive strength. It was also found that the filler content showed insignificant relationship with strain rate sensitivity and thermal activation volume. For the effect of silane coupling agent, the results indicate that compressive strength, stiffness properties and yield behaviour were improved for treated RH/LLDPE composites. Meanwhile, silane coupling agent showed significant relationship with strain rate sensitivity and thermal activation volume. As for the effect of particle size, it was found that the size of rice husk gave significant effects on the compressive properties of RH/LLDPE composites. The composites with smaller particle size has recorded higher compressive properties, in terms of yield strength, strength and stiffness as compared to composites with larger particle sizes. For the post damage analysis, the results show that applied strain rates affected the deformation behaviour of tested RH/LLDPE composites while at dynamic loading, the fracture surface analysis of the composites was examined. Overall, it can be concluded that these research finding can widen the scope of research area that related to the strain rate under dynamic loading for natural filler reinforced composites, and these RH/LLDPE composites also have the high potential to be applied in the industry application.

CHAPTER 1

INTRODUCTION

1.1 Static and dynamic mechanical properties of materials

The mechanical behaviour of materials is determined by their static and dynamic mechanical characterization. Regrettably, many researchers and scientists were only focused on the static rather than dynamic mechanical properties of materials. This is due to a very limited number of dynamic facilities and also the difficulty in running dynamic facilities. Therefore, a systematic research should be carried out in the future in order to improve the knowledge and understanding in the dynamic aspects of the material's behaviour especially for soft materials like polymeric materials.

1.2 Development of dynamic testing

Materials undergo different deformation under different strain rates loading especially at high strain rates. Hence, the knowledge of the material's characteristics in dynamic loading is becoming more crucial in order to produce the optimal products or structures that is able to stand up against high velocity impacts. Based on this highlighted issues, several conventional mechanical test have been developed to gain the mechanical properties of the materials at high strain rate (Hamouda & Hashmi, 1998). For example, Charpy impact test able to yield a strain rate of up to 100 s^{-1}, but only display fracture toughness data from the tests. Besides, this test also similar to the drop-weight test that cover the low strain rate (i.e. between 1 and 10 ms^{-1}) and only provide energy absorption and fracture toughness (Altenaiji et al., 2014).

One of the most promising techniques that can be used to characterise the mechanical behaviour of materials at very high strain rates is the Split Hopkinson Pressure Bar (SHPB) technique. The SHPB technique was invented by Kolsky (1949) and developed by Hauser (1966), consists of split bar system which includes two bars (known as incident bar and transmitted bar) with specimen in between. Then, a stress pulse travelled through elastic input bars through a sample and lastly travels into an elastic output bar. The SHPB technique can provide a stress-strain curve as the output, which holds useful information to characterise the materials. In the SHPB set-up, a semiconductor strain gauge is mounted on both incident and transmitted bar. These two strain gauges analyse the signal and produce stress and strain of the specimen. However, a conventional SHPB in not suitable for low impedance materials such as polymer and rubber due to the transmitted signal too small to be captured by strain gauge (Song & Chen, 2005; Van et al., 2006). In addition, the equilibrium state is slower in soft materials.

Based on this limitation, the conventional theory technique is invalid and other solution must be carried out. Lately, two common methods have been found to overcome this problem. In the first method, the application of pulse shaper is used to induce a faster dynamic equilibrium achievement (Frew et al., 2005; Vecchio & Jiang, 2007). Another alternative method is the implementation of a low-impedance pressure bar such as polymer bar which has an impedance value closer to that tested materials (Johnson et al., 2010). With this solution method, it is proved that a closer impedance mismatch will significantly enhance the propagation of the transmitted pulse. Based on this situation, it can say that the SHPB test is still relevance for performing of dynamic testing on soft specimen especially in polymer based materials.

1.3 Static/dynamic mechanical behaviour of natural filler reinforced polymer composites

Generally, linear low density polyethylene (LLDPE) is remain as a popular commodity plastic due to its commercial potential in many industrial applications. Sadly, this thermoplastic polymer is still referred to as a low cost engineering plastic and only applied in the conventional applications. The incorporation of natural fillers into LLDPE matrix has shown great potential as it shows increasing in the longevity and durability of LLDPE that fulfil the requirement for engineering application. Interestingly, the used of natural fillers as replacement of glass fibers and minerals in thermoplastic composites is increasing due to the environmental benefits, including their renewable and biodegradable resources and reduce the crude oil usage in the production of the natural fillers (Kim et al., 2011; Kwon et al., 2013). However, natural filler is poorly compatible with polymeric matrices that has lower resulted in mechanical strength of natural filler reinforced thermoplastic composites, especially at the filler/matrix interfaces (Kabir et al., 2013; Zhou et al., 2014). Thus, the surface modification of natural filler has become crucial to achieve the maximum compatibility between filler and matrix which indirectly lead to the improvement in the mechanical properties of composites (Huda et al., 2008; Kabir et al., 2012; Zhou et al., 2014).

Rice husk (RH) is used as reinforcing fillers in LLDPE matrix due to their properties are quite similar to other natural fillers (Tong et al., 2014). The incorporation of RH into polymer matrices provides advantages characteristics such as biodegradability, light weight, toughness, resistance to weathering and also makes final products more economically competitive (Arjmandi et al., 2015; Kwon et al., 2013; Zhao et al., 2009). Recently, many engineering products are exposed to dynamic loading and it is necessary to investigate the dynamic behaviours of these composite in order to prevent any unexpected failure during the service. In current situation, many of researches only focused on their static rather than dynamic mechanical properties of pure polymer. Unfortunately, the effect of fillers on strain rate sensitivity and dynamic behaviour of the composites were frequently neglected. This issue might be effectuated by the nature of the composite that bring difficulty in the specimen's geometry design for dynamic testing (Hamouda & Hashmi, 1998).

Besides, a few researchers have produced optimal specimen's geometry to overcome this drawback and proved that the dynamic facilities are also suitable for composite materials especially polymer matrix composites (PMCs) (Guo & Li, 2007; Hao et al., 2005). Thus, this is a huge opportunity to discover the capabilities and possibilities of these composites to replace conventional materials, especially in dynamic loading application. However, none of the previous work has specifically reported the dynamic mechanical properties of RH/LLDPE composites. One of the researches that has been demonstrated by Yang et al. (2004) only reported on the mechanical properties of rice husk reinforced polypropylene composites at low loading rates. Besides, another research that reported by Premalal et al. (2002) only focused on the mechanical properties of rice husk powder filled polypropylene at static loading rates. Thus, it is very important to carry out specific experiment to investigate the capability of RH/LLDPE composites under static and dynamic loading rates.

1.4 Problem statements

Nowadays, the use of natural filler reinforced polymer composites in the conventional application have been extended from conservative to more challenging application such as automobiles, construction, load-bearing application and engineering components. Mostly, all of those applications are mainly involve with different level of strain rates. So, it is compulsory to study the effect of strain rate on the highlighted application in order to prevent the unexpected failure during the service. Besides, the knowledge of rate sensitivity is also important during material selection to estimate the magnitude of changes in material's properties. However, there is a very limited number of research that focus on the dynamic behaviour as well as the rate sensitivity of natural filler reinforced polymer composites. Therefore, we believe that a systematic study under a dynamic condition of natural filler reinforced polymer composites is necessary to fulfil the insufficiencies of the information in this material.

1.5 Objectives of study

The objectives of this study are:

1) To analyze the effect of RH filler content on the static and dynamic compressive properties of RH/LLDPE composites.
2) To examine the effect of silane treatment on the static and dynamic compressive properties of RH/LLDPE composites.
3) To investigate the effect of particle size on the static and dynamic compressive properties of RH/LLDPE composites.

4) To distinguish the morphology characteristic of RH reinforced with LLDPE composites under various loading rates.

1.6 Scope of study

The scope of this study is to investigate the effect of strain rates on the compressive properties of rice husk reinforced linear low density polyethylene composites under static and dynamic loading. Five different compositions of RH/LLDPE composites will be prepared and mixed using twin screw extruder. Then, the specimens will be compacted using hot press machine. The sample will be compressed under three different strain rates loading at both static and dynamic loading, respectively. Besides, the effect of surface treatment and particle sizes of RH/LLDPE composites under both static and dynamic loading also will be investigated. The specimens will be characterized using Fourier Transform Infrared (FTIR) for compound identification and Scanning Electron Microscopy (SEM) for morphology study. At the end of this study, the compressive properties, strain rate sensitivity and thermal activation volume of the composites are analyzed based on the effect of strain rates toward filler contents, surface treatment and particle sizes.

1.7 Organisation of thesis

This thesis has been divided into eight chapters which each chapter provides the information about the research study as mentioned in the objectives.

- **Chapter 1** covers the introduction of the thesis. It contains a general overview on the development of the static and dynamic testing, summary about dynamic studies on the natural filler reinforced polymer composites, objectives of the research and organization of the thesis.

- **Chapter 2** provides some fundamental concepts of the split Hopkinson pressure bar technique with review of related works reported in previous findings.
- **Chapter 3** explains the material specifications, methodology and experimental procedures that has been performed in this study.
- **Chapter 4** discusses the calibration and verification of the SHPB results.
- **Chapter 5** discusses the effect of RH filler content on the static and dynamic compressive properties of RH/LLDPE composites.
- **Chapter 6** discusses the effect of silane treatment on the static and dynamic compressive properties of RH/LLDPE composites.
- **Chapter 7** discusses the effect of particle size on the static and dynamic compressive properties of RH/LLDPE composites.
- **Chapter 8** concludes the finding of the research and the assessment that has been made in order to achieve the objective of this study. A few suggestions for further study have been proposed.

CHAPTER 2

LITERATURE REVIEWS

2.1 Introduction

This chapter summaries the principle of the thermoplastic polymers followed by the overview of natural filler reinforced composites, explaining their increasing use in a wide range of engineering application. Besides, the review was also focused on the silane coupling agents as one of the treatment method that improves the properties of natural fillers. In addition, the literature study was carried out on the development of the dynamic facilities, especially in Split Hopkinson pressure bar apparatus (SHPBA). Besides, the study on static and dynamic behaviors of natural filler reinforced plastic was also comprehensively revised.

2.2 Polymer

Generally, the name polymer is derived from the Greek poly for many and *meros* for parts. A polymer molecule consists of a repetition of the unit called *mer* (Chanda & Roy, 2006). Basically, there are three main types of polymers which are thermoplastic, thermoset and elastomers (Harper, 2002). Among these three polymer groups, thermoplastic polymers have been widely used in both conservative and challenging applications.