STAMP FORMING PERFORMANCE OF PALM FIBER COMPOSITES

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ABSTRACT

Composite materials have been vastly known worldwide for its uses in various sectors such as aerospace, infrastructures and automotive industries. Natural fibres are gaining recognition as a substitute to synthetic fibres due to their recyclability and abundance. Oil palm fibre reinforced polypropylene composite panel has the potential to be stamp formed in order to build complex geometries. In stamp forming the most sensitive feature is elastic recovery during unloading. This phenomenon will affect the net dimension of the final product. This research studies the effects of tool radius, feed rate, temperature and weight ratio of fibre to polypropylene on the spring-back of oil palm fibre composite. A V-bending die will be used to characterise the spring-back angle of the oil palm fibre composite. Statistical analysis conducted shows all the studied parameters gave significant effect towards spring-back. The higher the temperature, feed rate and fibre composition (up to 30wt %) the smaller the spring-back and it is vice versa for tool radius. An empirical model was formulated to predict the spring-back angle. Using a stereo microscope as a visual aid shows that at the temperature of 150°C, fibre composition of 30wt%, tool radius of 2mm and feed rate of 500mm/min, the specimens deformed surface is smooth and cracks were not visible. Comparatively for specimens at a temperature of 130°C, fibre composition 10wt%, tool radius of 6mm and feed rate of 300mm/min, micro-cracks are visible. This may lead to failure of the oil palm fibre composite.

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ABSTRAK

Bahan komposit telah dikenali di seluruh dunia untuk kegunaan dalam pelbagai sektor seperti aeroangkasa, infrastruktur dan industri automotif. Gentian asli kini mendapat pengiktirafan sebagai pengganti kepada gentian sintetik kerana gentian asli boleh dikitar semula dan mudah didapati dalam kuantiti yang banyak. Gentian kelapa sawit diperkukuhkan dengan polipropilena panel komposit mempunyai potensi untuk dibengkokkan bagi membina geometri kompleks. Dalam proses pembentukan lengkungan yang paling sensitif adalah pemulihan anjal semasa memunggah. Fenomena ini akan memberi kesan kepada dimensi bersih produk akhir. Kajian ini mengkaji kesan-kesan alat jejari, kadar kelajuan, suhu dan nisbah berat gentian ke polipropilena pada 'spring-back' komposit serat kelapa sawit. Alat lengkungan V akan digunakan untuk mencirikan 'spring-back' komposit serat kelapa sawit. Analisis statistik yang dijalankan menunjukkan semua parameter tersebut memberikan kesan yang ketara ke arah 'spring-back'. Semakin tinggi suhu, kadar kelajuan dan komposisi serat (sehingga 30wt %), lebih kecil 'spring-back' dan ia adalah sebaliknya untuk alat jejari. Satu model empirikal telah dirangka untuk meramalkan sudut 'spring-back'. Menggunakan mikroskop stereo sebagai bantuan visual yang menunjukkan pada suhu 150°C, komposisi gentian 30wt % , alat jejari 2mm dan kadar kelajuan 500mm/min , lengkungan pada permukaan spesimen licin dan tiada keretakan. Secara perbandingan untuk spesimen pada suhu 130°C, komposisi serat 10wt%, alat jejari 6mm dan kadar kelajuan 300mm/min, mikro-retak hadir. Ini boleh membawa kepada kegagalan komposit serat kelapa sawit.

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α-value	-	alpha value
T_s	-	softening temperature
T_r	-	room temperature
α_r	-	radial expansion coefficient
α_l	-	linear expansion coefficient
$\Delta\theta$	-	deviation angle

LIST OF ABBREVIATIONS

EFB	-	empty fruit bunch
OPEFB	-	oil palm empty fruit bunch
OPF	-	oil palm fibre
OPFC	-	oil palm fibre composite
PP	-	Polypropylene
MAPP	-	Maleic Anhydride Polypropylene

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CHAPTER 1

INTRODUCTION

1.1 Background Research

Materials used in the automotive and aerospace industries have mainly been dominated by monolithic metals and plastics. Composite based materials have recently gained recognition due to its excellent mechanical and chemical properties. Some advantages that composite materials possess are, that it has higher specific strength, stiffness and fatigue characteristic that allows the materials to be more versatile in design.

Composite are materials comprises of reinforcement and a matrix. The reinforcement is the strong load material that provides strength and rigidity to help support the structural load. While the matrix is the weaker material that maintains the position and orientation of the reinforcement. Each reinforcement and matrix complements each other. The qualities that one does not possess may be found in another. This in turn will create a material that cannot be found in a single material alone.

Fibres can be classified into two groups which are natural fibres and synthetic fibre. Natural fibres include those made from animal, mineral sources and plant. Animal fibres generally consist of animal hair, silk fibres, and avian fibres. For synthetic fibres, it consists of asbestos, ceramic fibres, and metal fibres. While examples of the plant fibres are seed fibres, leaf and skin fibres (Kindo, 2010). However, many of the early work on composites focused almost entirely on inorganic materials. Natural fibres are currently being studied intensively by researchers to replace synthetic fibres. This is because natural fibres are lower in cost, greenability, low density, recyclable, biodegradable, with moderate properties and usually produced in an abundant amount at a time. These fibres are also renewable materials and have relatively high strength and stiffness (Joseph et al., 2006). Automotive giants such as Daimler Chrysler use flax–sisal fibre mat embedded in an epoxy matrix for the door panels of Mercedes Benz E-class models (John & Thomas, 2008). Coconut fibres bonded with natural rubber latex are being used in seats of the Mercedes Benz A-class models. Besides the automotive industry, lignocellulosic fibre composites have also been applied in buildings and construction industries for panels, ceilings, and partition boards (Hariharan & Khalil, 2005).

Malaysia is one of the world's largest producers and exporters of oil palm. The oil palm plantation has gradually dominated the Malaysian agricultural crop with a total plantation area exceeding 4 million hectares (Basri, 2005). To fully utilise Malaysia's natural resources, oil palm empty fruit bunch (OPEFB) fibres were chosen as the natural fibre for this research. The OPEFB fibre is clean, biodegradable and compatible compared to other fibre from wood species (Kwei et al., 2007). OPEFB fibre is extracted from empty fruit bunch (EFB) and during the manufacturing process of oil palm fibre; EFB is shredded, separated, refined and dried. The fresh oil palm fruit bunch contains about 21% palm oil, 6-7% palm kernel, 14-15% fibre, 6-7% shell, and 23% empty fruit bunch (Yusoff et al. 2009).

It is estimated that over 3.6 tonnes per hectare of oil palm waste product were produced annually (Yusoff et al., 2009). These wastes are usually burnt down to produce bunch ash that is used as fertilisers. These actions will result in environmental problems for the country such as air pollution and global warming. However recently, only a small part of oil palm waste is used as fertilisers. Thus a huge amount of EFB is left to decompose.

By using EFB as a natural resource for this research, not only can we fully utilise the natural fibre but in turn we can also reduce the environmental problems that comes with it. In the long run it can also enhance the nation's economy and resource. Various researchers had found that to obtain cost reduction and reinforcement, the incorporation of EFB into polymers plays an important role (Rozman et al., 2001; Ratnam et al., 2007; Kalam et al., 2005). The mechanical properties of EFB/polypropylene composites were investigated and had been found that EFB has increased the tensile modulus but decreased the tensile strength of the composites (Rozman et al., 2001).

Two main processing for thermoplastic composite materials are injection moulding and thermoforming or hot stamp forming. Both injection moulding and thermoforming have quite similar attributes regarding processing. However, the surface finish for thermoforming is greater than injection moulding or can be graded as class 'A' finish (Anonymous, 2012). The issues of swirls, sink marks, weld lines, gate marks, etc. are not present with thermoforming. On cars, plastic bumpers and plastic lower side panels are typically thermoformed.

Stamp forming is being used to produce mass production of products such as in the automotive industries. Thus, the stamp forming behaviour is very critical to predict and determined the exact parameters needed to produce the shape and size of their products. One of the stamp forming tests is the V-bend. V-bending is a single curvature deformation process often utilised to characterise the spring-back or deviation angle of a material. This will reduce the knowledge gap on the material's forming behaviour of the material. In stamp forming, the most sensitive feature is elastic recovery during unloading called spring-back. This phenomenon will affect bend angle and bend curvature.

For this research, Polypropylene (PP) and Maleic Anhydride Polypropylene (MAPP) were used acting as the matrix and as the coupling agent for the composite.

Polypropylene is a semi-crystalline polymer that is used extensively due to its unique properties which are inexpensive and easy to fabricate. MAPP act as an effective functional molecule for the reactive compatibility between PP and OPEFB. MAPP can improve the bonding between PP and OPEFB fibres. The variables that were investigated for this project are fibre content, temperature, feed rate and tool radius. The materials will undergo two mechanical testing which are tensile test and V-bending. Based on the data gathered, an analytical model will be produced in predicting the spring-back effect of the composite material.

1.2 Problem Statement

Many of the early work on composites focused almost entirely on inorganic materials, since the early 1980s the interest in composites made from cellulose fibres has been growing. This interest has largely stemmed from problems with recyclability, costs and the environmental effects of synthetic fibres, and the abundance of natural fibres (Bhattacharya et al., 2003). Renewable materials produce only minute levels of carbon emissions and therefore help to combat climate change.

In Malaysia, researches on palm fibre composite had mainly focused on tensile and flexural properties. Stamp forming behaviour of thermoplastic based oil palm fibre composite (OPFC) is yet to be well understood, thus there is great need to study this behaviour in order to improvise material characteristics in the production processes. Thermoforming of pre-consolidated composite sheets into 3-dimensional shapes is logical and the next step for product manufacturing (Bhattacharya et al., 2003). V-bending is a single curvature deformation test utilised to characterise the spring-back or deviation angle from the final shape of a product.

1.3 Objective

In tackling the problem discussed, the objectives have been determined as listed:

- To identify the effects of forming rate, tool radius, temperature and ratio of fibre to Polypropylene on the spring-back of palm fibre composite.
- To produce an empirical model in predicting the spring-back angle.

1.4 Scope

In order to achieve the objectives of the research, the scopes are listed:

a) V-bending will be utilised to characterise the spring-back angle of palm fibre composite.

b) This research will only be focusing on the forming rate, tool radius, temperature and ratio of Polypropylene on the spring-back angle of palm fibre composite.

This research was conducted to minimize the spring-back angle that is produced after the oil palm fibre composite is stamp formed.

1.5 Significant of study

The main aim of this research was to identify whether oil palm composite is suitable to be stamp formed to produce automotive parts such as cup holders, dashboards and speaker grilles. This is because stamp forming is normally associated with metal and not composite materials.

The effects of tool radius, feed rate, temperature and fibre composition on the oil palm fibre composite spring-back angle after stamping will be examine. The empirical equation will help in determining and predicting the effect of the parameters towards the spring-back angle. This can be a reference for industries to determine the necessary parameters that is required to produce a component made from oil palm fibre composite.

CHAPTER 2

LITERATURE REVIEW

2.1 Composite

The definition of composite materials are materials made from two or more constituent materials with significantly different physical or chemical properties, that when combined, produce a material with characteristics different from the individual components. The individual components remained separate and distinct within the finished structure. To be known as a composite material, it must satisfy three criteria. First, both constituents have to be present in reasonable proportions, say greater than 5%. Secondly, the constituent phases have different properties; hence the composite properties are noticeably different from the properties of the constituents. Finally, a composite is usually produced by intimately mixing and combining the constituents by various means.

There are three types of composites which are metal matrix composite, ceramic matrix composite and polymer matrix composite.

2.1.1 Metal matrix composite

Metal matrix composite have many advantages over monolithic metals which includes better properties at elevated temperatures, better wear resistance, have a higher strength and specific modulus. Metal matrix composite also has a lower coefficient of thermal expansion.

The term metal matrix composites are often associated with light metal matrix composites. Significant advancement in the development of light metal matrix composites has been achieved in recent decades. Especially in the automotive industry, MMCs have been used commercially in fibre reinforced pistons and aluminium crank cases with strengthened cylinder surfaces as well as particle-strengthened brake disks (Kainer, 2006).

2.1.2 Ceramic matrix composite

Ceramic matrix composites are produced from ceramic fibres embedded in a ceramic matrix. Various ceramic materials, oxide or non-oxide, are used for the fibres and the matrix. Also a large variety of fibre structures is available. So properties of ceramic matrix composites can be adapted to special construction tasks.

Ceramic matrix composites materials overcome the major disadvantages of conventional technical ceramics, namely brittle failure and low fracture toughness, and limited thermal shock resistance. Therefore, their applications are in fields requiring reliability at high-temperatures (beyond the capability of metals) and resistance to corrosion and wear. For example, heat shield systems for space vehicles, which are needed during the re-entry phase, where high temperatures, thermal shock conditions and heavy vibration loads take place.

2.1.3 Polymer matrix composite

Many structural applications are not suitable for polymers due to its poor mechanical properties. There is a considerable benefit gained by reinforcing polymers. The process of polymer matrix composites (PMCs) does not involve high pressures nor requires high temperatures. Hence issues linked with the degradation of the reinforcement during manufacture are less significant for PMCs than for composites with other matrices.

There are two types of matrices used for PMC which are thermoset and thermoplastic. Over three-quarters of all matrices of PMCs are thermosetting polymers. Thermosetting polymers, or thermosets, are resins which are readily cross-linked during curing. Curing involves the application of heat and pressure or the addition of a catalyst known as a curing agent or hardener. The bonds of the link are, similar to the bonds in the polymer chain, covalent (strong bonds).

These bonds have the effect of pulling the chains together. This restricts the movement of the polymer chains and so increases the glass transition temperature to above room temperature. Thermosets are brittle at room temperature and have low fracture toughness values. They cannot be reshaped by reheating. Thermosets degrades on reheating (in some cases may burn) but does not soften sufficiently for reshaping.

Thermoplastics meanwhile are readily flow under stress at elevated temperatures. It can be fabricated into the required component. When it is cooled down to room temperature, it becomes a solid and retains its shape. As compared with thermosets, thermoplastics can be repeatedly heated, fabricated and cooled. This will reduce the amount of waste or scrap as it can be recycled.

Thermoplastics do not cross-link to form a rigid network. The chains may be branched out but still discrete unlike the chains in a cross-linked network. This is due to weak Van der Waals forces between the chains. These bonds are easily broken by the combined action of thermal activation and applied stress. This is why the thermoplastics flow at elevated temperatures. Most thermoplastics are partially crystalline. Figure 2.1 shows the chain configuration and its strength.

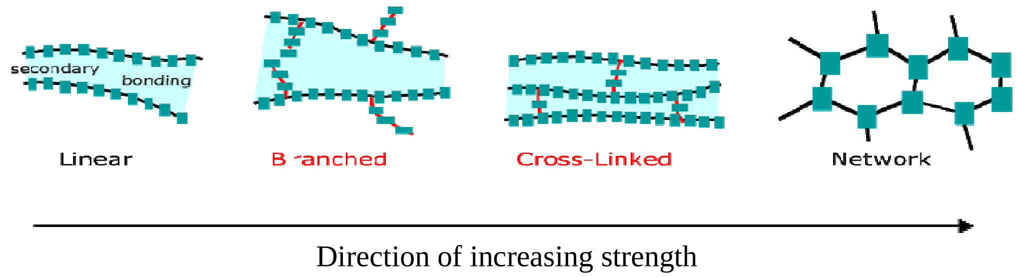

Figure 2.1: Chain Configurations and Strength (William D. Callister & Rethwisch, 2010)

2.2 Polypropylene

Polypropylene (PP) is a semi-crystalline polymer that is widely used due to its unique combined properties which are inexpensive and easy to fabricate. Polypropylene is a thermoplastic material which softens when heated and hardens when cooled. The process can be totally reversible and repeated. Polypropylene can be processed by various fabrication techniques such as injection moulding and profile extrusion. PP is an economical material that offers a combination of outstanding physical, chemical, thermal and electrical properties. PP has excellent resistance to organic solvents and electrolytic attack. PP has low impact strength but excellent in term of temperature and tensile strength than Polyethylene. Although PP has poor aliphatic, aromatic and chlorinated solvent resistance, but it has good resistance to alkalises and acids. Due to the non-polar nature of PP, it also has moisture resistance and dielectric properties among the best of all plastics (Shugg, 2002).

2.3 Maleic anhydride grafted Polypropylene (MAPP)

Natural fibres are hydrophilic in nature. This reduces its compatibility with hydrophobic polymer matrices. Furthermore, it also presents poor dimensional and environmental stability that averts a broader use of natural fiber composites. It is frequently observed that introducing coupling agents in fiber-reinforced plastic composites improves the adhesion and compatibility between non-polar polymer matrices and polar fibre by making bridges of chemical bonds between the fiber and the matrix. So far, more than forty coupling agents have been used both in production and research purposes. Among them, maleated polypropylene (MAPP) is the most popular (Ramli et al., 2011).

Maleic anhydride (MAH) grafted PP (MAPP) was proved to be an effective functional molecule for the reactive compatibility between polypropylene and polyamide. However, the miscibility between PP and mPP has not received much attention. Recent research has shown that PP and mPP can either be co-crystallised or phase separated, depending on the molecular weight and MAH content in mPP. In the case of high molecular weight and low MAH content, the pairs tend to co-crystallise. Otherwise, phase separation will occur, which would greatly influence the mechanical properties of PP/mPP-based materials (Cho et al., 1999).

It has been shown by Frukawa et al. (1994) that an introduction of a small amount of maleic anhydride (MA) into PP improves various practical characteristics such as stability, adhesion and charge storage. The most significant effect on strength and modulus were found by the addition of coupling agent. This attributes to the thermodynamic segregation of the MAPP toward the interface, resulting in the formation of covalent bonding to the –OH groups of the fibre surface. Composites with MAPP also provide better thermal stability (Ramli et al., 2011).

Beg and Pickering (2008) reported 3–5wt% coupling agent is optimum for good adhesion between fibre and matrix. This statement was supported by Lu et al. (2005) who found that the improvement on the flexural modulus, interfacial bonding strength and other mechanical properties were mainly related to the types of functional groups, chain structure, molecular weight, concentration, and coupling agents. The maximum value of interfacial adhesion was achieved with 3wt% concentration level for most maleate composites.

2.4 Natural fibre

The natural fibres obtained from plants and trees are reinforcement materials that attract many scholars to study about this fibre (Yusoff et al., 2009). Natural fibres are inexpensive, low density, have high specific properties, biodegradable, and non-abrasive. Natural fibres are progressively being studied for various usages in numerous structural and non-structural applications such as acoustic absorption barriers and automotive lining components. Malaysia has plenty of agricultural waste products such as coir (Cocos Nucifera) fibre, rice (Oryza Sativa) husk and oil palm (Elaeis Guinnesis) frond fibre (Zulkifli et al., 2009).

Natural fibre are not known to be hazardous as asbestos but there are concerns with the possible health effects and it is standard practice to take safety measures when installing or handling fibre glass or rock wool. The OPEFB fibres were chose to be studied in this research due to its availability and the oil palm fibre can be obtained directly from natural resources.

In the past, natural fibres are used in fabric application due to its high strength like jute, cotton and silk. These fibres are used extensively and directly in one-dimensional products like lines, ropes and cloths. While oil palm fibres, banana leaf fibres and rice stalks are residual of agriculture products and they are usually disposed into land fill or open burning. This activity causes environmental issues such as global warming and air pollution when the materials produce in large quantity. Therefore, these issues attract the technologist to study on the natural fibres (Chin, 2008).

2.4.1 Oil palm fibre

Palm fibres are extracted from empty fruit bunch (EFB). EFB is considered a waste product after the extraction of fruits from the fresh fruit bunch (FFB). Oil palm fibre is 100% natural, non-hazardous, biodegradable and environment friendly. Oil palm fibre is similarly to coir fibre due to its hardness and toughness. The fibres are versatile and sturdy. It is also strong, stable and could be easily processed into various dimensional grades to suit specific application such as in mattresses and cushion manufacture, landscaping and flat fibre board manufacture (Hamzah, 2008).

Generally, the fundamental properties of the materials can give a far insight in developing the final products with a desired property for a specific application. This knowledge also helps in industrial processing and potential use in value added products. Empty fruit bunch and the oil palm empty fruit bunch (OPEFB) fibre are shown in Figure 2.2.

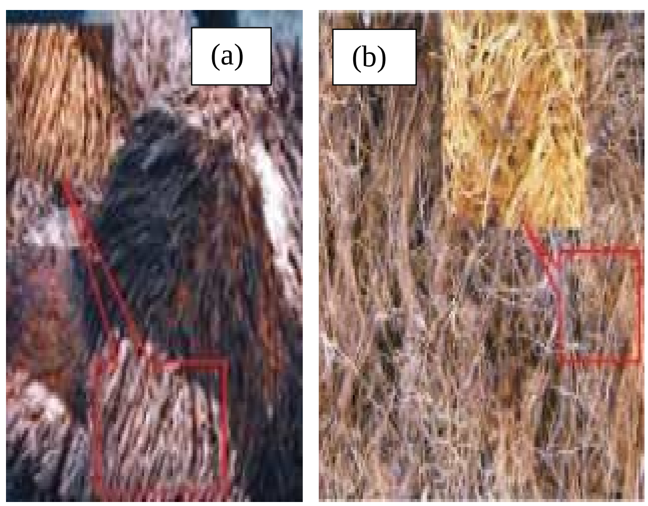

Figure 2.2: (a) Oil palm empty fruit bunch and (b) Oil palm empty fruit bunch fibers (Azman Hassan et al., 2010)

2.4.1.1 Types of oil palm fibres

Oil palm fibres are derived from two sources of oil palm tree, which are, OPEFB and mesocarp. Among these, an OPEFB fibre as shown in Figure 2.2(b) is commonly used