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ORIGINAL ARTICLE

Conceptual Design of Natural Composite Grating Platform

Ahmad Fuad Ab Ghani, Mohamad Kamarul Anwar Sahar, Muhammad Ridzuan Husyairi Azmi, Nurul Izzati Medon, Muhammad Syazwan Samsuri, and Muhammad Syurabil Abdani

Faculty of Mechanical Engineering. Universiti Teknikal Malaysia Melaka. Locked Bag 1200, Hang Tuah Jaya, 75450 Ayer Keroh, Melaka

*Corresponding author: ahmadfuad@utem.edu.my

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Abstract

There are several types of grating, such as platform, bridge decks and filters. In design process, there are several important terms that have to be prioritised; engineering design, strength to weight ratio, cost, maintainability, reparability etcetera. Advanced materials, such as composite materials offer great strength to weight ratio and high mechanical properties for grating fabrication. Furthermore the reparability and maintenance problems could be solved as it is anti corrosion and the long service life attribute of composite makes it a great design material for replacement of conventional steel or aluminium. Bio composites, such as bamboo and coir fiber yield advantage in terms of less cost and abundance availability compared to commercial unidirectional composite materials, such as glass fiber reinforced polymer (GFRP) and carbon fiber reinforced polymer (CFRP) which is considerably expensive yet possess higher mechanical properties. This papers presents a conceptual design of grating design utilizing bamboo composite as material. Pugh method has been chosen as design criteria selection matrix in finalizing the design of industrial grating for scaffolding (Pugh, 1991).

Keywords: Grating; composite grating; bamboo; natural composite.

Introduction

Scaffolding is important tool which utilized in construction industry particularly in constructing tall buildings. Platform is the scaffolding part for the maintenance personnel to stand on as well as to serve for supporting the weight of materials for maintenance or construction activity. Scaffolding which used in construction is normally made of metal poles or wooden pillars. The scaffolding also used to assist maintenance activities or building refurbishment work. Grating has many forms of pattern for instances moulded, expanded, pultruded, bar and plank. In expanded form, the grating is available in plain steel form. In plank form grating, it is normally formed by punched sheet metal or using aluminium extrusion as shown in Fig. 1(a) and Fig. 1(b).

Bamboo Composite Grating Design Materials and Methods

The advantages of using bamboo composite also known as natural composite such as anti-corrosion, anti-slip, lightweight, ergonomics, reliability and maintainability are highly considered in this proposed design work. The design intends to replace the composite metal gratings for floors, oil and gas decks, platform, jetty especially gratings which are formed mainly from metal. There are various other application of bamboo fibre composite in other industries which see similar replacement for the use of steel or fiberglass (Liu et al, 2012).

a) **b)**

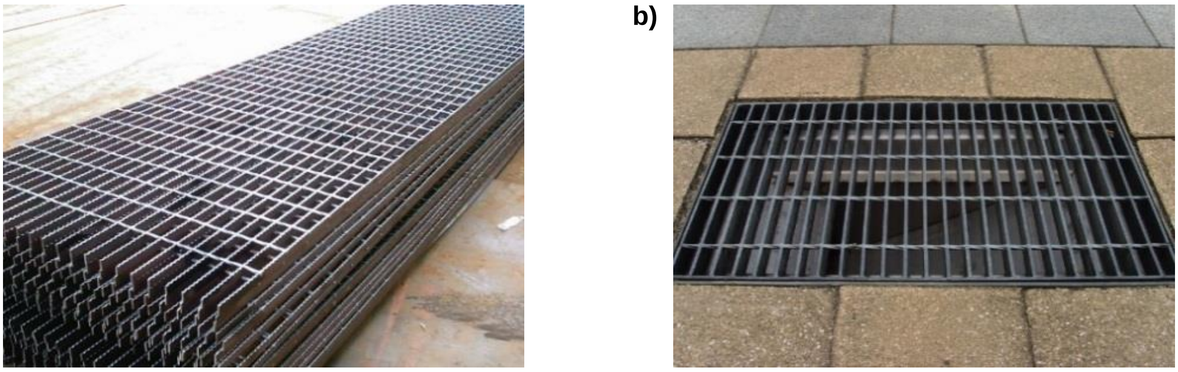


Figure 1. (a) Industrial Grating for scaffolding. **(b)** Grating used for drainage
(Source: www.metarialicious.com)

Figure 2. Example of bamboo in the market
(Source: www.bamboomoon.com)

Figure 3. Example extracted fiber fabric from bamboo
(Source: www.b92.net)

The bamboo fiber composite has significance advantages and used extensively globally as replace for the steel (Hojo et al, 2014). Fig. 2 shows application of bamboo composite in furniture industry. It is indeed more cost effective than steel due to abundance of supply available for bamboo plant. The bamboo fiber composite can be pressed into various form and sawn and sanded as shown in Fig. 3.

Objective of proposed design bamboo based grating

The aim of the project is fabricating sustainable maintenance structure/part. The objective is to replace new materials of grating which is made from steel to bamboo composite. The price of the natural composite also cheaper since bamboo is easily found compared to steel which has to undergo complex processes in order to be produced. The bamboo is also much lighter and yet stiff although lower than the steel (Jones, 1998). The weight of the composite bamboo is very light which offer high maintainability aspect for scaffolding structure. It will directly contribute to less efforts needed to lift, install and dismantle activities during maintenance or construction.

Proposed Design

Three proposed shape of grating by the use of bamboo composite are as shown in Fig. 4. The primary advantages of easy to manufacture, easy to maintain, consideration of flow of air during service, cost saving element and material compressive strength/flexural strength are considered during design stage for this grating design.

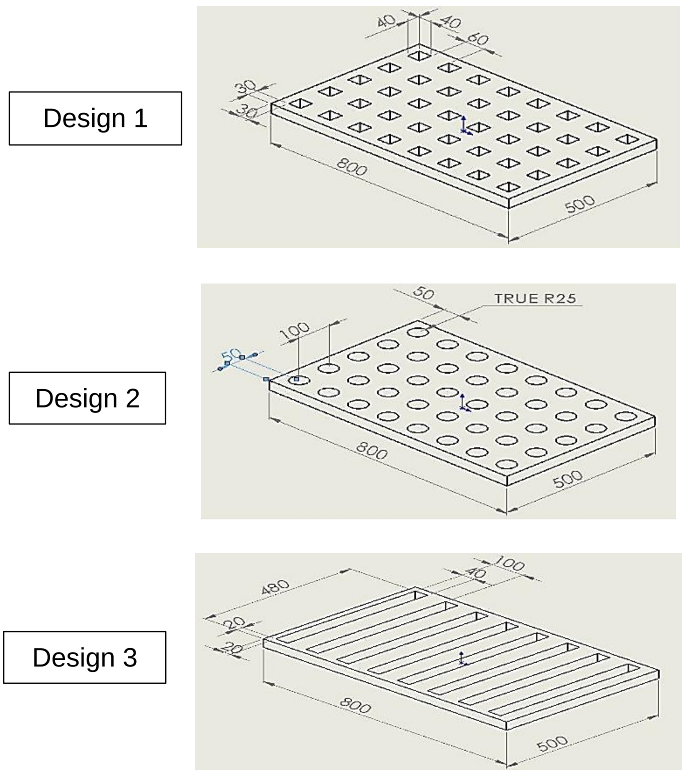


Figure 4. Proposed design for the grating platform

Physical and Mechanical Properties of Bamboo

Normally, bamboos consist of the culm, roots and leaves (Liese, 1986). They are usually hollow with varying in sizes, diameters, colours and textures. Numerous black spots could be noticed at the cross section of the culm where these are cellulose fibers acts as channel of carrying nutrients (Saheb & Jog, 1999). According to the analysis of mechanical properties of the bamboos, the investigation of behaviour specimen is different according to the materials under different loading conditions which is the types of the bamboo used (Thwe and Liao, 2000). Information about the deformation behaviour, such as tensile strength, compressive strength, shear strength, flexural strength, hardness test, stress state and the failure behaviour of different bamboo species in different forms are important parameters which are essential from design perspective including this project. Generally, bamboo is an orthotropic material (Wambua et al, 2003). Different test techniques, specimen preparation and test data have been studied for typical bamboo species in terms of fiber extraction, chemical treatment and composite formation. Some of the important mechanical properties of bamboo plywood are as below, (Nugroho & Ando, 2001):

Density (kg/m^3)	:	Longitudinal (700), Transverse (700)
Elastic Modulus (MPa)	:	Longitudinal (17500), Transverse (1750)
Poisson Ratio	:	Longitudinal (0.39), Transverse (0.04)
Shear Modulus (MPa)	:	Longitudinal (1285), Transverse (201)
Tensile Strength (MPa)	:	Longitudinal (240), Transverse (37.5)
Compressive Strength (MPa)	:	Longitudinal (80), Transverse (70)
Fatigue Strength (MPa)	:	Longitudinal (34.3), Transverse (10.735)

Conceptual Design of Bamboo Grating

The design and development of a new grating platform of the scaffolding is based on Pugh's total design process model (Pugh, 1991). The main human aspects that needs to be consider for the platform (also known as gratings) is the width of human foot (standing posture) which are needed to ensure that the designed product can be adapted to suit the majority of users . With the proposed fiber grating, user have a cheap solution to elevate grating 0.6 inch above the ground for required water flow, creating an anti-slip and ergonomic platform. The open mesh of the grating permits fluids to fall below the standing region. This protects users in assisting to eliminate slip and falling. Product design specification (PDS) are used to determine the safety of the product. It is performed by doing analysis on design and fabricating the structure of the grating based on specific criteria. Performance, safety (industrial material handling), weight, material, cost, machining, ergonomics and reliability were chosen in order to make the best grating platform for scaffolding (Table 1).

Concept Generation

Table 2 shows the concept generation considering the aspects of design elements discussed earlier in Product Design Specification. It is then synthesized and compared with each other design (1 and 2) for different material. Advantages and disadvantages from mechanical, design, safety perspective are discussed and assessed.

Table 1 Product design specification for grating platform

No.	Criteria	Specifications
1.	Performance	• Can support body weight of maximum 100 kg • A good rigid frame
2.	Safety	• Should not harm the workers to do work • The platform should not shake when the air flows on the surface.
3.	Weight	• Must be below than 5 kg
4.	Material	• Strong • Easy to fabricate • Low cost • Easy to get • Easy to form shape
5.	Cost	• Low cost relative to conventional unidirectional composite
6	Machining	• Ease to manufacture
7.	Ergonomics	• The design features are considered about the area which is relate with the maximum weight and also the maximum worker • User friendly • Practical for worker
8.	Reliability	• The stress and the strength of the product will be considered by simulating load on the grating during testing

Concept Evaluation

The Pugh Method was used to select the best conceptual design (Pugh, 1991).This method compares the material for each design and the criteria used in PDS table. The result is shown in Table 3. The best conceptual design with the highest score of +'s was selected. Table 3 clearly shows that Design 2 which grated with bamboo was selected with the best performance, safety, weight, cost, machining, ergonomics and reliability.

Fabrication Works

There are numerous methods for fabricating composite components. Selection of a method for a particular part, therefore, will depend on the materials, the part design and end-use or application. In this project the technique of hand layup was used to produce the composite platform. This technique typically consists of laying dry fabric layers, or "plies", or prepreg plies, by hand onto a tool to form a laminate stack. Resin was applied to the dry plies after layup is complete. In a variation known as wet layup, each ply is coated with resin and compacted after it is placed. Fiber bamboo, resin and fiberglass are the main material in forming our composite material. There are a few steps before the start of the fabrication process. First was to choose the ratio for each material. This ratio is important in order to ensure the composite stiffness and strength as needed. Based on the ratio the weight for each material was computed Based on literature, the common ratio commonly used was 50% for resin, 30% for bamboo fiber and 20% for fiberglass.

Table 2. Characteristics for each conceptual design

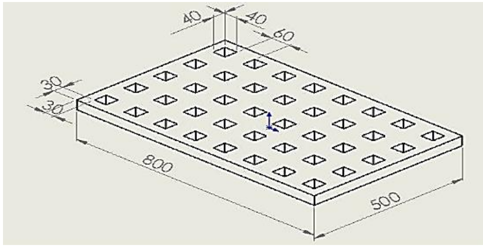
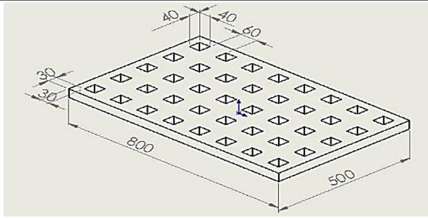
Type of design	 **Design 1**		 **Design 2**	
Product design specification	**Bamboo**	**Coir Fiber**	**Bamboo**	**Coir Fiber**
Performance	Great rigid pillar in fiber direction. Can support up to 100 kg.	Great in compressive but lower in bending.	Great rigid pillar in fiber direction. Can support slightly lower than 100 kg due to hollow section.	Great in compressive but lower in bending and stress concentration on hollow section.
Safety	Stable and lighter. Withstand to the compressive force and bending.	Anisotropic in properties, inconsistent throughout volume. Might subjected to crack.	Stable and lighter. Withstand to the compressive force and bending.	Anisotropic in properties, inconsistent throughout volume. Might subjected to crack.
Weight	In range of 1 to 1.25 kg.	About 2 kg.	Approximately 1 kg.	In range of 1 to 2 kg.
Material	Abundance in supply. Higher modulus and tensile/ compressive strength.	Easily available. Need to form a shape. Have high strength in compact form.	Abundance in supply. Higher modulus and tensile/ compressive strength.	Abundance in supply. Lower modulus and tensile/ compressive strength.
Cost	Low cost material, extracting of fiber.	Low cost material, extracting of fiber – slightly lower than bamboo.	Low cost material, extracting of fiber.	Low cost material, extracting of fiber – slightly lower than bamboo.
Machining	Easy to manufacture without changing the natural form. Need specific size and dimension to cut the section.	Requires a mold to produce design shape. Need a compressed machine to compress material after layup.		
Ergonomics	Capability of maximum weight of two people. Low maintenance and lightweight.	Capability of maximum weight of two people. Low maintenance and lightweight.	Capability of maximum weight of two people. Low maintenance and lightweight.	Capability of maximum weight of two people. Low maintenance and lightweight.
Reliability	Reasonable compressive strength and shear strength due to bending with the help of pillars underneath.	Slightly less than bamboo on compressive strength and shear strength due to bonding.	Reasonable adequate compressive strength and shear strength due to bending with the help of pillars underneath.	Slightly less than bamboo on compressive strength and shear strength due to bonding.

Table 3. Conceptual design evaluation using Pugh (1991) Method

Type of design

Design 1



Design 2

Characteristics	Weight	Bamboo	Coir Fiber	Bamboo	Coir Fiber
Performance	**4**	+	-	+	-
Safety	**4**	-	-	+	-
Weight	**3**	-	-	+	+
Cost	**3**	+	+	+	+
Machining	**2**	+	+	-	-
Ergonomics	**3**	+	+	+	+
Reliability	**4**	+	-	+	-
Total +		5	3	6	3
Total -		2	4	1	4
Overall Score		3	-1	5	-1
Weighted Total +		16	8	21	9
Weighted Total -		7	15	2	14
Weighted Overall Score		9	-7	19	-5

There is example of calculation to analyse the weight of each material (Nugroho & Ando, 2001);

Volume of composite:

Height x Wide x Thickness

130 mm x 68 mm x 25.4 mm = 224536mm^3 = 2.24 x 10^{-4} m^3

Volume of Resin = 0.5 x 2.24 x 10^{-4} =1.122 x 10^{-4} m^3

Volume of Bamboo fiber = 0.3 x 2.24 x 10^{-4} = 6.72 x 10^{-5} m^3

Volume of Fiberglass = 0.2 x 2.24 x 10^{-4} = 4.48 x 10^{-5} m^3

$$\rho, \text{density} = \frac{M, \text{mass}}{V, \text{volume}} \qquad M = \frac{\rho}{V}$$

Table 4. The data of each material

Material	Density (kg/m^3)	Volume (m^3)	Mass (kg)
Resin	10700	1.122 x 10^{-4} m^3	1.2
Bamboo Fiber	40000	6.72 x 10^{-5} m^3	2.6
Glass Fiber	32000	4.48 x 10^{-5} m^3	1.4

Moulding was used in order for getting precise size of the composite grating platform. The size of this moulding is 135 mm x 73 mm x 40 mm. The original moulding size is then extended to an extra of 5 mm then the actual size after taking into account the finishing process. The fabricated platform has 8 layers of fiber bamboo and fiberglass where first layer is fiberglass and the second layer is fiber bamboo and repeated until final layer. The resin was poured and distributed evenly before the new layer. Resin acts as a binder between fiber bamboo and fiberglass. The entrapped air in each layer should be removed because this entrapped air can cause the strength of composite lower and also it can make the composite easy to break. In this project the entrapped air removed manually with roller to complete the laminate structure.

Lastly, it was dried in a room temperature. Curing is initiated by a catalyst in the resin system, which hardens the fiber reinforced resin composite without external heat. Pigmented gel coat also applied to the mold surface prior the start of the layup process.

(a) (b) (c) (d) (e) (f)

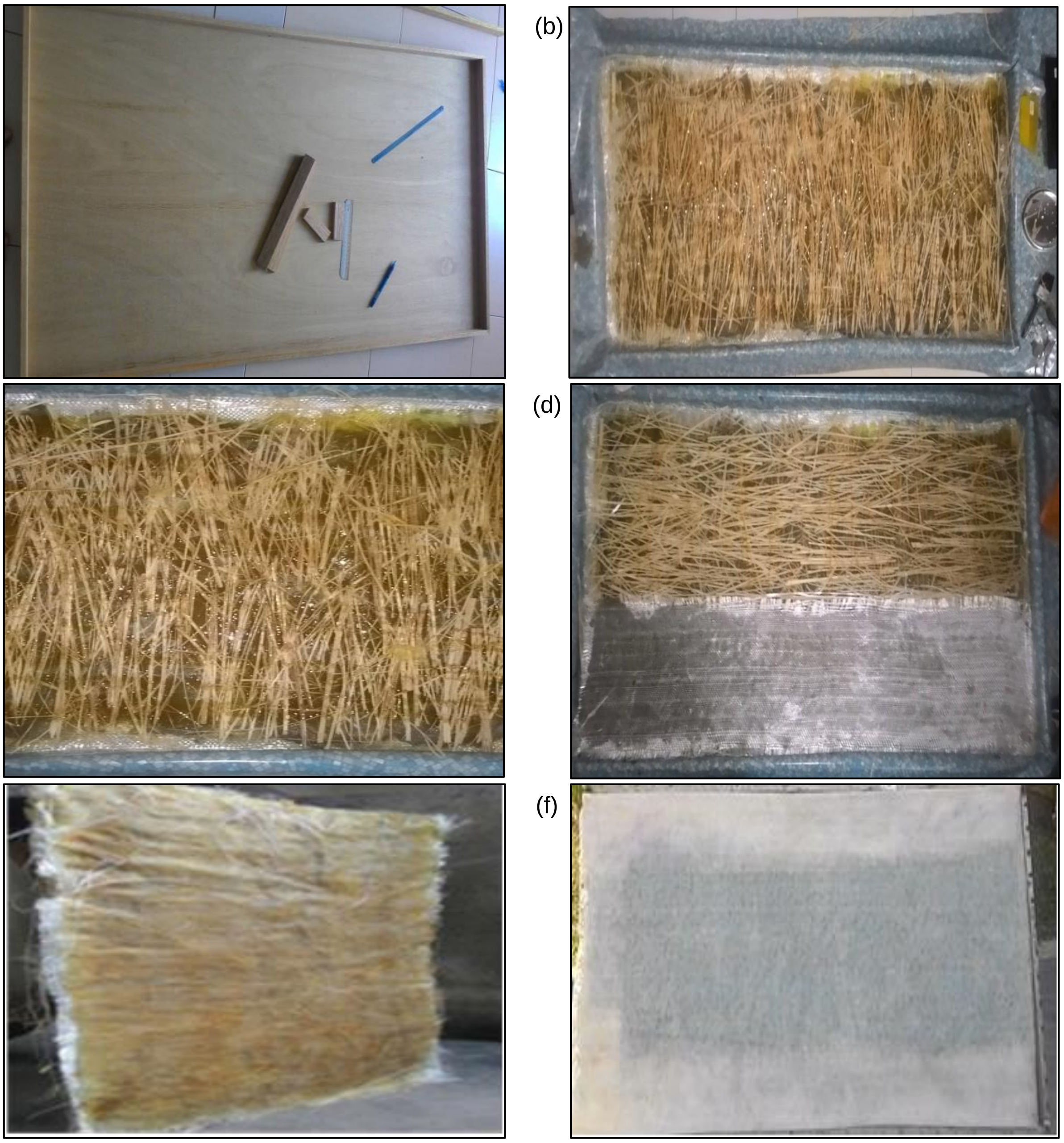


Figure 6 (a) Moulding frame **(b)** First layer of composite **(c)** 2nd layer of composite grating **(d)** 3rd layer of composite grating **(e)** Final layer of composite grating **(f)** Finished product of natural fiber grating

Conclusion

Bamboo grating has been studied, designed and fabricated at Faculty of Mechanical Engineering (FKM), Universiti Teknikal Malaysia Melaka (UTeM). Product design specification (PDS), concept generation, Pugh method for criteria decision making process during design has been performed in order to decide and select the best design from safety, performance, reliability, cost and mechanical properties perspective (Pugh, 1991). Bamboo based composite grating with holes in sectioning has been selected due to matching the best criteria set in Pugh selection method, yet additional pillars and reinforcement is proposed to strengthen the structure prior used during service stage (Pugh, 1991).

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