# RESPONSE OF FIBRE METAL LAMINATE UNDER LOW VELOCITY IMPACT

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**Report**

**Projek Sarjana Muda I**

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**SUPERVISOR'S DECLARATION**

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Date : …………………………………………………..

**APPROVAL**

I hereby declared that the work of this thesis is fully done by my own with some exceptions on for the summaries and quotation which had been acknowledged.

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Name : ………………………………………………….

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# ABSTRACT

Fibre metal laminate (FML) composite is a widely used material as a structural application for automotive, aerospace, aircraft and ship due to its lightweight, low maintenance cost and outstanding strength to weight ratio. It is the new family of laminate composites which consists of thin metal layers that bonded together with the fibre-reinforce composite layer. In past decades FML had become an interest in modern industry. This is because hybridisation of both natural and synthetic fibre enhances the mechanical properties and environmental performance. Furthermore, FML has low production cost and are used in wide applications. Therefore, to implement the usability of FML an understanding of its mechanical properties should be investigated. Therefore a study had been carried out to find the properties of this FML with its hybridisation composite under a low velocity impact test where and experimental and numerical had been carried out it this study. The variable used in this study is the stacking sequence of the fibre composite in the FML where there will be four stacking sequence (GGG, GPG,PGP,PPP) for the experimental investigation. For the numerical analysis, the variable would be the metal thickness of how those the metal thickness play a role is changing the properties of the FMLs. From the study, it had found out that FML with the stacking configuration of GPG able to a suitable substitute for FML with the configuration of GGG due to its similarity it most of its properties analysis and for the metal thickness the optimal thickness that can used for the shell of the FML would be 1.0 mm where too thick of the metal will cause a higher chance of delamination to occur where else too thin of the metal would cause perforation to occur easily on the FML

## ABSTRAK

Komposit laminasi logam adalah bahan yang banyak digunakan di dalam aplikasi automotif, aeroangkasa, pesawat dan kapal kerana keringanan, kos penyelenggaraan yang rendah dan nisbah kekuatan dan berat yang luar biasa. Ini adalah salah satu keluarga komposit lamina baru yang terdiri daripada lapisan logam nipis yang dicantumkan bersama dengan lapisan komposit penguat serat. Dalam beberapa dekad yang lalu komposit laminasi logam telah menjadikan minat dalam industri moden. Ini kerana hibridisasi gentian semula jadi dan sintetik meningkatkan sifat mekanikal dan prestasi persekitaran. Tambahan pula, FML mempunyai kos pengeluaran yang rendah dan digunakan dalam aplikasi yang luas. Oleh itu, untuk melaksanakan kebolehgunaan FML, pemahaman mengenai sifat mekaniknya harus diselidiki. Oleh itu, kajian telah dilakukan untuk mencari sifat FML ini dengan komposit hibridisasi di bawah ujian hentaman halaju rendah di mana dan eksperimen dan numerik analisi telah dilakukan dalam kajian ini. Ubahan yang digunakan dalam kajian ini adalah urutan susunan komposit serat di FML di mana akan ada empat urutan susunan iaitu (GGG, GPG, PGP, PPP) untuk penyelidikan eksperimen. Untuk analisis berangka ubahan yang dilakukan ialah ketebalan logam iaitu bagaimana ketebalan logam memainkan peranan mengubah sifat FML. Dari kajian tersebut, didapati bahawa FML dengan konfigurasi susun GPG dapat menjadi pengganti yang sesuai untuk FML dengan konfigurasi GGG kerana kesamaannya dengan kebanyakan analisis sifatnya dan untuk ketebalan logam optimum yang dapat digunakan untuk cengkerang FML akan menjadi 1.0 mm di mana  tebal logam yang terlalu tebal  akan menyebabkan pemisahan yang lebih tinggi di mana yang unuk terlalu tipis logam akan menyebabkan perforasi berlaku dengan mudah pada FML.

## ACKNOWLEDGEMENT

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# LIST OF ABBREVIATIONS

| | |
|---|---|
| FML | Fiber Metal Laminate |
| LVI | Low Velocity Impact |
| GGG | Glass/Glass/Glass epoxy composite |
| GPG | Glass/Pineapple/Glass epoxy composite |
| PGP | Pineapple/Glass/Pineapple epoxy composite |
| PPP | Pienapple/Pineapple/Pineapple epoxy composite |

# LIST OF SYMBOL

| | |
|---|---|
| E | Young’s modulus |
| G | Shear modulus |
| ν | Poisson’s ratio |
| $X_t$ | Ultimate tensile stress |
| $X_c$ | Ultimate compressive stress |
| S | Ultimate shear stress |

# CHAPTER 1

# INTRODUCTION

## 1.1 Background

Fibre metal laminate (FML) composite is a widely used material as a structural application for automotive, aerospace, aircraft and ship due to its lightweight, low maintenance cost and outstanding strength to weight ratio. Fibre metal laminates (FML) was developed at Delft University of Technology in The Netherlands during the beginning of the 1980s. (Asaee, Shadlou and Taheri, 2015). It is the new family of laminate composites which consists of thin metal layers that bonded together with fibre-reinforce composite layer. (Salve, Kulkarni and Mache, 2016).

From its superior characteristic, it had lured many interests in researchers to carry out a study on FML which had led them in exploring hybrid composite. Hybrid composites are the combination of different type of fibres bonded together by its reinforcement. This hybridization commonly usually occurs between natural fibres and synthetic fibres(Akil *et al.*, 2011). Both fibres have their advantages and disadvantages. For an instant natural fibre are much cheaper and environmentally friendly than synthetic fibres where else synthetic fibre have a better mechanical property. By combining both fibres in the same matrix of the composite it will result in full advantage of the best properties of the constituents, and thereby an optimal, superior but economical composite can be obtained.

Therefore, throughout the years, several types of FML had been introduced base on the metal plies. Figure 1 shows the classification of the FML's.

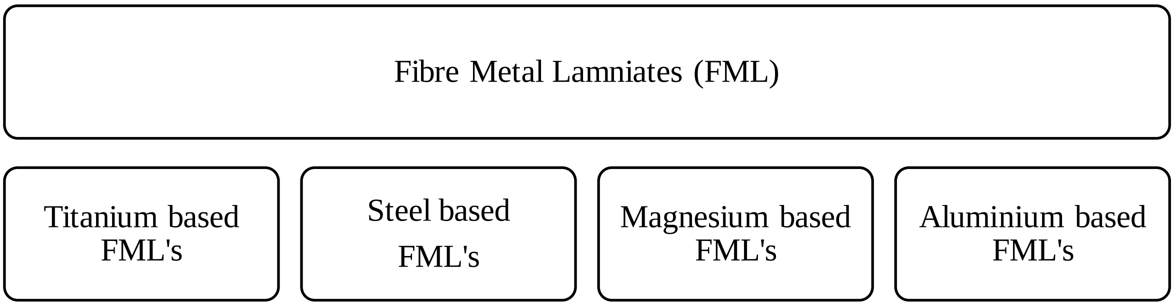


Figure 1. 1: Classes of FML’s

These days the widely used fibre metal laminate is glass-reinforced aluminium laminate (GLARE), based on high-strength glass fibres. This is due to its superior damage tolerance, better corrosion resistance, better fire resistance, and lower specific weight when compared to its metal (Wu and Yang, 2005). Therefore, a better understanding must be done on GLARE on its damage tolerance and strength to widen its usability based on complex applications.

## 1.2 Problem Statement

In past decades FML had become an interest in modern industry. This is because hybridisation of both natural and synthetic fibre enhances the mechanical properties and environmental performance. Furthermore, FML has low production cost and are used in wide applications. Therefore, to implement the usability of FML an understanding of its mechanical properties should be investigated.

## 1.3 Objectives

The objectives of this project are as follow:

1. To investigate the behaviour of FML with different woven lay-up of pineapple/glass fibre reinforcement composite which is subjected to low velocity impact.
2. To build a finite element model of FML for low velocity impact test.
3. To investigate the effect of metal thickness on FML that is subjected to low velocity impact.

## 1.4 Scope of Project

The FML test specimen for this project was prepared with different woven lay-up of pineapple/glass fibre reinforcement composite with the sample size of 150mm ×100mm. This sample is then tested under low velocity impact according to ASTM D7136. Then a finite element software ABAQUS/Explicitis was used for the simulation of low velocity impact on FML with a different metal thickness which consists of glass epoxy composite with the modal size of 150mm ×100mm. The results that had been obtained from both tests were be compared and analysed to find the optimal laminate composite layout.

# CHAPTER 2

# LITERATURE REVIEW

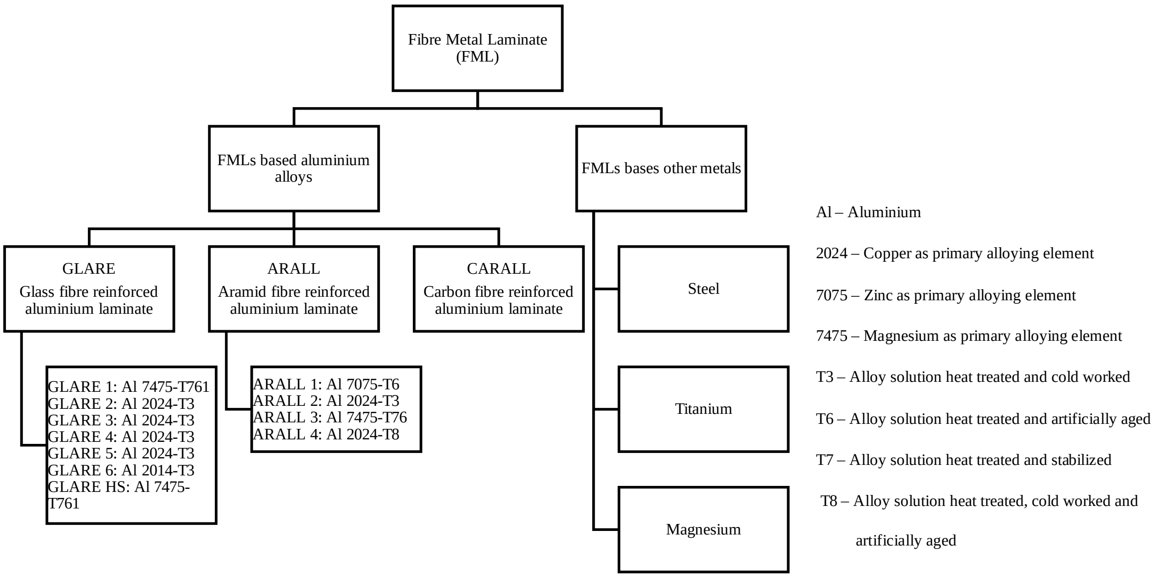
## 2.1 Introduction

This research literature review is the most crucial part that able to provide a proper understandings and guidelines base on the previous study that had been done regarding the research. The aim of this chapter is to widen the understandings and comparing the research of different authors on fibre metal laminate (FML) base on its constituents, mechanical properties, investigation on low-velocity impact test and compression strength after impact.

## 2.2 Fibre Metal Laminate

Fibre metal laminate or known as FML is a family of hybrid composite structure which having metal sheet bonded together with fibre reinforced polymer composite. The outside layer of a fibre metal laminate is a metal sheet shielding the fibre reinforcement polymer from moisture and scratches (Zhu and Chai, 2012). The polymer can be classified into two categories which are thermosets and thermoplastic. The most commonly used thermosets are phenolic, epoxy and polyester resins where else, on the other hand, the most commonly used thermoplastic is polypropylene (PP), polyethene (PE) and polyvinyl chloride (PVC).

Throughout the years' fibre metal laminate had grown major interest among the researches due to increasing demand for its superior lightweight, durable, and damage




tolerance material (Zhen, 2015). The common metals that are been used to fabricate fibre metal laminate are aluminium, magnesium, or titanium and the common composite reinforcement are glass fibre, carbon-fibre, or kevlar. Figure 2.1 shows the type of FML's that had been developed base on its metal and reinforcement.

Figure 2. 1: Type of FMLs where 'Al xxxx' defines the major aluminium alloying constituent and 'Txxx' demonstrates the type of heat treatment and tempering performed to the alloy solution (Das *et al.*, 2016).

Fibre metal laminate has optimal fatigue and fracture properties of fibre reinforced composite and superior durability characteristics of metal while at the same time eliminates their drawbacks (Zhen, 2015). Mechanical properties of the fibre metal laminate are influenced by certain factors such as the type of metal being used, matrix reinforcement, metal volume fraction and fibre volume fraction. Metal volume fraction (MVF) is defined as the ratio of the sum of the individual metal thickness to the thickness of the fibre metal laminate. The material properties base on metal volume fraction is determined by:

$$FML\ property\ = MVF + Metal\ Property + (1 - MVF) \times Fibre\ propert \qquad (1)$$

This equation can predict the tensile strength yield of the fibre metal laminate with a range of $0.45 < MVF < 0.85$ with the accuracy experiment results of 5% (Zhu and Chai, 2012). The fibre content in the composite also plays an important role in the mechanical properties where it enhances the impact resistance as the fibre percentage increase (Zhen, 2015). Fibre that aligned in loading direction is found to be having an improve considerably the modulus of elasticity, yield strength and ultimate tensile strength of the fibre metal laminate (Zhu and Chai, 2012). This shows that the orientation of the fibre is important in the fabrication of the fibre metal composite base on the applications. Figure 2.2 shows the composite reinforcement types.

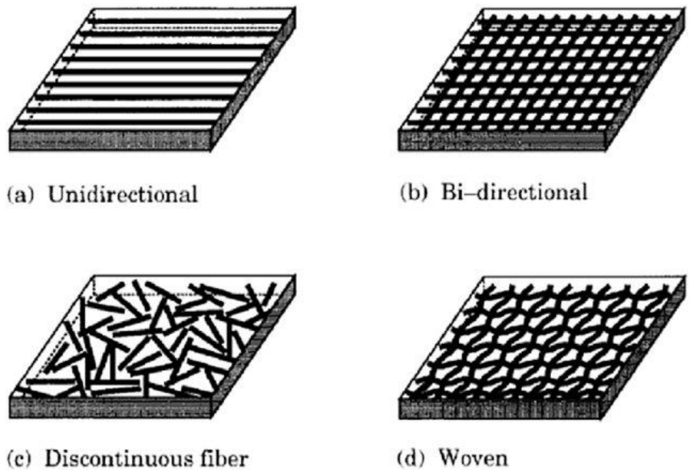
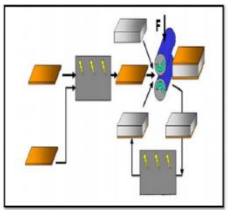
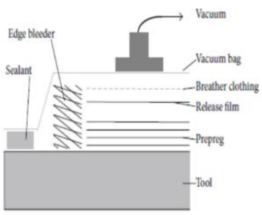



Figure 2. 2: Composites reinforcement types (Tawfik *et al.*, 2017).

There are several ways to fabricate fibre metal laminates. The fabrication process is depending on the type of reinforcement being used and the type of matrix used. Fabrication consists of four steps which are pre-treatment, preparation of prepreg, production of FML and post-treatment. Firstly, pre-treatment is required to obtain a proper bonding of the metal plate with the reinforcement. Secondly, is the manufacturing of the prepregs where the fibre is manufacture by a desirable dimension and is pre-impregnated with either thermoplastic or thermoset resin matrix with a certain ratio under a suitable designated curing condition. Then moving on with the fabrication of the fibre metal laminate where there are many methods of fabricating: hand layup, stamp forming, autoclave and Resin Transfer Moulding (RTM). Finally, is the post-treatment of the fibre metal laminate where the curing process of the resin that had been introduced into the reinforcement (Logesh *et al.*, 2017). Table 2.1 describes the

| Fabrication method | Descriptions |
| --- | --- |
| Hand Layup  | i. The reinforcement is usually in the form of fabrics, fibres, or powders where it is been mixed with resin and being bonded with metal skin.<br>ii. A moderated amount of pressure is applied to the skin in the form of pressing by hand or roller.<br>iii. Enough time is allowed for proper bonding. |
| Stamp Forming   | i. Stamp forming is similar to hand layup technique except heavy force is applied for the bonding process.<br>ii. The laminate and the prepreg are arranged as desired over the cavity of a blank and pressure is applied.<br>iii. The design of the FML is based on the shape of the die used. |
|   Autoclave | i. The prepregs and the polythene sheets are stacks between one another between a pre-treated metal laminate.<br>ii. Then it is placed into the autoclave and vacuumed.<br>iii. Pressure and heat are then applied to enhance the bonding between the metal and the prepregs. |

fabrication method of fibre metal laminate.

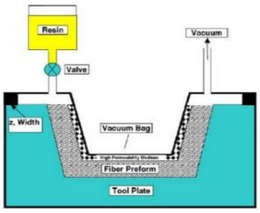
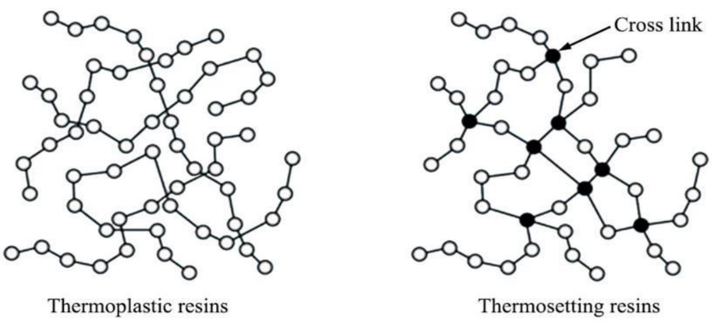
| | |
|---|---|
| Resin Transfer  Moulding | i. The reinforcement and the metal skin are arranged and are placed into a mould.<br>ii. The resin is then injected in to mould over the reinforcement with high pressure.<br>iii. Then the FML is left for curing for retained its desirable properties. |

Table 2. 1: Fabrication method of fibre metal laminate(Logesh *et al.*, 2017).

**2.3 Matrix**

Matrix is a medium that is used in making composite materials by embedding the reinforcement. The functions of the matrix are to transfer the load to the reinforcement of the composite and protect the reinforcement from mechanical and environmental damages. Three classifications of the matrix's being used which are a metal-ceramic matrix, metal matrix, and polymer matrix. In this review, polymer matrix would be the main interest due to certain advantages that gives the composite which is highly specific strength and high specific modulus.

The polymer matrix can be classified into two main groups which are thermoset (e.g., Polyester, Epoxy, Phenolic resins, etc.) and thermoplastics (e.g., Polypropylene, Polyethylene, Polyvinylchloride, etc.). It is known that the processing of thermoset composite




is much easier compared to thermoplastic due to the presence of the initial resin system in a liquid state where thermoplastic composite required an application of higher heat and pressure (Dogan and Arıkan, 2017). Besides, it is known that thermosets have a higher strength and stiffness compare to thermoplastic but has a lower ductility. The ductility of the thermoset can be explained by the molecular structure of the thermoset which is bonded together with crosslink and held by a strong covalent bond where else for thermoplastic do not have a permanent crosslink which benefits it by reheating and reshaping (Karuppiah and Engineering, 2016). Figure 2.3 shows the difference in the molecular structure of thermoplastic and thermoset.

Figure 2. 3: Molecular structure of thermoplastic and thermoset (Karuppiah and Engineering, 2016)

The distinguishing characteristic of thermosets compares to a thermoplastic that thermoset polymer cannot be remoulded or reform after the hardening process and this has given an advantage to thermoplastic. Therefore, it can be stated that thermosets are stiffer and strong compare to thermoplastics.

## 2.4 Reinforcement

Reinforcement composite gives a superior mechanical property to the composite. Most commonly phases of reinforcement will be fibre, particles, and flakes. The usually used reinforcement can be categorised into two classes which are synthetic fibre and natural fibre. Figure 2.4 shows the classification of natural and synthetic fibres.

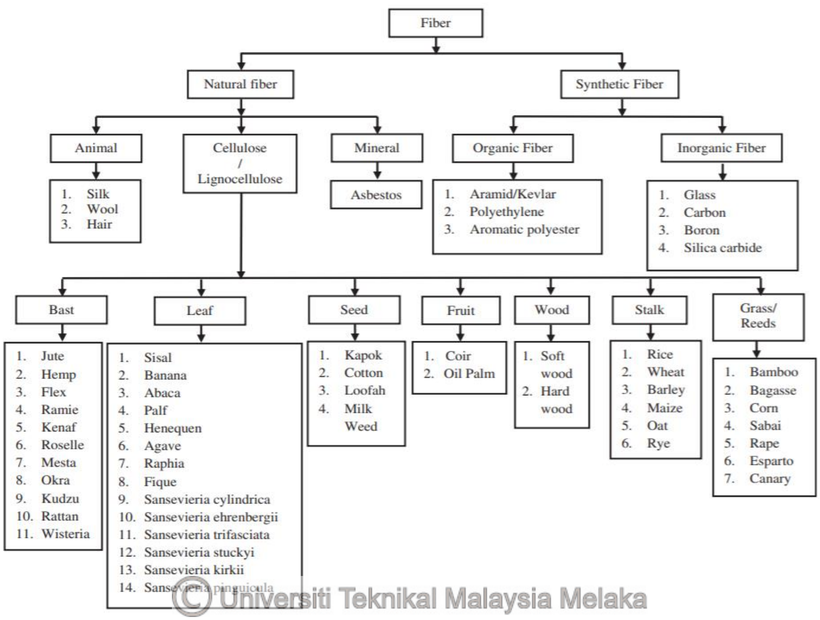
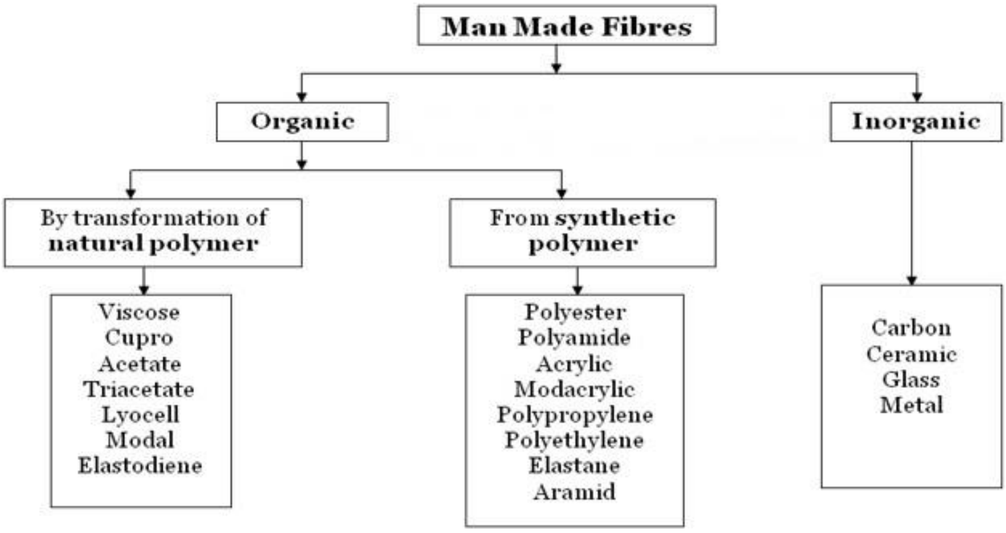


Figure 2. 4: Classification of natural and synthetic fibres (Jawaid and Abdul Khalil, 2011).

### 2.4.1 Synthetic Fibre

Synthetic fibre is known as a man-made fibre made from synthesized polymers or other small inorganic molecules). It was usually known that synthetic fibre has better mechanical properties compared to natural fibre. Synthetic fibre had been improved by scientists as a replacement option for metallic material. The main advantage of synthetic fibre is that it has high tensile modulus, ultimate strain, and low specific gravity but the downside




of it is that they are not recyclable after the end of the lifespan. Figure 2.5 shows the classifications of synthetic fibres.

Figure 2. 5**:** Classifications of synthetic fibres ( adapted from https://goo.gl/pUqixR).

#### 2.4.1.1 Glass Fibre

Glass fibre falls under the classification of synthetic fibre. Glass fibre is known to be one of the most famously used fibre among the others due to low-cost fabrication with comparable properties with other fibres. The fabrication process of fibre glass is that glass will be placed into the furnace and heated up to a very high temperature while the furnance temperature is kept control to attain a consistency glass flow. Once the molten glass is formed it will be extruded to fibre form (Arunabha Batabyal, Ramesh Kumar Nayak, 2018).