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MECHANICAL, THERMAL CONDUCTIVITY AND SOUND INSULATION PERFORMANCE OF INTER AND INTRALAYER GLASS-JUTE/EPOXY HYBRID WOVEN COMPOSITES

A thesis

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بِسمِ اللهِ الرحمنِ الرحيم

(وَلقَـــد آتينـــــا داوُوُد وسُلَيمان علمـــًا وقـــــالا

الحمـــــدُ لِلـــه الذي فضلَنـــا علـــى كثيـر مِـــن

عِبـــــادِه المؤمِنـــــين)

صَدقَ اللهُ العَلي العَظيم

(سورة النمل: الآية ١٥)

Dedication

To my mother & father

To my family

To my supervisor

With love and respect

ABSTRACT

Nowadays, the plant-base fibers have been widely used instead of synthetic ones due to their eco-friendly, biodegradability, abundance and lower cost in comparison to synthetic fibers which are relatively more expensive and have negative effects on the environment. However, natural fibers have mechanical properties generally lower than those of synthetic fibers. To make a balance between the disadvantages and advantages of the natural and synthetic fibers, fiber hybridization was employed.

In this work, jute (J) and plain weave E-glass (G) fabrics were hybridized in the form of interply and intraply configurations to fabricate different hybrid epoxy reinforced composites using hand lay-up method. All composite samples were laminated with five plies. Interply hybrid composites were fabricated with three lamination sequences: G3JG, GJGJG, and 2GJ2G; meanwhile, intraply hybrid composites with alternative replacement of glass yarns in both warp and weft directions by jute yarns included G_1J_1 (in which a single E-glass yarn was replaced by a single of jute yarn) and G_1J_2 (in which a single E-glass yarn was replaced by two of jute yarns). Pure glass and pure jute/epoxy composites were also fabricated. Ninety-one samples were prepared to conduct mechanical tests such as tensile, flexural, and impact according to the ASTM and ISO for each test, and some of physical tests such as thermal conductivity and sound insulation to find which composite has the best performance for each mentioned test.

Results showed that increasing the glass content in the interply hybrid composites increased their tensile properties. G_1J_2 and G_1J_1 intraply hybrid composites gave almost the same tensile modulus but differ in the tensile strength where G_1J_1 samples give tensile strength of about 41% higher than that of G_1J_2 samples. However, flexural properties have reached their maximum values for

2GJ2G composites followed by GJGJG and they were more than those of pure glass composite counterparts, where give flexural strength equal to 2.25 and 1.62 times the strength of pure glass composites, respectively. G_1J_1 intraply hybrid composites showed higher flexural strength but lower flexural modulus than that of pure glass counterparts. Pure glass composites offered the highest impact strength among other composites. The reduction in the impact strength of 2GJ2G and GJGJG were about only 4% and 16% when compared with pure glass counterparts, respectively. Meanwhile, GJGJG provided the highest specific impact strength followed by 5G, 2GJ2G, G_1J_2, G_1J_1, G3JG, and 5J composites, respectively. Increasing the content of jute fibers within the hybrid composite would decrease its thermal conductivity. Thermal insulation per thickness of jute/epoxy composites is about three times of glass/epoxy counterparts. G3JG interply hybrid composite provided thermal resistance per thickness about 80% higher than that of pure glass counterparts. G_1J_1 composites offered a slightly lower thermal insulation than interply hybrid composites with GJGJG configuration although they have almost similar fiber hybridization ratio. Regarding the sound insulation, increasing jute fiber content within the hybrid composite did not necessarily mean increasing its ability to insulate the noise. Nevertheless, G_1J_1 intraply hybrid composite offered the highest sound insulation ratio per thickness among all fabricated composites.

In summary, partial replacement of glass fiber (ply or yarn) by jute fiber counterparts could be successfully used in the applications that require intermediate mechanical properties and better insulation against heat and sound transfer if the cost and environment are the main concerns.

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Maysam Iqbal Hasson

2022

CERTIFICATION

We certify that this thesis entitled "**Mechanical, thermal conductivity and sound insulation performance of inter and intralayer glass-jute/epoxy hybrid woven composites**" was prepared by **Maysam Iqbal Hasson** under our direct supervision at the University of Babylon in a partial fulfilment of the requirements for the degree of Master of Science in Mechanical Engineering (Applied Mechanics). We recommend that this thesis be forwarded for examination in accordance with the regulation of the University of Babylon.

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Date: / /

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LISTS OF ABBRIVATIONS

ASTM	American Society for Testing & Materials
G	Glass fiber
HCs	Hybrid composites
ISO	International Standardization Organization
IR	Sound insulation ratio
IR_T	Sound insulation ratio per millimeter of thickness
J	Jute fiber
NaOH	Sodium hydroxide
SPL	Sound pressure level

CHAPTER ONE

INTRODUCTION

1.1 General

In recent years, polymer matrix composites have been used widely in the structures that require high stiffness and/or strength relative to their weight especially aerospace and automotive industries [1]. Synthetic fibers like glass, Kevlar and carbon have been commonly utilized in the fabrication of some composite structural parts of these applications for several decades ago instead of metal-base materials. Although these composites approved their ability to withstand exerted loadings, they have detrimental effects on the environment and their relatively high cost of production as well. Increasing the environmental awareness has enforced engineers to search for alternatives to reduce the cost and the detrimental effects of the extensive use of synthetic fibers within fiber reinforced polymeric matrix composites. One of these methods is by using natural fibers like jute, kenaf, sisal, flax, bamboo etc. instead of synthetic fibers to reinforce the composites, although they exhibited lower mechanical properties than synthetic fiber composites. With the aim of making a good balance between the acceptable mechanical properties of the composite material products and their lower detrimental impacts on the environment with lower cost, hybridization of natural-synthetic fibers has been used [2][3]. Moreover, natural fibers offer good thermal and acoustical properties due to their structures. Recently, many scientists and engineers have expressed interest in changing from synthetic to natural fibers in polymer matrix composites owing to their lower cost, lower density, ecofriendly, abundant in many regions, nonabrasive nature, lower energy consumption and good insulation of heat and sound. Glass fiber are widely used in many engineering applications such as the oil and gas industry, automotive, and aerospace fields. Most glass fibers are mainly composed of 50 to 60 % silica (SiO_2). There are several types of glass fibers; the most common ones are E-glass (good for electrical insulation), C-glass (better resistance to chemical corrosion) and S-glass (higher temperature resistance compared to other types as it contains a higher percentage of SiO_2 and AL_2O_3). These fibers are widely used in reinforcing the composites that require good resistance to chemical and thermal loads with good strength and durability. Therefore, in this work jute fibers would be hybridized with glass fibers and their composites' tensile, flexural, and impact properties along with some of their physical properties such as heat and sound insulations have been evaluated using two different general hybridization methods. This chapter briefly presents the applications of composite materials that were totally/partially reinforced with natural fibers, the problem statement, the limitations of the study, its objectives, its contributions, and finally the layout of the thesis.

1.2 Characteristics of natural fibers and their reinforced composite applications

Natural fibers are those not manmade or synthetic ones as they come directly from plants or animal resources. In the last decades, producing composite materials from plants reinforcements such as bamboo, jute, kenaf, flax, and sisal has received a substantial attention. Natural fibers are comparatively lower weight and cost than synthetic fibers but their mechanical properties are generally lower than that of synthetic fibers. These fibers are abundant, renewable, biodegradable, and have less damage to mechanical processing equipment. Jute fibers, which are the main concern in this work, have attracted a lot of interest in recent years due to their comparatively strong physical and mechanical properties. Jute fibers belong to the bast and core fiber types and they may readily be grown in a humid and warm environment, where they are typically grown in the tropical regions of China, India, Indonesia, and Bangladesh. Jute fibers can be joined together to form long fibers and a meshy network, but the geometry and composition of jute fibers can vary from plant to plant due to variations in growth conditions, their length, and chemical composition, all of which depend on a variety of factors, including the environment in which the plant grows, the weather, the maturity of the plant, extraction, and the methods used to modify the fibers [4]. The sectional area of the jute fiber contains many of hollow spaces called “lumen” that make it very light (low density) [5][6]. These air-filled or hollow spaces and pores would contribute the excellent insulation against heat and noise. The intermediate lamella, which is typically made up of lignin and cellulose, connects each unit cell of fiber with its neighboring cells. The cross-section of a jute fiber is shown in Figure (1.1).

The main problems of using natural fibers as reinforcements are their weak bonding strength with polymeric matrices due to the hydrophilic behavior and moisture absorption nature. Accordingly, this would weaken the strength and stiffness of the composites that reinforced by natural fibers [1]. To reduce these detrimental effects, chemical treatments of natural fibers were successfully employed. For example, alkali treatment of natural fibers like jute would increase their surface roughness and changing their composition; therefore, it improved the fiber-matrix adhesion strength and made them more compatible and this in turn would improve the transfer of loads and stresses from the matrix to the fibers.

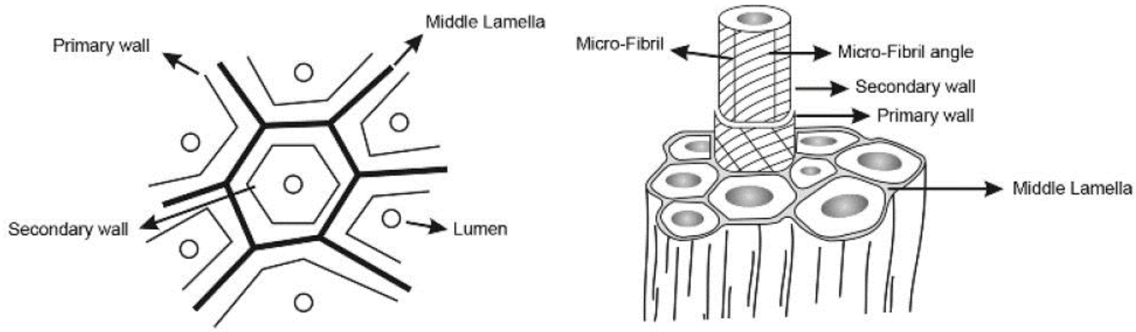

Figure (1.1): Jute fiber's cross-sectional area [7]**.**

The potential usage of composites reinforced with natural fibers has increased in many applications and fields owing to their good mechanical and physical properties [8] . The most important industries such as construction, automotive, sports, machinery office products, and packaging have large concern in developing of innovative composite materials that based on plant fibers as alternative to synthetic fibers reinforced composites. Many of great automotive companies have been utilizing natural fibers like jute, flex, and hemp for introducing change interior and exterior automobile parts [9]. Hybrid jute-glass fiber composites could potentially be used in many interior components of cars (i.e., door panels, roof panels, parcel shelves, and instrumental panels) or buildings' interior insulation against heat and noise owing to their attractive synergistic structural-physical properties and more importantly their lower cost, lighter weight, and lower harmful effects on the environment and human health. Table (1.1) lists the automobile companies that used cellulose fiber to make their different cars' parts. Jute fibers have also found use in the transport industry, packaging, geotextiles, chipboards, door frames, roofing sheets, and building materials [10].

Table (1.1): Natural fiber-base composites used in the automotive industry [10]**.**

Manufacturer	Model	Application
Rover	2000 and others	Rear storage shelf/panel, and insulations
Opel	Vectra, Astra, Zafira	Door panels, pillar cover panel, head-liner panel, and instrumental panel
Volkswagen	Passat Variant, Golf, A4, Bora	Seat back, door panel, boot-lid finish panel, and boot-liner
Audi	A2, A3, A4, A4 Avant, A6, A8, Roadstar, Coupe	Boot-liner, spare tire-lining, side and back door panel, seat back, and hat rack
Daimler Chrysler	A, C, E, and S class, EvoBus (exterior)	Pillar cover panel, door panels, car windshield/car dashboard, and business table
BMW	3, 5 and 7 series and other Pilot	Seat back, headliner panel, boot-lining, door panels, noise insulation panels, and moulded foot well linings
Peugeot	406	Front and rear door panels, seat backs, and parcel shelf
Fiat	Punto, Brava, Marea, Alfa Romeo 146, 156, 159	Door panel
General Motors	Cadillac De Ville, Chevrolet Trail Blazer	Seat backs, cargo area floor mat
Toyota	ES3	Pillar garnish and other interior parts
Saturn	L300	Package trays and door panel
Volvo	V70, C70	Seat padding, natural foams, and cargo floor tray
Ford	Mondeo CD 162, Focus	Floor trays, door inserts, door panels, B-pillar, and boot-liner
Saab	9S	Door panels
Renault	Clio, Twingo	Rear parcel shelf
Toyota	Raum, Brevis, Harrier, Celsior,	Floor mats, spare tire cover, door panels, and seat backs
Mitsubishi		Cargo area floor, door panels, and instrumental panel

1.3 Hybrid composites

Hybrid composite materials can be defined as a composite material which include more than one type of reinforcing material within a single matrix phase. Some of the particular features of hybrid composites over classical composites include: balanced stiffness and strength, improved impact resistance, reduced cost and/or weight, improved crack arresting properties and/or fracture toughness, good corrosion resistance, and balanced thermal distortion stability [2][11]. In general, the aim of combining two fiber types into a single composite is to keep their respective benefits and mitigate some of their drawbacks. In the hybrid fiber reinforced composites, the more brittle fibers would fail before the more ductile fibers if they were subjected to tensile loading along the fibers' direction. It is possible to use this fracture behavior for structural health monitoring of the composite's structure [12] or it can be used as a warning sign prior to the final fracture [13]. Hybrid composites are broadly used for the design of aerospace, biotechnology, automobile, sport and civil engineering structure. There are mainly three hybridizing configurations of two different fiber materials as shown in Figure (1.2). Interply (interlayer) or sometimes called layer-by-layer hybridization in which the two types of fiber layers are laminated onto each other. Intraply (intralayer) or what is called yarn-by-yarn hybridization in which the two fiber types are interlacing within the same layers. The intrayarn or fiber-by-fiber hybridization method in which the two types of fiber are co-mingled or mixed within the level of fiber itself.

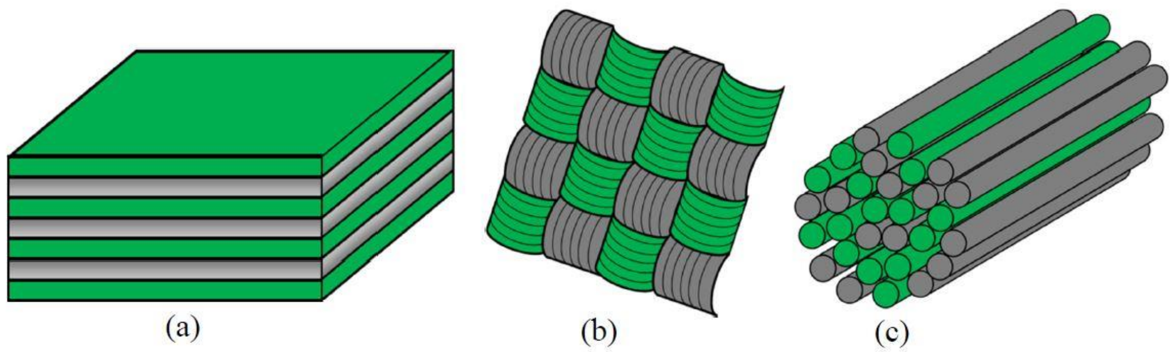

Figure (1.2) : The three basic hybrid configurations: (a) Interply (layer by layer), (b) intraply (yarn by yarn), and (c) intraply (fiber by fiber) [14]**.**

1.4 Motivation behind the present work

Jute is one of the most abundant and biodegradable natural fibers with annual production exceeded 3600×10^3 ton [7]. This type of fiber has acceptable mechanical properties and very light weight with density about 1.46 g/cm^3 [15]. The price of jute fibers is much lower than that of synthetic fibers. These properties encourage engineers to use them as a reinforcement in the composite materials, but not alone;

which means trying to hybridize them with those made from synthetic materials such as glass fibers. The final hybrid composites would definitely be lower cost, lower harmful to the environment, energy conservative and they might have higher mechanical/physical properties than pure synthetic fiber reinforced composites. This would become an interesting subject that needs some investigation as the fiber hybridization has different configurations with a wide range of applications.

1.5 Problem statement

Synthetic fibers that have been used widely to reinforce composites are expensive and have negative impacts on the environment both at the beginning of its manufacturing and after the end of their service life or failure. In recent years, big efforts have begun to find a solution to this problem or at least reducing the detrimental effects without big sacrifices of their reinforcement role within the composites. Hybridizing of natural fibers such as jute with synthetic fibers in the form of interply or intraply configuration might be one of the most efficient method available nowadays. Partial replacement of glass fibers (synthetic) by jute fibers (natural) in the form of whole ply or yarn in a planned manner or style would partially reduce the overall cost of the composites and make them more ecofriendly (greener) with acceptable mechanical properties. Another big issue that starts to raise is the global warming especially in the middle east countries; therefore, introducing efficient composite materials that able to keep the interior temperature of the building or vehicle in the comfort level without a considerable cost and with lower impact on the environment which is now the biggest concern due to the increasing pollution levels. On the other hand, noise is considered one of the main pollution types and when its loudness or what is called sound pressure level (*SPL*) is higher than 65 decibels (dB), it is considered noisy pollution according to World Health Organization [16]. When *SPL* is between 120–140 dB, it can cause a pain (pain threshold) to the human. Excessive *SPL* can have harmful impacts on health of human, wildlife, and the quality of environment. This problem has been arisen with increasing industrialization, technology, urbanization, etc. [17]. There are two methods to attenuate the noise, namely active and passive controls. The former is by reducing the noise that generated from the source itself, while the later utilized insulating materials at recipient's location [18]. Owing to the high cost and inability to carry out the mechanism of active noise control, the passive noise method is widely used. In summary, there is an urgent need to fabricate innovative composites that able to withstand different external loads and their thermal and acoustical insulations can meet the need taking into account the environmental concerns and economic factors.

1.6 Research objectives

The objectives of this work are:

1- Two main different kinds of jute-glass fiber hybridization would be employed to fabricate five different interply and intraply composites.
2- Testing the specimens for mechanical (tensile, flexural, and impact) properties and their results were evaluated to determine the best one for each property.
3- The proposed hybrid composites were tested against thermal and noise insulations and their results were assessed to find the best hybridizing configuration.
4- The fabricated composite samples were tested against sound (noise) insulation to find the best one.

1.7 Research contributions

The contributions of this work are:

1- Increasing the usage of the natural fiber reinforcements in the composite parts that already used in various applications to decrease the overall cost of the composite production and save the environment as can as possible.
2- The encouraging results obtained in this work could open a new vision of how to exploit natural-synthetic fibers hybrid composites efficiently and what they could suit of new potential applications.

1.8 The present study limitations

Limitation of the present study include:

1- Five hybrid composite materials (glass and jute fibers/epoxy) were fabricated; three of them were made by interply hybridization method and the rest by the intraply hybridization method due to time limitation.
2- Thermal tests were performed in a level of temperature that doesn't exceed thermal stability of the composite and their constituents.
3- Sound insulation tests of composite samples were conducted at only two levels of frequency (i.e., 1000 and 3500 Hz) as an average between low and high frequencies.

1.9 Thesis layout

Five detailed chapters with supplementary appendices make up this thesis.

The current chapter presented a brief background of using natural fibers in the composites and natural-synthetic fiber hybrid composites applications, research motivation, problem statement, aims and contributions of this thesis.

Chapter two deals with the literature review of the published studies on the main topics of the present work.

Chapter three describes the specifications and characteristics of the materials that were used in this work (experimental work only). Moreover, it focuses on the work steps and how to prepare samples before tests. Also, it deals with the equipment that were used to determine the mechanical properties (tensile, bending, and impact) of the composite materials. It also shows the methods of conducting thermal conductivity and sound insulation tests.

Chapter four lists the results obtained from investigational work, along with their discussion.

Chapter five summarizes the study's findings and makes some suggestions for potential future research in a related field.

CHAPTER TWO

LITERATURE REVIEW

2.1 General

The review of literatures presented in this chapter aims to give the reader an idea about the work implemented in the fields of mechanical properties (i.e., tensile, impact, and flexural), thermal conductivity and sound insulation of the synthetic–natural hybrid fibers composite material. The most important related studied are presented in the following articles:

2.2 Mechanical properties

2.2.1 Interply hybridization method

Ahmed et al. [19], (2006) examined how hybridization could affect the mechanical properties (flexural, tensile, and impact strength) of polyester composites made from untreated woven jute (J) and glass (G) fabrics. All of the laminates were constructed entirely of ten plies while impact specimens were fabricated from 16 plies via changing glass plies' number for producing different hybrid combinations. Except for the impact test, where the total fiber weight fraction was kept at 46%, all composites were constructed with a total fiber weight fraction of 42%. It was illustrated that tensile properties such as tensile strength and modulus along with impact properties of jute–polyester composites were improved by the incorporation of glass fibers. Maximum flexural properties were obtained with the addition of 16 weight percent of (G) fiber.

Ahmed and Vijayarangan [20], (2008) investigated the effect of stacking sequence on the tensile, flexural and interlaminar shear properties of untreated woven jute (J) and glass fabric (G) reinforced polyester hybrid composites (HCs). All laminates were fabricated from 10 plies via changing the position and number of G plies in order to obtain 6 different stacking sequence of (G8JG, 2G6J2G, 3G4J3G, JGJGJJGJGJ, GJJGJJGJJG, and GJGJGGJGJG). The findings showed that inserting G fiber as external plies significantly improved the composite's properties. The layer sequence has greater effect on flexural properties than tensile properties as the flexural strength and stiffness were controlled by strongest layers of reinforcement, where arranging glass fiber plies at the outermost and jute fiber plies at the middle leads to considerable improvement in the flexural strength. Comparing all of the laminated composites exhibited that the hybrid laminate with stacking sequence of (2G6J2G) was the best hybrid configuration among other stacking sequences in regard to the cost and properties.

Amico et al. [21], (2010) investigated the mechanical properties of neat sisal (S), neat glass(G), and hybrid S/G polyester composites. Different stacking sequences of fiber mat plies were used such as 4G4S, GSGSGSGS, 2G4S2G, 2S4G2S, SGS2GSGS, and GSG2SGSG. Hybridizing of S with G fibers created a material having intermediate properties. According to the stacking sequence and loading type, it offered properties almost similar to that of G fiber composites, particularly concerning the impact strength and flexural modulus. To highly improve the flexural properties, G fibers must be at the upper and lower surfaces, but maintaining several (G) at the mid-plane was also showed substantial effect. Concerning the impact properties, the hybrid composites with 4 adjoining G plies exhibited the highest impact strength.

Shahzad [22], (2011) studied the effect of hybridization of hemp fibers (H) with glass fibers (G) on the impact properties of the hybrid fiber reinforced polyester composites. The two types of fiber configurations that were used in which the hybrid composites either G2HG or H2GH. Pure hemp composites were also prepared. Hybrid G-H fiber reinforced composites provided up to a 75% and 15% improvement in tensile strength and modulus, respectively, in comparison to pure hemp composites. A considerable improvement has been obtained in the tolerance of impact damage by inserting G fibers instead of only 11% of H fibers.

Zhang et al. [15], (2013) investigated the tensile properties of glass (G) and flax (F) unidirectional fibers reinforced HCs. Six different types of unidirectional HCs with different G-F fiber hybridization ratios were fabricated for studying the influence of fiber hybridizing ratio on the composites' tensile properties. The fabricated composites include 10G, 10F, G8FG, G2FG2FG2FG, GFGF2GFGFG, 3GF2GF3G, GFGFGFGFFGFGFGFG, 2G2F2G4F2G2F2G, and 4G8F4G. Tensile properties of the hybrid composites improved with increasing the glass fiber content. The stacking sequence of the F-G fibers exhibited a great effect on the tensile strength of the hybrid composites. GFGFGFGFFGFGFGFG samples provided the higher tensile strength and stain-to-failure than 2G2F2G4F2G2F2G and 4G8F4G hybrid counterparts although they have the same number of plies and fiber type. Authors claimed that this behavior could be attributed to the more interaction between different fibers that led to improve the tensile strength and stain-to-failure while the tensile modulus is almost unchanged.

Ramesh et al. [23], (2013) investigated the hybridization influence of sisal–jute–glass fiber reinforced polyester composites and evaluated their mechanical properties such as tensile strength, flexural strength and impact strength. The hybrid composite samples were fabricated from five plies with three types of fibers (i.e., sisal (S)/glass(G), jute(J)/glass, and mixed sisal-jute/glass fibers). Unidirectional glass mat and chopped sisal-jute natural fibers with 30 mm in length were used in their study. The hybrid composite samples were fabricated in the sequence of GSGSG, GJGJG, and GS-JGS-JG. The results indicated that maximum tensile strength was obtained from GJGJG samples followed by GSJGSJG and GSGSG, respectively. Concerning the flexural loading, GS-JGS-JG samples exhibited the maximum value followed by GSGSG and GJGJG, respectively. Meanwhile, GSGSG samples showed the maximum impact strength followed by GSJGSJG and GJGJG respectively.

Braga and Magalhaes [24], (2015) investigated the tensile, flexural, and impact properties of pure jute and jute/glass fibers reinforced epoxy polymer matrix composites. Three layers of fabrics were used to reinforce the epoxy. The composite samples of 3J (31 wt% of jute fibers), JGJ (25 wt% of jute fibers and 7 wt% of glass fibers), and GJG (18 wt% of jute fibers and 19 wt% of glass fibers) were used in the tensile, flexural, and impact tests. Tensile strength of JGJ and GJG samples exhibited 92% and 69% compared with 3J counterparts, respectively. Meanwhile, flexural strength increased by only 2% and 2.24% when testing JGJ and GJG samples compared to 3J samples, respectively. Concerning the impact energy, the GJG composite samples offered improvement of 2.62% and 60% compared with JGJ and 3J counterparts, respectively.

Sharba et al. [25], (2015) investigated monotonic (tensile and compression) properties of woven kenaf (K)/glass (G) reinforced unsaturated polyester sandwich hybrid composites. Five different kinds of fiber configurations were used (i.e., 6G, 3GK3G, 3G2K3G, 3G3K3G, and 3K). Results exhibited that increasing the content of K fiber into the composite resulted in a decline in the tensile strength of the hybrid composites within an acceptable domain with very slight impact on the tensile modulus; meanwhile, no change in the tensile strain of hybrid composites had been examined. Moreover, almost no effect of hybridization on compressive strength had been obtained. 3GK3G hybrid composite samples provided the highest compressive modulus. Nevertheless, the compressive strains of the HCs showed increasing trend when adding the natural fiber into the hybrid composites.

Samanta et al. [26], (2015) investigated the flexural and tensile properties of glass (G), jute (J), and bamboo (B) fibers reinforced epoxy composites and their hybridization in interply manner. All composites were fabricated from four layers with stacking order of 4G, 4J, 4B, 3JG, 2J2G, J3G, 3BG, 2B2G, and B3G. Tensile properties (tensile strength and modulus) of the jute and bamboo hybrid composites increased with increasing the glass content. Flexural modulus of a bamboo-glass and jute-glass hybrid composites were higher when the bamboo or jute reinforcement was at bottom (under tension) and glass reinforcement was on top (under compression) while flexural strength showed the reverse trend.

Sanjay and Yogesha [27], (2016) studied tensile, flexural and impactproperties of jute/E-glass fibers reinforced epoxy matrix HCs. Four configurations of layering sequence were prepared which include ten layers of glass fabrics (i.e. 10G), 2J3G2J, 6J, and 2G4J2G. In general, the tests showed that pure jute composites had very poor mechanical performance compared with pure glass composites. Hybrid composites 2J3G2J and 2G4J2G exhibited better results than 5J counterparts for all tests. 2G4J2G laminated composite gave higher mechanical properties than 2J3G2J owing to the existence of glass fiber plies in the outermost position and it contains a higher fraction of glass fibers.

Sharba et al. [28], (2016) investigated the influence of hybridizing of kenaf (K)-glass (G) fibers reinforced unsaturated polyester matrix on the tensile and compression properties. Three different kinds of composites were prepared (K, K-G and K). K-G hybrid composite samples exhibited higher tensile properties than pure K composites and higher compression strength than G composites, resulting in overall enhancement mechanical properties. Authors claimed that kenaf fiber could potentially be employed in the aerospace field and structural applications.

Sezgin and Berkalp [29], (2017) investigated the hybridization influence of jute (J) fabric-reinforced polyester matrix composite with carbon (C) or E-glass (G) fabrics along with the influence of fabric lamination stacking sequence on the mechanical properties (impact and tensile strengths) of the fabricated composites. All samples were fabricated from four layers which include: 4J, 4G, 4C, JGJG, J2GJ, G2JG, JCJC, J2CJ, and C2JC. Higher impact values can be achieved by adding high impact resistant fibers into the outer layers of composites. On the other hand, inserting of high C fibers into the interior layer resulted in improvement in TS of the composite laminates; while, the jute-glass hybrid composites did not exhibit significant difference. Authors claimed that the adhesion between carbon fabrics with polyester matrix was stronger than those between jute and between glass fabrics with polyester and this firm adhesion at the interface contributed the higher tensile strength of carbon/polyester composites.

Chandramohan et al. [30], (2019) investigated the tensile, impact, and flexural properties of jute (J) and bamboo (B) and glass (G) fibers polyester composites. Seven configurations of various composites were fabricated with five layers that include (unreinforced polyester, 5J, 5B, G3JG, G3BG, GJBJG and GBJBG). Incorporation of bamboo and jute fibers into a glass fiber-reinforced composite resulted in good mechanical properties. The specimen GBJBG give the best results for all mechanical tests followed by the specimen GJBJG. For the tensile test, this composite GBJBG give the results with values of 77.23MPa and that the tensile modulus was 2.85 MPa, followed by composite specimen GJBJG (2.658 MPa). For the flexural test, the composite GBJBG give values of 57.21MPa, as well as flexural modulus of 4.987 MPa. The impact test gave value of 23.41 J for GBJBG, followed by the GJBJG reinforced composites.

Ali et al. [31], (2019) studied the low velocity impact and flexural properties of hybrid composites fabricated from carbon/jute fiber and epoxy matrix. Three sequences of stacking layers were used to fabricate HCs: 2CJ2C, CJCJC, and C3JC. Composite samples that having more outer carbon fabric layers (i.e., 2CJ2C) exhibited the highest flexural strength than other configurations owing to high stiffness of carbon fibers. Meanwhile, the IS and impact damaged area were decreased with decreasing the carbon fiber content. The study showed that CJCJC composite configuration could replace 2CJ2C counterpart in the impact applications without substantial loss in impact damage resistance.

Prabhu et al. [32], (2019) investigated the mechanical properties such as tensile, flexural, and impact strength of glass-jute-tea leaf fibers reinforced hybrid epoxy composites. The used forms of these fibers were woven fabric for glass, 50 mm length and 0.04–0.4 mm in diameter for jute, and particulate for tea leaf. The composite samples were fabricated from glass-jute-tea leaf-glass sequence. The fiber volume fraction was kept constant with 10% of glass, 30% of aggregate jute and tea leaf. The results figured out that increasing the jute content instead tea leaf in the core of the hybrid laminated composite could increase the tensile, flexural, and impact strength of the hybrid composites.

Mostafa [1], (2019) investigated the tensile properties of woven jute/glass hybrid fiber reinforced epoxy composite. Various types of composite materials were fabricated, which included 4G, 3J, and hybrid G/J having fiber’s weight ratios of 45/55% (with two jute fabric) and 30/70% (with single jute layers) of the total fiber content. The study figured out that increasing the glass fiber weight fraction led to increase the tensile properties of the hybrid composites; meanwhile, the voids’ fraction had decreased. Author indicated that hybridization of G-J fibers in the composites exposed to fatigue loading was recommended if the cost of production and the environment were the main concerns.

Mostafa and Hunain [33], (2019) studied the mechanical properties such as tensile, flexural, and the impact of glass (G), jute (J), and hybrid G-J composite specimens. Composites that were prepared included 4G, 3J, GJG, and G3JG stacking sequences. The tensile, flexural and impact properties were enhanced by incorporation of glass with jute fibers in the HCs when compared with pure jute composite's counterparts. Results of the study showed that hybrid composites with a lamination sequence of GJG had encouraging tensile and flexural properties and good absorbed impact energy. Higher mechanical properties of the hybrid composites have been obtained when they were related to their densities (i.e., specific properties).

El-baky et al. [34], (2020) studied the mechanical properties (impact, tensile, and flexural) of flax (F), basalt (B), and E-glass (G) epoxy composites with their hybridizations. All composite configurations were consisted from six plies to form pure flax, pure basalt, pure glass, G4FG, G4BG, GF2BFG, GB2FBG, GBFBFG, BG2FGB, BF2GFB, and FB2GBF composites. The fabricated hybrid composites demonstrate improved impact, tensile, and flexural properties. It had been figured out that putting the high-strength fibers in the composite's exterior layers (skin) such as glass or basalt and flax fibers in the core could improve flexural properties of the hybrid composites while it had the reverse effect on tensile properties. The mechanical properties are greatly influenced by fiber-relative quantities and stacking sequence. The existence of the layers of flax inside the hybrid composite showed a significant impact on the mechanical properties of hybrid laminates. Hybridizing of F with B and/or G fibers was an excellent way for improving mechanical properties of the composites.

Sujon et al. [35], (2020) studied the influence of lamination sequence of unidirectional carbon (C)-jute (J) hybrid fibers in the epoxy matrix on their flexural, tensile, and impact properties. All hybrid composites were consisted of four layers of carbon with six layers of jute to keep the weight ratio of jute to carbon fibers always equal to 2.7 while keeping the overall fiber weight fraction relative to the epoxy equal to 1.17. The stacking sequence of the plies were 3J4C3J, 2J2C2J2C2J, 2C3J2C3J, and 2C6J2C. Tensile strength was maximum when carbon fibers were inserted in the core of the hybrid composites (due to decreasing the delamination at carbon-jute joining interface); while, flexural strength showed the reversed trend. Impact strengths of all hybrid composites were almost similar with a little advantage when using carbon plies at the farthest distance from the midplane.

Salman [36], (2020) studied the tensile and compression properties (i.e., strength and strain-to-failure) and fatigue life of plain-weave jute (J)/carbon (C) reinforced polyvinyl butyral (PVB) composites. Six different types of composites were fabricated using J, C, and their hybrids (CJC, JCJ, CJ, and CJCJ). The layering sequences and fiber type content had a significant impact on the tensile and compressive properties of J-C laminated HCs. J-C hybrid composites exhibited higher tensile properties than J composites and higher compressive strain than C composites. J composites have both high strain and a semi-brittle behavior and fatigue characteristics, resulting in a slower development of the damage and degradation in the fatigue strength than neat C composites.

Das et al. [37], (2021) investigated the stacking sequence effect on the mechanical properties (tensile, flexural and impact strength) of composites using jute (J), glass mat (G), and unsaturated polyester resin. Eight samples were fabricated (i.e., 5J, 5G, JG, JGJ, GJG, JGJG, JGJGJ, and GJGJG). Pure G composites exhibited higher mechanical properties than other composite configurations. The presence of G fibers in the hybridized composites substantially affected their properties. GJGJG samples showed highest tensile strength (87% of pure glass composite) while GJG samples showed the highest flexural strength (92% of pure glass composite) among other hybrid sequences. Concerning the tensile and bending moduli, JGJG (43% higher than pure glass) and GJGJG (13% higher than pure glass) owned the highest tensile and bending moduli than other composites including pure glass composites, respectively. The impact test results figured out that pure glass composites possessed the highest IS followed by GJGJG (78% of pure glass-polyester composite) and GJG (70% of pure glass-polyester composite), respectively.

Mohanavel et al. [38], (2021) studied the influence of fibers (glass fiber mats (G), jute fibers (J), and madar fibers (M)) content and stacking pattern on the mechanical properties (tensile, impact, and flexural strength) of hybrid epoxy composites. GJMJG, GMJMG, GJGJG, and GMGMG stacking sequences were tested. They discovered that using G mats in the skin and core plies had a greater impact on the composites' mechanical properties than using other sequences. The tensile, impact, and flexural strength of composites were affected by the strength of the fibers in the skin and core layers. More madar fibers in hybrid samples resulted in composites with higher strain and toughness. Jute fibers gave the hybrid sample a higher level of strength, load bearing ability, and energy absorption capacity. The flexural strength of composites was controlled by the less extensible fibers in the skin and its surrounding layer. Also, among the samples that contain a higher percentage of jute fibers (i.e., GJMJG) than madar fibers (i.e., GMJMG), resulted in higher mechanical properties because J fibers were more durable than M fibers and could handle more stresses.

Selver et al. [39], (2022) conducted the dropped weight impact test of epoxy composite laminates reinforced with glass (G), flax (F), jute (J) fabrics along with their hybrid combinations (G/J and G/F) fabricated from different lamination sequences.

Composite laminates were manufactured as (12G, 4J, 5F, 3G2J3G, J6GJ, 4G2F4G, F8GF). The results of impact tests revealed that glass composites were more impact resistant than natural and hybrid composites. When compared to composites with F or J fabrics located in the core, hybrid composites with G fabric layers on the skins performed better in terms of impact resistance. Changing the stacking sequence had a substantial impact on post-impact performance, and using natural fibers on the outside reduced glass fiber breakages. Higher damage in the area after impact test occurred in hybrid composites where natural fiber layers were placed on the skins, whereas composites with G fiber layers on the skins minimized the damage.

2.2.2 Intraply hybridization method

Ramnath et al. [40], (2014) investigated the tensile, flexural, and impact properties of intralayer abaca–jute–glass fibers reinforced epoxy composite. The fabricated composite samples had been prepared with a stacking sequence consisted of glass fabrics on the skin and three intralayers of jute and abaca fibers in the form of strips in the core of the composite. Three different jute-abaca contents of 50% jute with 50% abaca, 25% jute with 75% abaca, and 75% jute with 25% abaca were utilized in the intralayer hybrid plies. It was found that samples having higher abaca content exhibits better tensile, flexural, and impact properties as abaca fibers have higher stiffness, strength, and elongation to break than jute fibers.

Rajesh and Pitchaimani [41], (2017) investigated the tensile, flexural, and impact properties of intraply glass-jute-banana hybrid woven fabric polyester composite. Six different combinations of hybrid intraply composites were fabricated along with individual glass, jute, and banana composites. Natural fibers were inserted either along the warp or weft direction and another direction was filled by glass fibers only within the intraply hybrid lamina. Therefore, only three distinct weaving styles were obtained. These styles were grouped as glass-jute, glass-banana, and glass-jute-banana. No significant effect on the flexural properties and tensile properties had been found when using intraply hybridization of synthetic and natural fiber yarns within the woven fabric. Though, the intraply woven fabric hybridization improved the impact strength significantly.

Ouarhim et al. [42], (2020) studied the flexural and tensile properties of two different hybrid configurations: inter-layer (layer by layer) and intra-layer (yarn by yarn) for glass (G) and jute (J) fibers in the polyester matrix. Tensile test was performed for three types of composites reinforced with only one layer of woven glass, jute, or hybrid intraply glass-jute fibers (in both warp and weft direction in alternating sequence that makes about 85 wt% of G and 15 wt% of J fibers). The intraply hybrid composite provided intermediate values of the tested properties when compared with pure jute and pure glass fibers reinforced composite counterparts. Concerning the flexural properties, three-point bending tests were conducted to the composite sample fabricated from five intraply hybrid layers (85 wt% of glass fiber and ply orientation of 0/22.5/45/67.5/0) and seven interply hybrid layers (GJGJGJG, with ply orientation of 0/15/30/45/60/75/0) with 74 wt% of glass fiber content. The results figured out that GJGJGJG configuration has higher flexural strength (about 63%) and modulus (about 40%) compared to intraply hybrid composite samples.

Islam et al. [43], (2021) studied tensile and fatigue properties of intralayer hybrid flax (F)-carbon (C) fibers reinforced epoxy composites and did a comparison with those prepared from interlayer hybrid F-C fiber reinforced epoxy composites. Composite samples with interply hybrid fiber configuration were prepared using seven layers of different unidirectional fibers having the sequence of (CFFCFFC). Intraply unidirectional HCs (F-C fibers that co-woven together) were prepared with fourteen plies of a hybrid fabric (49% of C and 51% of F fibers by weight). Under tensile testing, both hybrid configurations showed almost the same tensile strength. However, F-C intralayer hybrid composites showed extension in the fatigue life about 2000% more than that of interlayer HCs counterparts. This extraordinary behavior was attributed to the higher damping performance of uniformly distributed flax fibers within the hybrid layer, which played a noteworthy role in enhancing the characteristics of fatigue life of intralayer hybrid composites, as well as the better capability for transferring the external applied load and showing a uniformly distributed modes of failure.

Agaliotis et al. [44], (2021) investigated the tensile properties of the intraply hybrid composites made of filaments of the poly-lactic acid (PLA) and sisal (S) fibers reinforced PLA matrix. To fabricate a hybrid intraply layer, yarns of PLA were aligned in the warp direction and S yarns were aligned in the weft direction only. Two lamination arrangements were used. In the first arrangement, a total of seven alternating layers were used in the sequence of [PLA-S] with sisal fibers aligned in the sequence of [0_S-0_S-0_S] along with weft direction. The second configuration was fabricated with seven alternating layers of [PLA-S] with stacking sequence of sisal fibers in the sequence of [0_S-90_S-0_S]. Both intraply HCs exhibited higher tensile properties than PLA matrix in the direction of sisal fiber alignment (i.e., fill direction). Higher improvement in these properties were obtained in the direction were sisal fibers have higher yarns (content); therefore, the first configuration exhibited higher tensile properties than the second configuration when both configurations were tested in the fill direction. Nevertheless, both intraply hybrid composites displayed lower value of the strain-to-failure values relative to the PLA matrix because the reinforcement increased the composites' stiffness, which reduced their ductility.

2.3 Thermal conductivity

Kalaprasad et al. [45], (2000) investigated the thermal conductivity of chopped sisal/low-density polyethylene, chopped glass-reinforced polyethylene (CGRP) and chopped sisal-glass hybrid fiber-reinforced polyethylene. Different fiber volume fractions were used. It was found that the thermal conductivity of pure polyethylene and sisal-reinforced polyethylene (20% sisal) was almost similar with very small increase in the presence of sisal reinforcement. CGRP samples exhibited higher thermal conductivity values than neat polyethylene and they increased as volume fraction of glass fiber increased in the composite. Meanwhile, the effect of sisal fibers on thermal conductivity of the composites when they were hybridized with glass fibers was enormous. Increasing sisal fiber volume fraction relative to the glass fibers led to reduce the thermal conductivity of the hybrid composite.

Devireddy and Biswas [46], (2016) studied the thermal conductivity of unidirectional banana/jute hybrid fibers reinforced epoxy matrix composites. Thermal conductivities of the used epoxy, banana, and jute were 0.363, 0.09, and 0.036 (W/m K), respectively. Composite samples had been fabricated by adjusting the content of fiber from 0 to 40 wt% with various weight ratios of both banana and jute fibers (from 0 to 30 wt%). Owing to the lower thermal conductivity of natural fibers, the transverse thermal conductivities of hybrid composites decreased when the fiber loading was increased. Maximum decrease in the thermal conductivity was approximately equal to 44% when using 30 wt% of jute with 10 wt% of the banana fibers within the epoxy matrix.

Subrahmanyam et al. [47], (2019) studied the influence of jute fibers loading on the thermal conductivity of jute fiber reinforced polyester matrix composites. Short jute fiber reinforced polyester composites were prepared by varying the fiber loading (0–40 wt%). The findings revealed that the addition of these natural fibers into polymer matrix decreased the thermal conductivity of composites due to increasing the possibility of fibers contacting with other fibers that led to increase the resistance to transfer the heat and decreased the overall thermal conductivity of the hybrid composites.

Hamdan et al. [48], (2021) investigated the thermal properties of glass-jute fiber/epoxy hybrid composite. Three samples were fabricated (pure glass/epoxy with volume fraction 50%, pure jute/epoxy with volume fraction (50%) and hybrid glass-jute/epoxy with volume fraction of (25% glass + 25% jute). The stacking sequence and number of plies were not indicated. Results showed that the thermal conductivity of pure glass sample was much higher than other two samples, while the pure jute sample showed the lowest thermal conductivity value. Hybrid glass-jute/epoxy composites gave very close value of thermal conductivity to that of pure jute/epoxy counterparts.

Aly et al. [49], (2021) investigated thermal performance of composite panels fabricated from green thermoplastic sandwich to be used in buildings' floor constructions. Three different recycled nonwoven fabrics were employed as reinforcement in composites: jute (J), polyester (PY), and a hybrid jute-polyester (80:20%) with polypropylene (PP) as the matrix. The compression molding process was utilized to create eighteen sandwich composite sheets with varying reinforcement (nonwoven fabric) kinds and ratios, as well as varying PP matrix ratios. Results showed that the samples (PP/J/PP) with one layer of reinforcement had higher number of pockets filled by air within the jute fabric. This stationary air functioned as a barrier to heat movement and therefore the thermal conductivity of this composites (i.e., PP/J/PP) was the lowest one among other samples. For hybrid jute-polyester/polypropylene composites, the best configuration was the (PP/J+PY/PP) with only single ply of each material.

Pakdel and Alemi [50], (2022) studied theoretically the thermal insulation of composites fabricated from different natural fibers like chopped jute, flax, hemp, coir, and cotton with different fiber volume fractions (70, 80, and 90%) and sericin binder (natural water-soluble protein polymer extracted from cocoon) as a bio-matrix. Results showed that jute/sericin composite possessed the lowest thermal conductivity among other composite materials. Decreasing the natural fiber's volume fraction within the composite led to decrease its thermal conductivity due to decreasing the porosity in the composite that filled by sericin matrix.

2.4 Sound insulation

Fatima and Mohanty [51], (2011) studied the acoustical properties of jute fibers and their composites with natural rubber latex for noise reduction. They found that noise reduction coefficient increased with increasing the air gaps within the fibers (i.e., decreasing the density). Alkali treatment of the jute fiber at lower concentration (with 1%) would separate fiber strands and make its the surface rougher that enhance the sound absorption level, but higher concentration of alkali treatment of jute fibers (2 and 3%) could reduce the sound absorption due to the severe loss in the hemi-cellulose content. The presence of natural rubber in jute felt would reduce the sound absorption properties of composite and increasing its content would make further reduction owing to bonding enhancement between jute fibers which in turn reduces the porosity.

Büyükakinci et al. [52], (2011) investigated the acoustic properties of composites fabricated from chopped cotton, bamboo and wool fibers (length of 1 mm) mixed individually with polyurethane (PU) foam matrix. Nine samples were fabricated with various weight fractions (4, 8, and 12%) of bamboo, cotton or wool fibers. The testing frequency of the sound is up to 6.3 kHz. Generally, adding these natural fibers to PU enhanced the coefficient of sound absorption especially at frequencies lower than 3 kHz, but cotton fibers reinforced PU composite provided the highest sound absorption coefficient than other tested composites. Using 12 wt% of cotton fibers within the PU foam resulted in four times rise of sound absorption coefficient over that of pure PU foam at sound testing frequencies above 2 kHz.

Fatima and Mohanty [53], (2012) studied the noise reduction in some domestic electrical devices using jute fiber material as insulation. Jute acoustical blanket was used to control the noise generated in the home clothes dryer during the drying process. Moreover, a domestic vacuum dust cleaner was insulated by jute felt by lining its enclosure along with using jute dissipative silencer. The intensity of the noise emitted by these appliances was measured before and after using jute felt. Results showed that the levels of the emitted noise were decreased by 10 dB and 6 dB in the vacuum cleaner and household dryer, respectively.

Yang and Li [54], (2012) studied the sound absorption properties of natural fibers (i.e., jute, ramie and flax) and their reinforced epoxy composites and compared them with the other type of the synthetic fibers such as carbon and glass and their individual composites. Three types of natural fibers reinforced epoxy composites were created with fiber volume fractions around 65%. Each natural fiber and its composites showed greater noise reduction capabilities than synthetic counterparts. They found that the materials with the highest sound absorption coefficient were on the following order: jute, flax, ramie, carbon and then glass fibers especially when the sound frequency was above 1000 Hz; therefore, natural fibers will be very useful for aviation appliances due to the high frequency acoustic service environment. Natural fibers are porous and multi-scaled structure. Each single natural fiber consisted of a bundle of hollow sub-fibers their cell-walls have been constructed from millions of nano fibrils.

These main two facts would contribute the sound absorption ability compared to synthetic fibers.

Abdullah et al. [55], (2015) investigated the coefficient of sound absorption of chopped banana stem fiber, alkali treated sugarcane bagasse fiber and their hybrid polyester-based composites under different fiber volume fractions (10%, 20%, and 30%). The testing frequency of the sound is up to 4 kHz. The combination of both fibers provides significant sound absorption at both low and high frequencies. Results showed that at low and high frequencies levels, better sound absorption coefficient was achieved by combining various natural fibers than by using as individual. The outcomes also showed that the frequencies would be extended by the increased fiber volume fraction, providing higher sound absorption ability.

Lee et al. [18], (2017) examined and compared the abilities of absorption the sound by flax (F) and glass (G) fibers reinforced epoxy matrix composites. The specimens used were unidirectional glass fiber-epoxy composites (16G and 24G with fiber volume fraction equals to 53 and 55%, respectively), unidirectional flax epoxy composite (20F with fiber volume fraction equals to 26%) and cross-ply flax epoxy composite (20F with fiber volume fraction equals to 32%). Tests were conducted for a frequency up to 6300 Hz. Results figured out the noise reduction coefficient of flax/epoxy composites were better than that of glass/epoxy counterparts. According to authors, flax fibers are a more effective sound absorber than glass fibers because of the presence of a special lumen structure that causes significant thermal and frictional losses as sound waves attempt to travel through air spaces.

Jayamani et al. [56], (2017) investigated the coefficients of sound absorption of chopped coconut coir, sugarcane bagasse, kenaf fibers reinforced epoxy matrix composites. Each composite had fabricated with four fiber weight fractions of 5%, 10%, 15%, and 20%. The coefficient sound absorption of the composites improved as the fiber loading was increased. The highest coefficients of sound absorption were found in 20 wt% for both coconut coir and kenaf fiber epoxy composites, both of which have 0.078 coefficient sound absorption at 5 kHz. Meanwhile, it is about 0.075 and 0.04 for 20 wt% sugarcane bagasse epoxy composites and pure epoxy, respectively. The higher the fiber content, the better ability to absorb the sound.

Selver [57], (2019) studied the relationship between sound absorption properties and stacking sequence of natural fiber (jute (J) and flax (F) fabrics) and hybrid (glass (G)-flax or glass-jute fabrics) epoxy composites at frequencies from 100 to 3500 Hz and compared them with those made from pure glass/epoxy composites. Seven different types of composites were manufactured through different fabric types and sequences: pure glass (12G), pure jute (4J), pure flax (5F), and hybrids (3G2J3G, J6GJ, 4G2F4G, and F8GF) using [0/90] stacking sequence. Results showed that pure flax and pure jute composites showed better sound absorption than pure glass composite (at all frequencies) and that composite laminates made from hybrid fabrics showed higher sound absorption coefficient than pure glass and natural fiber composites. Using of natural fibers at faces (i.e., F/G/F or J/G/J) exhibited higher sound absorption compared to using them at the core (i.e., G/F/G or G/J/G) parts in the composites.

Shen et al. [58], (2021) examined the acoustical properties of short jute fibers/polypropylene composite materials with various fiber contents and two different NaOH treatments. The fiber weight fractions used in their study were 5, 20, 35, and 50%. Untreated jute fibers, treated with 5 % NaOH solution for 1 h at 25 ^{o}C, and treated with 5 % NaOH solution at high temperature for 1 h were used individually to fabricated the composites. The sound absorption performance was best when using high temperature treated jute fibers and the sound absorption coefficient was 0.54 at 100 to 2500 Hz when the content of jute fibers was 50%.

Prabhu et al. [59], (2022) studied the characteristics of sound absorption of industrial treated waste particulate tea leaf fiber (T), treated unidirectional kenaf (K) and woven E-glass (G) fiber–reinforced hybrid epoxy composites. The fabricated hybrid samples with a lamination sequences GKGTGKG. Various weight fractions of kenaf (5 to 25 wt% in 5 interval), and tea leaf (5 to 25 wt% in 5 interval) were used while keeping the glass weight fraction constant (10 wt%) and the aggregate weight fraction of kenaf and tea leaf fibers always equal to 30 wt%. The tested sound frequency was ranged from 0 to 6300 Hz. It was observed that the HCs with a maximum waste tea leaf fiber content (i.e., 25 wt%) exhibited the best sound-absorbing material. Authors attributed this result to the higher frictional losses that sound waves faced when passed through a hybrid composite containing higher particulate tea leaf fibers.

2.5 Concluding remarks

The following notes could be stated from the published studies that were reviewed in previous sections:

1. Natural fibers could be successfully hybridized with synthetic fibers within the polymeric matrix composites mainly to reduce the cost and detrimental effects on the environment.

2. In the interply hybrid configuration, the stacking (lamination) sequence of both synthetic and natural fibers showed a considerable influence on the mechanical properties of the hybrid composites.

3. It was pointed out that increasing the fraction of stronger fibers (i.e., synthetic) in the interply natural–synthetic hybrid composites enhanced their tensile properties

while laminating the strongest fiber type on the outermost of the laminated composites gave the highest flexural properties and impact strength.

4. So far, a relatively few studies concerning the natural–synthetic intraply hybrid composites were published and the effect of this hybridization method on composites' mechanical properties still not clear enough.

5. Natural fibers have a clear positive effect on sound insulation, so their hybridization with synthetic fibers exhibited encouraging results to maintain the mechanical properties within acceptable level in addition to the sound insulation characteristic.

6. Natural fibers own lower thermal conductivities than most of synthetic fibers mainly due to the presence of cellulose and lumen (voids) in their internal structures. Therefore, hybridizing them with synthetic fibers could improve the thermal insulation of the hybrid composites.

7. According to our knowledge, there is no published study has dealt with investigating thermal and sound insulations of intraply natural–synthetic fibers hybrid composites up to the writing of this thesis.

Therefore, this work aims to fill some of the scientific gaps in the related subjects which have not well investigated (especially intraply natural–synthetic fibers hybrid composites) and trying to enrich the field of natural–synthetic fibers hybrid composites by new findings and deeper justifications that could help structural design engineers to develop new composites that could fit the application with lower detrimental impact on the environment and lower cost as well.

CHAPTER THREE

MATERIALS AND METHOD

3.1 Introduction

This chapter illustrates the preparation of the composite material samples, which that consisted from jute fiber, glass fiber and epoxy resin according to the ASTM/ISO standards to conduct tensile, flexural, and impact tests along with performing the thermal conductivity and sound insulation tests. The raw materials, method of testing, and the required equations are also listed herein.

3.2 Raw materials

3.2.1 Jute fibers

Jute (J) is one of the most popular natural fibers that used in the worldwide. This type of natural fibers is derived from plants that growing best in warm and humid climates. Jute fiber characterized by its low cost, ecofriendly, sustainable, low energy consumption, nonabrasive nature and good insulator against heat and noise. The chemical composition of jute fibers consists of lignin ranged from 12 to 14 wt%, waxes from 0.4 to 0.8 wt%, pectin from 0.2 to 0.5 wt%, cellulose from 59 to 71 wt%, hemicellulose from 22 to 26 wt% substances [60][62]. The used jute fiber in this work is in the form of woven jute fabric that available in the local market as shown in Figure (3.1). It's areal density equal to 225g/m^2 and it was interlaced with 4.18 end/cm in both warp and weft directions. Mechanical and physical properties of jute fibers are listed in Table (3.1).

Figure (3.1): Woven jute fabric used in the current work.

Table (3.1): Mechanical and physical properties of jute fibers [63], [64]**.**

Properties	**Value**
Strain-to-failure (%)	1.1–1.5
Elastic modulus (GPa)	10 –32
Tensile strength (MPa)	450–550
Thermal conductivity (W/m.K)	0.038–0.055

3.2.2 Glass fibers

Glass fibers (G) is material made from extremely fine fibers of glass. They are the most common among all reinforcing fibers in the field of polymer composites. Glass fiber is relatively heavier than carbon and aramid fibers, strong and less brittle than regular glass. The best property of fiberglass is its ability to get molded into various complex shapes. The composite material made of economical glass fiber has become an alternative to stainless steel or other materials in the industry. The E-glass plain-weave woven fabric is used in this work as a synthetic reinforcing phase as shown in Figure (3.2). It's areal density equal to 600 g/m² and it was interlaced with 2.4 end/cm in both warp and weft directions. Table (3.2) lists the mechanical and physical properties of E-glass fibers.

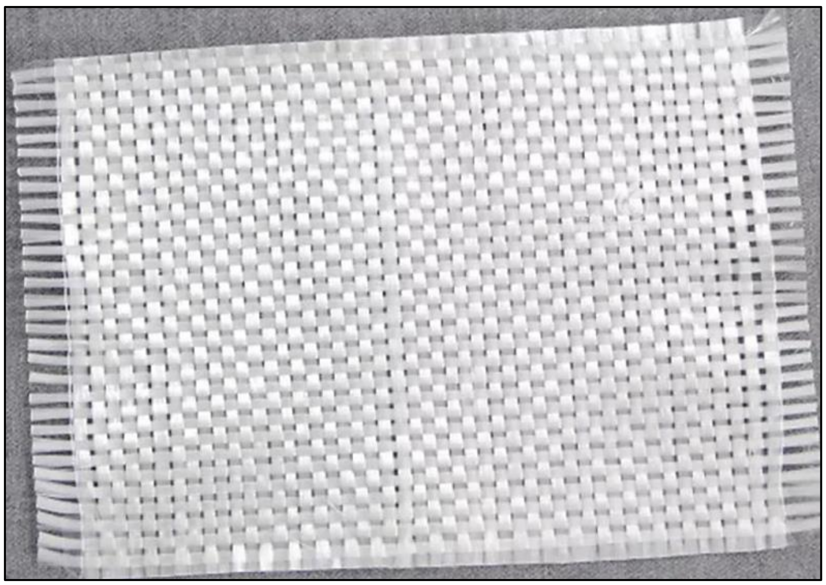

Figure (3.2): A plain-weave E-glass fabric.

Table (3.2): Mechanical and physical properties of E-glass fibers [65]**.**

Properties	**Value**
Strain-to-failure (%)	1.8–3.2
Elastic modulus (GPa)	72.4
Tensile strength (MPa)	3450
Thermal conductivity (W/m.K)	1.3

3.2.3 Epoxy resin

The epoxy resin (commercially branded as Quickmast 105, DCP) was used in this work. It characterizes by its low viscosity that able to be used in concrete crack injection. It provides excellent bonding strength to concrete, brickwork, and masonry with good chemical resistance. Quickmast 105 epoxy resin can be utilized in wet or dry environments with low creep. The mixing weight ratio of this type of epoxy resin with the hardener is 2.72 as recommended by the manufacturer. Table (3.3) lists the properties of the used epoxy resin.

Table (3.3): Properties of epoxy Quickmast 105 (DCP) resin provided by the supplier.

Property	Value
Compressive strength:	≥ 70 MPa @ 7 days @ 25°C
Flexural strength:	≥ 50 MPa @ 7 days
Tensile strength:	≥ 25 MPa
Pot life	50 - 70 min @ 25°C
Density	1.1 ± 0.05 g/cm^3
Viscosity	3 - 5 poise @ 25°C, 1 - 2 poise @ 35°C
Application's minimum temperature	5°C

3.3 Jute fibers' chemical treatment

Jute fabrics were cleaned well and chemically treated before using them in the composite's fabrication. They were firstly washed three times by means of deionized distilled water for removing the impurities and dust and then fully immersed in 0.5 wt% sodium hydroxide (NaOH) solution for one day at 22±2°C [66]. Subsequently, they were washed again using distilled water to remove the NaOH residues (i.e., the pH of the rinsing water becomes neutral). This alkali treatment of jute fibers would remove the wax substance, reduce the hemicellulose content, lignin, and pectin.

Consequently, many micro-voids, gaps and wrinkles are created on the surface of the fiber. After alkali treatment, the surface of the jute fiber becomes cleaner and rougher; therefore, increasing the adhesion strength with polymeric resins [67]. On the other hand, the cellulose crystalline structure improved and the cellulose chains would become more compacted leading to increase the strength of the fiber [68]; meanwhile, the hollow lumen inside the fiber would reduce in number and/or size [69]. Chemical treatment of jute fibers by NaOH would eliminate the groups of hydroxyl that responsible to absorb the moisture; therefore, it reduces the hydrophilicity nature of the jute fibers. The treated jute fibers were then dried by putting them in an electrical oven at 50 ^{o}C for four hours and kept them inside zipped bags until needing them in the composite's fabrication process.

3.4 Fabrication of composite sheets

Hand-layup method was adopted to fabricate composite sheets with dimensions equal to 20 cm × 30 cm × thickness. Firstly, glass and jute fabric were cut with the same dimensions as the steel mold shown in Figure (3.4) and their weight have been measured using a high accuracy digital balance and then a predefined charge or weight of epoxy resin that mixed with a recommended amount of hardener has been prepared for composite fabrication process. The internal surfaces of the mold were smeared by Vaseline oil (petroleum jelly-based products) and wiped gently using tissues paper to keep just a thin layer on the surfaces; therefore, the composite sheet could be detached easily in the demolding process. A suitable charge of epoxy resin was gently poured and distributed onto the entire bottom surface of the mold and the first single layer of the fabric has been inserted. Another amount of epoxy charge was poured and the second layer is inserted. This procedure is repeated till finishing all layers. During the hand-layup process, the trapped air was gently squeezed out using a suitable roller.

The cover plate was mounted gently on the top surface of the composite and a dead weight load that generate a compressive pressure equal to 7.5 kPa (cold press) was applied till the epoxy cured well at room temperature which is equal to 20±2 ^{o}C. After several trials, this level of pressure seems suitable for the different composite sheets in which it did not squeeze out a lot of resin from the molded composite sheets that might result in a deficiency (starving) in the amount of the matrix within the composite especially for pure glass/epoxy samples. Meanwhile, it looks suitable for the pure jute/epoxy composite samples as it led to reduce the thickness of the composite and provided a well distribution of the resin between the interlaced yarns within the fabrics. After the composite material gets hardened completely (about 48 h), the composite sheet has been taken out from the mold, the composite samples were then cut to the required dimensions according to the standards using a bandsaw machine, The cut edges were then polished to remove imperfections and provide a smooth, crack-free surface.

Figure (3.3): The steel mold used in this work.

The non-hybrid composite sheets that fabricated in this work are either made from five E-glass woven fabrics (i.e., 5G) or from five jute fabrics (i.e., 5J) reinforced with epoxy resin. The hybrid glass-jute/epoxy composite sheets are either interply (layer-by-layer) or intraply (yarn-by-yarn) pattern. For interply hybrid fiber configuration, three layering sequences with overall of five layers were adopted: G3JG (three jute plies in the core and single ply in in each outer surface), GJGJG (glass and jute fabrics were stacking in alternative form but keeping glass fabric on the skin of the composite), and 2GJ2G (double plies of glass fabric sandwiching a single ply of jute fabric in the core) as shown in Figure (3.5). Using of glass fiber layers on the outer surfaces of the interply hybrid composites was intended in this work. For some applications, smooth and hard surfaces are required to withstand external mechanical loading, environmental condition and fire flammability [1][70][71]. Meanwhile, intraply hybrid composite sheets were handwoven by either alternative replacing of a single E-glass yarn by a single jute in both warp and weft directions of the E-glass fabric or by alternative replacing of a single E-glass yarn by two yarns of jute in both fabric's yarn directions as shown in Figure (3.6). In this work, the former (i.e., single E-glass yarn that was replaced by a single jute yarn) would be designated as G_1J_1 and the later (i.e., single E-glass yarn that was replaced by two yarns of jute) as G_1J_2, respectively. The intraply hybrid composite sheets were also consist of five layers. Table (3.4) lists the specifications of the prepared composite sheets.

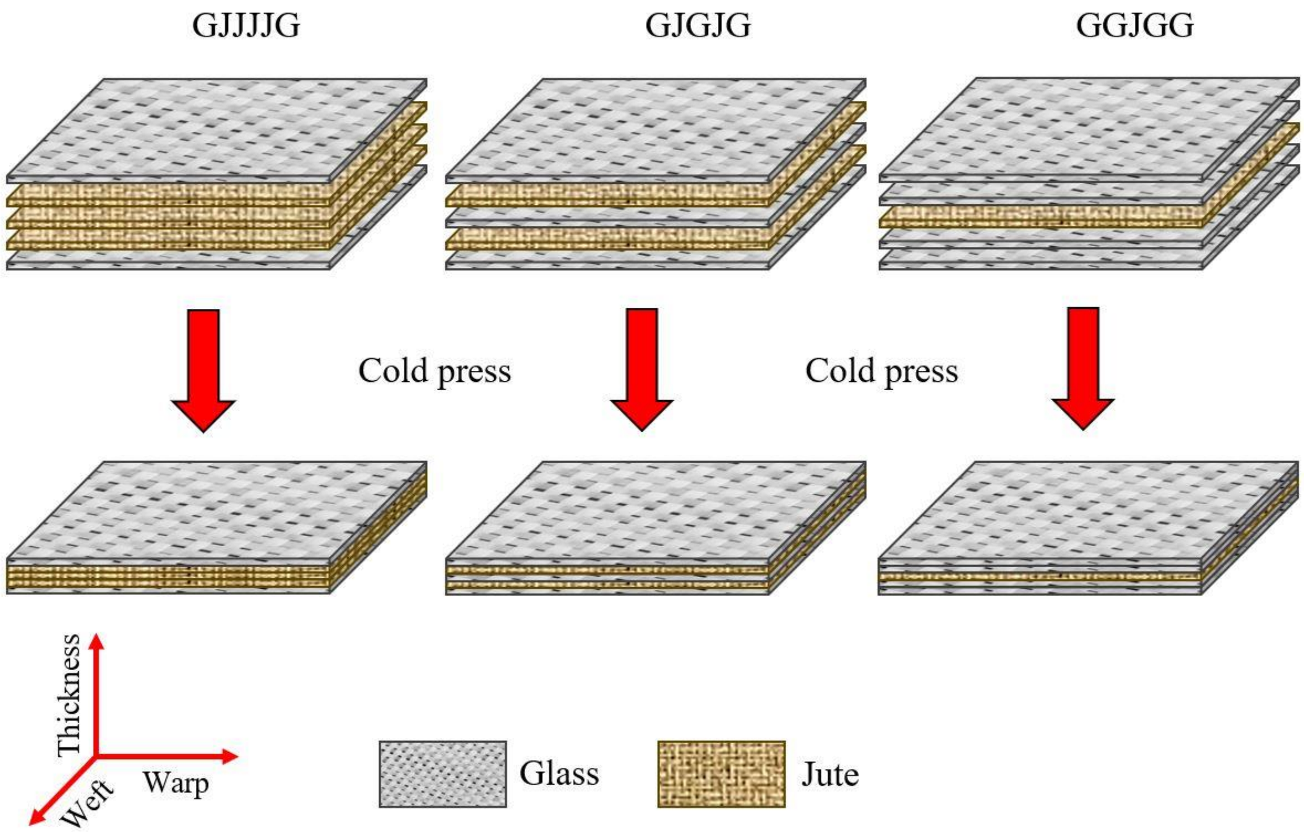

Figure (3.4): Configuration of interply hybrid composite sheets.

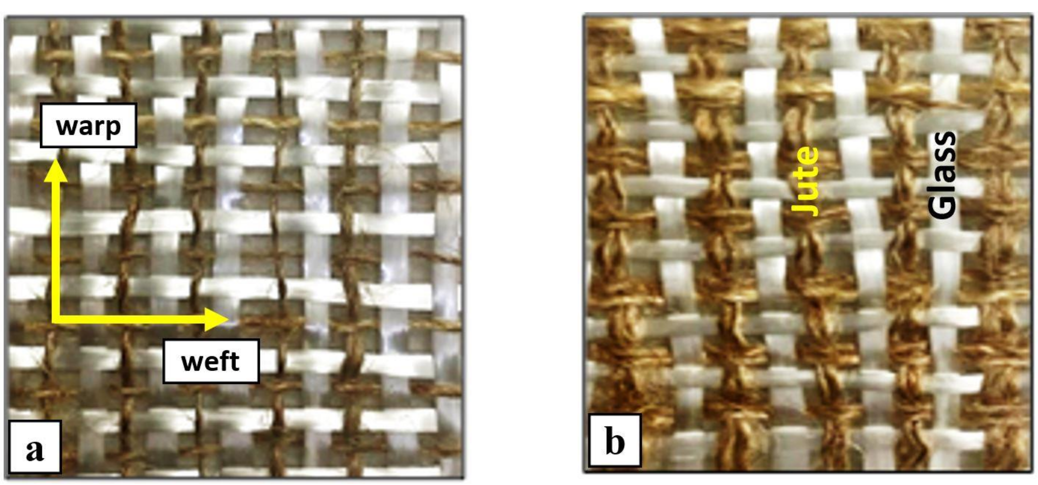

Figure (3.5): Intraply hybridization methods: (a) yarn-by-yarn [G_1J_1], and (b) yarn-by-two yearns [G_1J_2].

Table (3.4): Specifications of the fabricated composite sheets.

Designation	Thickness (mm)	Weight of ($0.06\ m^2$) composite sheet (g)	Density (g/cm^3)	Weight of (J+G) fibers (g)	Fiber type weight content (J + G) %	Fiber weight fraction (%)
5J	4.15	295	1.185	(67 + 0)	(100 + 0)	23
G3JG	3.34	272	1.357	(40 + 67)	(37 + 63)	39
GJGJG	3.26	263	1.345	(26 + 95.5)	(21 + 79)	46
2GJ2G	2.67	290	1.810	(13 + 130)	(9 + 91)	49
5G	2.80	290	1.726	(0 + 175)	(0 + 100)	61
G_1J_1	2.48	220	1.478	(21 + 81)	(21 + 79)	46
G_1J_2	3.74	275	1.225	(40 + 85)	(32 + 68)	45

3.5 Research methodology

In this work, non-hybrid and two general types of fibers hybridization (interply and intraply) composites were used to investigate their mechanical properties (tensile, flexural, and impact) along with thermal and sound insulations. E-glass woven fabric (synthetic) and jute fabric (natural) were used in the adopted hybridization methods. Jute fibers were chemically treated by alkalization method to improve their internal structure and increase the adhesion strength with polymeric resin before using them in the reinforcement of the epoxy matrix. The sheets with different compositions were fabricated using the hand layup method and a predefined compression load is applied during the matrix curing process that conducted at environmental conditions. The required shape and dimensions of samples for each test were prepared for being ready to the test. Samples' results of each test were compared and the best one of them would be pointed out. The block diagram shown in Figure (3.6) clarified the main steps and their flowing sequence to achieve the objectives of this work.

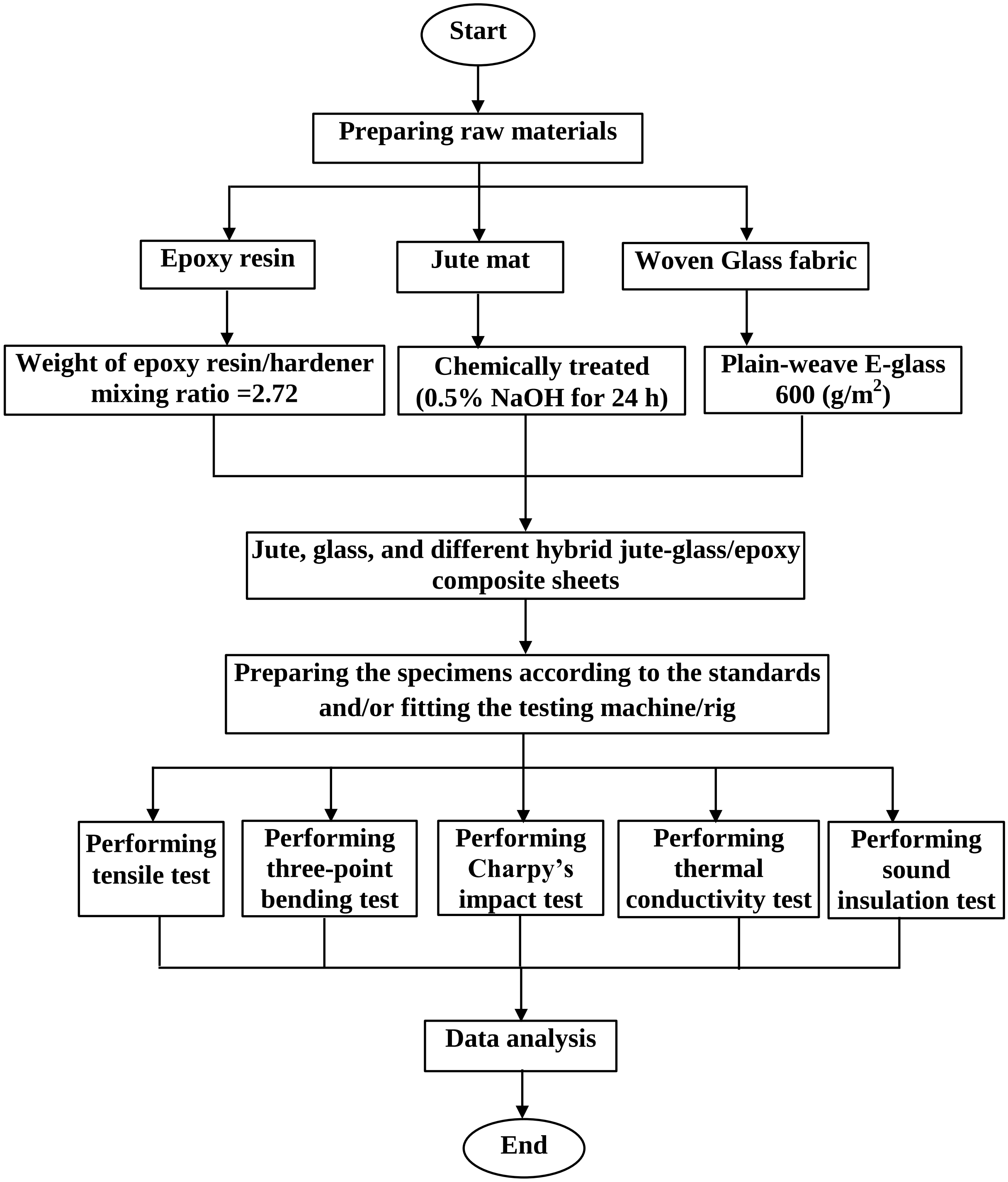

Figure (3.6): Block diagram of the research methodology.

3.6 Mechanical and physical tests

In this study, the following testing was done on the composite's samples that were prepared throughout this work:

3.6.1 Tensile test

Tensile specimens were prepared according to ASTM D3039 [72] as shown in Figure (3.7). The size of the fiber reinforced composite sample measured 250 mm (length) × 25 mm (width) × (thickness). Universal tensile testing machine (200 KN WDW-200E III), shown in Figure (3.8), was used to conduct the tensile testing at a constant head displacement rate of 2 mm/min. By the end of the tests, the tensile stress-strain relationships were provided. Figure (3.9) shows some of fabricated samples for the tensile test. For each type of composite, three samples were used, and the average outcomes were taken into consideration. Tensile tests were carried out in the strength of materials' lab, department of production engineering and metallurgy, University of Technology, Iraq.

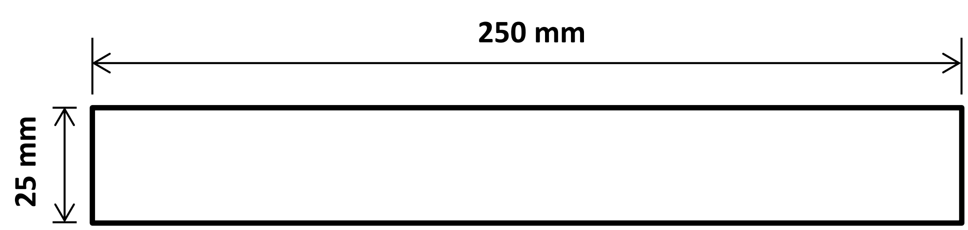

Figure (3.7): Tensile test specimen according to ASTM D3039.

Figure (3.8): Universal tensile testing machine and specimen mounting.

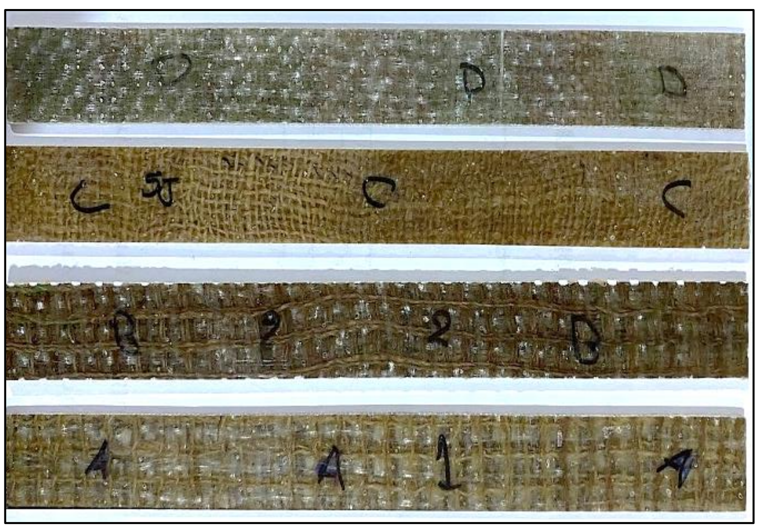

Figure (3.9): Fabricated composite specimens for tensile test.

3.6.2 Flexural test

Flexural test with three-point bending setting was conducted in accordance to ASTM D790 [73], flexural characteristics of composite samples to be measured. The dimensions of all composite sample types were 128 mm (length) × 12.7 mm (width) × (thickness) as shown in Figure (3.10). The bending machine and specimen setting are shown in Figure (3.11). With a strain rate of 0.01 mm/mm/min, the machine crosshead speed was held constant at 3 mm/min. The final outcomes were derived from the average of three replication. Figure (3.12) shows some of the specimens that ready for flexural test. Flexural tests were carried out in the strength of materials' lab, department of production engineering and metallurgy, University of Technology, Iraq.

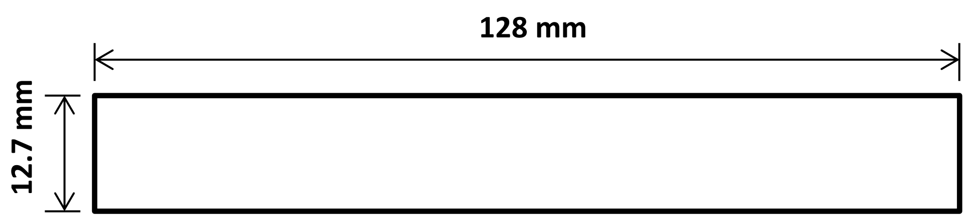

Figure (3.10): Specimen's dimensions of flexural test.

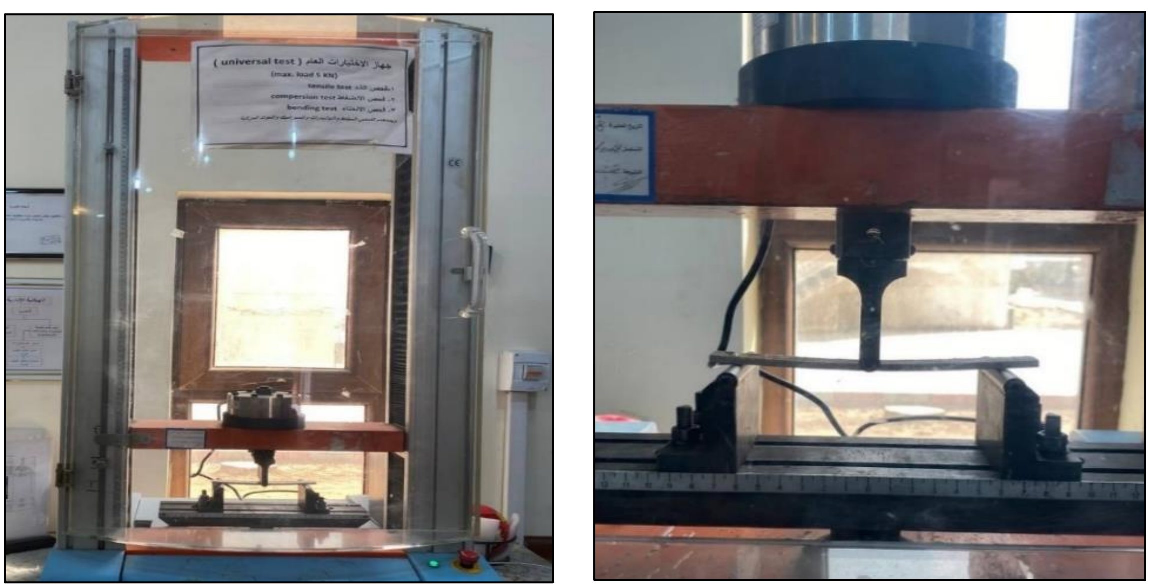

Figure (3.11): Flexural testing machine and specimen mounting.

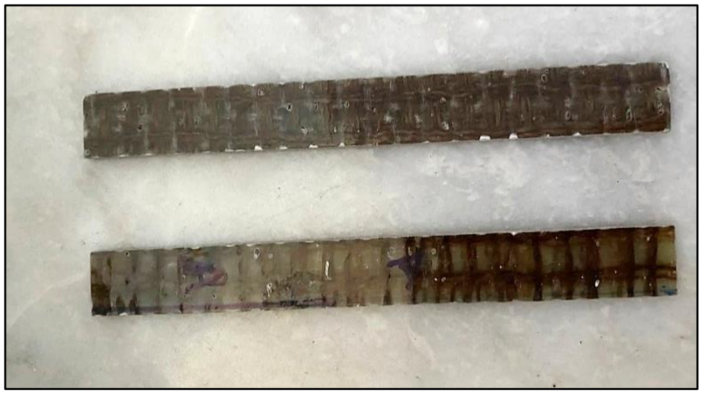

Figure (3.12): Some of fabricated composite specimens for flexural test.

When large support span-to-depth ratios greater than 16 to 1 are used, significant end forces are developed at the supports with relatively large deflection *D* existed. According to ASTM D790 [73], an approximated correction factor was given in flexural stress equation to correct the relatively large deflection *D*:

$$\sigma_{max} = \left(\frac{3PL}{2bh^2}\right)\left[1 + 6\left(\frac{D}{L}\right)^2 - 4\left(\frac{h}{L}\right).\left(\frac{D}{L}\right)\right] \qquad (3.1)$$

where:

P: is the applied load at the mid span

L: is the span length

h: is the span depth

b: is the span width

D: is the maximum deflection at mid span

The tangent modulus of elasticity can be calculated from the load deflection curve using the following equation given by ASTM D790 [73]:

$$E_b = \frac{L^3 m}{4bh^3} \quad (3.2)$$

where:

E_b: is the elastic bending modulus

m: The slope of the load-deflection curve's tangent to its starting straight-line segment

3.6.3 Impact test

Charpy's impact test is one of the most common tests for characterizing the mechanical behavior subjected to low-speed impact. The specimen is held at both ends so the hammer will strike it in the middle. The pendulum is raised to its highest point and fixed as indicated in Figure (3.13) as part of the instrument's testing procedure. After the specimen is set in position, the energy gauge is initialized (on zero position). The pendulum is then released, converting its potential energy into kinetic energy. While the energy gauge measures the absorbed energy used to break the test sample, some of this kinetic energy is used to fracture the specimen. To determine the amount of energy absorbed by the composite materials subjected to impact load, the Charpy's impact test was performed. The impact velocity was set at 3.8 m/s, and the impactor's weight was set at 2.05 kg. The fabricated impact samples are shown in Figure (3.14). Unnotched Impact composites' samples were made in accordance with ISO 179 [74] in which the dimensions are 55 mm in length, 10 mm in width × (thickness). Three samples for each group were tested and the average values have been considered. Impact tests were carried out in department of polymers and petrochemicals industrials engineering's labs, college of materials engineering, University of Babylon, Iraq. The impact strength (S) in kJ/m^2 was estimated according to equation (3.3) [74].

$$S = \frac{E_i}{h\ b} \times 10^3 \tag{3.3}$$

where:

E_i : is the breaking absorbed energy in (J)

h: is the thickness of the sample in (mm)

b: is the width of the sample in (mm)

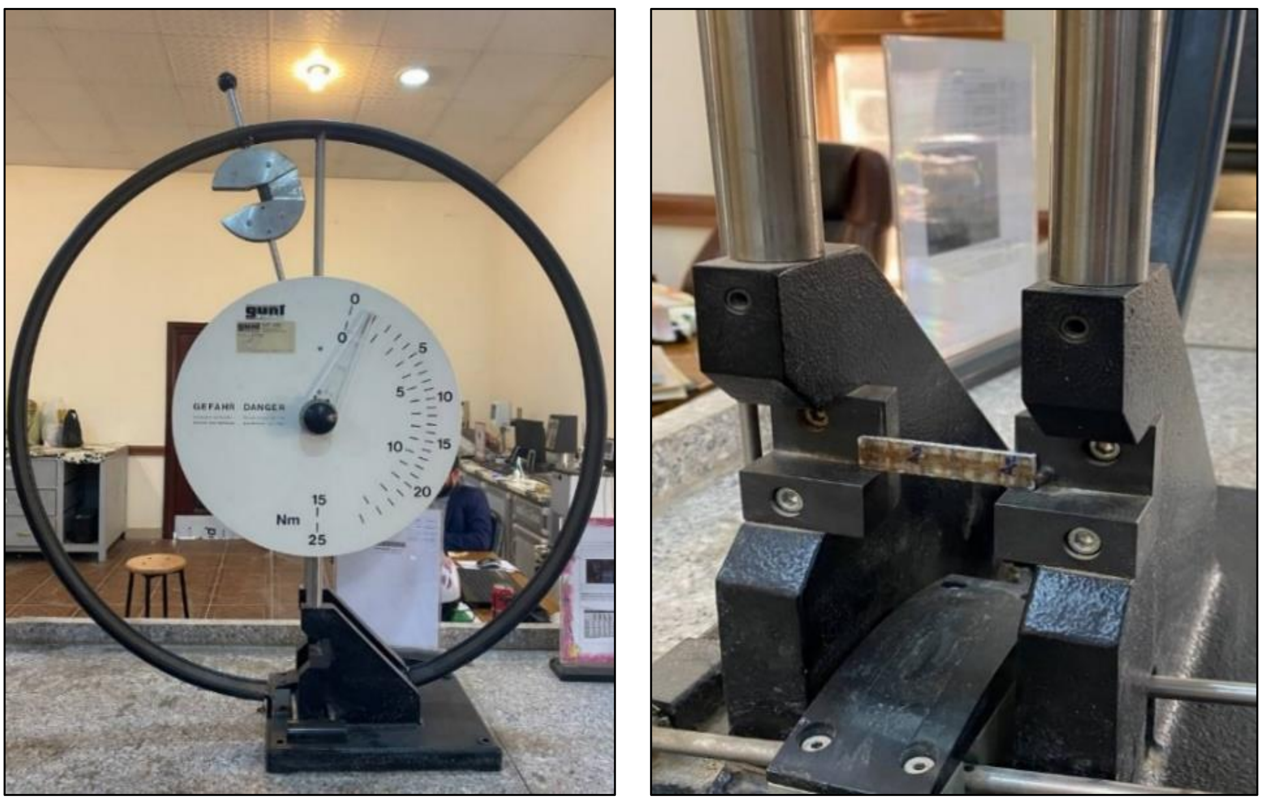

Figure (3.13): The WP 400 gunt brand impact testing machine and specimen setting.

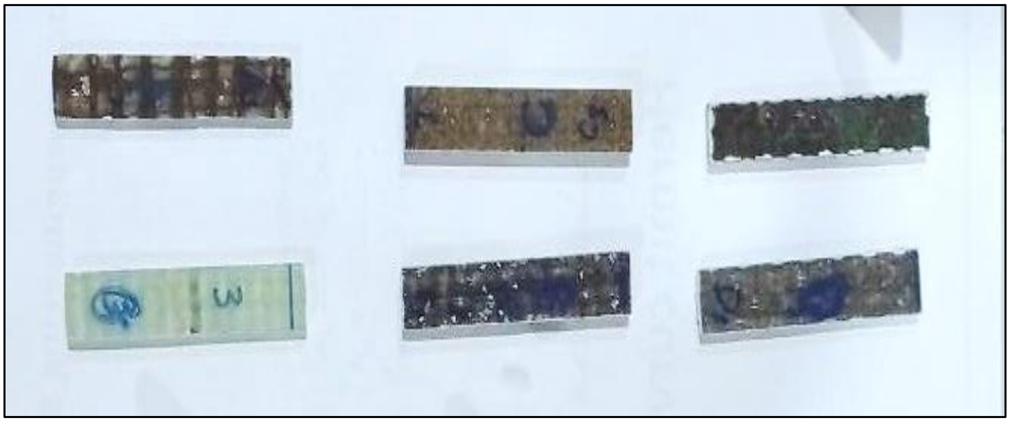

Figure (3.14): The fabricated composite specimens for impact test.

3.6.4 Thermal conductivity test

Thermal conductivity is a material intrinsic property that relates its ability to transfer heat perpendicularly through its cross-sectional area when there is a gradient in the temperature through the thickness. The device used for testing the conductivity of samples is shown in Figure (3.15). Disk shaped samples with diameters equal to 19 mm were cut from the composite sheets to be placed in the described apparatus. The lateral surface area of the disk was well insulated in the radial direction to ensure the heat transfer through one-dimension (i.e., thickness of the disk). The applied power used in the tests is equal to 12 W. After applying the power, the temperatures at both sides of the disk sample are increased. When these temperatures reached equilibrium condition, they are measured. The final readings were taken from the average of testing three samples for each composite designation. One dimension Fourier's law is applied to find the conductivity (k) of the samples as per equation (3.4) according to heat transfer book [75]:

$$k = \left(\frac{Q}{A}\right)\frac{\Delta x}{\Delta T} \tag{3.4}$$

Thermal resistance R is equal to [75] :

$$R = \frac{\Delta x}{A\,k} \qquad (3.5)$$

For a case of comparison, thermal resistance R is divided by the sample's thickness to get the thermal resistance per millimeter (R_T). This would lead to equation (3.6) according to heat transfer book [75].

$$R_T = \frac{R}{1000 * \Delta x} = \frac{0.001}{A\,k} \qquad (3.6)$$

where:

k: the thermal conductivity of the material (W/m.^{o}K)
R: is thermal resistance (^{o}K/W)
R_T: is the thermal resistance per thickness (^{o}K/ W.mm)
Q: is the local heat flux (W/m^2)
A: is the area of the cross-sectional surface (m^2)
ΔT: is the temperature difference thickness (^{o}K)
Δx: is the distance in (m) between the two isothermal ends (i.e., thickness)

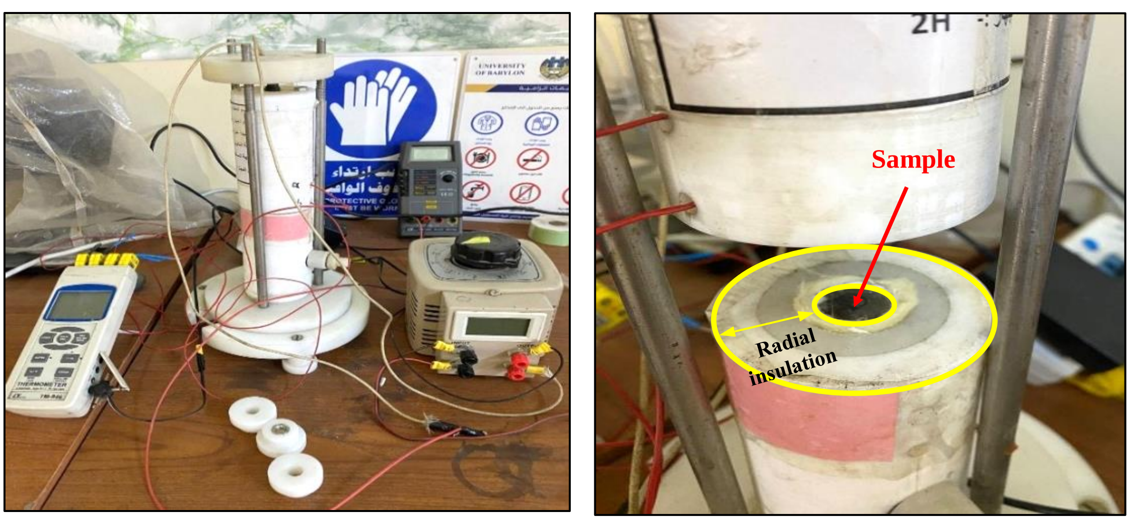

Figure (3.15): Thermal conductivity device and sample mounting.

3.6.5 Sound insulation test

Sound insulation test is performed using an insulated closed wooden chamber or box as shown in Figure (3.16). The box has been fabricated from plywood with thickness equal to 2 cm and the dimensions of the interior volume of this box are 30 cm (width) × 15 cm (height) × 50 cm (length). All interior surfaces are well insulated by sponge layer with 3 cm of thickness to eliminate the possibility of sound rebound from these surfaces as shown in Figure (3.17). This chamber is not ideal for measuring the acoustical characteristics, but it could provide a good comparison of the samples under the same conditions. Two frequency levels, 1000 and 3500 Hz, were used. The sound wave is converted to an electrical signal using a microphone. This signal is transfer to the computer to measure the *SPL* in dB using a sound meter software. Firstly, the noise source was placed inside the box and sound wave has been applied without inserting the insulated sample that acts as a separating wall between the sound source and the microphone. Subsequently, the composite sample was inserted at the designed place and the sound wave has been measured. The reduction or attenuation in the *SPL* (i.e., ΔSPL) and the insulation ratio (*IR*) are calculated according to equations (3.7) and (3.8), respectively.

$$\Delta SPL = SPL_{without\ insulation} - SPL_{with\ insulation} \tag{3.7}$$

$$IR(\%) = \frac{\Delta SPL}{SPL_{without\ insulation}} * 100 \tag{3.8}$$

For a case of comparison between the different composite materials and their thicknesses, the *IR* ratio is divided by the thickness of the sample to obtain the sound insulation ratio per millimeter (IR_T) as per equation (3.9).

$$IR_T(\%) = \frac{IR}{1000 * \Delta x} \tag{3.9}$$

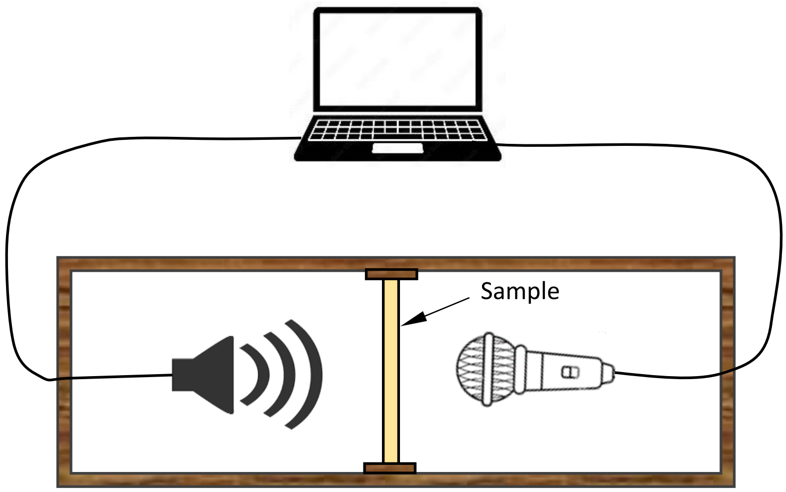

Figure (3.16): A scheme of the sound insulation measuring pickup.

Figure (3.17): Interior view of the sound insulation testing box.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

In this chapter, the findings provided from the experimental tests are presented and discussed which include the mechanical properties like tensile, flexural, impact, and physical characteristics such thermal and sound insulations. The best hybrid configuration for each test were identified.

4.2 Tensile properties

Table (4.1) lists the tensile properties of the different composites that were fabricated in this work. The strain to failure of pure jute and pure glass composites indicated that failure occurs in the jute composites was earlier than that of glass composites. The strain to failure of pure glass composites were more than three times of pure jute composites. It is clear from Figure (4.1) that composites reinforced with only glass fibers have the highest tensile properties than other types of composites used in this work. Accordingly, it is obvious that tensile properties of the interply hybrid composites increased with increasing the glass fibers fraction within the composite. 2GJ2G hybrid composites exhibited the highest tensile strength among other interply hybrid configurations with about 71% of pure glass composites. Meanwhile GJGJG and G3JG interply hybrid composites have tensile strengths about 50% and 30% of pure glass composites, respectively. This behavior could be attributed to the higher strength of the glass fibers than the strength of jute fibers and the stronger adhesion with the epoxy matrix as well.

Table (4.1): Tensile properties of different composites.

Designation	Tensile modulus (GPa)	Tensile strength (MPa)	Failure strain (%)	Specific tensile modulus (GPa.cm^3/g)	Specific tensile strength (MPa.cm^3/g)
5J	2.80	40.71	2.15	2.37	34.36
G3JG	4.75	112.19	3.53	3.50	82.66
GJGJG	5.13	187.38	5.13	3.82	139.36
2GJ2G	6.85	263.36	5.16	3.78	145.48
5G	8.63	371.67	7.31	5.00	215.31
G_1J_1	4.96	159.61	4.87	3.36	107.95
G_1J_2	5.02	113.02	4.55	4.10	92.23

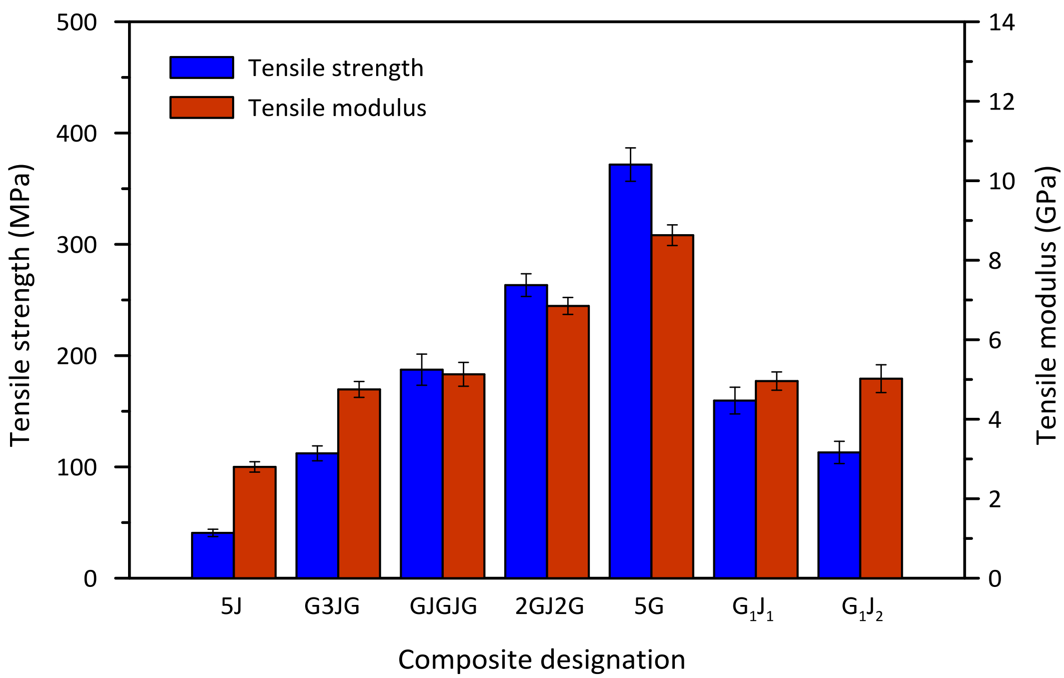

Figure (4.1): Tensile properties of jute/glass fibers composites and their hybrids.

Tensile modulus of the interply hybrid composites followed the same trend that tensile strength did. Increasing the content fraction of stiffer fibers (i.e., glass fibers) within the hybrid composites definitely would increase the composite stiffness and higher stress is required to produce a specific deformation. This observation was in agreement with the study achieved by [33]. Also this was recorded by [27][37].

Failure modes of the pure glass, pure jute, and 2GJ2G interply hybrid composite samples after tensile test are shown in Figure (4.2). The failed samples showed in Figure (4.2a) indicated that pure glass/epoxy composite samples during the tensile test was suffered from fiber-matrix debonding close to the fractured surfaces with fibers' pull-out and fracture. However, the dominant failure in the pure jute composites was the brittle fracture pattern in which the jute fibers were broken without any sign of jute fiber pull out as shown in Figure (4.2b). This doesn't necessarily mean that the adhesion strength between jute fibers and epoxy matrix is strong, rather it can be attributed to the low tensile strength of the jute fiber itself. Consequently, jute fibers were broken early before the incidence of any sign of fiber-matrix debonding. Whereas in interply hybrid laminates designated by 2GJ2G, failure was administrated by extensive glass fiber pull out, glass fiber-matrix debonding, and breakage as shown in Figure (4.2c). Another reason is that the percentage crimp (waviness) of jute yarns within the woven textile is relatively higher when compared with glass yarn within the woven fabric as shown in Figure (4.3). The loosen jute yarns embedded in the polymeric matrix cannot carry the load transferred from the matrix instantly [76]. Therefore, the micro cracks within the matrix phase were developed early when the jute fiber reinforced composite was subjected to tensile loading and a sudden brittle failure has occurred [77].

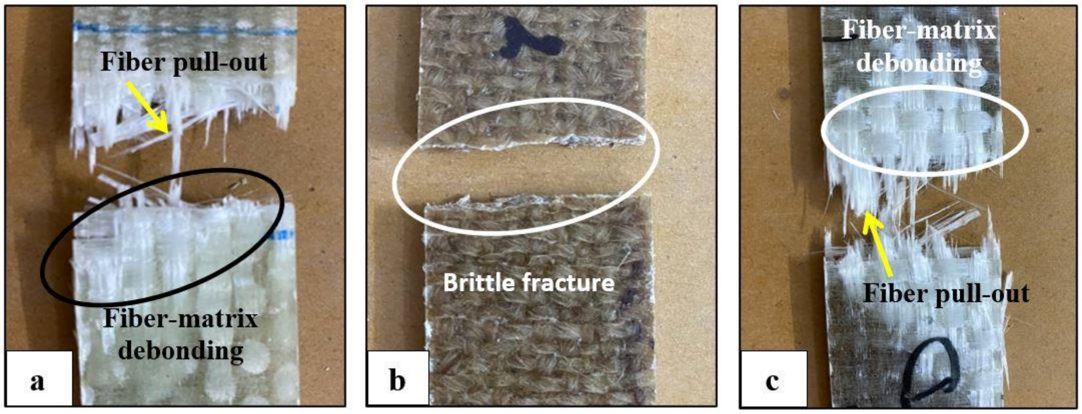

Figure (4.2): Images of specimen after tensile test. (a) 5G, (b) 5J, and (c) 2GJ2G.

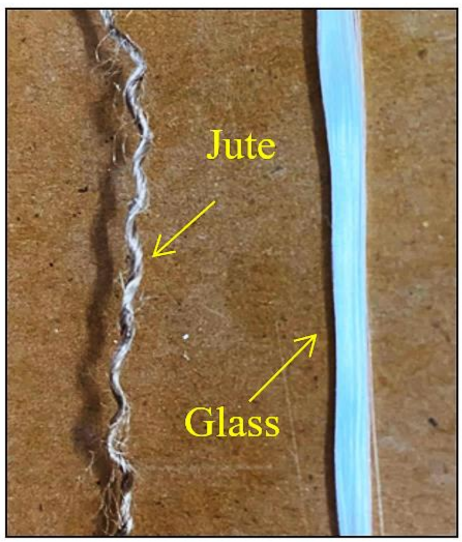

Figure (4.3): Waviness of jute yarn compared to glass yarn.

For intraply hybrid composites, results indicated that this hybridization method could produce a material with intermediate tensile properties between glass and jute fibers used alone as indicated by [42]. The hybrid composites G_1J_1 and G_1J_2 exhibited approximately the same results regarding the tensile modulus but differ in the tensile strength values. G_1J_1 samples give tensile strength of about 41% higher than that of G_1J_2 samples although they have approximately the same content of the glass fibers, but the later contain higher content of jute fiber relative to the glass fiber which lead to accelerate sample's failure probably due to the earlier fracture of jute fibers that leave many severe defects in the intraply hybrid composites (G_1J_2) in form of macro longitudinal pores aligned parallelly on both sides of glass yarns (alternative replacement) when the composite undergoes deformation while glass fibers haven't fractured yet as shown in Figure (4.4). Regarding the tensile modulus, G_1J_2 has tensile modulus slightly higher than of G_1J_1. It was noted that G3JG and GJGJG interply hybrid composites have tensile moduli very close to that of G_1J_1 and G_1J_2 intraply hybrid composites although they have different fiber type contents (i.e., hybridization ratio). This behavior could be attributed to the good mechanical compatibility between the two different fibers (i.e., glass and jute) at a relatively low strain in which the elastic modulus has been calculated. Stress-strain curves shown in appendixes (figure A-1).

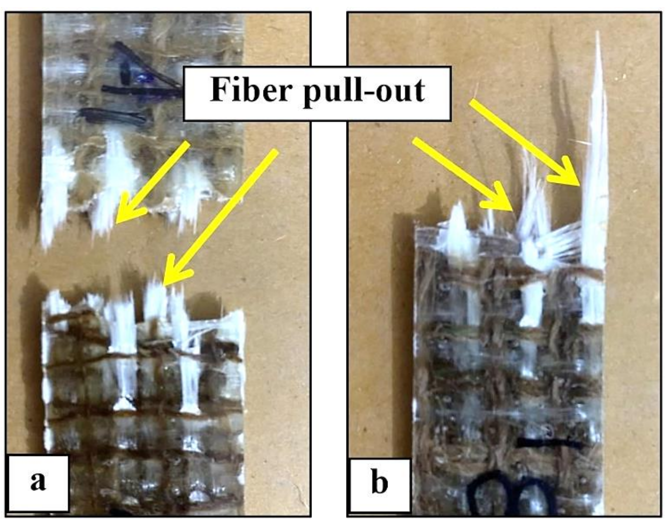

Figure (4.4): Images of fractured intraply specimens after tensile test. (a) G_1J_1, and (b) G_1J_2.

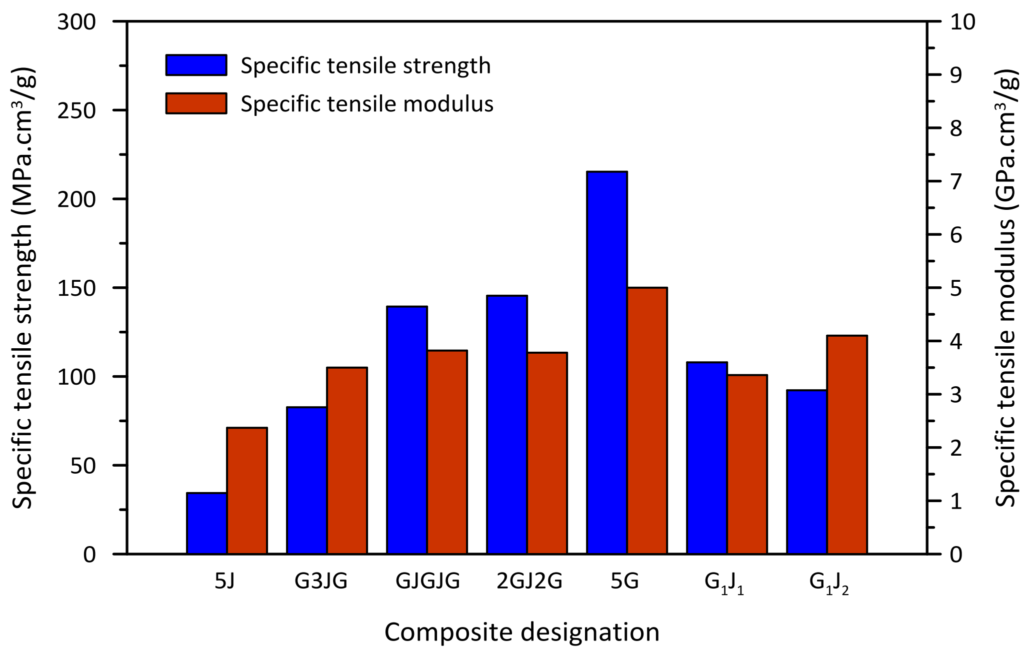

Figure (4.5): Specific tensile properties of jute/glass fibers composites and their hybrids.

It is well known that the strength and stiffness-to-weight ratios are the most important characteristics of composite materials. Therefore, the specific tensile properties of the different composites were investigated. The specific tensile properties of the composite were calculated in this work by dividing the composite's tensile property by its density in order to compare the composite properties taking into consideration its weight and volume as listed in Table (4.1) and also shown in Figure (4.5). Some additional improvement in the tensile properties might be obtained. For example, the tensile strength of the interply G3JG composite gives 30% of glass fiber reinforced composite (5G). The specific tensile strength of this hybrid composite type was improved to 38%. Concerning the tensile modulus, the incorporation of 63% of glass fiber weight content within the G3JG hybrid composite gives tensile modulus about 55% of glass composite counterparts; however, this value reached up to 70% when using the specific values of elastic modulus. The same behavior of GJGJG hybrid composite was noted when compared with glass composites. The tensile properties (i.e., strength and modulus) of GJGJG hybrid composite were 50% and 59% of glass composite counterparts, respectively. However; the corresponding specific tensile properties give 65% and 76% of glass composite specimens, respectively. This interply hybrid configuration (i.e., GJGJG) showed the highest improvement in the specific tensile modulus among other counterparts. For higher content of glass fiber hybrid composites that represented by 2GJ2G configuration, the tensile strength and modulus give 71% and 79% of pure glass fiber reinforced composite, and these values were slightly reduced when considering their specific properties that equal to 68% and 76%, respectively. Concerning the two intraply hybrid composites, and G_1J_2 samples offered more improvement than G_1J_1 counterparts when their tensile properties were calculated relative to their densities. This result accord closely with our predictions as G_1J_2 samples contain more jute fibers with relatively light weight and this in turn led to decrease its density when compared to G_1J_1.

4.3 Flexural properties

Table (4.2) lists the flexural properties of the composites prepared in this work along with their specific properties. Figure (4.6) shows the results of flexural strength and modulus of the jute, glass reinforced epoxy composites and their various hybridizations that include interply and intraply configurations. It is well known that any beam when subjected to flexural loading its outer surfaces will undergo the highest tensile and compressive strains depending on the sign of the developed bending moment along the beam's length. Accordingly, the outermost layers of the rectangular cross-sectional beam would be exposed to the highest stress and if the stress becomes higher than the allowable stress of the material the failure starts to happen. Hence, flexural strength and stiffness of the layered composites are mostly controlled by the properties of the external layers of the reinforcement. The failure begins with the development of crack on the tension side. Obviously, by inserting the glass layers on the skin, the flexural strength is found to increase significantly. This is because glass fibers have greater strength and good resistance against propagation of cracks than that of jute fibers.

Table (4.2): Flexural properties of different composites.

Designation	Flexural modulus (GPa)	Flexural strength (MPa)	Specific Flexural modulus (GPa.cm^3/g)	Specific Flexural strength (MPa.cm^3/g)
5J	2.044	34.221	28.88	1.73
G3JG	6.568	90.192	66.45	4.84
GJGJG	8.674	130.420	97.00	6.45
2GJ2G	9.606	180.707	99.83	5.31
5G	8.572	80.393	46.57	4.97
G_1J_1	5.859	125.867	85.13	3.96
G_1J_2	4.631	78.786	64.29	3.78

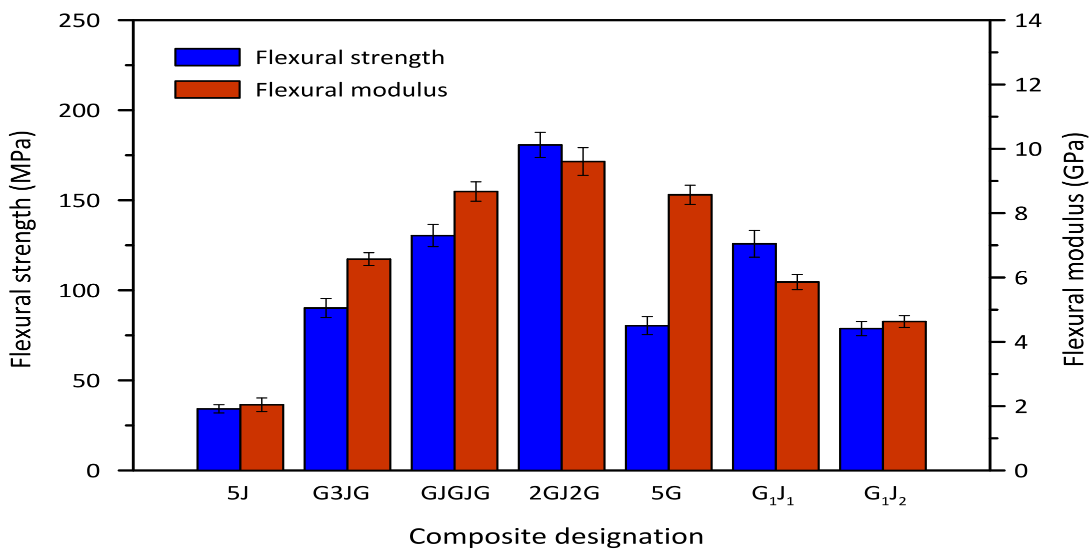

Figure (4.6): Flexural properties of jute/glass fibers composite and their hybrids.

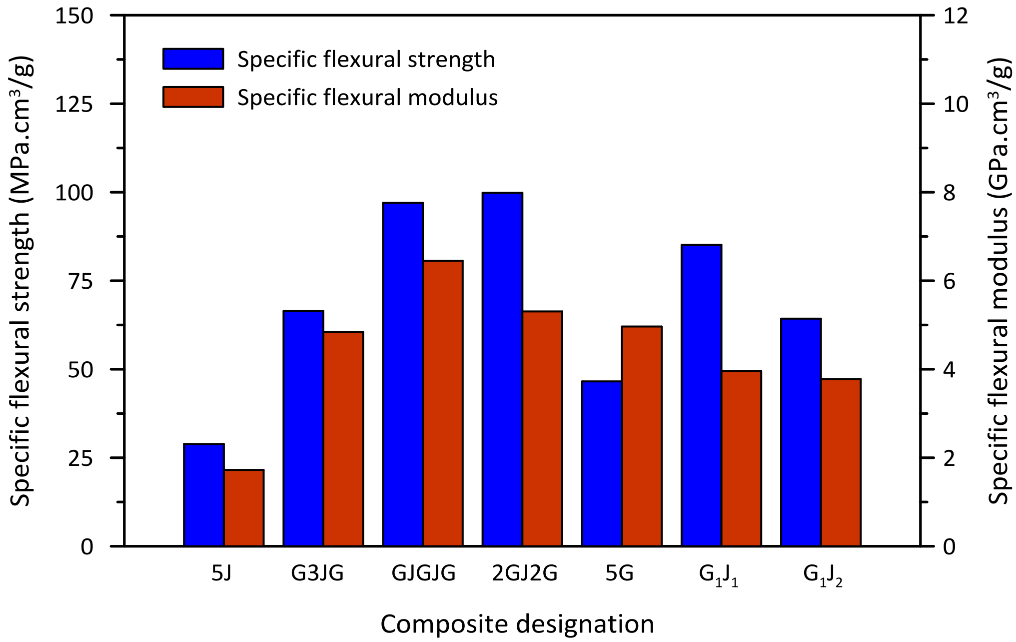

Figure (4.7): Specific flexural strength and specific modulus strength of jute/glass fibers composites and their hybrids.

As observed from Figure (4.6), the flexural strength and modulus of the jute fiber composites, which are about 34 MPa and 2 GPa, respectively, are lower than that of the glass fiber reinforced composites which have the flexural strength and modulus of about 80 MPa and 8.6 GPa, respectively. This is mainly due to the lower mechanical properties of reinforcement phase (i.e., jute fibers) and its weaker adhesion strength with epoxy matrix than glass fibers. Additionally, interply hybrid composites designated by 2GJ2G, GJGJG, and G3JG give flexural strengths equal to 2.25, 1.62, and 1.12 times the strength of pure glass composites, respectively. Regarding the flexural modulus, 2GJ2G samples is about 12% higher than that of glass composite counterparts; the improvement in the flexural modulus is gradually decreased for GJGJG and G3JG samples.

For two intraply hybrid composites, G_1J_1 specimens recorded the higher flexural strength and modulus than G_1J_2 although the later has higher content of jute fibers and higher composite beam thickness as well. The flexural strength of G_1J_1 composites is about 60% higher than that of G_1J_2, while their flexural modulus is only 27% higher than that of G_1J_2. This behavior could be related to the elongation ability or what is called strain to failure of the composite constituents. Jute fibers would be fracture firstly when they were stretched beyond their highest limit and this in turn leaving intrinsic defects within the intraply hybrid composite layer in forms of pores (longitudinal voids) that weaken the composite by increasing the developed stress in two ways: the first one is by decreasing the cross-sectional area that would sustain the load while the second way is the stress concentration that developed around these pores. Consequently, G_1J_2 samples would fracture earlier than G_1J_1 counterparts did as they would contain higher and/or larger pores after jute yarn breakage. Concerning the flexural modulus, the degradation in the G_1J_2 stiffness is lower than that what happened in the strength when compared with G_1J_1 samples possibly due to the little weakening sources at the early stage during the bending test. These defects confined to the relatively weaker adhesion strength between the jute fiber-epoxy matrix that resulted in imperfect transfer of loads from the matrix to the jute fibers. The impressive result is that although GJGJG and G_1J_1 samples have almost the same fiber type percentage weight content, but interply hybrid composite designated by GJGJG recorded a little higher flexural strength than intraply hybrid composite G_1J_1 (about 3.6% higher than that of G_1J_1) which cannot be considered an improvement in the statistical and engineering point of view. However, the flexural modulus of GJGJG interply hybrid composites gives a clear difference (about 48% higher) when compared with G_1J_1 counterparts. GJGJG composite contains full glass fabric layers in both the compressive and tension external sides allowing to explain the difference with G_1J_1 composites, this also illustrated by [42]. It is interesting to note that the majority of hybrid composites prepared in this work have flexural strength higher than that of pure glass composites; meanwhile, the flexural modulus did not follow the same trend.

Only 2GJ2G and GJGJG interply hybrid composites exhibited better flexural stiffness than pure glass counterparts, but still other hybrid composites give encouraging overall results if they are related to the environmental concern. Figure (4.7) shows an exceptional performance of GJGJG samples when their flexural properties were related to the samples' density in which the specific flexural modulus becomes the highest one and flexural strength in the second order among other composite samples. GJGJG composite has lower density but higher thickness than 2GJ2G counterpart and this might make it the best configuration against flexural loading if the cost and preservation of the environment are the main concerns.

Figure (4.8) and (4.9) show the failure of different interply and intraply hybrid specimens after the test. The overall brittle fracture is the most dominant failure mode of the pure jute composite samples due to the early breakage of jute fibers during the bending test. Meanwhile, pure glass composites exhibited fiber-matrix delamination and debonding close to the broken surfaces with a considerable fiber pull-out mode. Therefore, trying to hybridize jute with glass fibers might improve the flexural properties without affecting the environment and keeping the cost as lower as possible if it well achieved. Indeed, 2GJ2G interply hybrid specimens (with about 91% content of glass fibers) showed the highest flexural strength and modulus among other hybrid specimens as they contain the highest wight content of glass fibers located at the farthest distance from the neutral axis of the composite's beam or what is called the mid-plane while a single layer of jute is inserted in the core. These results are in agreement with results obtained by [31][33][78] . Load-displacement cures shown in appendixes (figure A-2).

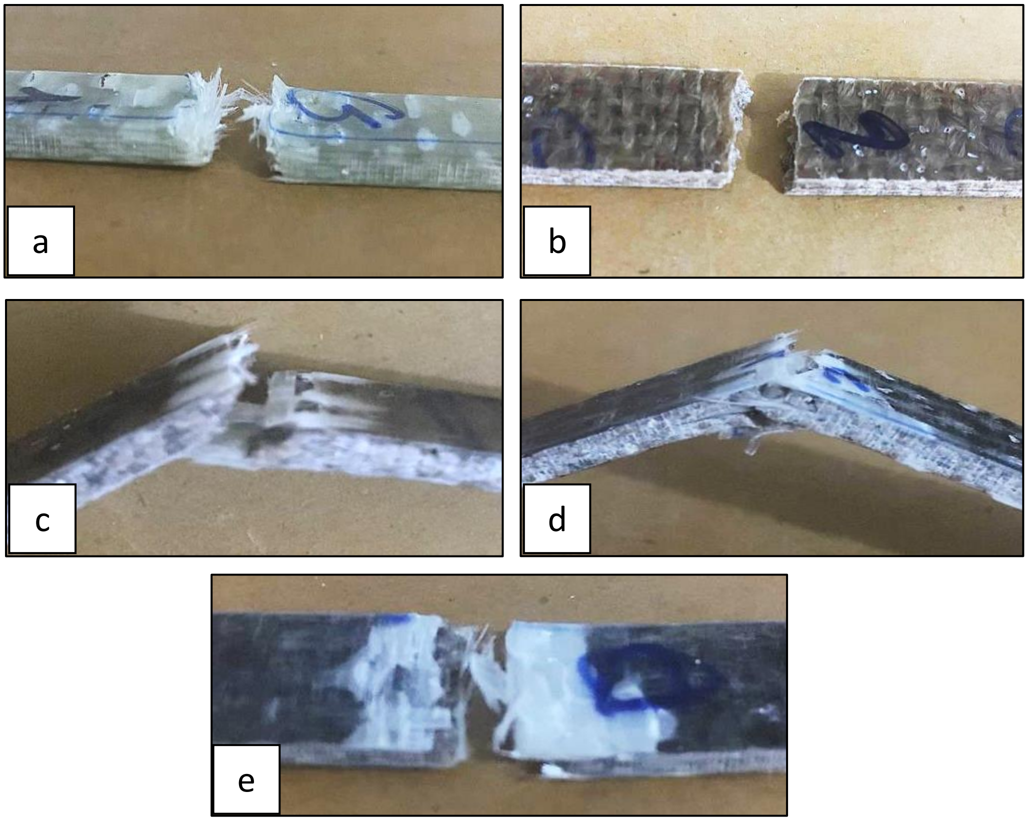

Figure (4.8): Images of pure glass, pure jute specimens and their interply hybrids after bending test. (a) 5G, (b) 5J, (c) G3JG, (d) GJGJG, and (e) 2GJ2G.

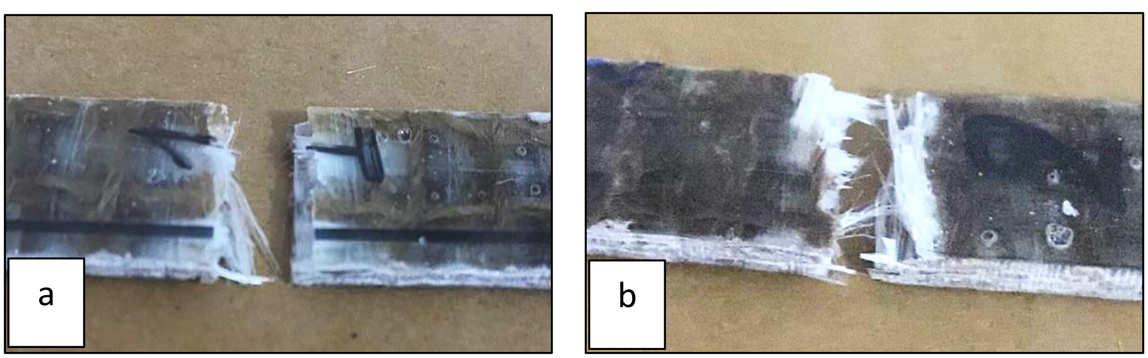

Figure (4.9): Images of fractured intraply specimen after bending test. (a) G_1J_1, and (b) G_1J_2.

4.4 Impact properties

The loss of energy during impact test is the energy absorbed by the specimen during the impact event. Table (4.3) and Figure (4.10) showed the impact strength and the specific values of the various samples using Charpy's impact test. Pure glass composite samples exhibited the highest strength against impact while pure jute composites showed the lowest strength among other composite configurations. It is clear that increasing the content of glass fiber within the composite relative to the jute content would increase the impact strength of the hybrid composite as glass fibers are more durable and can sustain more energy prior to they undergo fracture. However, this is not always true due to the dependency of impact strength on several parameters such as the sequence of different materials lamination, the location of the higher strength layers (innermost or outermost), the compatibility between the various fibers' properties and their adhesion strength with the polymeric matrix.

Table (4.3): Impact properties of different composites.

Designation	Impact strength (kJ/m^2)	Specific impact strength (J.m/kg)
5J	5.51	4.65
G3JG	58.67	43.23
GJGJG	132.54	98.57
2GJ2G	151.97	83.95
5G	158.19	91.64
G_1J_1	70.45	47.65
G_1J_2	79.41	64.80

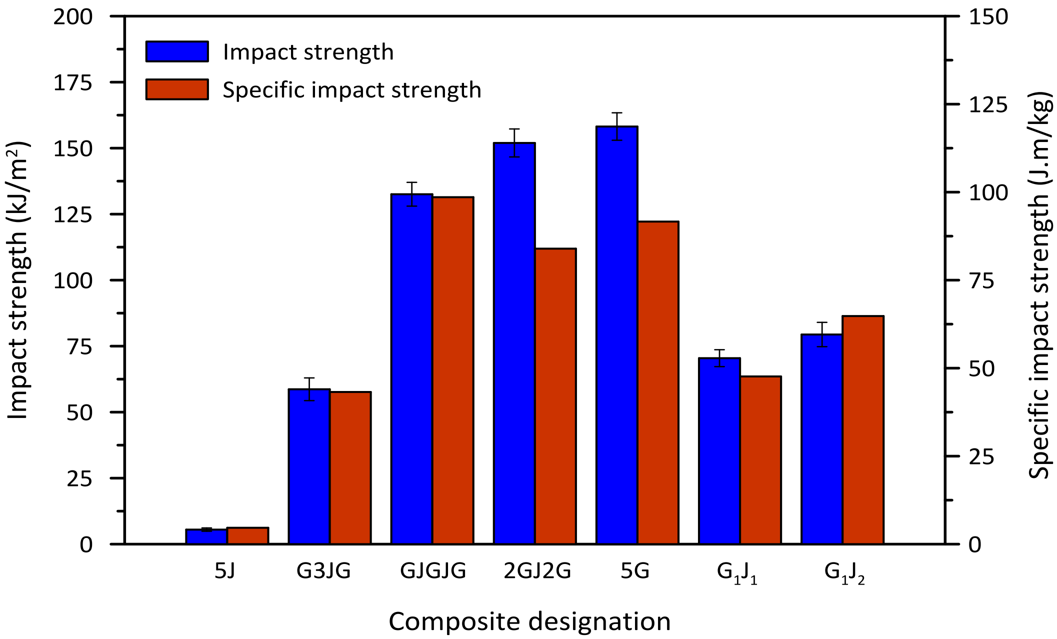

Figure (4.10): Impact strength and specific impact strength of jute/glass fibers composites and their hybrids.

A close look to the impact strength of GJGJG and G_1J_1 samples displayed that although both configurations have almost the same percentage of fiber type weight content, but interply hybrid composite designated by GJGJG can withstand more impact load (about twice of G_1J_1) as it contains about 18% higher content of glass fiber than that of G_1J_1 samples. If one considered the environment concern and the cost of production, GJGJG hybrid configuration is the best one among other types of interply hybrid samples prepared in this work with about only 16% of reduction in the impact strength in comparison with 5G counterparts and this result is in agreement with the results obtained by [37]. 2GJ2G hybrid composite exhibited the highest impact strength among other interply hybrid configurations with about just 4% lower impact strength than pure glass/epoxy composite. The reason for this is that glass fiber has a higher modulus than that of natural fiber, which increases the resistance against deformation. Glass fiber has higher stiffness, strength and toughness than those of jute fiber. Hence, glass fibers can absorb more energy compared with jute fibers. It is noteworthy that placing glass fabric layers at the outermost layer in the composites also has a positive effect on the impact properties as mentioned by [30][37][39]. It was reported that increasing the glass fiber volume fraction increased the impact properties of the hybrid composite. Moreover, inserting the more strength fiber type in the farthest distance from the composite midplane would increase its ability to absorb more impact energy. In regard with the two intraply hybrid fiber configurations, it was noted that a relatively slight increase in the impact strength could be obtained when increasing the jute fibers content relative to glass fibers. This is not encouraging results as the content of the glass fiber in the G_1J_2 samples is almost the same of that used in the G_1J_1 counterpart and the only difference is that the former contains more jute fiber content relative to the glass fiber (i.e., percentage of jute fiber content). Another drawback is the higher thickness and weight of the G_1J_2 samples in comparison to G_1J_1 samples. Consequently, it can be considered just a depleting of the resin and natural fiber without a considerable improvement regarding impact resistance.

The specific impact strengths of different composites are shown in Figure (4.10). The impact strength of G3JG interply hybrid composite gives about 37% of the glass composite, while it gives 47% if they are compared regarding their specific impact strengths. The second configuration of interply hybrid composites (GJGJG) offers 84% impact strength of glass composites. This proportion increased up to 108% when using specific impact strengths. The third configuration of interply hybrid composites (2GJ2G) offers 96% impact strength of glass composites which decreased to 92% when using specific impact strengths. For the two intraply hybrid composites, G_1J_1 hybrid composite gives about 44% of the glass composite, while it gives 52% if they are compared regarding their specific impact strengths, and G_1J_2 hybrid composite gives about 50% of the glass composite, while it improved up to 71% regarding the specific properties. This would confirm that GJGJG hybrid configuration is the best one among other composites that were prepared in this work. However, the intraply hybrid composite designated by G_1J_2 exhibited a considerable increase if the specific impact strength is the concern.

Figures (4.11) and (4.12) show composite samples after impact test. The dominant failure mode of 5G composite samples was the fiber–matrix debonding in limited region without any separation in the specimen body. There was no clear sign of glass fiber's fracture. However, the 5J specimens showed a brittle failure mode with full separation in the specimen's body without any clear sign of fiber pull-out and fiber–matrix debonding. 2GJ2G interply hybrid specimens exhibited almost the same failure mode of pure glass composites counterparts. Increasing the jute fiber fraction in the GJGJG and G3JG hybrid composite specimens resulted in breaking an taking off the outer plies (i.e., glass fibers) close to the broken surfaces. The presence of a glass layer in the alternative sequence like in GJGJG samples would make adjacent jute fibers exposed to a lower level of impact energy. Intraply hybrid composites showed mixed failure modes that include fiber–matrix debonding of glass fibers, glass fiber pull–out, and partial glass–jute fiber breakage.

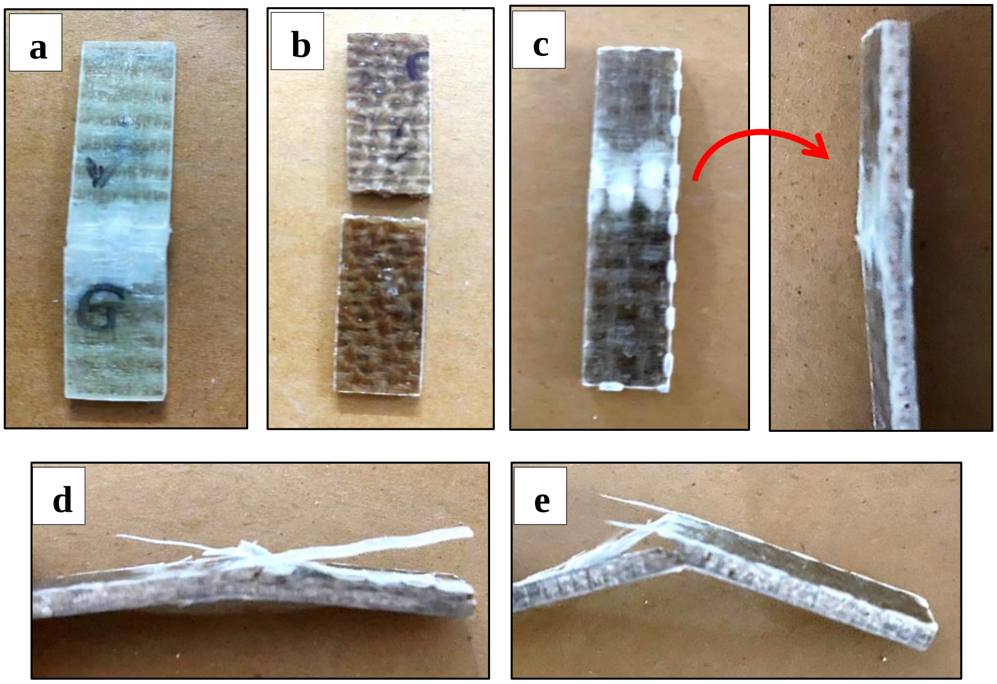

Figure (4.11): Images of pure glass, pure jute specimens and their interply hybrids after impact test. (a) 5G, (b) 5J, (c) 2GJ2G, (d) GJGJG, and (e) G3JG.

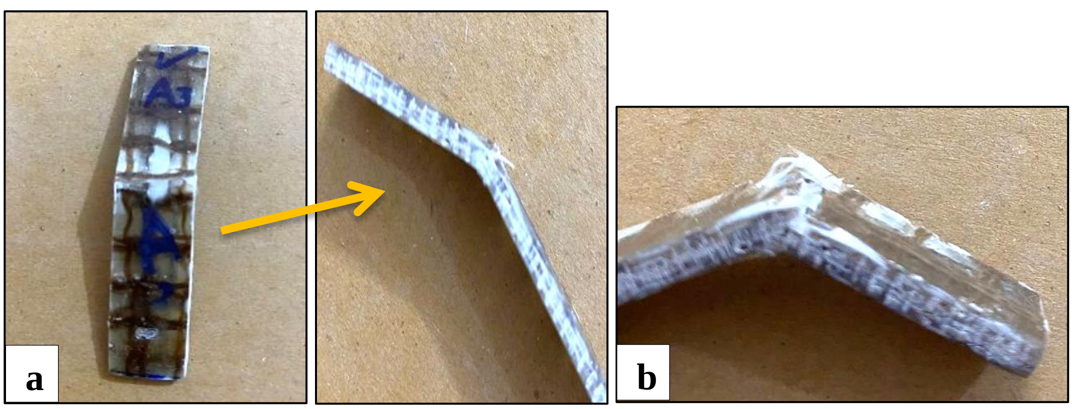

Figure (4.12): Images of intraply hybrid specimens after impact test. (a) G_1J_1 hybrid composite, and (b) G_1J_2 hybrid composite.

4.5 Thermal insulation

Thermal conductivity, thermal resistance, and thermal resistance per thickness of the different composite specimens that were fabricated in this work are listed in Table (4.4). It is obvious that increasing the percentage content of jute fiber within the composite would decrease its thermal conductivity to transfer the heat throughout the laminated composite.

Thermal conductivity of pure jute/epoxy laminated composite is about 67% lower than that of pure glass/epoxy composite, meanwhile its thermal resistance per millimeter of thickness (R_T) is about three times of pure glass/epoxy counterpart. Interply hybrid composites exhibited a gradual increase in their thermal resistance per millimeter of thickness with increasing the glass layer replacement by that made from jute fibers as shown in Figure (4.13). Accordingly, G3JG hybrid composite exhibited the highest heat insulation among other interply hybrid configurations with about 80% improvement in the R_T value compared with pure glass/epoxy composite. Concerning the intraply hybrid configuration, G_1J_1 samples offered about 38% improvement in the thermal resistance per thickness compared with pure glass composite samples. However, G_1J_2 samples offered about only 11% thermal resistance improvement compared to G_1J_1 composite samples. The main reason of this behavior is that jute fiber has thermal conductivity lower than that of glass fiber. Therefore, increasing the content of a fiber material with lower thermal conductivity would increase the composite insulation.

Table (4.4):Thermal conductivity and resistance of different composite designations.

Designation	k (W/m.°K)	R (°K/W)	R_T (°K/W.mm)
5J	0.229	63.92	15.4
G3JG	0.381	30.92	9.26
GJGJG	0.450	25.55	7.84
2GJ2G	0.542	17.37	6.51
5G	0.684	14.44	5.16
G_1J_1	0.494	17.71	7.14
G_1J_2	0.444	29.71	7.94

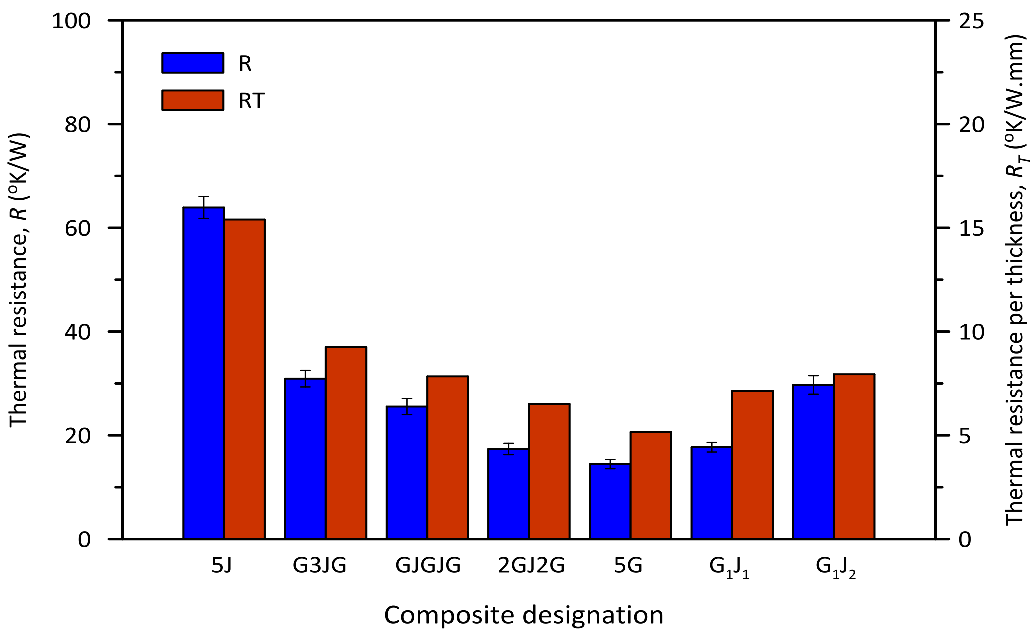

Figure (4.13): Thermal resistance and thermal resistance per millimeter of sample's thickness of jute/glass fibers composites and their hybrids.

It is well known that jute fibers are entanglement and their cells contain pores filled with air that make the structure of the fiber like a porous media. The presence of these pores within the internal structure of natural fibers such as jute would make the system microscopically heterogeneous. Even though the air motion occurs in the closed pores owing to a body force (such as gravity), the air average velocity in a closed pore is almost equal to zero [79]. This makes the dominant heat transfer inside these pores by conduction rather than convection. Therefore, they attributed the lower conduction of heat throughout jute fibers when compared to glass fibers with solid structure. On the other hand, solid materials have thermal conductivity much higher than that of air inside the voids [80][81] . It is noteworthy that GJGJG and G_1J_1 samples have almost same weight fraction of jute and glass fibers (21% wt of jute and 79% wt of glass) and this offered almost the same thermal conductivities as listed in Table (4.4). The GJGJG pattern is recommended for thermal insulation purpose although it is thicker and heavier than G_1J_1 counterpart owing to its easier preparation and fabrication. However, G_1J_1 configuration is recommended if the design requires lower weight and smaller thickness of insulation.

4.6 Sound insulation

Table (4.5) showed the sound test results of the different composites that prepared in this study. It is clear that sound was more attenuated when increasing the frequency of the sound source from 1000 to 3500 Hz. This is due to the fact that the length of sound wave becomes shorter when the frequency increased to 3500 Hz. Therefore, longer part of the wave's length will pass through the same thickness of composite samples and this in turn increase the amount of sound absorption level [57]. Figures (4.14) and (4.15) show the sound insulation ratios and their values per millimeter of sample's thickness at different frequencies.

Table (4.5): Sound insulation of different composite designations at different frequencies.

Frequency (Hz)	Designation	*SPL* without insulation (dB)	*SPL* with insulation (dB)	Δ*SPL* (dB)	*IR* (%)	IR_T (%) per mm of thickness
1000	5J	90	75	15	16.67	4.02
	G3JG	90	75	15	16.67	4.99
	GJGJG	90	71	19	21.11	6.48
	2GJ2G	90	74	16	17.78	6.66
	5G	90	75	15	16.67	5.95
	G_1J_1	90	73	17	18.89	7.62
	G_1J_2	90	76	14	15.56	4.16
3500	5J	90	60	30	33.33	8.03
	G3JG	90	59	31	34.44	10.31
	GJGJG	90	64	26	28.89	8.86
	2GJ2G	90	70	20	22.22	8.32
	5G	90	71	19	21.11	7.54
	G_1J_1	90	64	26	28.89	11.65
	G_1J_2	90	61	29	32.22	8.62

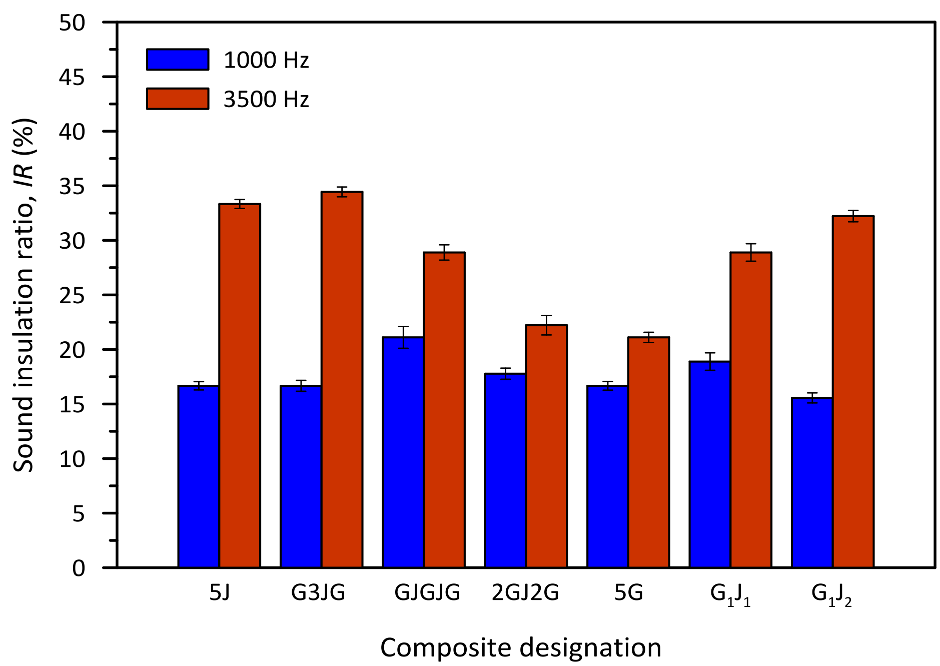

Figure (4.14): Sound insulation ratio of jute/glass fibers composites and their hybrids at different frequencies.

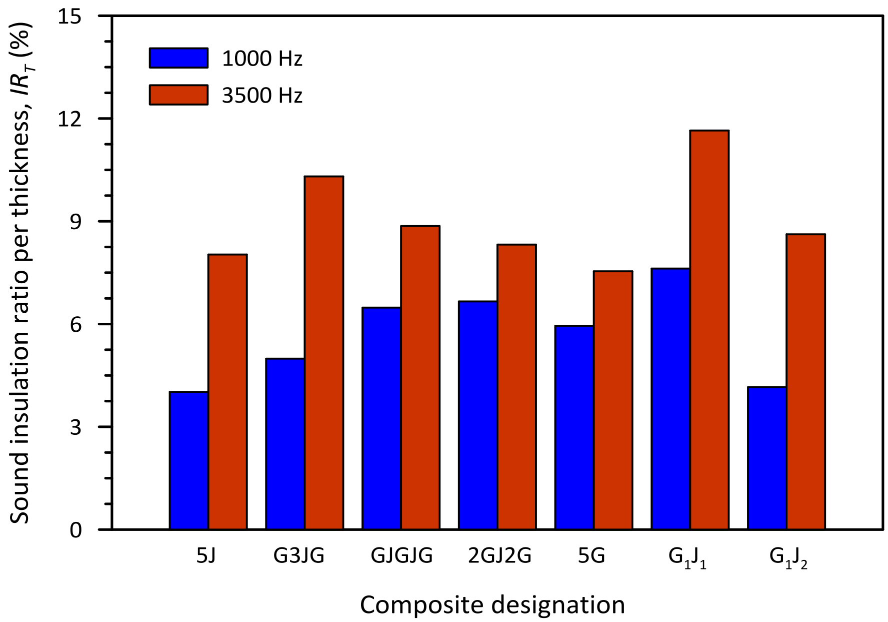

Figure (4.15): Sound insulation ratio per millimeter of sample's thickness of jute/glass fibers composites and their hybrids at different frequencies.

In general, increasing the composite sheet thickness would attenuate more sound's energy since the sound wave would pass through a longer path leading to dissipate more energy. The highest reduction in the *SPL* (frequency of 1000 Hz) is found for GJGJG sample followed by G_1J_1 with about 21% and 19% of insulation ratio, respectively, but a close look to the insulation ratio relative to its thickness (i.e., IR_T) for all composite samples exhibited that G_1J_1 hybrid composite belongs the highest insulation value among other composite designations followed by 2GJ2G counterpart with 7.62 and 6.66% per each millimeter, respectively. The IR_T of G_1J_1 sample provided an improvement in the sound insulation about 28% when compared with that of pure glass composite. However, when the frequency of the incident sound wave is increased to 3500 Hz the highest sound insulation is provided by G_1J_1 sample followed by G3JG sample. At this frequency, the IR_T value of G_1J_1 sample exhibited about 55% more insulation than that of pure glass samples. These results indicated that intraply hybridization of glass and jute fibers offered the best configuration within the tested frequencies regarding the acoustic insulation. This could be attributed to the more complicated reflection and absorption of the incident sound wave-front when reaching and propagating through a ply having two entangled different fiber materials (i.e., different density, elasticity, porosity etc.) in both the frontal area and through-thickness. The improvement obtained in the sound insulation of G3JG samples when the frequency of the sound is increased from 1000 Hz to 3500 Hz is mainly come from the increase in the absorption level provided by jute fibers as the wave length become shorter. Moreover, it was noted that even though G_1J_2 sample has more jute content and its structure looks similar to that of G_1J_1 sample, its sound insulation relative to its thickness doesn't provide higher insulation characteristics.

It is noteworthy to point out that increasing the jute content ratio in the composite doesn't necessarily mean increasing its acoustical insulation as the incident sound wave would suffer from reflection and absorption depending on the material type. This behavior is attributed to the increase in the sample's thickness and epoxy resin fraction with increasing jute fiber content in the hybrid composite as listed in Table (4.5). The epoxy matrix has a relatively lower sound insulation than glass and jute fibers [82]. On the other hand, denser material such as glass fiber could reflect the sound more than a material with lower density like jute fiber. When the sound wave strikes the outer face of the interply hybrid composites that fabricated with glass outer plies, the reflected part of the incident sound wave was higher than that the absorbed one when passed through the first glass layer(s). The passed sound wave has then faced jute fibers that have multi-scale structures and contain many of lumen (hollow voids) and their outer surfaces are rough with separated strands. Therefore, the passed sound wave would be absorbed more than reflected due to energy lose by friction. This variation in the reflection and absorption levels during the sound wave trip within the composite thickness offered the lower passed sound level to the other side of the hybrid composite sample. Using of different fibrous layers with different densities within the composite materials could increase the sound absorption and extended the sound wave frequency bands of absorption [83][84].

4.7 Comparison with other studies

This section aims to compare the results obtained in the present work with the available related data in the literatures that were reviewed in chapter two. As the hybrid composites (interlayer and intralayer configurations) could have wide varieties such as areal density of natural and synthetic fabrics, ends (yarns)/cm, weight and volume fractions of fibers within the composite, stacking sequence, fabric's weaving type (woven, mat, chopped … etc.), the configuration and number of yarn replacement for intraply fiber hybridization, matrix type, and manufacturing method. Accordingly, it is very difficult to find identical cases of composites to be compared with this work. Nevertheless, the current work results could be compared with those found in some of the related published papers and the conformity or harmony of the general trend of the compared data have been clarified to show if there is any agreement or disagreement in the general behaviors. Figures (4.16), (4.17), and (4.18) show comparisons of the present work results concerning the mechanical properties (tensile, flexural, and impact) for interply fiber hybridizing configuration with other researchers' results. Good agreements had been obtained in the general trend of the mechanical properties of the composites tested in these studies. Meanwhile, tensile properties of the intraply fiber hybrid composites obtained in this work were compared with Ouarhim et al. (2020) results and it is clear that the two general trends are similar.

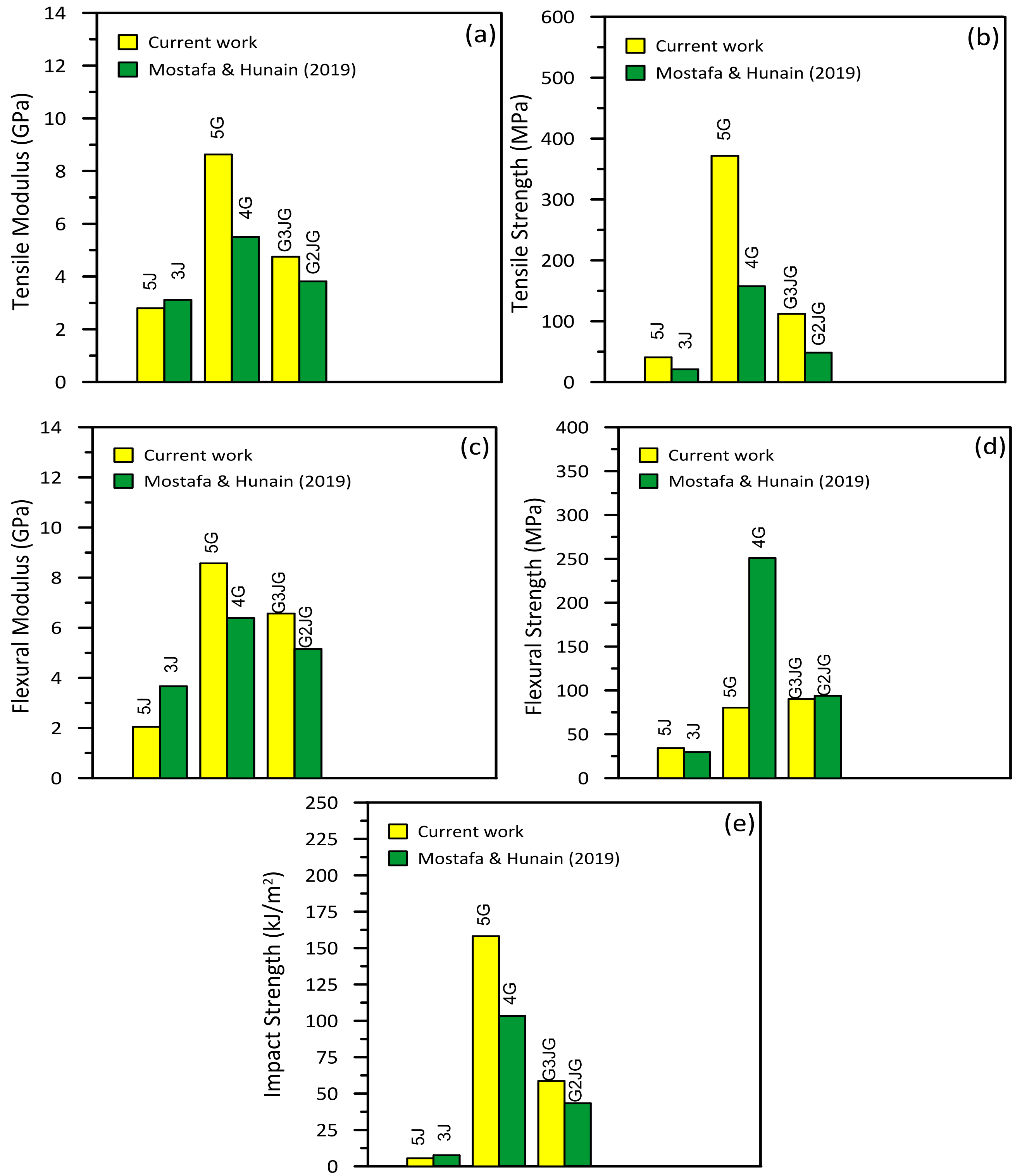

Figure (4.16): Comparison of mechanical properties obtained in the current work with Mostafa and Hunain's (2019) results. (a) Tensile modulus, (b) Tensile strength, (c) Flexural modulus, (d) Flexural strength, and (e) Impact strength.

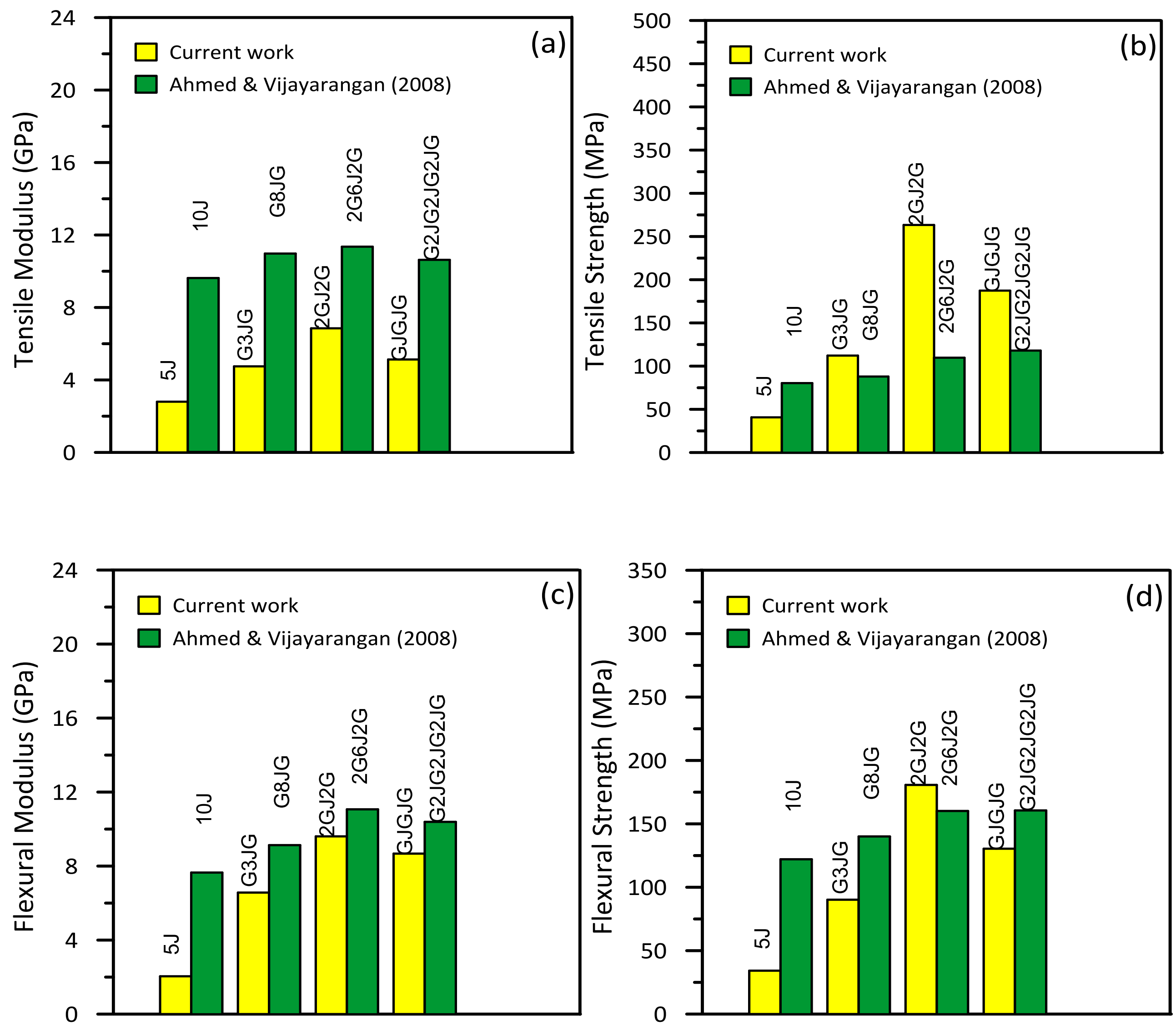

Figure (4.17): Comparison of mechanical properties obtained in the current work with Ahmed and Vijayarangan's (2008) results. (a) Tensile modulus, (b) Tensile strength, (c) Flexural modulus, and (d) Flexural strength.

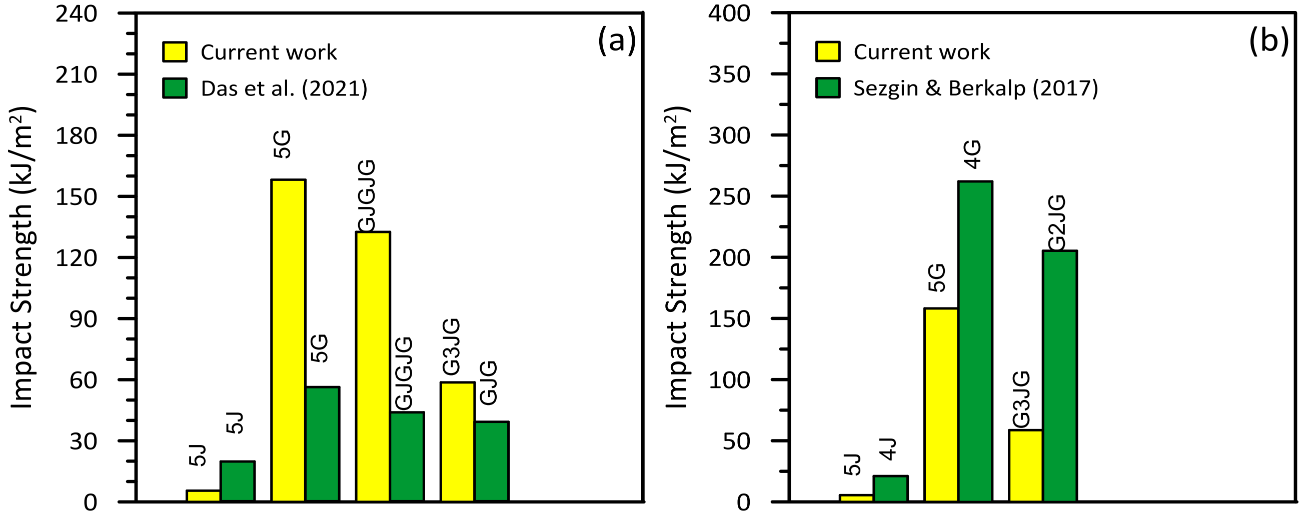

Figure (4.18): Comparison of impact strength obtained in the current work with other studies. (a) Das et al. (2021), and (b) Sezgin and Berklap (2017).

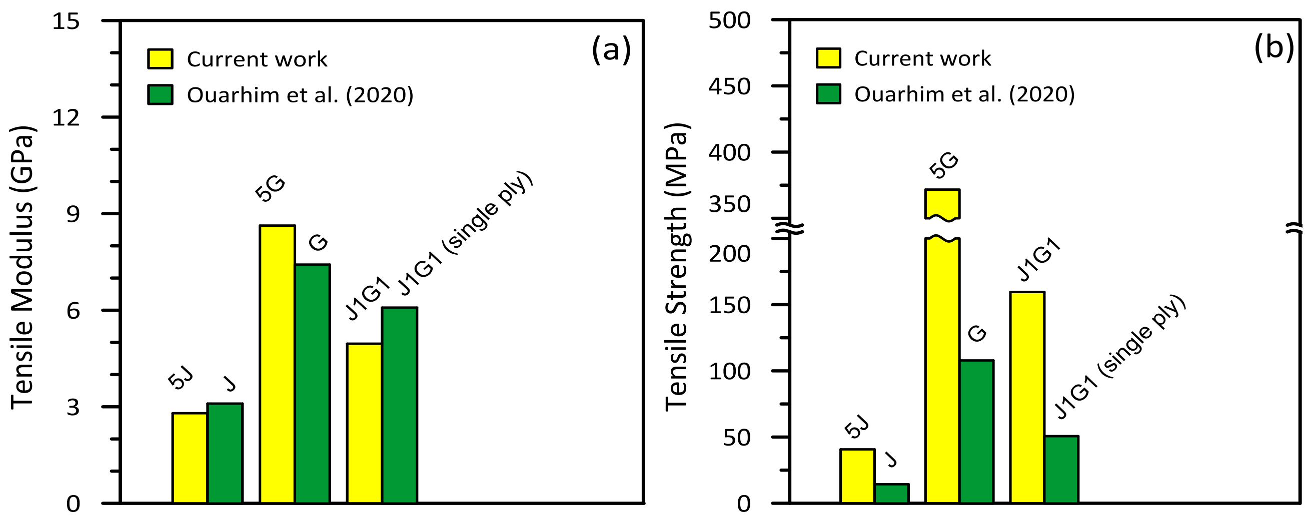

Figure (4.19): Comparison of tensile properties obtained in the current work with Ouarhim et al. (2020) results. (a) Tensile modulus, and (b) Tensile strength.

Thermal conductivities of some composite samples tested in the current work were compared with Aly et al. (2021) results as shown in Figure (4.20). The agreements in the general behaviors of the compared results are acceptable.

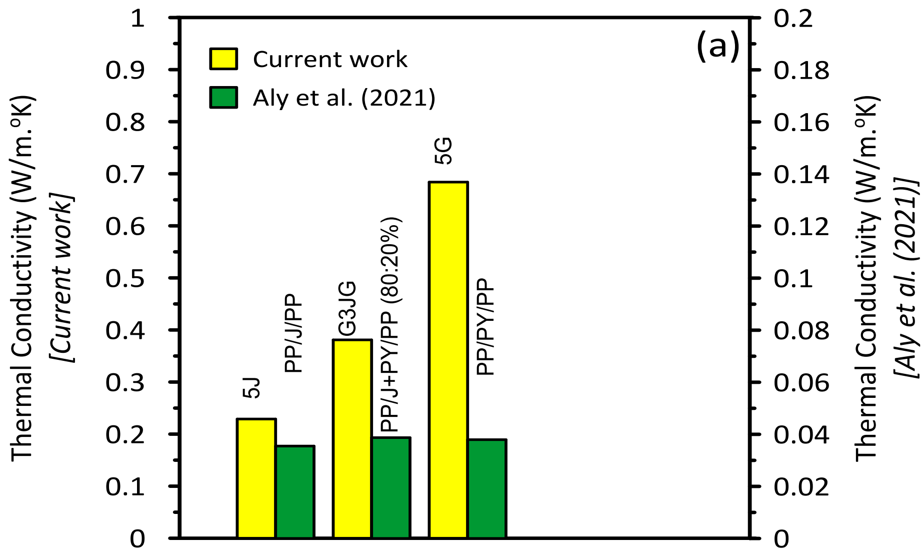

Figure (4.20): Comparison of thermal conductivity obtained in the current work with Aly et al. (2021) results.

Regarding to sound insulation results, the current work results were compared with those obtained by Selver (2019) as shown in Figure (4.21). The general behavior of the compared sound insulation ratio per millimeter of sample thickness (i.e., IR_T) results of pure jute, pure glass, and interply hybrid glass-jute composites showed good compatibility in the general behavior.

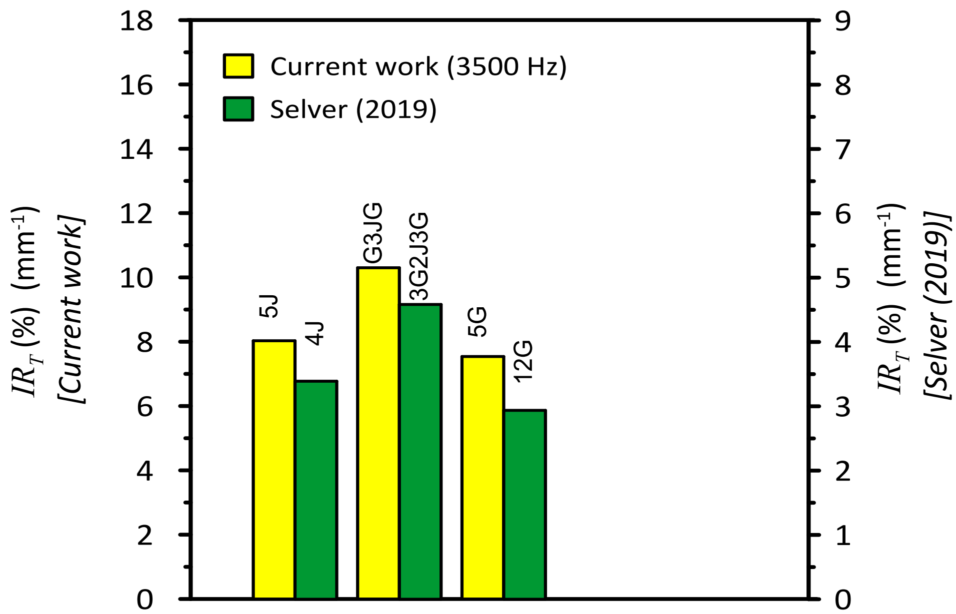

Figure (4.21): Comparison of sound insulation ratio per millimeter (IR_T) obtained in the current work with Selver (2019) results.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Overview

In this study, mechanical properties such as tensile, flexural and impact along with physical properties such as sound and thermal insulation of pure glass and pure jute fibers laminated reinforced epoxy composites and some of their hybridizations were experimentally investigated. Two main methods of fibers hybridization namely interply and intraply were used to investigate the influences of stacking sequence and alternative yarn replacement on the mechanical properties and physical characteristics of the hybrid composites.

5.2 Conclusions

The following conclusions could be drawn:

1. In tensile test, the tensile properties (strength and modulus) of the interply hybrid composites increased with increasing the glass fibers fraction within the composite in which they followed the same general trends that were found in the literature. Interply 2GJ2G hybrid composites exhibited the highest tensile strength among other interply hybrid configurations with about 71% of pure glass composites followed by GJGJG and G3JG, respectively. For intraply hybrid composites, they have intermediate tensile properties results between pure glass and pure jute fibers/epoxy composites. G_1J_2 and G_1J_1 have almost the same tensile modulus but differ in the tensile strength where G_1J_1 samples give tensile strength of about 41% higher than that of G_1J_2 samples. The specific tensile properties of the composites showed almost the same general trend of tensile properties with only one exceptional behavior in the specific tensile modulus obtained for G_1J_2 composites that offered the highest specific tensile modulus among other hybrid composites.

2. In flexural test, 2GJ2G interply hybrid specimens (with about 91% content of glass fibers) showed the highest flexural strength and modulus among all hybrid and non–hybrid composites followed by GJGJG. For the two intraply hybrid composites, G_1J_1 specimens recorded the higher flexural strength and modulus than G_1J_2 with about 60% and 27%, respectively. Moreover, G_1J_1 intraply hybrid composites showed higher strength but lower flexural modulus than that of pure glass counterparts. In general, hybridizing jute with glass fibers offered positive impact of the flexural properties and would help the environment as well.

3. Highest impact strength was provided by pure glass/epoxy composites which is in agreement with the results found in the related literature. It decreased with increasing the jute fiber fraction in the interply hybrid composites. The reduction in the impact strength of 2GJ2G and GJGJG were about only 4% and 16% when compared with pure glass counterparts, respectively. G_1J_1 intraply hybrid composites might be better than G_1J_2 counterparts if the cost is the main concern. However, GJGJG provided the highest specific impact strength followed by 5G, 2GJ2G, G_1J_2, G_1J_1, G3JG, and 5J composites, respectively.

4. Highest thermal insulation has been obtained for pure jute/epoxy composites followed by G3JG interply hybrid composite and it reduced steadily with decreasing the jute fiber fraction. Intraply hybrid fibers configuration showed the same behavior. G3JG interply hybrid composites exhibited the highest thermal resistance per thickness among all other hybrid samples prepared in this study with about 80% higher than that of pure glass counterparts.

5. The best interply hybrid fibers configuration that gave the highest sound insulation ratio per thickness was 2GJ2G and G3JG for sound wave frequencies of 1000 and 3500 Hz, respectively. Meanwhile, intraply hybridization of G_1J_1 exhibited the highest sound insulation among other samples for the two tested frequencies. Moreover, increasing jute fiber content within the hybrid composite did not necessarily mean increasing its ability to insulate the noise.

5.3 Recommendations

The following recommendations may find interest for future studies:

1. Studying other fiber's stacking sequences of interply hybrid composites.
2. Trying to use the mixed interply-intraply hybridization in the same composite with different stacking sequences and configurations to evaluate its advantages on the mechanical and physical properties if any.

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APPENDECIES

A. Raw data of tensile and flexural tests

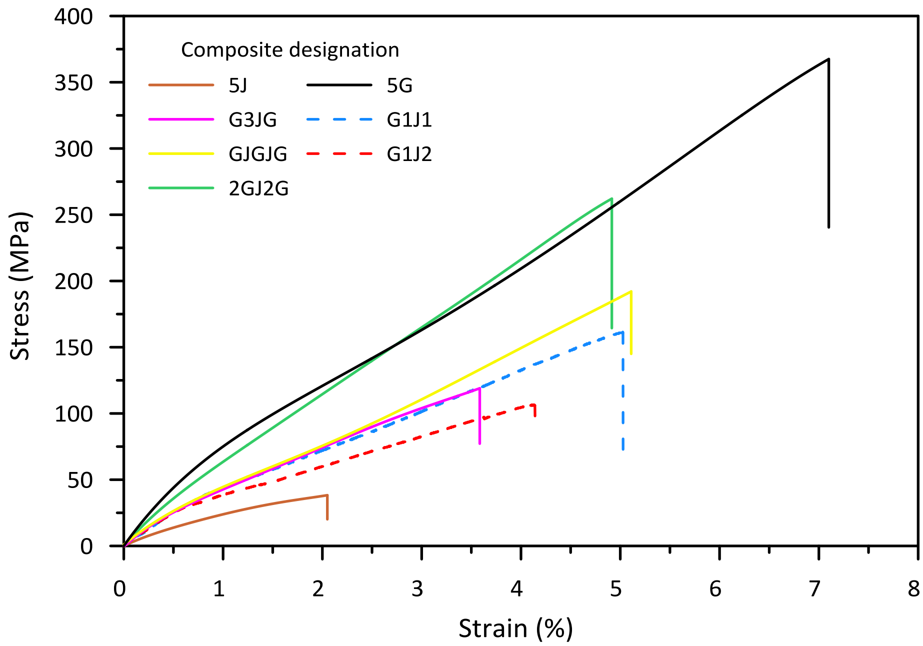

Figure (A-1): Stress-strain curves of tensile test.

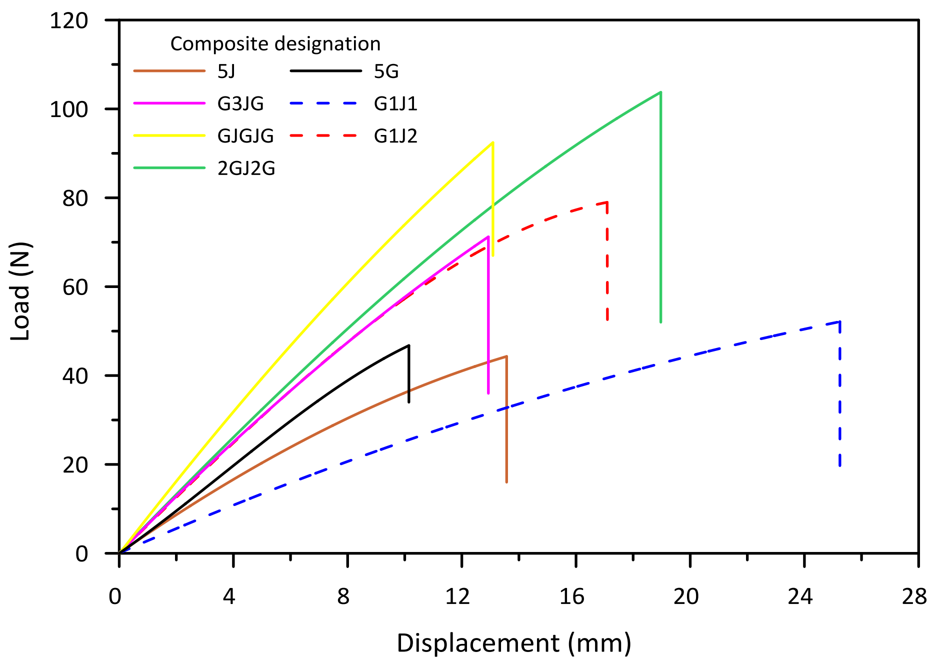

Figure (A-2): Load-displacement curves of flexural test.

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الخلاصـــــــــــة

في الوقت الحاضر، تم استخدام الألياف النباتية على نطاق واسع كبديل للألياف المصنعة نظرًا لقدرتها على التحلل البيولوجي، وفرتها، كونها صديقة للبيئة وتكلفتها منخفضة نسبيا مقارنةً بالألياف المصنعة التي تكون اعلى تكلفة ولها آثار سلبية على البيئة. ومع ذلك، فإن الخواص الميكانيكية للألياف الطبيعية تكون اضعف بالعموم اذ ما قورنت بتلك الخاصة بالألياف المصنعة. استخدم تهجين الالياف لتحقيق التوازن بين مزايا وعيوب الألياف الطبيعية والمصنعة.

في هذا العمل ، تم تهجين انسجة الياف الجوت (J) و الزجاج E-glass (G) بأوضاع بينية ومتداخلة لتصنيع مركبات هجينة مختلفة معززة بالإيبوكسي باستخدام الطريقة اليدوية. تتكون جميع العينات المركبة من خمسة طبقات. تم تصنيع المركبات الهجينة البينية من ثلاثة صفائح متوالية وبترتيب: G3JG، GJGJG و 2GJ2G ؛ في حين تضمنت المركبات الهجينة المتداخلة استبدال متعاقب للخيوط الزجاجية في كلا اتجاهي الالياف بخيوط الجوت والمتضمنة النمط G_1J_1 (حيث تم استبدال خيط زجاج واحد بخيط واحد من خيوط الجوت) والنمط G_1J_2 (حيث تم استبدال خيط زجاج واحد باثنين من خيوط الجوت). كما تم تصنيع مركبات الزجاج و مركبات الجوت/ الإيبوكسي النقية. تم تجهيز واحد وتسعين عينة لإجراء اختبارات ميكانيكية (شد - انحناء - صدمة) وفقًا لـ ASTM و ISO لكل اختبار ، وبعض الاختبارات الفيزيائية مثل التوصيل الحراري والعزل الصوتي لمعرفة المركب الذي يتمتع بأفضل أداء لكل اختبار مذكور.

أظهرت النتائج أن زيادة محتوى الزجاج في المركبات الهجينة البينية يزيد من خصائص الشد. أعطت المركبات الهجينة الداخلية G_1J_2 و G_1J_1 نفس معامل الشد تقريبًا ولكنها تختلف في مقاومة الشد حيث تعطي عينات G_1J_1 قوة شد أعلى بحوالي ٤١٪ من عينات G_1J_2. في حين وصلت خصائص الانحناء إلى قيمها القصوى لمركبات 2GJ2G تليها GJGJG وكانت أعلى من نظيراتها من الزجاج النقي، حيث اعطت قوة الانحناء قيمة ٢،٢٥ و١،٦٢ مرات اعلى من مركبات الزجاج النقي على التوالي.أظهرت المركبات الهجينة G_1J_1 اجهاد انحناء أعلى ولكن معامل الانحناء كان أقل من نظائرها من الزجاج النقي. قدمت المركبات الزجاجية النقية أعلى مقاومة للصدمة من بين المركبات الأخرى. كان الانخفاض في مقاومة الصدمة للنماذج 2GJ2G و GJGJG حوالي ٤٪ و ١٦٪ فقط بالمقارنة مع نظرائهم من الزجاج النقي وعلى التوالي. ومع ذلك، كان للنموذج GJGJG أعلى مقاومة صدمة نوعية تليها مركبات 5G و 2GJ2G و G_1J_2 و G_1J_1 و G3JG و 5J على التوالي. كان لزيادة محتوى ألياف الجوت داخل المركب الهجين اثر واضح بتقليل موصليته للحرارة . بلغ العزل الحراري لمركبات الجوت/ايبوكسي نسبة الى سمكها حوالي ثلاث مرات من تلك المصنوعة من الزجاج/ايبوكسي. قدم المركب الهجين البيني G3JG عزل حراري أعلى من مركبات الزجاج بحوالي ٨٠٪ نسبة الى السمك. قدمت مركبات G_1J_1 عزلًا حراريًا أقل قليلاً من المركبات الهجينة بتكوين GJGJG على الرغم من كون نسبة تهجين أليافهما في المركب متماثلة تقريبًا. فيما يتعلق بعزل الصوت ، فإن زيادة محتوى ألياف الجوت داخل المركب الهجين لا يعني بالضرورة زيادة قدرته على عزل الضوضاء. ومع ذلك،

فإن المركب الهجين G_1J_1 اظهر أعلى نسبة عزل صوتي نسبة الى سمكه من بين جميع المركبات المصنعة.

باختصار ، يمكن استخدام الاستبدال الجزئي للألياف الزجاجية (انسجة أو خيوط) بنظيراتها من ألياف الجوت بنجاح في التطبيقات التي تتطلب خصائص ميكانيكية وسطية وعزل حراري و صوتي جيد إذا كانت التكلفة والاثر البيئي هي المعايير الاكثر اهمية.

جمهـــــــــورية العـــــــــراق
وزارة التعليم العالي والبحث العلمــي
جـــــامعـــــــة بابـــــــــــل
كليـــــــــة الهـــــندســــــــة
قســـــم الهندســـــة الميكـــــانيكية

الأداء الميكانيكي، الموصلية الحرارية والعزل الصوتي لهجائن الانسجة البينية والمتداخلة لمركبات زجاج–جوت / ايبوكسي

رسالة مقدمة الى
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كجزء من متطلبات نيل شهادة الماجستير
في الهندسة / الهندسة الميكانيكية / ميكانيك تطبيقي

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