DEVELOPMENT OF SANDWICH COMPOSITES FROM NATURAL MATERIALS FOR BULLET PROOFING

Thesis

Submitted in partial fulfilment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

by

SANGAMESH

(145039MT14F06)

DEPARTMENT OF METALLURGICAL AND MATERIALS ENGINEERING

NATIONAL INSTITUTE OF TECHNOLOGY KARNATAKA

SURATHKAL, MANGALURU-575025

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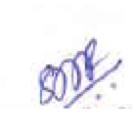
DECLARATION

by the Ph.D. Research Scholar

I hereby *declare* that the Research Thesis titled "**Development of Sandwich Composites from Natural Materials for Bullet Proofing**", which is being submitted to the **National Institute of Technology Karnataka, Surathkal** in partial fulfilment of the requirements for the award of the Degree of **Doctor of Philosophy** in **Metallurgical and Materials Engineering** is a *bonafide report of the research work carried out by me*. The material contained in this Research Thesis has not been submitted to any University or Institution for the award of any degree.



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Register Number: 145039MT14F06

Department of Metallurgical and Materials Engineering

Place: NITK-Surathkal

Date: 25-10-2019

CERTIFICATE

This is to *certify* that the Research Thesis titled "**Development of Sandwich Composites from Natural Materials for Bullet Proofing**", submitted by **Sangamesh** (Register Number: **145039MT14F06**) as the record of the research work carried out by him, is *accepted as the Research Thesis submission* in partial fulfilment of the requirements for the award of degree of **Doctor of Philosophy**.

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ACKNOWLEDGEMENT

I want to express gratitude, special appreciation and thanks to my advisors Dr. Ravishankar K.S., Associate Professor, Department of Metallurgical and Materials Engineering, NITK, Surathkal, and Dr. S.M. Kulkarni, Professor, Department of Mechanical Engineering for their ready and able guidance and inspiration throughout the course of my work.

I express my sincere thanks to Director NITK Surathkal Prof. K.Uma Maheshwar Rao and Prof. S. Anandhan, Head of the Department of Metallurgical and Materials Engineering, for providing all academic and administrative help during the course of my work.

The guidance, review, and critical suggestion of the Research Progress Assessment Committee (RPAC) during various presentations and review meeting comprising of Dr. Saumen Mandal, Prof. Vijay H. Desai are acknowledged. I also express my thanks to all the faculties of the Department of Metallurgical and Materials Engineering, NITK Surathkal.

I am thankful to all the non-teaching staffs of Department of MME NITK Surathkal as they were very supportive in all kinds of my laboratory and administrative work. I wish to acknowledge the support given to me by all the Ph.D. and M.Tech friends during the course of my work. I am pleased and thankful to the Council of Scientific and Industrial Research(CSIR), and Science and Engineering Research Board (SERB), Department of Science and Technology, New Delhi for granting International Travel Support, and Alumni Association, NITK for their financial support to present part of this research work at NUS Singapore and UMM Malaysia.

This work is also the outcome of the blessing guidance, love, and support of my father Mr. Mahadevappa, my mother Mrs. Shridevi, my sister Ms. Soni, and my brother Mr.Bomgond. This thesis is the outcome of the sincere prayers and dedicated support of my family.

Finally, I thank all my friends, well-wishers, and anonymous souls for their love and regards, prayers, and wishes, that directly and indirectly helped me for completing this research work.

Date: 25-10-2019 (SANGAMESH)

ABSTRACT

Ballistic protective materials have been used in the past are replaced with synthetic polymer composites due to their strength to weight ratio. Nowadays, these synthetic materials are being replaced by natural fiber reinforced composites due to the cost and environmental issues. The present investigation relates to the development of natural sandwich/laminated composite material interlock blocks for bullet arresting. Bullet arresting capacity depends on energy absorption. The energy absorption of the material could be increased by different ways. Among which sandwich form of the composite is one of the effective ways of improving the energy absorption capability of PMCs. This study was undertaken to explore the use of natural materials such as Jute epoxy fly ash composite (JEFC), Jute-epoxy fly ash rubber (JEFRC) sandwich composite for ballistic energy absorption. Prior to FE analysis, mechanical characterization of three varieties of jute composites were carried out namely Tossa jute single woven composite (TSWC), White jute single woven composite (WSWC), White jute double woven composite (WDWC) among all Tossa jute single woven composite (TSWC) revealed better mechanical properties. Hence for further analysis, Tossa jute single woven epoxy fly ash composite nothing but Jute epoxy fly ash composite (JEFC) is only used for ballistic FE simulation and as well as for ballistic impact testing of composite plates, blocks and interlock blocks.

Finite Element analysis of these plates was carried out for thicknesses (5, 10, 15 mm). JEFC plates and JEFRC sandwiches with the same thickness (15 mm) were fabricated and tested to measure residual velocity and energy absorbed. Among JEFC and JEFRC, JEFRC showed better ballistic performance hence further analysis is carried out on jute-epoxy-fly ash natural rubber sandwich block composite (JEFRC), at different thicknesses of the target plate (50, 75, 100, 150 mm) and three velocities of the projectile (150, 250, 350 m/s). Ballistic parameters were evaluated using commercial FE software. Further same thickness and same configuration sandwich blocks were produced using compression molding machine; these prepared samples were subjected to ballistic impact test by impacting the projectile. From FE analysis and ballistic test, it is confirmed that at about 75 mm thickness the sandwich blocks were capable of arresting the bullet. Further interlock sandwich blocks were produced and tested for ballistic impact, which arrested the bullet half of its thickness. Hence such sandwich interlock blocks are produced to prototype for arresting bullet up to velocity 350 m/s. Fracture behavior is analyzed using SEM.

Keywords: Natural composites, sandwich composites, jute, epoxy, flyash, natural rubber, mechanical properties, density, hardness, ballistic impact, interlock blocks, velocity.

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ACRONYMS

PMC	Polymer Matrix Composite
RTM	Resin Transfer Molding
NR	Natural Rubber
ASTM	American Society for Testing of Materials
ISO	International Organization for Standardization
JEFC	Jute Epoxy Fly ash Composites
JEF	Jute Epoxy Fly ash
JEFRC	Jute Epoxy Fly ash Rubber Sandwich Composite
SEM	Scanning Electron Microscope
FEM	Finite Element Modeling
FEA	Finite Element Analysis
NIJ	National Institute of Justice
TSW	Tossa Jute Single Woven
WSW	White Jute Single Woven
WDW	White Jute Double Woven
TSWC	Tossa Jute Single Woven Composite
WSWC	White Jute Single Woven Composite
WDWC	White Jute Double Woven Composite

CHAPTER 1

INTRODUCTION

Over the years, people are using different methods to protect themselves and their armors from the impact of bullets/projectiles by using structures made out of wood, metal, glass, and sandbags (Mazumdar 2002). These structures are generally heavy and incur the cost and inconvenient to transport. Of late, they are being replaced by structures of polymers and their composites, due to their properties such as lightweight and good corrosion resistance (Morye et al. 2000; Shokrieh en Javadpour 2008).

Ballistic impact analysis of composite materials is necessary in order to establish their use in military, aerospace and automotive applications. The ballistic limit velocity and energy absorption capacity of material are the important factors for the design of these protective structures (Vaidya. U.K., 2011). The ballistic Limit depends on size, shape, mass, velocity and the material properties of the impactor and it also depends on the geometry and material properties of the protecting structure (Tan et al. 2003) Generally, the ballistic limit is determined through analysis of material either by modeling or by experiments.

Currently, the emphasis is on using environmentally friendly composite materials made of natural materials for such applications whose ballistic analysis is required. Rubber is a natural material with low cost, abundant in availability and has high energy absorption capacity, and also suitable for ballistic impact protection(Ahmad et al. 2007; Ciesielski 1999). Also natural fibers, such as jute which are biodegradable, economically available and have better properties, are emerging as the substitutes for the conventional fibers in composites (Gowda et al. 1999). At present, epoxy resins are widely used in various engineering and structural applications such as electrical industries, and commercial and military aircrafts industries. In order to improve their processing and product performances, and to reduce cost, various fillers are being introduced into the resins during processing(Saleh en Al-jebory 2014). Fly ash, a by-product of thermal power plants and available in abundance, is used to harness lower densities, high modulus and strength thereby enhancing specific strength and stiffness of polymer systems. These materials in combination as composites need to be harnessed for providing the required protection against ballistic impact.

The aim of the present investigation is to model and analyze the behavior of composites with Jute-Epoxy-Fly ash (JEF) and rubber under ballistic impact for different impact velocities and thicknesses of the composite. The analysis is carried out using commercially available software based on the finite element analysis technique. Thickness and number of layers of JEF and rubber required to stop the projectile are optimized. Later bullet resistant sandwich interlock blocks are produced for the optimized composites to replace sandbags which are generally used for protection. These blocks are lightweight and easily transportable and quickly assemble.

1.1 Bullet-Proofing Materials

After World War II, numerous researches have been put into the field of bullet-proof materials for the national defense in many countries because of the exciting protection ability. The historic development of bullet-proof materials experienced from the raw steel and alloy to the high-performance fibers. Currently, materials that widely used in the bullet-proof field covered the aramid fibers, Ultra-High Molecular Weight Polyethylene Fibers (UHMWPE) and liquid crystal polymer matrix fibers and so on.

Most anti-ballistic materials used in bulletproofing or explosion-proof blankets are made of Kevlar, Twaron or Dyneema fibers, which stop bullets from penetrating the surface by spreading and absorbing the impact of the bullet's force. These products were a significant step forward, but often still result in the target suffering from blunt force trauma, severe bruising or damage to vital organs. This is because the force from the bullet reaches the wearer even when the bullet itself is stopped. These high-performance fibers are combined with polymers to produce composites for developing better bullet resistant materials.

1.2 Composites

A composite is a heterogeneous mixture of two or more materials which are combined macroscopically to enhance the properties. Composite materials consisting of constituent elements, one is a continuous phase called matrix, and another is discontinuous phase called reinforcement. The reinforcement material always is in the form of fibers, particles, or flakes. Some examples of the composite systems include- natural composite wood, concrete reinforced with steel and fly-ash reinforced to epoxy.

1.3 Classification of Composites

Based on the types of reinforcement used, the composite materials can be classified as

a) Particulate reinforced composites
b) Fiber reinforced composites
c) Hybrid composites
d) Laminate composites
e) Sandwich structures

a) Particulate Reinforced Composites

A composite whose reinforcement is a particle with all the dimensions roughly equal is called particulate reinforced composites. Particulate fillers are employed to improve high-temperature performance, reduce friction, increase wear resistance and to reduce shrinkage. The particles will also share the load with the matrix, but to a lesser extent than a fiber. A particulate reinforcement will, therefore, improve stiffness, but will not generally strengthen.

b) FRCs (Fiber Reinforced Composites)

FRCs comprises fibers have better spans compared to cross-sectional dimensions. Physically a material is replaced called as fiber reinforcements instead of chemically replacing to make suitable for required applications. These can be broadly classified as:

- Single layer composites
  - Continuous
    - ✓ Unidirectional
    - ✓ Bidirectional
  - Discontinuous
    - ✓ Oriented
    - ✓ Random
- Multilayer composites
  - Laminated
  - Hybrid

c) Hybrid Composite Materials

The physical mixture of two or more than two fibers or fillers in a matrix or resin to form a composite is known as Hybrid Composite. These hybrid composites help in improving the property of composite at a reasonable cost.

The classification of hybrid composites is done based on the method of incorporating the constituent materials. The hybrid composites designated as 1) Sandwiched Type, 2) Hybrid Interply Type, 3) Hybrid Intraply Type, 4) Hybrid Intimately mixed (Mallick 1988). The sandwiched hybrid composites, set of layers are surrounding the single material. In case of interply, two or even higher number of material combinations of layers are placed or kept one over another in a repeated sequence. In case of intraply the varied rows of varied material compositions are stacked in properly repeated or arbitrary pattern. The compositions are mixed thoroughly in order to ensure no concentration of any single type exists in the composite, in case of interply mixed type.

d) Laminates

The set of laminates are arranged in the direction of the required thickness to fabricate the laminate. In general, 3-layers are stacked in an alternative way in order to have proper bonding at interface of fibers and resin, for e.g. paper and plywood can have either or both single and bi-directional alignment of reinforcement as per final usage of a composite. The fabrication of composite laminates can be done in alternative ways such as by varying either stacking sequence of the same material or by varying essential materials used. The synthetic (man-made) fibers are used to fabricate laminated composites as they are popular in many applications in various industries due to their combination of multiple properties such as mechanical, thermal, physical (Mallick 1988).

e) Sandwich Composites

A sandwich composite is a special form of laminated composites. In which two thin-high strength skins or face sheets bonded to thick, lightweight core material. Face sheets(top and bottom sheets) are rigid and core is relatively weak and flexible, but when combined in a sandwich panel form they produce a structure that is stiff, strong and lightweight (Rocca en A.Nanni 2005).

1.4 Polymer Matrix Composites

Polymer matrix composites are the combination of reinforcements which are made of thin sized (diameter) fibers (e.g. Boron, Graphite, Aramid) and polymers (e.g. polyurethane, epoxy, polyester) and hence they are also called next level composites. For example, roughly on a weight to weight ratio, the steels are five to six times weaker than Caron-Epoxy (graphite-epoxy) Composites. The ease of manufacturing processes, better strength parameters, cheaper price is the primary factors for the popularity of PMCs. Some of the limitations of polymer matrix composites are lower elasticity property in a few directions, very high thermal and moisture expansion coefficient, poor lower temperature operation capacity (Kaw 2006),

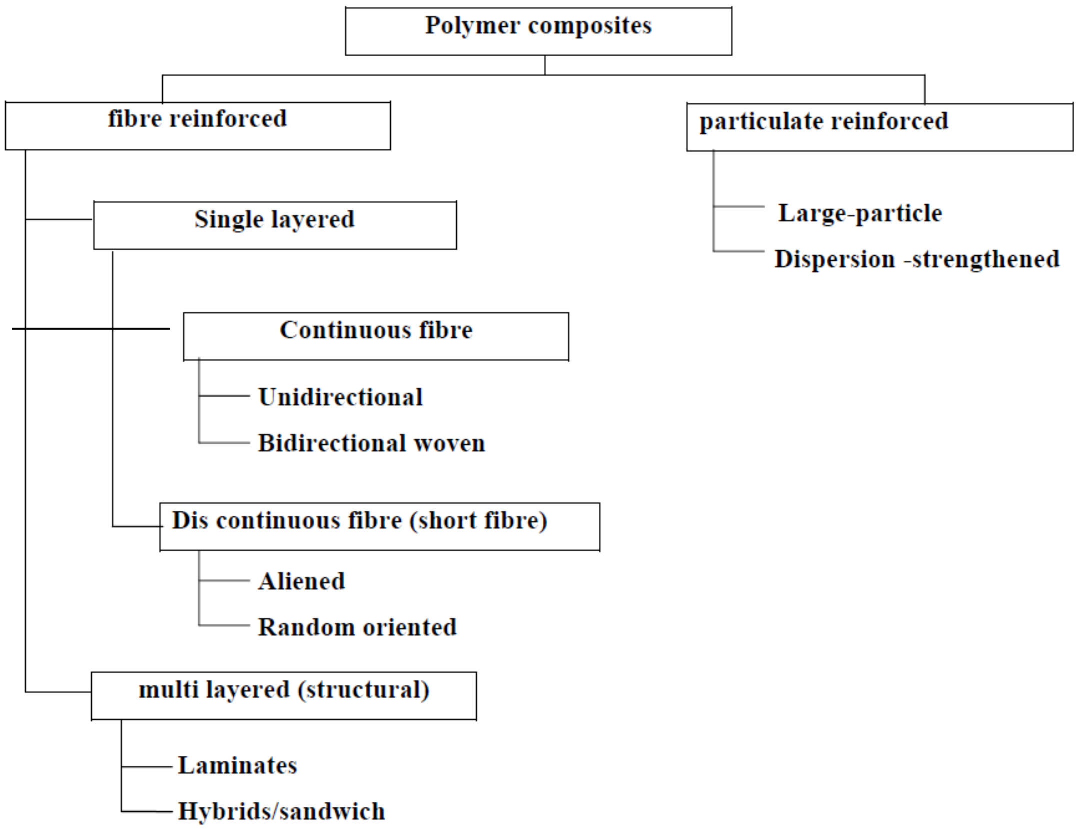


Figure 1.1 Classification of polymer composite

1.5 Reinforcements

In any FRCs, the major element is fiber; hence these are very essential elements in making composites. The fibers or reinforcements take larger section of loads acting on composite structures; also it is the highest volume fraction in most of the composite laminates. The following characteristics of any composite laminate are mainly influenced by fiber orientations, volume fraction, dimension, and type of fiber.

1. Mass density
2. Modulus of elasticity and ultimate tensile strength
3. Compressive Modulus and ultimate compressive strength
4. Fatigue failure mechanisms and its strength
5. Conductivities (electrical and thermal)
6. Price (Mallick 1988)

Table 1.1 Different types of fibers

Fibers	Particulate
➢ Aluminum, Aluminum oxide, Aluminum silica ➢ Asbestos ➢ Carbon (Graphite) ➢ Glass (E-glass, S-glass, D-glass) ➢ Polyamide (Aromatic polyamide, Aramid), e.g., Kevlar 29 and Kevlar 49 ➢ Molybdenum ➢ Polyester ➢ Quartz (Fused silica) ➢ Steel ➢ Tantalum ➢ Titanium ➢ Tungsten, Tungsten monocarbide Natural Fibers ➢ Jute, woven mat ➢ Flax ➢ Hemp ➢ Sisal ➢ Coconut fiber (coir) ➢ Banana fiber (abaca)	➢ Wood powder ➢ Carbon black ➢ Graphite ➢ Fly ash ➢ Alumina

1.5.1 Natural Fibers

Natural fibers which are highlighted or listed in Table 1.1 are some of the naturally available fibers in the Mother Nature. The due to various industrial or domestic outcomes such as bags, ropes, carpets, decorative items, etc. of these naturally available fibers their demand in agricultural sector has in increased drastically in various places of the world. The cellulose, microfibrils are the important components of natural fiber. These components are spread in the amorphous matrix of hemicellulose and lignin. The cellulose and lignin weight fraction varies based on the type of natural fiber. In general, the lignin is varying from 5%-20%wt, whereas cellulose is varying from 60%-80%wt. Table 1.2 shows the few properties of natural fibers. Some following reasons which are directing towards the use of natural fiber reinforced polymers in automotive sectors- door inner panel, seat back cover, roof inner panel and so on are some of the applications of natural fiber reinforced composites in the automotive sector.

1. They are environment-friendly, meaning that they are biodegradable, and unlike glass and carbon fibers, the energy consumption to produce them is very small.

2. The density of natural fibers is in the range of 1.25-1.5 g/cm^{3}compared with 2.54 g/cm^3 for E-glass fibers and 1.8–2.1 g/cm^3 for carbon fibers.

3. The strength to weight ratio of some natural fibers is greater than that of E-glass fibers, which means that they can be very competitive with E-glass fibers in stiffness-critical designs.

4. Natural fiber composites provide higher acoustic damping than glass or carbon fiber composites and therefore are more suitable for noise attenuation, an increasingly important requirement in interior automotive applications.

5. Natural fibers are much cheaper than glass and carbon fibers.

However, there are several limitations to natural fibers. The tensile strength of natural fibers is relatively low. Among the other limitations are low melting point and moisture absorption. At temperatures higher than 200 ^{o}C, natural fibers start to degrade, first by the degradation of hemicellulose and then by the degradation of lignin. The degradation leads to odor, discoloration, the release of volatiles, and deterioration of mechanical properties.

Table 1.2 Properties of natural fibers
(John en Anandjiwala 2008)

Fiber	Tensile strength (MPa)	Young's modulus (GPa)	Elongation at break (%)	Density (g/cm^3)
Abaca	400	12	3-10	1.5
Alfa	350	22	5.8	0.89
Bagasse	290	17	-	1.25
Bamboo	140-230	11-17	-	0.6-1.1
Banana	500	12	5.9	1.35
Coir	175	4-6	30	1.2
Cotton	287-597	5.5-12.6	7-8	1.5-1.6
Curaua	500-1,150	11.8	3.7-4.3	1.4
Date palm	97-196	2.5-5.4	2-4.5	1-1.2
Flax	345-1,035	27.6	2.7-3.2	1.5
Hemp	690	70	1.6	1.48
Henequen	500 ± 70	13.2 ± 3.1	4.8 ± 1.1	1.2
Jute	393-773	26.5	1.5-1.8	1.3
Kenaf	930	53	1.6	-
Nettle	650	38	1.7	-
Oil palm	248	3.2	25	0.7-1.55
Piassava	134-143	1.07-4.59	21.9-7.8	1.4
Pineapple	400-627	1.44	14.5	0.8-1.6
Ramie	560	24.5	2.5	1.5
Sisal	511-635	9.4-22	2.0-2.5	1.5
E-Glass	3400	72	-	2.5

1.5.2 Jute

Based on botanical origin, the two cultivated species of jute out of eight species discovered so far – Corchorus olitorius L. (Tossa jute) and Corchorus capsularies L. (White jute) constitute world's foremost bast fiber cash crops and the second most important textile fibre next to cotton Jute is mainly grown in South East Asian countries like India, Bangladesh, China, Nepal, Indonesia, Thailand, Myanmar and some South American countries. In India jute is grown in Eastern region covering over 0.8 million hectare, producing 1.8 million tons of fiber, including the production of two cultivated species of Mesta (Hibiscus cannabinus L and Hibiscus sabdariffa L.) which is about 50 percent of world production. Jute is mainly composed of polysaccharides and lignin but it also contains smaller amounts of fats and waxes, pectin, nitrogenous, coloring, and inorganic matters. The polysaccharides or glucose units are of two types such as alpha-cellulose $(C_6H_{10}O_6)_n$ and hemi-cellulose, which as shown in Figure 1.2. The composition of jute is shown in Table 1.3.

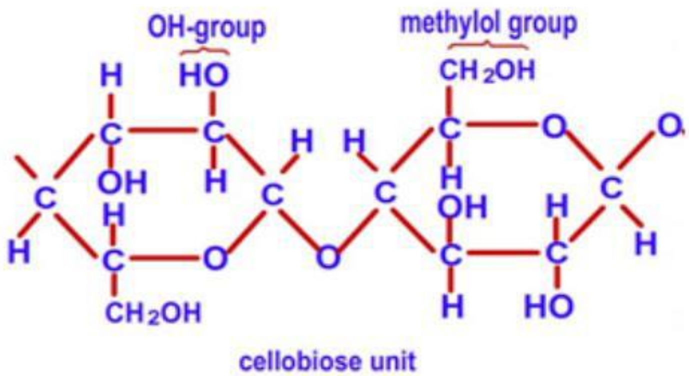


Figure 1.2 Structure of cellobiose unit

Table 1.3 Composition of jute fiber

Composition	Jute
Alpha-Cellulose	59 to 63%
Hemi-Cellulose	22 to 26%
Lignin (Insoluble resin-like substance)	12 to 14
Oils, fats, waxes, minerals & N2 Matters	03 to 04%

Further, it is decided to employ jute instead of artificial fibers like glass, carbon or aramid a fairly strong and naturally occurring one going by the name ‘jute fiber’ and known for its inexpensiveness. Jute is an attractive natural fiber for use as reinforcement in composites because of its low cost, renewable nature, and much low energy requirement for processing. In comparison with glass, jute has a high specific modulus and low specific gravity as against that of the glass fiber. Jute reinforced plastic offer attractive propositions for cost-effective applications (Mohan et al. 1983). Jute fibers in the form of laminates have much better properties than their neat resin counterparts (A. N. Shah and S. C. Lakkad 1981). Woven jute fabric reinforced composites gave better properties. Hence, they found to be potential for use in several consumable goods in literature, (Gowda et al. 1999). Substantial increase in flexural modulus and strength with small amounts of reinforcement with unidirectional jute have also been reported (Mohan et al.. 1985) considering these aspects bi-directionally woven jute fabric is used in different orientations Table 1.4 gives a brief overview of the comparison between glass fibers and jute fibers.

Table 1.4 Properties of E-glass and jute fiber

Property	E-Glass	Jute
Density kg/m^3	2600	1460
Specific Gravity	2.5	1.3
Tensile Modulus (MPa)	3400	442
Young’s Modulus(MPa)	72	55.5
Specific Strength (MPa)	1360	340
Specific Modulus (GPa)	28.8	42.7

The major drawbacks of natural fiber reinforced composites are due to its affinity towards moisture. Many experimental studies show that compatible coupling agents are capable of either slowing down or preventing the de-bonding process, and hence moisture absorption under severe environmental conditions such as exposed to boiling water. Jute fibers/fabrics are modified chemically through graft copolymerization and through the incorporation of different resin systems by different approaches.

Commercial jute ranges from pale cream to golden yellow and from light brown to dirty gay in color. Jute is relatively coarse, stiff, inelastic and somewhat rigid fiber. Good frictional property, tenacity, very high modulus and other than being of agro origin (renewable) and biodegradable (environmentally friendly), the major advantage features of jute are its high strength and initial modulus moderate moisture regain, good sound and heat insulation properties and low cost. The major disadvantages of jute are its low wet strength, stiffness, coarseness hairiness and high fiber shedding (A. N. Shah and S. C. Lakkad 1981; Saheb et al. 1999).

1.5.4 Fly Ash

Fly ashes are fine particulate waste product derived during the generation of power in a thermal power plant. These have the aspect ratio closer to unity and hence expected to display near isotropic characteristics these are inexpensive and possessing good mechanical properties when used with well-established matrix system helps to reduce the cost of the system and at the same time either retain or improve the specific or desirable properties. Fly ash has attracted interest (Kulkarni 2002) lately, because of the abundance in terms of the volume of the material generated and environmental-linked problems in the subsequent disposal. Fly ash mainly consists of alumina and silica, which are expected to improve the composite properties (Sampathkumaran et al. 2015). To some extent fly ash also consist of hollow spherical particles termed as cenosphere which aid in the maintenance of low-density values for the composite, a feature of considerable significance in weight-specific applications (Mohapatra en Rao 2001). Fly ash is a byproduct of burning coal in thermal power plant. It consists of fine spherical particles of varying size, chemical composition and other characteristics depending on the origin (type of coal burnt and the procedure followed for collection). As the characteristics differ, characterization of fly ash becomes important before it is utilized properly. According to ASTM C-618, two major classes of fly ash are recognized. These two classes are related to the type of coal burned and are designated Class F and Class C in most of the current literature. Class F fly ash is normally produced by burning anthracite or bituminous coal while Class C fly ash is generally obtained by burning sub-bituminous or lignite coal.

1.6 Matrix Materials

Composites are made of reinforcing fibers and matrix materials. Matrix surrounds the fibers and thus protects those fibers against chemical and environmental attack. For fibers carry a maximum load, the matrix must have a lower modulus and greater elongation than the reinforcement (Mazumdar 2002). The general matrix materials used are listed in Table 1.5.

Table 1.5 Different matrix materials

Thermosets	Thermoplastics
➢ Vinyl ester ➢ Polyester ➢ Phenolics ➢ Epoxy ➢ Cyanate esters ➢ Bismaleimide ➢ Rubber	➢ Polyethylene ➢ Polypropylene ➢ Acetal ➢ Nylon ➢ PPS ➢ PEEK ➢ Teflon

1.6.1 Epoxy

Epoxy is a very versatile resin system, allowing for a broad range of properties and processing capabilities. It exhibits low shrinkage as well as excellent adhesion to a variety of substrate materials. Epoxies are the most widely used resin materials and are used in many applications, from aerospace to sporting goods. There are varying grades of epoxies with varying levels of performance to meet different application needs. They can be formulated with other materials or can be mixed with other epoxies to meet a specific performance need. By changing the formulation, properties of epoxies can be changed; the cure rate can be modified, the processing temperature requirement can be changed, the cycle time can be changed, the drape and tack can be varied, the toughness can be changed, the temperature resistance can be improved, etc. Epoxies are cured by chemical reaction with amines, anhydrides, phenols, carboxylic acids, and alcohols. Epoxy is a liquid resin containing several epoxide groups, such as diglycidylether of bisphenol A (DGEBA), which has two epoxide groups. In an epoxide group, there is a three-membered ring of two carbon atoms and one oxygen atom. In addition to this starting material, other liquids such as diluents to reduce its viscosity and flexibilizers to increase toughness are mixed. The curing (crosslinking) reaction takes place by adding a hardener or curing agent (e.g., diethylenetriamine [DETA]). During curing, DGEBA molecules form crosslinks with each other as shown in Figure 1.3. These cross-links grow into a three-dimensional network and finally form a solid epoxy resin. Cure rates can be controlled through proper selection of hardeners and/or catalysts. Each hardener provides different cure characteristics and different properties to the final product. The higher the cure rate, the lower the process cycle time and thus higher production volume rates. Epoxy-based composites provide good performance at room and elevated temperatures. Epoxies can operate well up to temperatures of 93.33 °C to 121.11 °C, and there are epoxies that can perform well up to 204.4 °F. For high-temperature and high-performance epoxies, the cost increases, but they offer good chemical and corrosion resistance. Epoxies come in liquid, solid, and semi-solid forms.

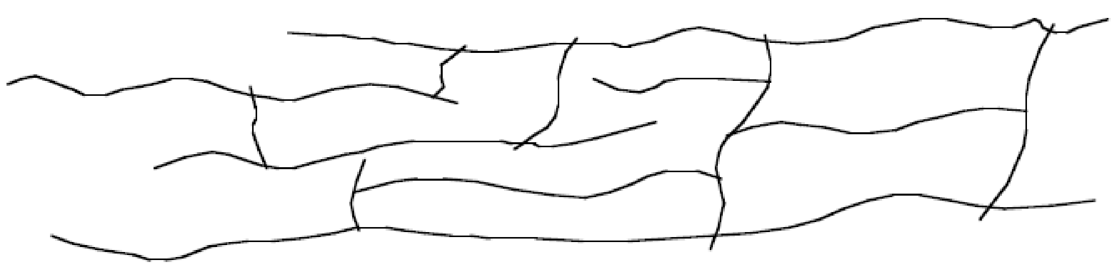


Figure 1.3 Cross-linking of thermoset molecules during curing

Liquid epoxies are used in Resin Transfer Molding (RTM), filament winding, pultrusion, hand lay-up, and other processes with various reinforcing fibers such as glass, carbon, aramid, boron, etc. Semi-solid epoxies are used in prepeg for vacuum bagging and autoclave processes. Solid epoxy capsules are used for bonding purposes. Epoxies are more costly than polyester and vinyl esters and are therefore not used in cost-sensitive markets (e.g., automotive and marine) unless the specific performance is needed. Epoxies are generally brittle, but to meet various application needs, toughened epoxies have been developed that combine the excellent thermal properties of a thermoset with the toughness of a thermoplastic. Toughened epoxies are made by adding thermoplastics to the epoxy resin by various patented processes. Some of the thermoset resin properties are listed in Table 1.6.

Table 1.6 Typical thermosetting resin properties

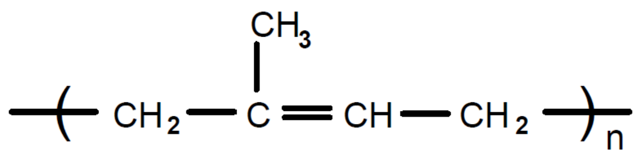
Resin Material	Density (g/cm^3)	Tensile Modulus (GPa)	Tensile Strength (MPa)
Epoxy	1.2–1.4	2.5–5.0	50–110
Phenolic	1.2–1.4	2.7–4.1	35–60
Polyester	1.1–1.4	1.6–4.1	35–95

1.6.2 Rubber

The rubber compound was first developed by Goodyear and Hancock and it continues to develop as new materials and new variations on old ones appear in the marketplace. The compound that is observed in rubber, such as in a tire or pencil eraser, is a mixture of a number of different ingredients. It starts with the raw gum elastomer, supplied by the plantation owner as Natural Rubber (NR), or by the petrochemical complex converting petroleum products such as ethylene, propylene, and butadiene into ‘raw’ bales or chips of rubbery polymers. It is shipped to the rubber processor who blends it with various ingredients. The raw gum elastomer itself has very limited use, although adhesives provide one example. Most are mechanically weak and subject to significant swelling in liquids, and will not retain their shape after molding. Many of its other properties could also benefit from enhancement. It is at this point that the rubber compounder takes over, and all of his art and science is dedicated to modifying the raw gum elastomer, changing it into a more useful material (Ciesielski 1999).

Designation in ISO 1629 – NR

Repeat Unit



NR can be isolated from more than 200 different species of plant; including surprising examples such as dandelions. Only one tree source, Hevea Brasiliensis, is commercially significant. Latex is an aqueous colloid of NR, and is obtained from the tree by ‘tapping’ into the inner bark and collecting the latex in cups. The latex typically contains 30%-40% dry rubber by weight, and 10%-20% of the collected latex is concentrated by creaming, or centrifuging, and used in its latex form. Historically, such latex would be exported to consumer countries, but as it is expensive to ship a product with a high percentage of water, consumer companies are increasingly siting their latex processing plants in the producer countries, where the cheaper labor rates are an additional incentive. The remaining latex is processed into dry rubber as sheets, crepes, and bales. There is an international standard for the quality and packing for natural rubber grades, the so-called ‘Green Book’, published by the rubber manufacturers’ association. The following grades of NR listed in the ‘Green Book’ are sold to visual inspection standards only:(R.B. Simpson 2002)

- Ribbed smoke sheets
- White and pale crepes
- Estate brown crepes
- Pure smoked crepe.
- Properties of rubber

The advantages of rubber are good tearing strength, abrasive resistance, flexibility, elongation, acid, and alkali resistant.

1.7 Processing of Composites

Composite processing is the science of products being transformed from one form to the other. Due to the fact that composite materials contain two or more distinct materials, the handling methods used with composites are quite distinct from those used for processing metals and ceramics. Different composite processing methods are shown in Figure 1.4. There are different kinds of composite processing methods available for handling the different kinds of fillers and resin. A manufacturing engineer's task is to select the right processing technique and processing conditions to satisfy an application's efficiency, production rate, and cost specifications. Composite products are manufactured using one of the manufacturing procedures by transforming the raw material into the final form is mentioned in (Mazumdar 2002).

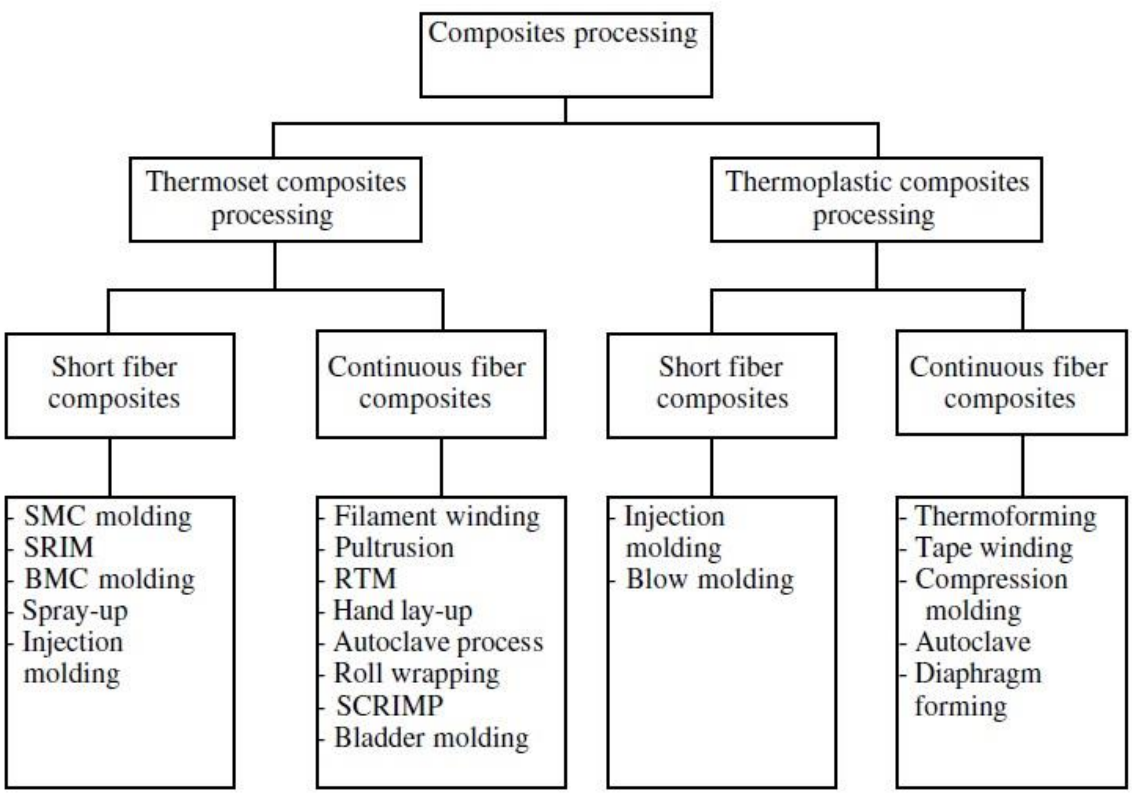


Figure 1.4 Composite processing methods

For composites with thermoset matrix materials, there are many processing techniques, including epoxy, unsaturated polyester, and vinyl ester. It is possible to classify polymer matrix products as thermosets and thermoplastics conveniently. In thermosets, the appropriate chemical agents are used in composite processing. Hand layup, compression molding, bag molding, filament winding, RTM and pultrusion are the various processing methods for thermoset matrix composites (Chawla 2012) are applied.

1.7.1 Hand Lay-up Technique

Hand lay-up and spray-up methods may be the easiest polymer processing methods. Fibers can be placed by manually on mold, and the resin is sprayed or brushed. Resin and fibers (chopped) are often sprayed together onto the surface of the mold. The layers deposited are densified with rollers is shown in Figure.1.5. There is frequent use of accelerators and catalysts for processing. These curing can be performed at room temperature or in an oven at a moderately elevated temperature.

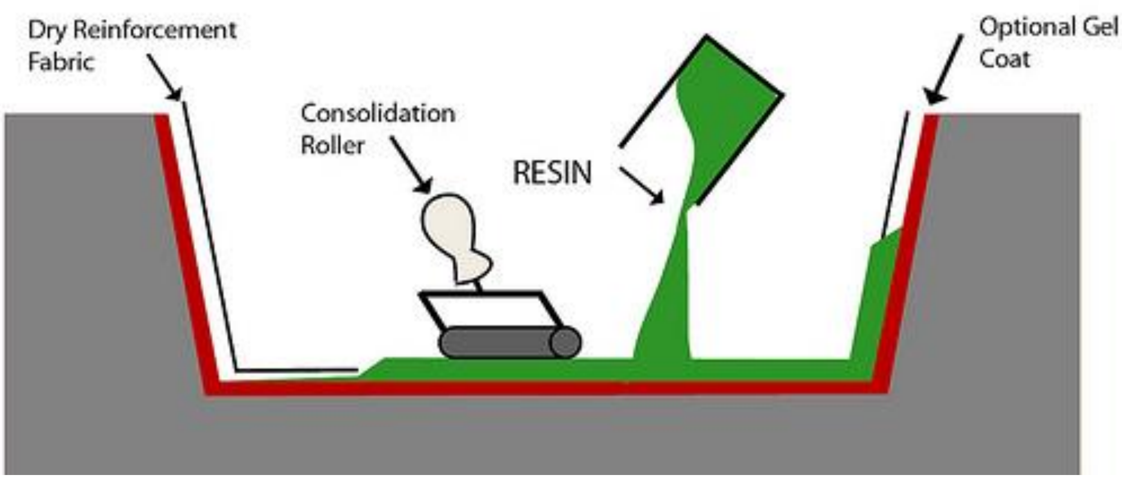


Figure 1.5 Hand layup technique

1.7.2 Compression Molding Technique

Compression molding is a manufacturing method of closed mold composite fabrication that utilizes matched metal molds with external pressure. An engineered composite lay-up is positioned in the open mold cavity during the compression molding process; the mold is closed, and the consolidating force is applied. Throughout the curing process, which generally takes place in the oven, the pressure stays on the mold. The combination of temperature and pressure results in a composite component with low void content and high fiber volume fraction. Compression molding often produces composite components with optimum mechanical characteristics from the specific mixture of component materials (Chawla 2012; Kaw 2006). Typical compression molding method is shown in Figure 1.6.

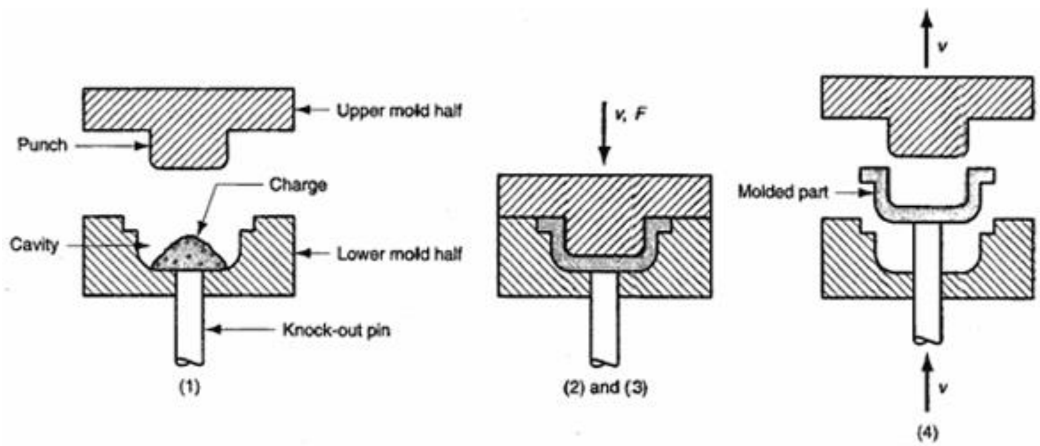


Figure 1.6 Compression molding method: (1) charge loaded, (2) and (3) charge is compressed and cured, (4) part is removed from cavity

1.8 Mechanical Testing of Composite Materials

Mechanical testing of composite structures is a time-consuming and often difficult method for obtaining parameters such as strength and elongation. However, composite coupons samples are tested for mechanical properties. In modeling, the information extracted from these experiments can then be used immediately. The test techniques described in this section are simply a small range accessible to the researcher. Some of the coupon tests on tensile, compression, and flexure are widely recognized as standards.

1.8.1 Tensile Testing

Tensile testing uses the classic coupon inspection geometry, as shown below in Figure 1.7 following the ASTM 3039 M standard. It comprises of two areas: a key region called the gauge length, within which failure is supposed to happen, and the two end areas that are caught in a grip system linked to a test machine.

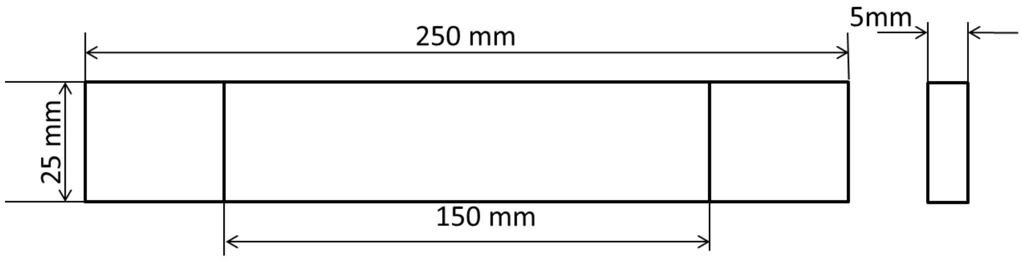


Figure 1.7 Tensile test specimen

To safeguard the specimen from being crushed by the handles, these ends are generally tabbed with a material such as aluminum or emery paper. For longitudinal, transverse, cross-ply, and angle-ply testing, this test specimen can be used.

1.8.2 Compression Testing

Compression testing samples are prepared according to ASTM standards. A schematic diagram is shown in Figure 1.8. The sample is loaded in the longitudinal or transverse direction, between two compressions plates in the direction, in which strength has to be determined. This compressive testing method is most commonly used for polymer composites (Deepthi et al. 2014).

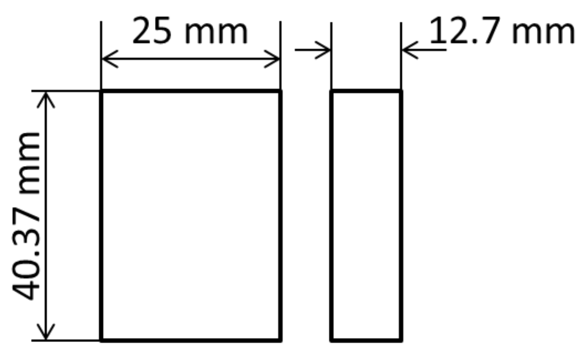


Figure 1.8 Compression test specimen

1.8.3 Flexural Testing

The flexural tests are performed to determine the mechanical characteristics of composite materials enhanced by resin and laminated fiber. Also, these experiments are used together with flexural and shear stiffness to determine the interlaminar shear strength of a laminate, shear moduli, shear strength, tensile, and strain module. Not only for composites, but also sandwich beams, these experiments are used.

Flexural tests are a simple one and used simple equipment for composite testing. These experiments were performed on standardized cross-section beams, as shown in Figure 1.9. As in the case of tensile testing, these beam samples do not involve end tabs. These experiments are conducted using two techniques. The beam is a flat rectangular specimen, supporting it merely near its ends. The beam is centrally loaded in the first technique. Thus it provides a bending of three points.

Hence, this technique is called a three-point bending test because there are three significant points (two end supports and one main charging point) along the beam span. In the second technique, the beam is loaded symmetrically by two loads. There are four significant points along the span of the beam in this technique (two end supports and two loading points). It provides four-point bending. Therefore, it is called a four-point bending method.

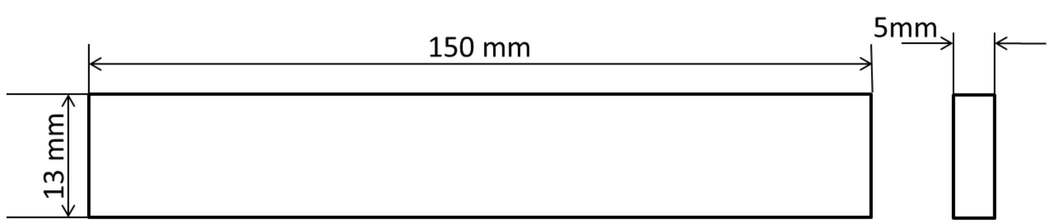


Figure 1.9 Flexural testing specimen

1.8.4 Impact Testing

The impact responses of the materials generally categorized as follows.

(i) Low-velocity impact: Large mass hit with low velocity this effect is also known as low velocity (LVI) impact effect, typically occurring at speeds below 10 m/s.

(ii) Intermediate-velocity impact: Intermediate impact event occurs at speeds ranging from 10 m/s to 50 m/s.

(iii) High-velocity impact (Ballistic impact): The high-velocity effect is generally due to small arms or explosive warhead fragments, the high-velocity reaction is dominated by the propagation of the stress wave by the thickness of the material in which the structure has no time to react, resulting in localized harm. High-velocity impact ranges from 50 to 1000 m/s.

(iv) Hypervelocity Impact: This usually occurs at velocities between 2000 to 5000 m/s projectile is moving at high velocity; hence, the target material behaves like a fluid.

1.9 Ballistic Impact Testing of Composite Materials

The process of making something capable of stopping the bullet or high-velocity projectile is called bullet proofing. The material which provides the protection against the bullet called bullet resistance, the material used for bulletproof should absorb the kinetic energy of the bullet and thereby stopping the bullet from further penetration. The ballistic impact is a high-velocity impact of a small mass object analogous to runway debris or small arms (Cantwell en Morton 1991).

A light gas gun or ballistic launch system can be used to achieve a ballistic impact study. The study's need for the composite reaction to ballistic impact load applications of such studies involves body armor, armored vehicles, and fortified buildings (WJ Cantwell 1991 & A R Boccaccini, 2005). Composites strengthened with fiber are widely used in armor applications, Fibre-reinforced composites are widely used for armor applications, so it is essential to study their failure and perforation processes.

The ballistics field can be widely divided into three main fields: interior ballistics, exterior ballistics, and ballistics of terminals. A fourth category called intermediate ballistics had been used in some cases.

i. Interior ballistics: It's the study of movement and forces acting on an object when it's still inside the launcher.
ii. Exterior Ballistics: The study of movement and forces are acting on the object during free flight.

iii. Terminal Ballistics: The study of the interaction between projectile and the target (Carlucci, D. E.,2013).

Terminal ballistics is the area of greatest interest with respect to fortification; Penetration is defined as the progressive entry of the projectile into any region of a target material.

1.9.1 Ballistic Impact Testing

The ballistic tests were done to determine the ballistic parameters according to National Institute of Justice (NIJ) standard (NIJ 1008). When a projectile hits the target it transfers its energy into target material. The energy is absorbed by the fabric system or composite target and this can represent 3 situations:

i) The projectile rebounds from the target material upon impact (no penetration occur)

ii) The projectile penetrates a few layers of the target material and rests within the target material (partial penetration), or

iii) The projectile penetrates the target material completely (complete penetration).

In the situation where there is rebound or no penetration or partial penetration, there no residual (exit) velocity will exist and therefore the energy absorbed (E) by the fabric system upon impact is given by

$$E_{\text{target}} = \tfrac{1}{2} m_p (V_i)^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

m_p is the projectile mass and V_i is the impact velocity. For completely penetrated composite target materials system, the energy absorbed by the system is given by

$$E_{\text{target}} = \tfrac{1}{2} m_p (V_i^2 - V_r^2) \ldots\ldots\ldots\ldots\ldots (2)$$

V_r is the residual velocity.

The target sample was clamped at all four edges and positioned at 5 meters away from the muzzle of the test gun. The impact and residual velocities were measured using the Doppler Radar System (Weibel) and Projectile Velocity Measuring System (PVMS) (Ahmad et al. 2007).

1.10 FE Modeling of Composite Materials

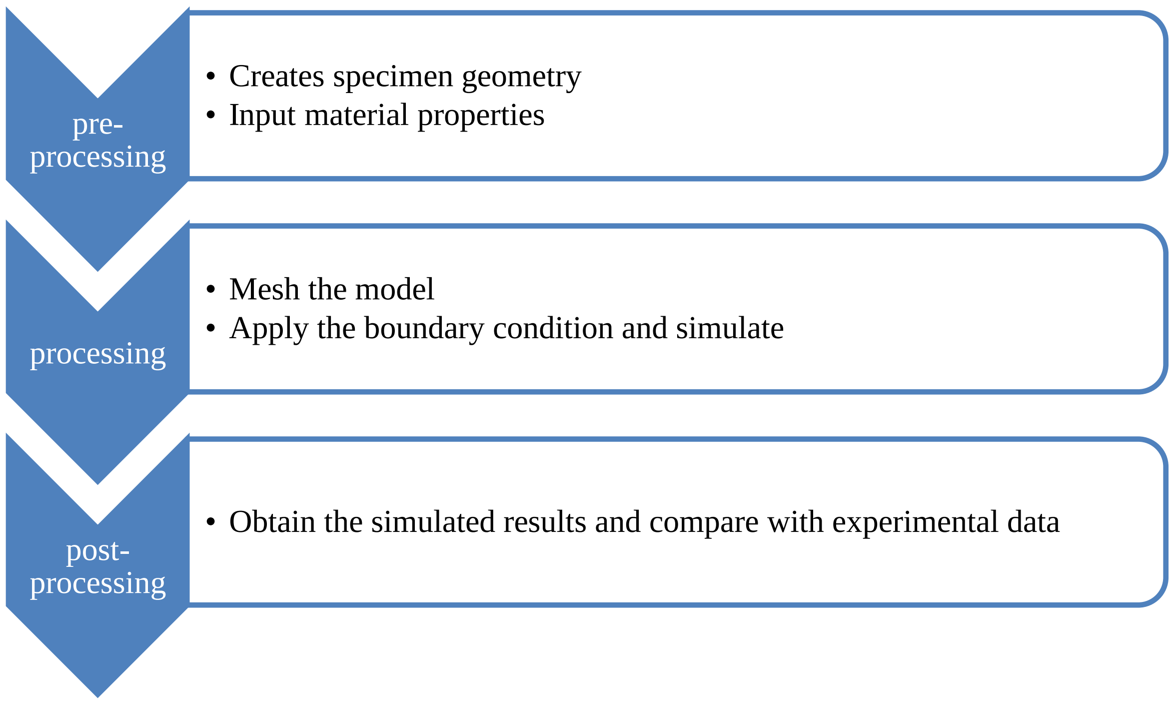
ABAQUS is a finite element analysis (FEA) commercially available software package is used for performing the simulations. The methodology used in ABAQUS software is divided into three parts preprocessing, processing and post-processing as shown below.

The preprocessing part consists of five modules

1. Part module: This is the section where specimen geometry is designed. Partitions can be created in this module to assign different material properties at different parts.
2. Material module: The stress-strain behavior of the materials is inputted in this module like Young's modulus, poisons ratio along with yield stress yield strain is to be entered and failure criteria can also be entered
3. Section module: This module is utilized to assign sections to individual materials.
4. Assembly module: when we create the geometries they are independent of the other sections, this model is present to position the sections by applying the constraints. There are two ways in which instances can be defined: dependent and independent. In this case, we use independent instances. The difference between the two is that a dependent instance shares the geometry of the original part whereas an independent instance is a copy of the original. Hence a dependent instance cannot mesh in a manner different from the original geometry while and an independent instance can. An independent instance, however, occupy more memory resources
5. Step module: To create an analysis step and specify the output requests in this module. Multiple analysis steps may be required when we change e the loading conditions or when boundary conditions are being altered, usually static, general step type is used for analysis.
6. Analysis module: in this module jobs have been created and are checked for data given for pre-correction and then finally job is submitted for the analysis. Once the analysis is completed. Then comes visualization mode where have to analyze the obtained results for the given data input and capture the videos, graphs or raw data etc.

The processing part consists of two modules.

7. Mesh module: in this module, the job to be submitted the part has meshed. The fineness of the mesh depends on the situation. The finer the mesh, the more memory space it going to require. Reduce integration is used. The mesh type may be triangular or quadrilateral for 2D system and tetrahedral for the 3D system.



8. Job module: in this module, the job to be submitted for analysis is selected and submitted. It is possible to delay the start of the job to the required time.
9. Visualization module: this the post-processing section. In this module, the results of the simulations are obtained. The stress contours and output requests are processed to get the desired results.

1.11 Literature Survey on Composite Preparation and Mechanical Testing

Some of the papers dealing in the preparation of composite and testing for mechanical characterization.

Authors **Title**	**Fiber (or) reinforcement (F)** **Matrix material (M)** **Preparation (or) Processing** **Testing (or) experiment technique**	**Conclusion & applications**	**Variables**
(A. N. Shah and S. C. Lakkad 1981) Mechanical Properties Of Jute Reinforced-Plastics	**Composites Made Up of** : **F-** jute and glass Fibres, **M-** Epoxy Resin **Manufacturing Method**: The unidirectional composite laminate is fabricated by filament winding on a flat mandrel, 30 x 60cm in size **Test**: Compression and Flexural	Some amount of jute fiber can be used for replacement material when strength is not a priority for the required application **Applications**: structural	
(Gowda et al. 1999) "Some Mechanical Properties Of Untreated Jute Fabric-Reinforced/Polyester Composites"	**Composites Made Up of :** **F-** Woven jute, **M-** Polyester. **Manufacturing Method**: Hand Layup technique. **Test:** Tensile Strength(ASTM D 3039-76), Compressive Strength(ASTM D 3410) , Flexural Strength(ASTM D 790), Impact Strength(ASTM D 256), In-plane Shear Strength,(ASTM D 3518) Interlaminar Shear strength(ASTM D 2344) and Hardness	It is concluded that jute/polyester composites are not superior to synthetic composites but they are better than wood composites. Applications: Partitions, Wash basins roofing, automobile components, electrical fittings.	---------
(Shaikh en Channiwala 2010) "To Study The Characteristics Of	**Composites Made Up of :** **F-** Jute, **M-** Polyester. **Manufacturing Method:** hand	The modulus of composite for short random reinforcement is observed to be in the range of 20.30 N/m^2 to	The volume fraction of fibers (11to 25%)

Jute/Polyester Composite For Randomly Distributed Fiber Reinforcement”	layup technique **Test**: tensile and hardness	28.64 N/m^2 for the same v_f range. The predictions of modulus of composites and constituents are based on assumptions of perfect bonding and experimental strain values. The FEA package IDEAS are higher as compare to experimental results. This is basically due to the inattention of interphase.	
(T. H. Shubhra et al. 2011) “Effect Of Matrix Modification By Natural Rubber On The Performance Of Silk Reinforced /Polypropylene Composites”	**Composites Made Up of :** **F-** Silk, **M-** Polypropylene and natural rubber **Manufacturing Method:** Compression molding **Test:** tensile modulus, bending strength, bending modulus, impact strength (IS), hardness and Environmental effect on composite, Thermal degradation Soil burial test of the composites	By incorporating natural rubber with polypropylene, the mechanical properties of the composite produced was decreased and impact strength improved. Mechanical properties silk/ Polypropylene composites are greater than those of silk/ Polypropylene plus Natural Rubber Composites. But silk/ Polypropylene plus Natural Rubber composites are more degradable than silk/ Polypropylene composites **Applications**: structural	Natural rubber films of three varying compositions are prepared with 10%, 25%, and 50% NR content, respectively
(Rajesh en Prasad 2013) “Effect Of Fibre Loading And Successive Alkali Treatments On Tensile Properties Of Short Jute Fibre Reinforced /Polypropylene Composites”	**Composites Made Up of** : **F-** Jute short fiber, **M-** Polypropylene **Manufacturing Method**: vertical injection molding machine **Test**: Tensile test	By treating the fiber with NaOH up 10%, strength of composite produced has increased compared to untreated fiber composite. **Applications** : structural	Fiber % in matrix (5%, 7.5%, 10%, 12.5% & 15%
(Boopalan et al. 2013) “Study On The Mechanical Properties And Thermal Properties Of Jute	**Composites Made Up of :** **F-** Jute & Banana, **M-** Epoxy. **Manufacturing Method**: Hand	This study shows that the addition of banana fiber in jute/epoxy composites of up to 50% by weight results in increasing the mechanical and thermal properties and	Various weight % of banana and jute fiber composite

And Banana Fiber Reinforced /Epoxy Hybrid Composites"	Layup technique. **Test:** Tensile Strength, Flexural Strength, Water Absorption Test. Impact Test SEM Analysis for fractured components	decreasing the moisture absorption property. **Applications** : structural	Banana to jute ratios- (100/0, 75/25, 50/50, 25/75 and 0/100)
(Madhukiran et al. 2013) "Tensile And Hardness Properties Of Banana/Pineapple Natural Fibre Reinforced Hybrid Composites"	**Composites Made Up of :** **F**-Banana/Pineapple, **M-** Epoxy **Manufacturing Method:** hand layup technique **Test:** Tensile and Hardness	Hybrid composite yielded better properties than single fiber composite. **Applications**: structural	Banana/Pineapple in the weight ratios of 0/40, 15/25, 20/20, 25/15, and 40/0
(Sakthivel en Ramesh 2013) "Mechanical Properties Of Natural Fibre (Banana, Coir, Sisal)/Polymer Composites"	**Composites Made Up of :** **F-**Coir banana and sisal, **M-** Epoxy **Manufacturing Method:** hand layup technique **Test**: Hardness Test, Impact Test Flexural test Density Test	It is found that polymer banana reinforced natural composites are the best natural composites among the various combination manufacturing of automotive seat shell. **Applications**: structural	Variation (Banana, Coir, Sisal)
(Á en Á 2013) "Mechanical Testing Of Natural Fiber-Composites For Automotive Industry"	**Composites Made Up of** : **F-** corn, sunflower and hop fiber, **M-**polyester **Manufacturing Method:** hand layup technique **Test:** Tensile test	The tensile strength of hop and corn fiber was 8 MPa whereas the sunflower was 5 MPa Applications: Hop and corn fibers reinforced composites can be used to automobile interior part	Volume fraction varied (24.6, 26.11, 36.23) And fibre (hop ,corn and sunflower)
(Naveen en Dharma Raju 2013) "Evaluation Of Mechanical Properties Of Coir Fiber/Reinforced Polyester Matrix Composites"	**Composites Made Up of :** **F-** Coconut fibers or coir fiber, **M-**polyester **Manufacturing Method:** hand layup technique	In general, the composite having a coir fibers volume of 5% showed a significant **Applications:** Door panels Dashboards	Volume fraction (5% to 10%.)

	Test: Tensile test	Seat Backs	
(Acharya 2014) "Study on Mechanical Properties of Natural Fiber Reinforced Woven-Jute/Glass Hybrid Epoxy Composites"	**Composites Made Up of :** **F-**Woven Jute /glass mat, **M-** Epoxy **Manufacturing Method**: Hand Layup Technique. **Test**: Tensile (ASTM D 3039-76)and flexural (ASTM D790-03)	On hybridization mechanical properties of composites almost enhanced to a greater extent. Tensile strength of composites increased from (JJJJ- 21MPa) to (GJJG-42MPa) Flexural Strength of composites increases from (JJJJ- 117 MPa) to (GJJG-241.3 MPa). **Applications** : structural	Stacking sequence (GJGJ) (JGGJ) (GJJG) (0/-90) (+45/-45)
(Gopinath et al. 2014) "Experimental Investigations On Mechanical Properties Of Jute Fiber Reinforced Composites With -Polyester And Epoxy Resin Matrices"	**Composites Made Up of :** **F-** jute, **M-** Polyester, and epoxy **Manufacturing Method**: Hand Layup technique. **Test:** tensile strength, flexural strength, impact strength, and hardness	Jute/epoxy composites gave better properties than jute/polyester composite. **Applications**: aerospace, automotive, marine and sporting industries **Applications**: structural	
(Berhanu et al. 2014) "Mechanical Behavior Of Jute Fibre Reinforced /Polypropylene Composites"	**Composites Made Up of :** **F-** jute, **M-**Polypropylene **Manufacturing Method**: Hand Layup technique. **Test:** compression molding process Tensile and bending	This investigation has found that the 40 Wt. % Jute fiber reinforced PP composite exhibited the highest tensile strength. The flexural strength linearly increased until the amount of Jute fiber reinforcement reached about 40%, and then suddenly went down with a further increase in the fiber reinforcement. **Applications:** aerospace, automotive, and rail sectors	weight % of the fiber- 30, 40, and 50
(Arpitha et al. 2014)	**Composites Made Up of** : **F-**Sisal fiber, Glass fiber, (sic filler)	Sisal-glass composites without silicon carbide filler showing good tensile strength	Silicon Carbide filler variation in (3, 6, 9 wt. %) in

"Mechanical Properties Of Epoxy Based Hybrid Composites Reinforced With Sisal/SIC/Glass Fibers"	**M-** Epoxy **Manufacturing Method:** hand layup technique **Test**: Tensile strength, flexural strength, and impact strength	Sisal-glass with 3% of SiC filler show good flexural strength compared to other composites, and also the composites without filler of sisal-glass performing good impact strength compared to composites filled with SiC filler. **Applications** : Structural	epoxy matrix
Ing. Eva Aková et al.(2013) Development Of Natural Fiber Reinforced Polymer Composites (Singh et al. 2017)	**Composites Made Up of :** **F**-hop fiber, **M**-polyester **Manufacturing Method:** hand layup technique **Test:** Tensile test	Tensile strength has been improved **Applications**: Door panels, seat backs, spare tire covers	------
(I Wayan et al. 2014) "Mechanical Properties Of Rice Husks Fiber Reinforced/Polyester Composites"	Composites Made Up of : **F-** rice husks as fiber **M**-polyester Manufacturing Method: hand layup technique **Test:** Tensile Properties, Flexural Properties	Tensile and flexural strength increased as the weight fraction of rice husk increases And by adding alkalization increases the interfacial bonding between fiber and matrix Applications: structural	Weight fraction (0,20,30,40,50)
(Sagar 2014) "MWCNTS-Incorporated Natural Rubber Composites:-Thermal Insulation, Phase Transition And Mechanical Properties"	**Composites Made Up of :** **F-** Multi-Walled Carbon Nano Tubes **M-**natural rubber **Manufacturing Method:** shear mixing techniques **Test**: Tensile and compression and thermal analysis	MWCNTs incorporation into the rubber matrix has efficiently enhanced the mechanical characteristics of the fabricated composites. **Applications:** automobile industry, sports industry, membrane technology, aerospace industry, energy storage and many more	MWCNTs in Natural Rubber is varied form (0,0.1,0.3,0.5,1.0)

1.12 Literature Survey on Ballistic Impact Testing and FE Modeling of Composites

This literature survey includes FE modeling of composites on ballistic impact, and also fabrication and testing of composites for ballistic impact.

Authors **Title**	**Fiber (or) reinforcement (F)** **Matrix material (M)** **Preparation (or) Processing** **Testing (or) Experimental technique**	**Conclusion and Application**	**Modeling method** **(Software used- S)** **Variables**
(Patel et al. 2004) "Penetration of Projectiles in Composite-Laminates"	**Composites Made Up of** : **F-E-**Kevlar, **M-**Epoxy. **Manufacturing Method**: Hand Layup technique. **Test**: Ballistic Impact by using GAS gun Firing Setup.	(a) A linear relationship exists between the ballistic limit and thickness of the composite laminate. (b) The energy absorption and ballistic limit of the composite target increase with thickness for a given impact velocity.	------ Thickness, Number of Layers, Input Velocities
(Vanichayangkuranont et al. 2006) "Numerical Simulations of Level 3-A Ballistic Impact on Ceramic-Steel Armor"	**Composites Made Up of** : Alumina ceramics and steel plates **Manufacturing Method**: Hand Layup technique. **Test**: Ballistic Impact by using gun Firing Setup. The impact falls under the 3-Threat-level of the NIJ standard	Damage appeared at the back portion of the ceramic plate compared to the front portion. The bullet has penetrated in the 4-mm-thick ceramic plate but in other thickness ceramic plate bullet has not penetrated.	**S**-ABAQUS The thickness of the plate Ceramic plate 4,6,8 mm and steel plate 1.5 mm constant Velocity 419,422,426,431 m/s.

(Ahmad et al. 2007a) "Performance of Natural Rubber-Coated Fabrics under-Ballistic Impact"	**Composites Made Up of** : **F**-Twaron, **M**-Natural rubber. **Manufacturing Method**: Coating technique by dipping Trawon into NR **Test**: Ballistic Impact by using 7.62 Mauser Test Gun at 0^o obliquity	The Trawon fabric coated- in single dip with natural rubber show, better ballistic impact resistance. Natural rubber coated Trawon fabric gave higher energy absorption than neat Trawon fabric hence coating is helps in improving the ballistic properties of the fabric system.	Experimentally Variation in coating thickness
(Grujicic et al. 2009) "Material Modeling and Ballistic/Resistance Analysis of Armor/Grade Composites Reinforced with High/Performance Fibers"	**Composites Made Up of** : **F-** ultra-high molecular weight (UHMW) polyethylene, **M**-polymeric-matrix **Manufacturing Method**: Hand Layup technique. **Test:** Ballistic Impact.	From the analysis, it can be concluded that -Starting filament shearing or cutting-dominated phase; -Intermediate phase characterized by pronounced filament-matrix debonding -At the end extensive filament stretching of armor which leads to buckling of back phase.	**S**-ANSYS/Autodyn version 11.0 Only 0/90 Cross plied
(Gopinath et al. 2012) "Effect of matrix on ballistic performance of soft body armor"	**Composites Made Up of** : **F-** Kevlar yarn, **M-**Resin. Only software Designed Impact analysis	In the composites-Matrix material significantly influences the ballistic performance of body armors. The stiffer polymer materials enable the system to absorb more of the kinetic energy of the projectile. **Applications-**Body armor	**S**-LS-DYNA Only yarn Yarn+soft matrix Yarn +stiff matrix
(Ramadhan et al. 2012) "The Influence of impact on Composite-Armour System Kevlar29/polyester/Al_2O_3"	**Composites Made Up of** : **F**-E-Kevlar-29, **M**-Polyester-Al_2O_3. **Manufacturing Method**: Hand Layup technique. **Test**: Ballistic Impact by using	There was a very good agreement exists between the FE simulated and experimentally tested results with a maximum error of 4.1%. The thickness of the composite plate	**S-**ANSYS AUTODYN 3D-v.12 Stacking sequence varied. Thickness of plate = (4,8,12 mm) Impact velocity =

	GAS gun Firing Setup. Impact test: 7.62 mm projectile diameter and velocity ranges used are 160-400 m/s.	influences the ballistic behavior of the composite structures. 12 mm composite has the capacity to resist the impact of 200 m/s velocity projectile.	160 - 400 m/s
(Ramadhan 2012) "Experimental and Numerical Simulation of Energy Absorption on Composite Kevlar 29-Polyester Under High Velocity Impact"	**Composites Made Up of** : **F-** Kevlar29, **M-**Epoxy. **Manufacturing Method**: Hand Layup technique. **Test**: Ballistic Impact by using GAS gun Firing Set-Up. Cylindrical 7.62 mm projectile	There was a very good agreement exists between the FE simulated and experimentally tested results with maximum errors 3.6% The thickness of the composite plate influences the ballistic behavior of the composite structures. 12 mm composite has the capacity to resist the impact of 200 m/s velocity projectile.	**S-**ANSYS AUTODYN 3D-v.12.1 Thickness of plate = 12 to 16 mm Impact velocity =160-400m/s
(Ramadhan et al. 2013) "High velocity impact response of Kevlar29/epoxy and 6061-T6-aluminum laminated panels"	**Composites Made Up of** : **F**-Kevlar-29&Al-6061-T6,**M-**Epoxy. **Manufacturing Method:**Hand Layup technique. **Test:** Ballistic Impact by using GAS gun Firing Setup. Velocity- (180–400 m/s)	Sandwich structures gave excellent energy absorption under high-velocity impact condition. It is considered suitable for applications of armor system	**S**-ANSYS Autodyn 3D v.12 software Stacking sequence varied. Shape of projectile- Range of velocities (180–400 m/s)
(Sikarwar et al. 2013) "Ballistic performance of Kevlar-epoxy composite laminates"	**Composites Made Up of** : **F**-Kevlar, **M-**Epoxy. **Manufacturing Method**: Hand Layup technique. **Test**: Analytical and Numerical simulation study	Cross-ply laminates absorb more energy The residual velocity of FEA results has good agreement with Experimental results.	**S**-ABAQUS Layup sequence, Thickness and velocity of projectile

(Phadnis et al. 2013) "Ballistic impact behaviour of woven fabric-composite:- Finite element analysis and experiments"	**Composites Made Up of** : **F**-E-Glass, **M**-Epoxy. **Manufacturing Method**: Hand Layup technique. Test: Ballistic Impact by using GAS gun Firing SetUp.	FE simulated and experimental results were matching each other for different thickness of composites simulated.	ABAQUS/Explicit Thickness of the composite plate 2.5, 4.5, and 5 mm.
(Sikarwar en Velmurugan 2014) "Ballistic Impact on Glass-Epoxy Composite Laminates"	**Composites Made Up of** : **F**-Glass, **M**-Epoxy. **Manufacturing Method**: Hand Layup technique. **Test**: Analytical and Numerical simulation.	The analytical results are compared with FE results for the glass/epoxy laminates with different fiber orientations and thickness values. The results obtained from the analytical match well with FE results. With increasing the impact velocity, energy absorption capacity decreases. Compared to other lay-up the (0/90) laminate is a most effective.	**S**-ABAQUS Layup sequence, Thickness and velocity of projectile
(Randjbaran et al. 2014) "Hybrid Composite-Laminates Reinforced with Kevlar-Carbon-Glass Woven Fabrics for Ballistic Impact Testing"	**Composites Made Up of** : **F**- Kevlar, Carbon&Glass, **M**-Epoxy. **Manufacturing Method**: Hand Layup technique. **Test**: Ballistic Impact by using GAS gun Firing Setup. Bullet is fired at 182 m/s for all case.	Among all the sequences studied H2 is better over other stacked composites.	Stacking sequence H1-KCGKCG H2-GCKCKG H3-KGCGCK H4-GKCCGK H5-KCGGCK
(Bandaru et al. 2016) "Ballistic impact response of Kevlar®	**Composites Made Up of** : **F**- Kevlar® **M**- polypropylenematrix **Manufacturing Method**: Hand	3D orthogonal and interlock fabric armor composite were able to arrest the 9mm FMJ bullets whereas other fabric composite fail to arrest.	**S**-ANSYS AUTODYN Variation: 2D plain woven, 3D orthogonal and

reinforced/thermoplastic composite armors”	Layup-Compression molding technique. **Test:** Ballistic Impact.		3Dangle interlock fabrics
(Martínez-Hergueta et al. 2017) “Ballistic performance of hybrid nonwoven-woven polyethylene fabric shields”	**Composites Made Up of** : **F**-Polyethylene nonwoven/woven **M-** polymeric-matrix **Manufacturing Method**: Hand Layup technique. **Test:** Ballistic Impact.	Among non-woven and woven composite testing, non-woven has higher ballistic performance over woven. While hybrid composites gives the better performance than the rest. The damage results from FEM and experimental are in good agreement.	Stacking sequence-[NW/0W/90W/0W/90W] Impact velocity- 280 to 380m/s,
(Nascimento et al. 2017) “Ballistic Performance of Mallow and Jute Natural Fabrics Reinforced-Epoxy Composites in-Multilayered Armor”	**Composites Made Up of** : **F**-Mallow and Jute fabric **M-** Epoxy **Manufacturing Method**: Hand Layup technique. **Test:** Ballistic Impact.	The composites of all the combination tested are passed the NIJ standard. Hence suitable for ballistic multilayered armor system second layer.	Mallow100% Mallow 70& Jute 30, Mallow 50& Jute 50,
(Palta et al. 2018) “Finite element analysis of the Advanced Combat Helmet under various ballistic impacts”	**Composites Made Up of** : **F-** ultra-high molecular weight (UHMW)polyethylene, **M**-polymeric-matrix **Manufacturing Method**: Hand Layup technique. **Test:** Ballistic Impact.	Ballistic impact study on advanced combat helmet is performed, the reveals that, helmet produced are capable of arresting 9 mm bullet, whereas fails to arrest the .223 caliber bullets. FEA and Experimental results show good agreement.	**S-**LS-DYNA. Type of bullets-9 mm and .223 caliber

1.13 Literature Summary and Research Gap

From the literature survey, it is revealed that a series of investigations have been carried out by the researchers regarding mechanical characterization of the natural fiber reinforced composites, by reinforcing the natural fibers in the form of short and random orientation and with a different fiber combination (two or more fibers), variation in stacking sequence, treating the fibers with alkali. Low-velocity impact characterization is also carried out for different natural fiber reinforced composites. Still, very limited work could be observed for the combination of natural woven fiber and particulate fiber composites (hybrid composite) for mechanical and ballistic studies.

Many researchers and ballistic agencies have focused on the synthetic fiber reinforced composite (Kevlar epoxy, aluminum with Kevlar epoxy, Kevlar polyester) to study the ballistic properties using experimentally as well as from the numerical simulations. Due to the increasing environmental issues. There is a necessity of exploring the natural fibers to produce the green composites for ballistic applications. Thus the present study is envisaged to harness natural fibers and particulates for composites and study their mechanical properties as well as ballistic impact resistance.

1.14 Objectives and Scope of Present Work

Objectives

- To propose sandwich composites and evaluate their ability for bullet proofing from FE modeling.
- Evaluate the mechanical properties of composites required for FE simulation.
- Modeling of the composite sandwiches with the above determined mechanical properties to optimize the geometric properties for ballistic energy absorption.
- To fabricate sandwich composite plates and test them for ballistic energy absorption.
- To fabricate and test the bullet resistance blocks and interlock blocks made from sandwich composites.
- To build and test the working prototype of a protective wall with interlock blocks produced.

Scope

- Propose sandwiches made of jute, fly ash, epoxy, rubber, and estimate their bullet resistance in FE modeling
- Prepare samples of Jute Epoxy Fly ash Composite (with single woven tossa jute and single, double woven white jute composite) and evaluate mechanical properties (Tensile, Compression, and Flexural).
- Modeling and simulation of sandwiches with under the ballistic impact (from 5 to 150 mm thick) of projectiles impacting at velocities 150 to 350 m/s
- Prepare sandwich plates, blocks of various thickness, interlocking blocks (150 mm) and testing them under field ballistic impact using short-range bullets with a maximum velocity of 350 m/s.

These polymer composite blocks which form protective structures could be used in defense, aerospace, and automotive sectors. In defense, these blocks could be used as a replacement for sandbags which are cumbersome to transport. These blocks could be used for protective covers in the bunkers and storage spaces. These can be also used as protective walls for components in nuclear, aerospace and automobile applications.

1.15 Proposal/Concept

Presently cement concrete/sandbag bunkers are used to prepare the defense bunkers which are used to safeguard military persons from the impact of bullets. Construction of these bunkers/barricades requires huge time and effort. To overcome the limitation following concept proposed for the present investigation.

The present study relates to the development of quick self-assembling composite interlock blocks produced from environmentally friendly recycled materials, using a compression molding technique.

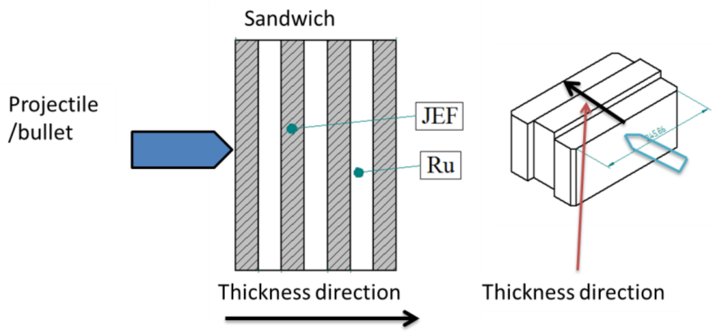
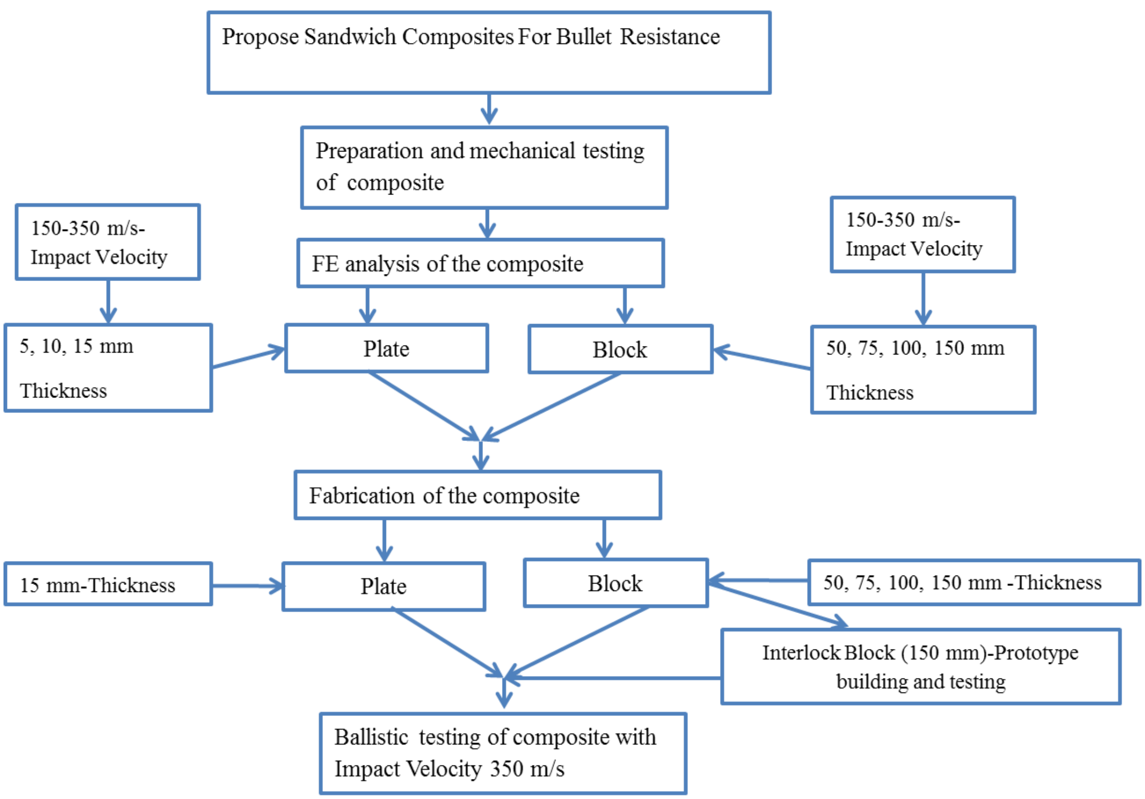


Figure 1.10 Schematic view of proposed concept

These composite interlock blocks could be stacked to the required height to provide all-around protection against short-range bullet impact up to a velocity of 350 m/s. The concept is evaluated through modeling and validated through experimental testing. The systematic study is carried out to achieve the mentioned product development is given in the flowing flow chart.

Implementation Procedure for Proposed Concept



CHAPTER 2

METHODOLOGY

This chapter describes the FE modeling and experimental techniques used in the present investigation.

2.1 Finite Element Modeling

Generally, the effect of the impact phenomenon is analyzed with the help of one, two or three-dimensional approaches. Three-dimensional approaches take the account of thickness whereas one and two-dimensional approach ignores the plate thickness. Three-dimensional approaches are useful in studying the deformation and fracture behavior for the plate. This approach considers the material either as isotropic or orthotropic.

Modeling consists of part creation in which part was created to the required dimension as shown in Figure 2.1. After creating parts, material properties were applied to the created part as is shown in Figure 2.2. These created plates and projectile/bullet are assembled in such a way that normal impact occurs as Figure 2.3. In the next step, these parts have meshed as shown in Figure 2.4. After assembling, boundary conditions were imposed on the parts as shown in Figure 2.5. After imposing boundary conditions and loading the model is submitted and extracted results were analyzed.

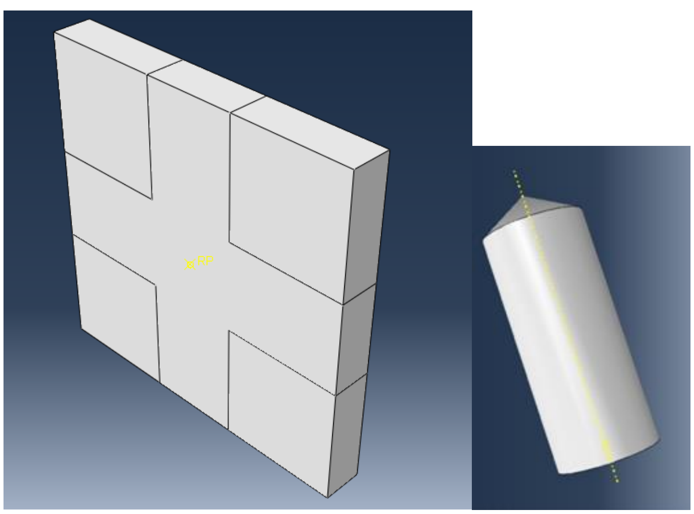


Figure 2.1 Part module of composite plate and bullet

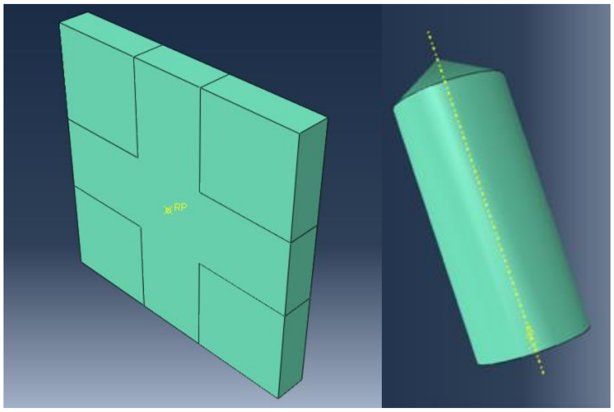


Figure 2.2 Material modules of composite plate and bullet

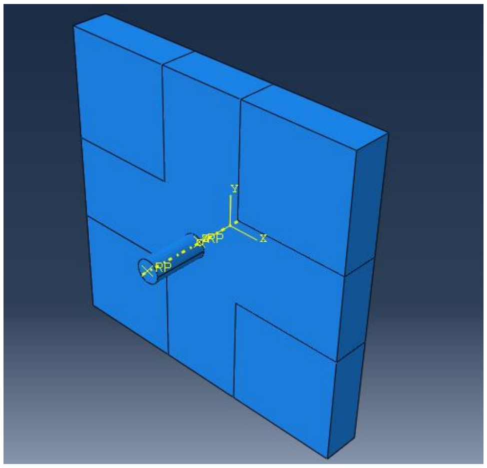


Figure 2.3 Assembly module of composite plate and bullet

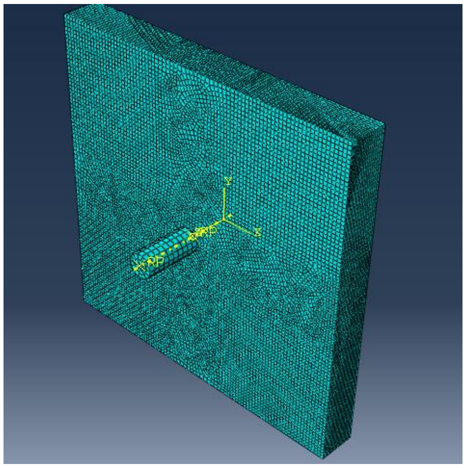


Figure 2.4 Mesh module of composite plate and bullet

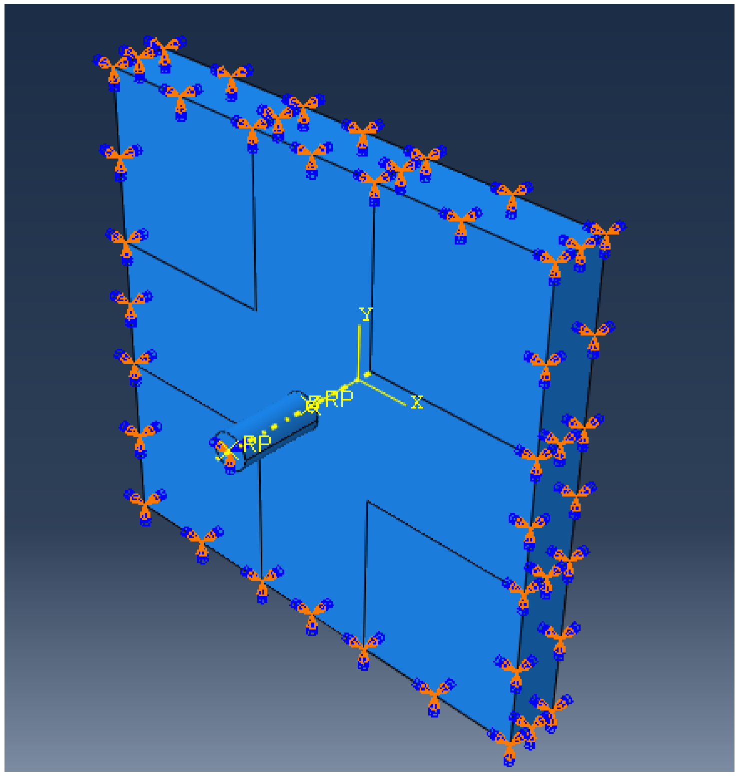


Figure 2.5 Assembly with boundary conditions module of composite plate and bullet

2.1.1 Modeling of Composite Plate

FE analysis was carried out for composite plates for ballistic impact is explained below:

Finite Element model for the composite plates was developed using commercial Finite Element Modeling software ABAQUS. The composite plates of 100 mm X 100 mm with different thickness were considered for FE analysis is shown in Figure 2.6 (a). A projectile of 7.62 mm diameter, weighing 5 g was considered for analysis to represent the bullet/projectile of a self-loading rifle (Figure 2.6 (b)). Composite target plate was considered as deformable whereas projectile/bullet was considered to be rigid. Target plate and the projectile geometries were created, discretized, following which material properties were assigned. The projectile was made to impact the target normally.

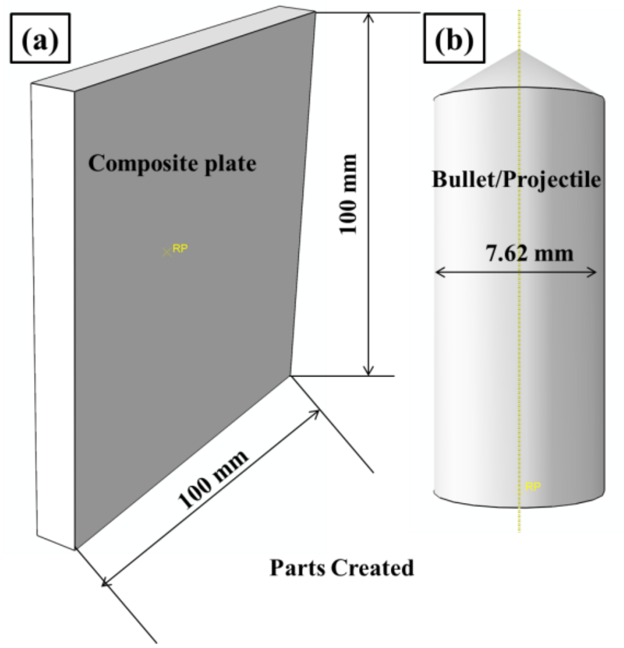


Figure 2.6 (a) composite target plate, (b) projectile/bullet

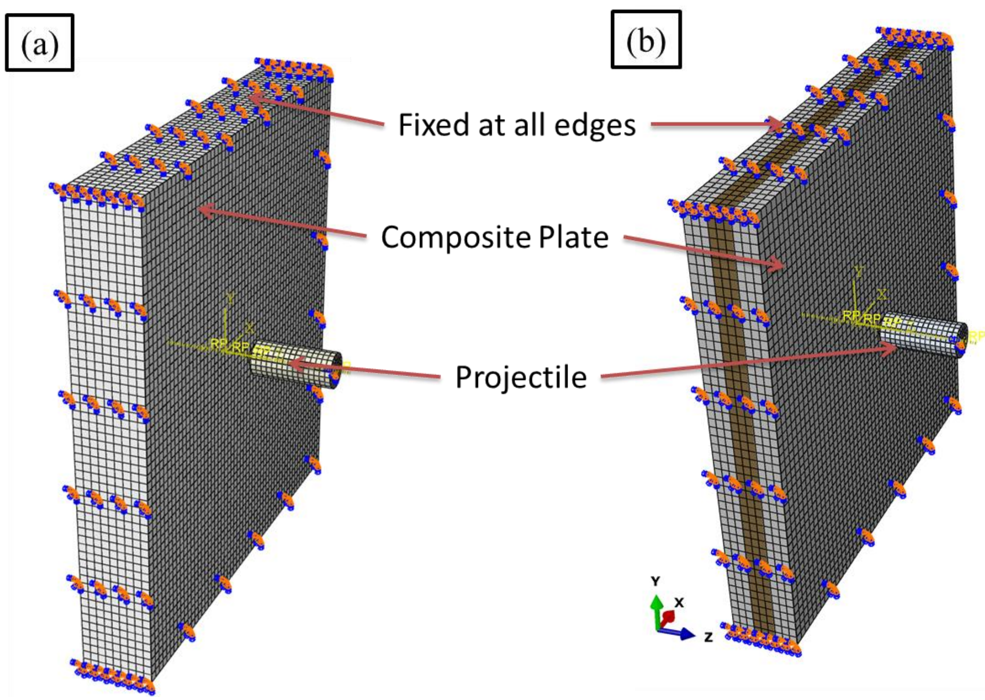


Figure 2.7 (a) JEFC, (b) JEFRC sandwich composite with boundary conditions imposed

Meshed projectile and target plate with boundary conditions are shown in Figure. 2.7 (a) and (b). Details of element type and mesh density are furnished in Table 2.2.

Table 2.1 Properties of composite target plates
(Ramadhan 2012; Sabeel Ahmed en Vijayarangan 2006; Sangamesh et al. 2017a)

Properties	Density (ϱ) kg/m^3	Modulus of Elasticity (E) GPa	Poisson's ratio (ʋ)	Shear Modulus(G) GPa	Tensile Strength MPa
Jute	1450	20	0.38	7.24	--
Epoxy	1200	3.2	0.29	--	--
Fly ash	2250	98	0.21	--	--
JEF Composite	1337.5*	E1=12.57* E2= 12.57*	0.3395*	2.452*	56MPa#
Rubber	1060*	Neo and hookean parameters C11=μ/2, D1=2/ K C11=16.77E9 Pa D1=1.2E-9 Pa-1			0.3MPa#

#Experiment * Rule of Mixture 55% fiber and 45% Matrix

Table 2.2 Details of the mesh for composite plate and projectile

Parts	Type of element	No of elements
Plate	SC8R	5 mm- 55835 10 mm-111670 15 mm-167505
Projectile	C3D8R	1260

FE analysis of composite was carried out at different velocities (150 m/s, 250 m/s and 350 m/s) and different thicknesses (5, 10, and 15 mm) of JEFC plates and rubber plate. Sandwich (JEFRC) consisting of both sides JEF 5 mm with rubber core 5 mm thickness is shown in Figure. 2.7 (b) whose analysis was carried out similar to other plates. Rubber material properties considered for the analysis are given in Table 2.1.

2.1.2 Modeling of Composite Sandwich Block

The analysis of composite for ballistic impact was carried out as follows.

Modeling of composite blocks also carried out similar to the composite plate. In which a section of the composite target plate considered for modeling is shown in Figure 2.8. Target plate (25 × 25 × X mm) made of Jute-Epoxy-Fly ash (JEF) and rubber was modeled as the 3D deformable solid element is shown in Figure 2.9. Different thicknesses (50, 75, 100, 150 mm) of the target plate considered are listed in Table 2.3.

Table 2.3 Thickness of the sandwich composite targets

JEF Thickness (mm)	Natural Rubber Thickness (mm)	JEF Thickness (mm)	JEFRC Sandwich Thickness (mm)
50	--	--	--
15	20	15	50
20	35	20	75
30	40	40	100
50	50	50	150
Alternate layer of JEFC and rubber			150

Projectile and target were assembled in such ways that, the projectile tip impacts normally to target plate which is shown in Figure 2.10. Target plate was fixed at the edges as shown in Figure 2.11. The projectile velocity at impact was set at three different values 150, 250 and 350 m/s for the study. Both target and projectile were meshed according to the details are given in Table 2.4. The meshed model is shown in Figure 2.10.

The residual velocity of the projectile after impact and the energy absorbed were recorded for each analysis. The analysis was carried out for Jute-Epoxy-Fly ash composite (JEFC) and Jute-Epoxy-Fly ash Rubber sandwich composite (JEFRC) for different thicknesses of the target plate (50, 75, 100, 150 mm) and three different velocities of the projectile (150, 250, 350 m/s).

Table 2.4 Details of mesh for target plates and projectile

Parts	Number of elements	Type of Element
Plate	50 mm-55835 75 mm-76620 100 mm-111670 150 mm-167505	Rubber = C3D8R JEFC =SC8R
Projectile	2123	C3D10M

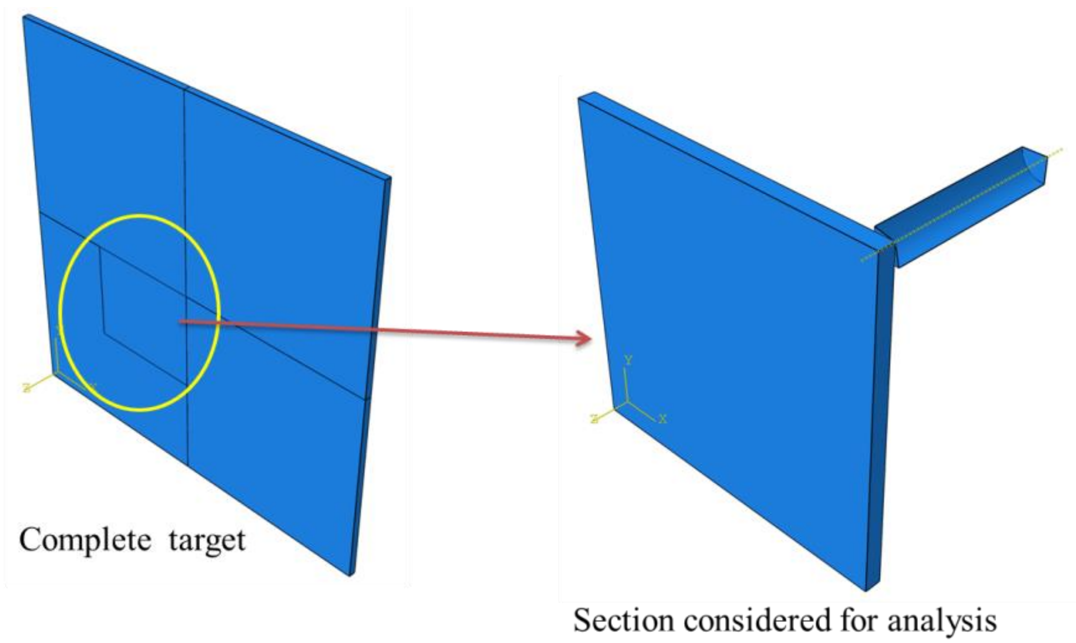


Figure 2.8 Composite target plate considered for modeling

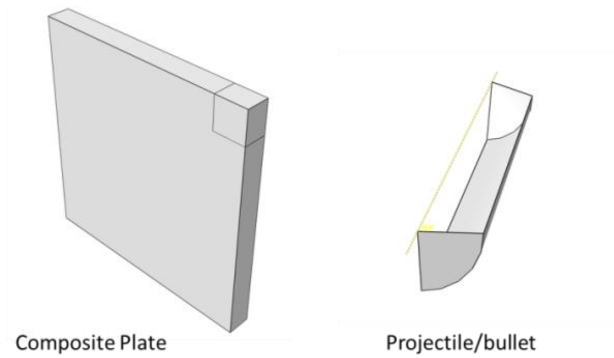


Figure 2.9 Part module of composite plate and bullet

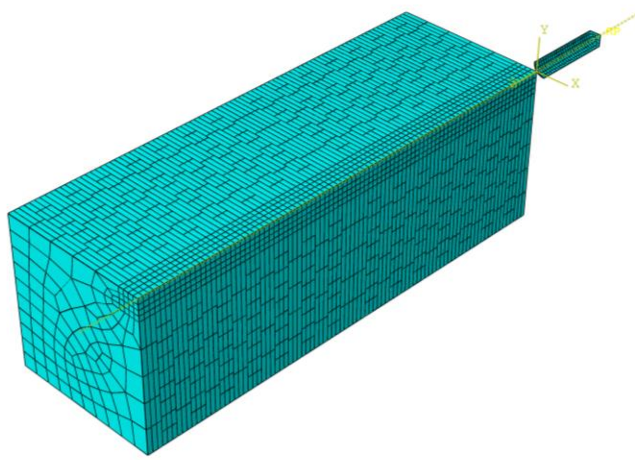


Figure 2.10 Mesh module of composite plate and bullet

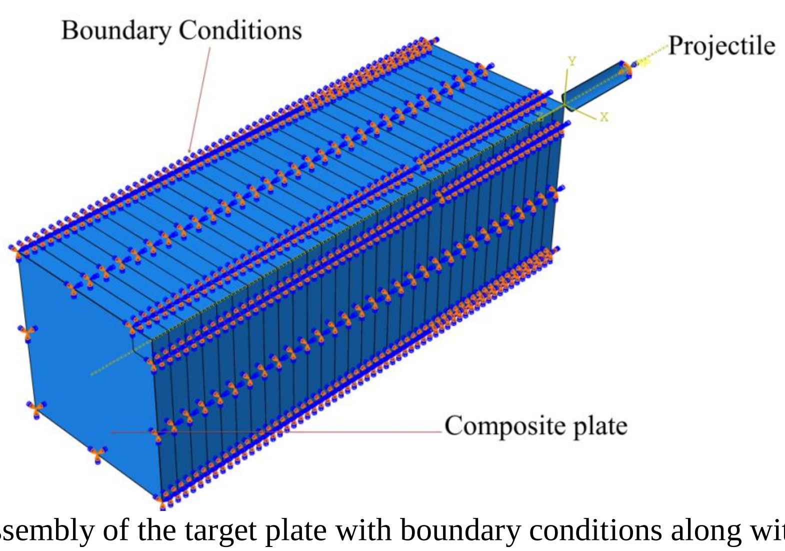


Figure 2.11 Assembly of the target plate with boundary conditions along with a projectile

2.2 Materials, Fabrication Methods and Testing

This section presents the processing of composites for the different testing condition.

2.2.1 Raw Materials

The materials used for the present investigation are natural rubber sheets, three varieties of jute, epoxy resin &hardener and fly-ash.

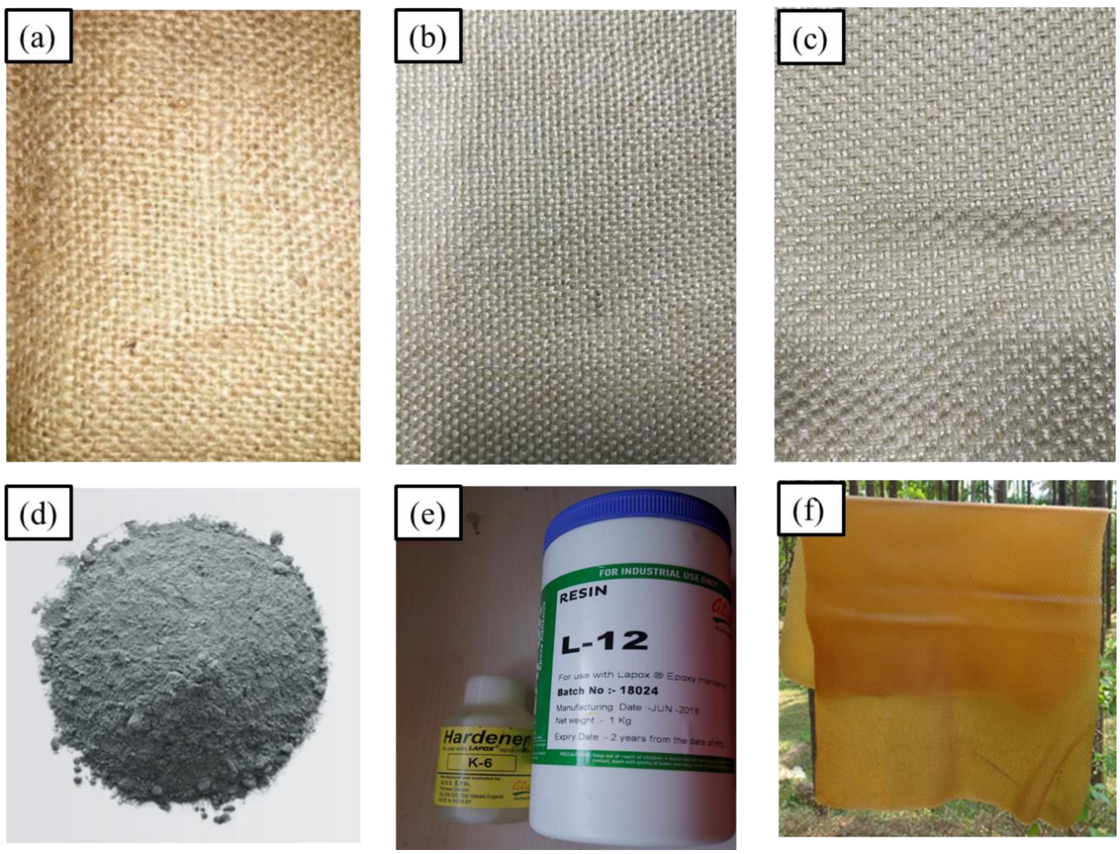


Figure 2.12 (a) Tossa jute single woven (TSW), (b) white jute single woven (WSW), (c) white jute double woven (WDW), (d) fly ash, (e) epoxy and hardener, and (f) natural rubber sheet

The Jute used was procured from the local dealer from Bangalore, which is shown in Figure 2.12 (a) to 2.12 (c). Jute is a lingo-cellulosic fiber, and its composites have high impact strength with moderate tensile and flexural properties compared to other fibers like coir, sisal, pineapple, banana, etc. The inborn properties of jute fiber, such as low density, low elongation at break and its specific stiffness and strength comparable to those of glass fiber, draws the attention of the world. The properties of the jute are listed in Table 2.8.

Table 2.5 Properties of jute
(Saheb en Jog 1999)

Property	Density (kg/m^3)	Tensile Strength (MPa)	Young's Modulus (MPa)
Jute	1.4	393	55

The fly ash used was acquired from Raichur Thermal Power Plant Corporation Ltd., Raichur-India has shown in Figure 2.12 (d). This ASTM class 'C' fly ash is found to consist of a mixture of solid/hollow spheres of different sizes. The composition details of a fly ash particle are tabulated in Table 2.6. The Rubber sheets used were acquired from Mr. Dinesh Shettigar, Bajagoli-Karkala. Rubber sheets as shown in Figure 2.12 (f) were prepared by deliberate coagulation of fresh natural rubber latex. Properties of the fly ash and natural rubber are shown in Table 2.7.

Table 2.6 Composition details of fly ash particles
(Kishore en Santra 2005; Kulkarni 2002; Kulkarni en Kishore 2002)

Constituent	SiO_2	Al_2O_3	CaO	Fe_2O_3	TiO_2
Weight %	63	26.55	.42	6.7	2.47

Table 2.7 Properties of fly ash and NR
(Sangamesh et al. 2017)

Material	Young's modulus (GPa)	Density (kg/m^3)	Poison's ratio
Fly-ash	98.0	2250	0.21
Latex (Natural rubber)	1.00	1060	0.49

The matrix consists of a medium viscosity epoxy resin (LAPOX L-12) and polyamine hardener (K-6), a room temperature curing agent supplied by ATUL India Ltd., which is shown in Figure 2.12 (e). Epoxy resin was selected as the material for the matrix system because of its wide application, good mechanical properties, excellent corrosion resistance and ease of processing. Some details, including the density of the constituent of the matrix system, are listed in Table 2.8.

Table 2.8 Properties of resin & hardener

Constituent	Trade name	Chemical name	Epoxide equivalent	Density kg/m^3	Supplier	Parts by weight
Resin	LAPOX L-12	Diglycidyl Ether of bisphonol A (DGEBA)	182-192	1200	ATUL India Ltd	100
Hardener	K-6	Tri ethylene Tetra amine (TETA)	--	954	-Do-	10-12*

*as suggested by the manufacturer's catalogue

2.2.1.1 Preparation of Natural Rubber Sheet

Natural rubber sheets are produced using subsequent steps.

i) Rubber Extraction

Natural rubber (NR) is extracted from a tree source called "heveabrasiliensis", that is "para" rubber tree which is shown in Figure 2.13 (a). Rubber is extracted by proper tapping method in which the rubber comes in the form of liquid and is collected in coconut shell as shown in Figure 2.13 (b).

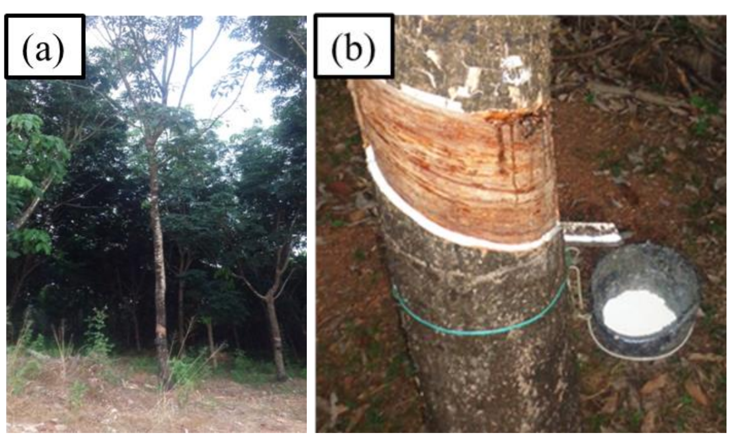


Figure 2.13 (a) Rubber tree, (b) rubber tapping

ii) Mixing of Rubber

Rubber milk, which is collected earlier, is mixed in the container of 30% water and 10% formic acid. This mixture is poured into a tray which is as shown in Figure 2.14 and is kept for 5 hours for coagulation.

Figure 2.14 Natural rubber and formic acid mixture

iii) Rubber Sheet Making

After coagulation, water stays bellow and the upper part is removed and cold rolled to form sheets as shown in Figure 2.15.

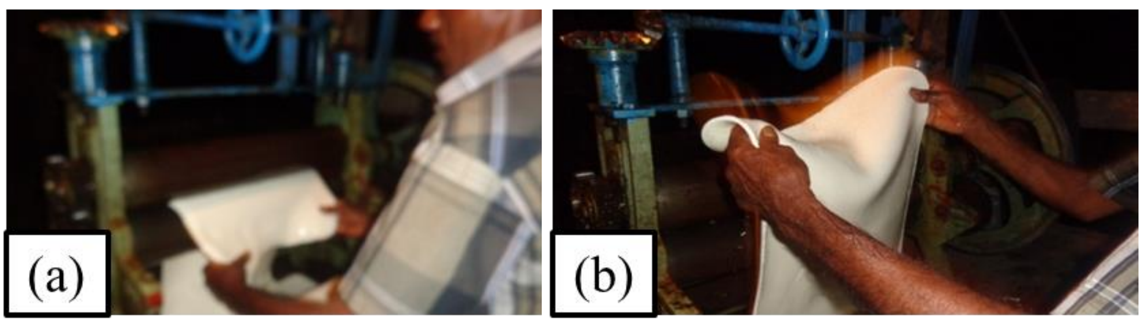


Figure 2.15 Rubber sheet making

Finally, the sheet is impression rolled and allowed for drying by exposing to the sun for to 3-8 days. Figure 2.16 shows completely dried rubber sheet.

Figure 2.16 Rubber sheets drying under sun

2.2.2 Fabrication of Composites for Mechanical and Ballistic Impact Test

This section explains about the composite fabrication techniques carried for mechanical and ballistic impact testing.

2.2.2.1. Fabrication of Composites for Mechanical Test

The composite was fabricated using three different jute fibers namely Tossa jute single woven (TSW), White jute single woven (WSW) and White jute double woven (WDW). The fabricated composite consists of 55% fiber by volume fraction and 45% matrix. In the fiber- 50% jute and 5% fly ash. The fabrication procedure of the composite is described below.

The required amount of epoxy and hardener were added to a glass jar, in the ratio of 10:1 (as suggested by manufactures) and is mixed well. A known amount of fly-ash was added to this mixture and stirred well using mechanical stirrer for 5 minutes. Then woven jute mat was soaked into the mixture of epoxy, hardener and fly ash. After soaking, these jute mats were placed in a square shape steel mold (300 × 300 × X mm) of X-required thickness as shown in Figure 2.17 (a). Compression molding techniques have been adopted for the preparation of the test specimen. The working surfaces of the mold were bonded with Teflon sticker to facilitate the easy removal of the specimen from the mold. Then it was covered by a removable plate above it and this assembly was placed under a compression molding machine (Figure 2.17 (b)), subjected to a constant pressure of 25 kg/cm^2 for to 24 hours to cure. After curing, the composite plate was removed from the mold (Figure 2.17 (c)), thereafter the composite plate was cut into the required dimensions using CNC machine as per respective ASTM Standards. ASTM- D3039 for tension (ASTM D3039/3039M-14 2013), ASTM-D695-02a for compression (ASTM D695-15 2015) and ASTM- D7264 for flexural (ASTM D 7264 2007) which are shown in Figure 2.18, 2.19 and 2.20 respectively.

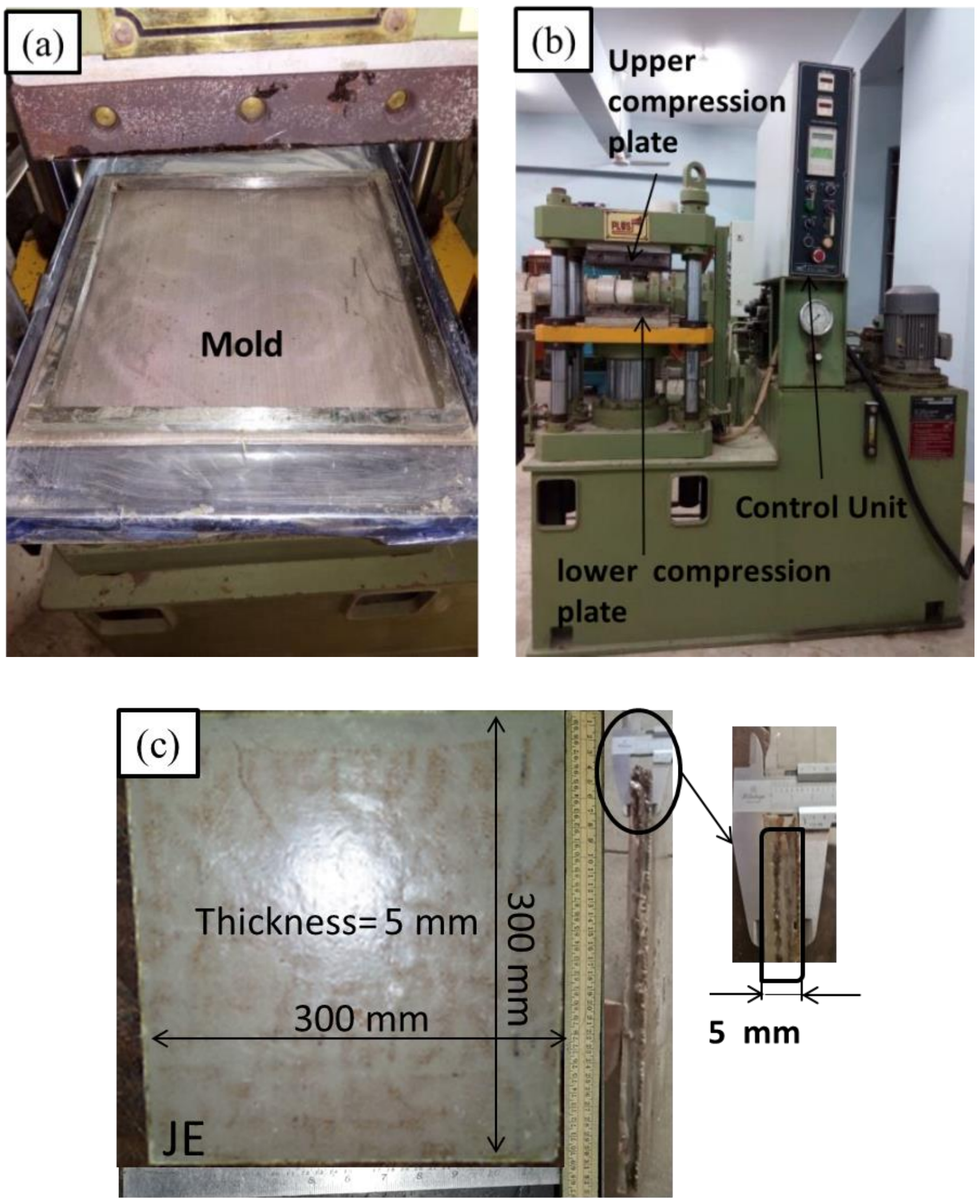


Figure 2.17 (a) Mold used for specimen preparation, (b) compression molding machine, and (c) fabricated typical jute fiber reinforced fly ash filled epoxy composite

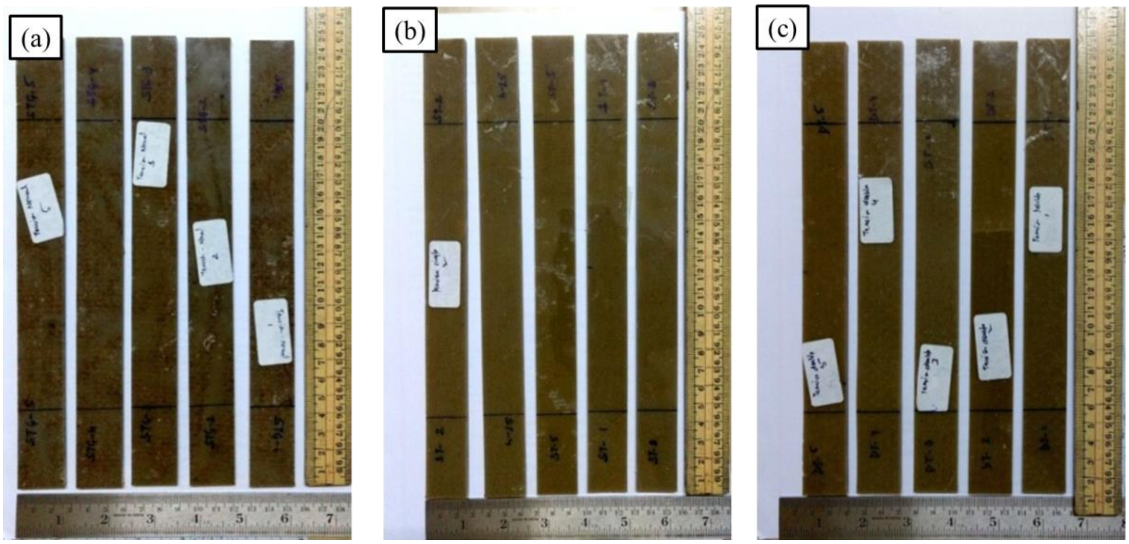


Figure 2.18 Tensile testing samples for (a) tossa jute single woven composite (TSWC), (b) white jute single woven composite (WSWC), and (c) white jute double woven composite (WDWC)

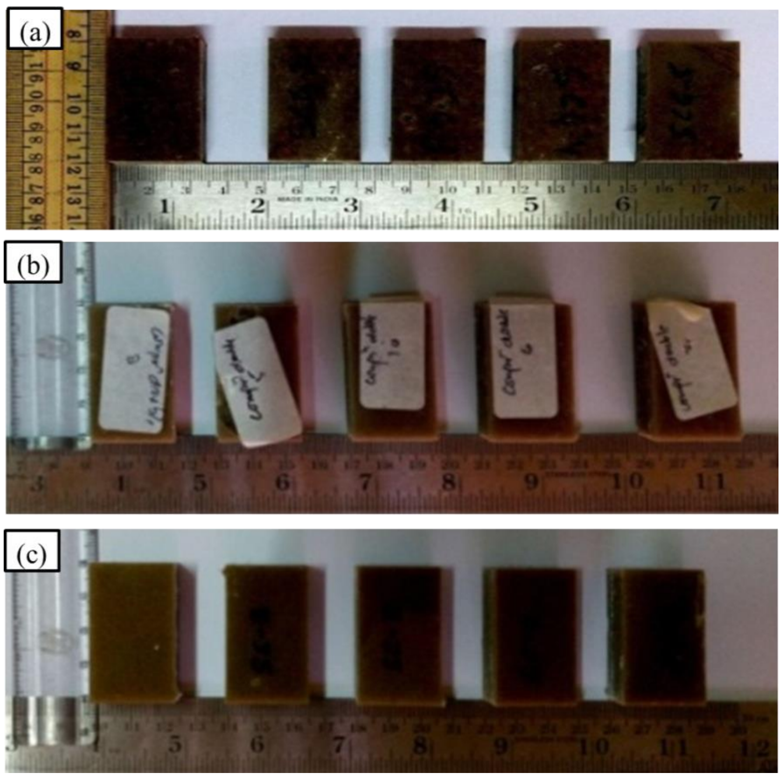


Figure 2.19 Compression testing samples for (a) tossa jute single woven composite (TSWC), (b) white jute single woven composite (WSWC), and (c) white jute double woven composite (WDWC)

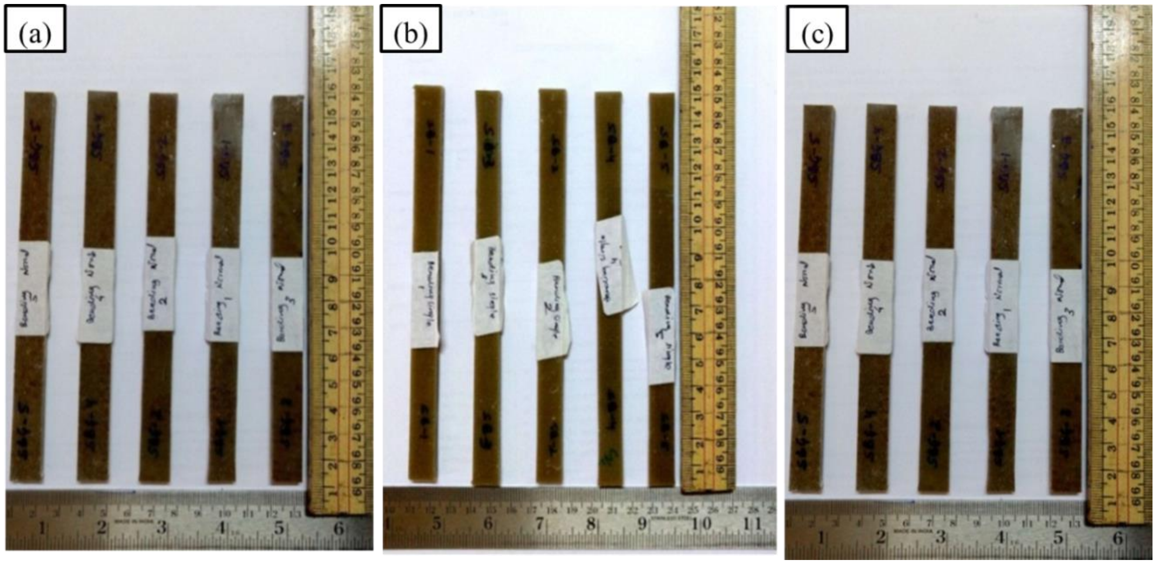


Figure 2.20 Bending testing samples for (a) tossa jute single woven composite (TSWC), (b) white jute single woven composite (WSWC), and (c) white jute double woven composite (WDWC)

Natural rubber sheets were cut in the form of dumbbell shape as per ASTM 412-06(ASTM D412-06 2012), shown in Figure 2.21 were tested for tensile properties.

Figure 2.21 Natural rubber tensile test samples

2.2.2.2. Fabrication of Composites Plate for Ballistic Impact Test

Fabrication of all ballistic testing samples was carried out using tossa jute single woven fibers whose properties are superior to other jute considered in the present study. For fabrication of ballistic test specimen, the similar compression molding technique was used as that of the mechanical testing samples with mold thickness 15 mm. Schematic diagram and configuration considered are clearly shown in Figure 2.22 (a) For jute fibre reinforced fly ash filled epoxy composite (JEFC), and Figure 2.22 (b) For jute fiber reinforced fly ash filled rubber epoxy sandwich composite (JEFRC). Fabricated JEFC and JEFRC are shown in Figure 2.22 (c) and 2.22 (d) respectively.

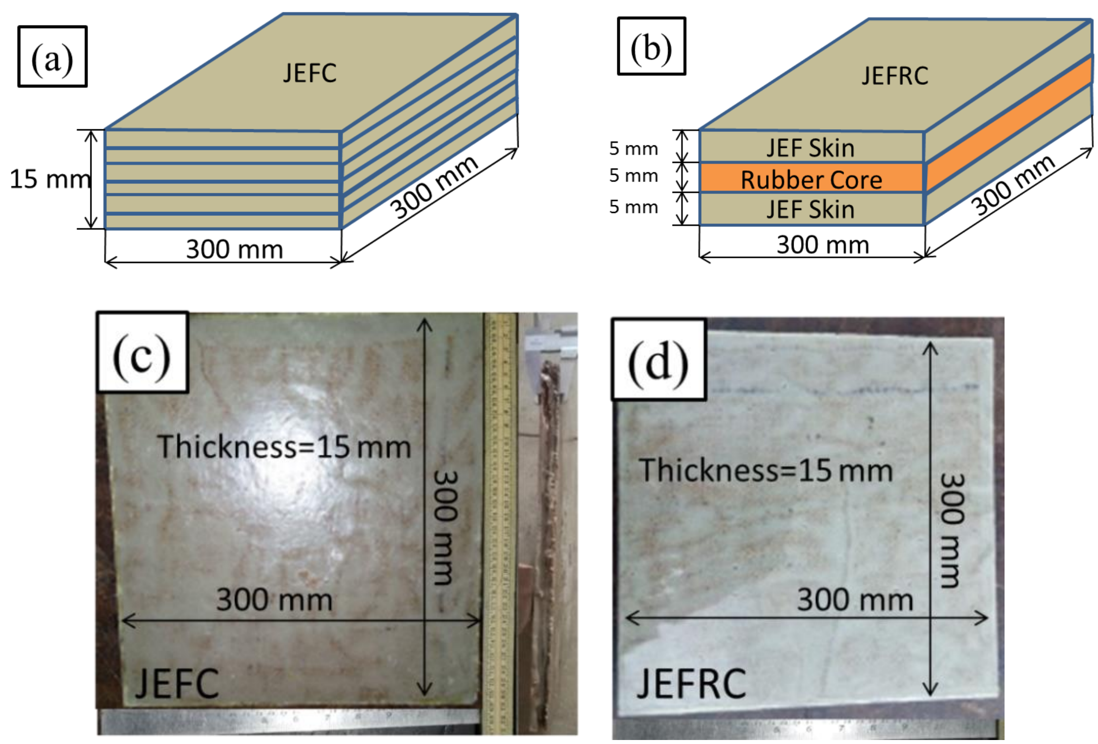


Figure 2.22 Schematic of (a) Jute fiber reinforced fly ash filled epoxy composite (JEFC), (b) Jute fiber reinforced fly ash filled rubber epoxy sandwich composite (JEFRC), fabricated, (c) JEFC, and (d) JEFRC

2.2.2.3. Fabrication of sandwich composite blocks for ballistic impact test

Sandwich composites were fabricated to different thickness as required, with the procedure similar to those of composite plates, which is explained in the previous section.

The variable thicknesses of sandwich considered for fabrication are (50, 75, 100, 150 mm). Schematic dimensions and configuration considered are shown in Figure 2.23. The sandwich block produced with different thicknesses is shown in Figure 2.24.

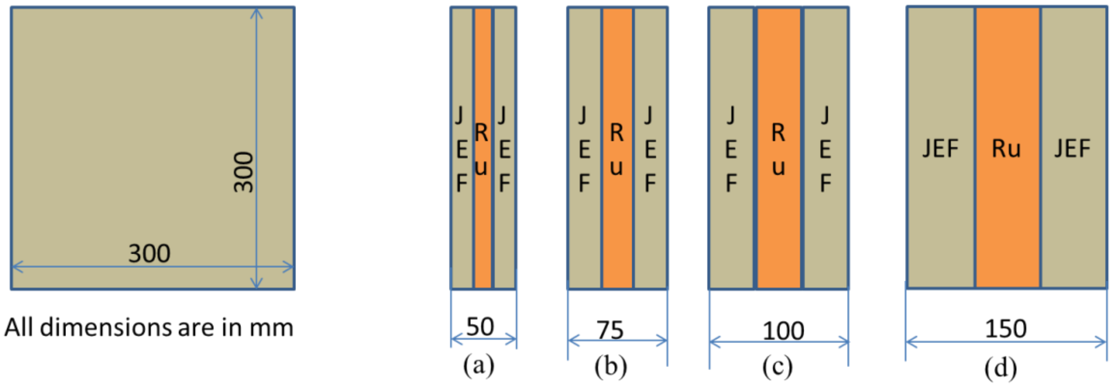


Figure 2.23 Schematic diagram and configuration of (a) 50 mm JEFRC, (b) 75 mm JEFRC, (c) 100 mm JEFRC, and (d) 150 mm JEFRC

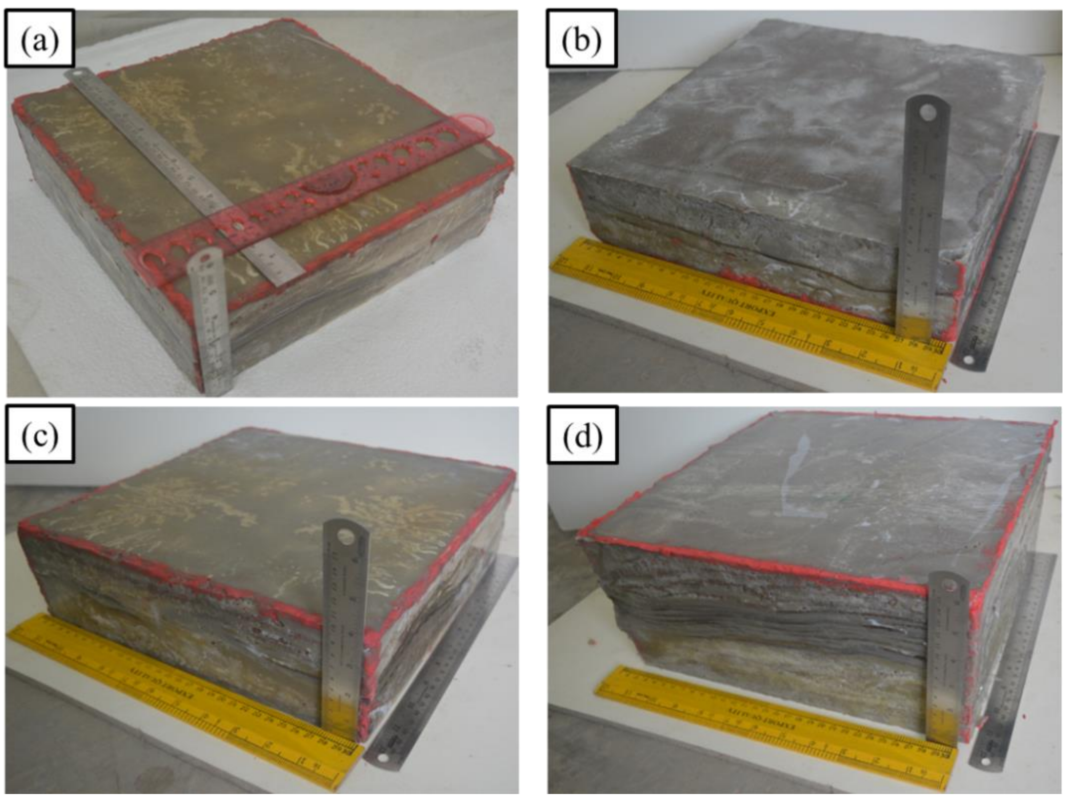


Figure 2.24 Fabricated sandwich composites of (a) 50 mm JEFRC, (b) 75 mm JEFRC, (c) 100 mm JEFRC, and (d) 150 mm JEFRC

2.2.3 Testing of Composites for Mechanical and Physical Properties

The fabricated composites were tested for tensile, compression and flexural properties. Rubber samples were tested for tensile properties. The testing was carried out using universal testing machine SHIMADZU autograph AGX plus 100 kN at NITK, shown in Figure 2.25 (a). The testing arrangements for tensile, compression and flexural are shown in Figure 2.25 (b), (c) and (d) respectively.

Hardness and density of the composite produced were measured using Shore D for hardness and density kit for density which is shown in Figure 2.25 (e) and (f).

Density measurement was carried out for the composite specimens using a density kit. The principle of density measurement was based on buoyancy. The density of the composite specimens was measured by checking their dry weight, immersed weight and soaked weight.

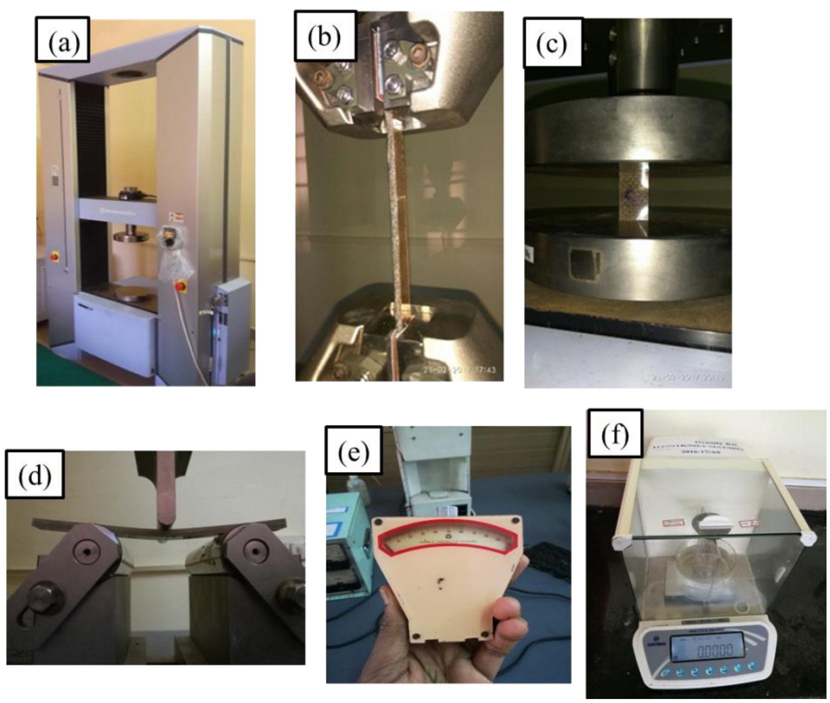


Figure 2.25 (a) Universal testing machine, (b) tensile test, (c) compression test, (d) flexural test, (e) hardness test, and (f) density kit, set-ups

2.2.4 Ballistic Impact Test of Composite Plates and Sandwiches

The ballistic test was carried out on the prepared samples, in order to find the energy absorbed, ballistic limit velocity and thickness required to arrest the bullet, according to NIJ Standard 0108.01(U.S. Department of Justice 2008). Schematic and actual experimental set-up for ballistic impact test is shown in Figure 2.26 and 2.27 respectively.

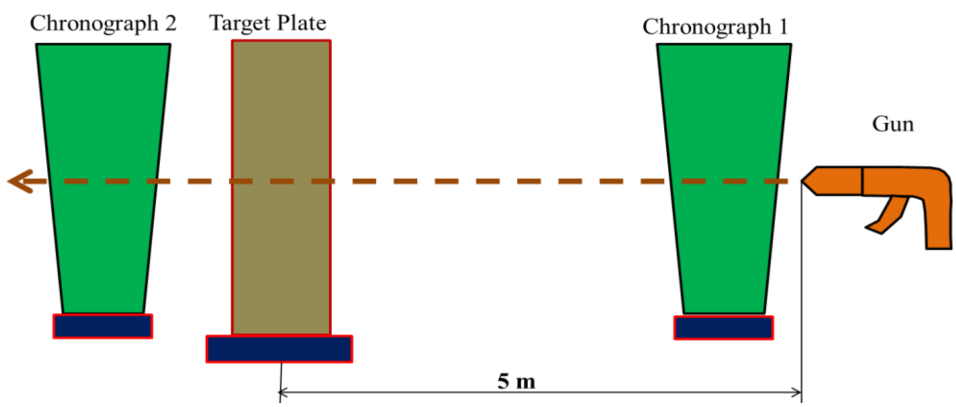


Figure 2.26 Schematic diagram of ballistic impact test

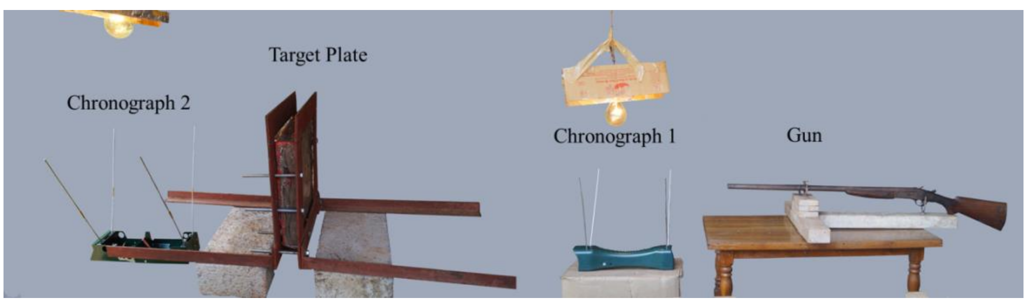


Figure 2.27 Experimental setup for ballistic impact test

2.2.5 Scanning Electron Microscopy (SEM)

The JEOL JSM-6380LA scanning electron microscope was used for fracture surface analysis of tensile and ballistic samples.

2.2.6 Prototype Fabrication

The schematic diagram of the interlock block configuration is shown in Figure 2.28. The interlock blocks were produced similar to those of the JEFRC sandwich block using the compression molding method. The mold used for producing the interlock block is shown in Figure 2.29 (a). The sandwich interlock block produced is shown in Figure 2.29 (b) which consists of alternate layers of JEF and Rubber (Each of 5mm thickness). Produced interlock blocks were assembled together and a prototype is build shown in Figure 2.30.

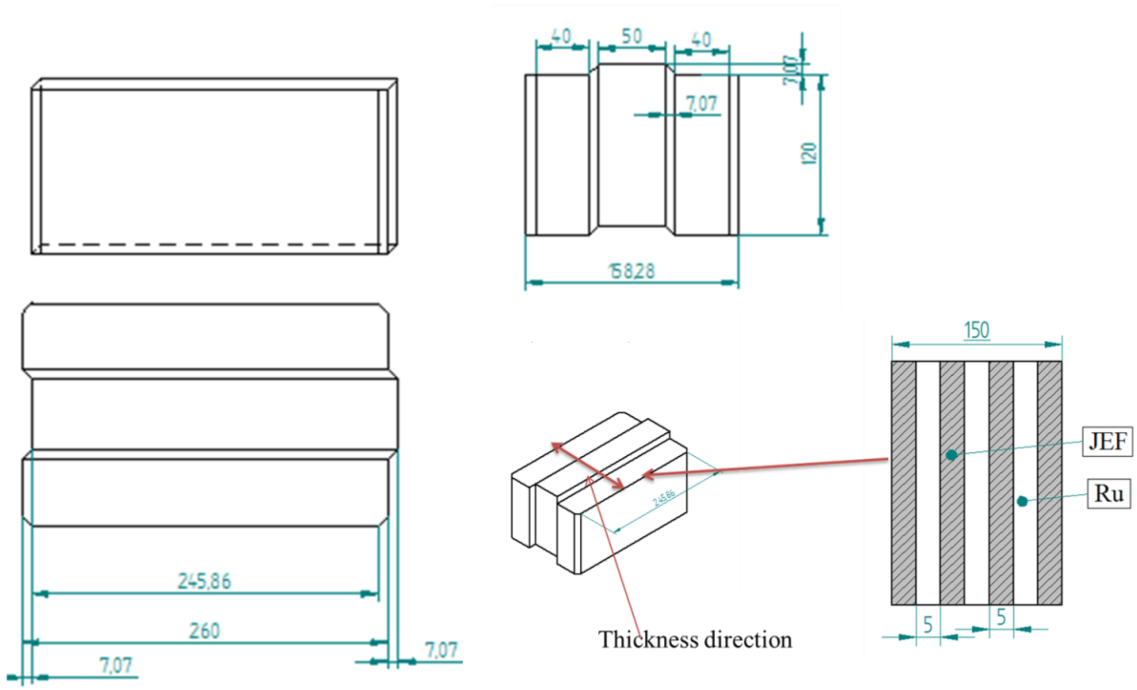


Figure 2.28 Schematic diagram of interlock block configuration

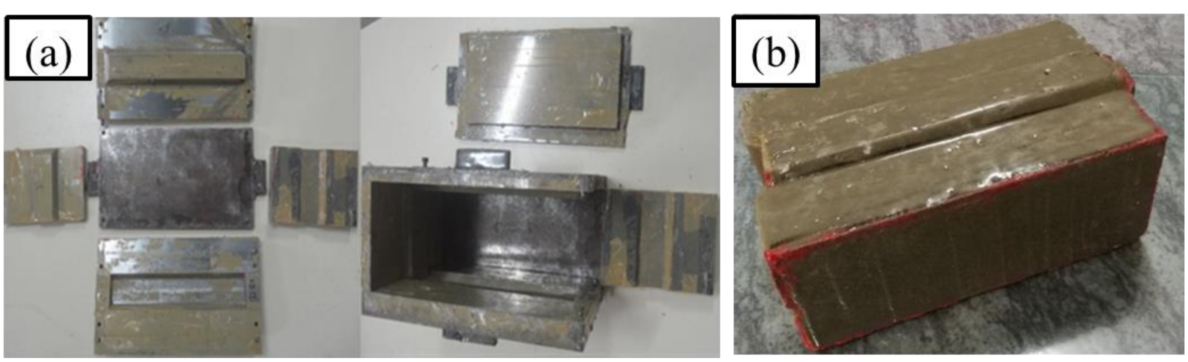


Figure 2. 29 (a) Mold used for producing interlock block, and (b) A sample of interlock block

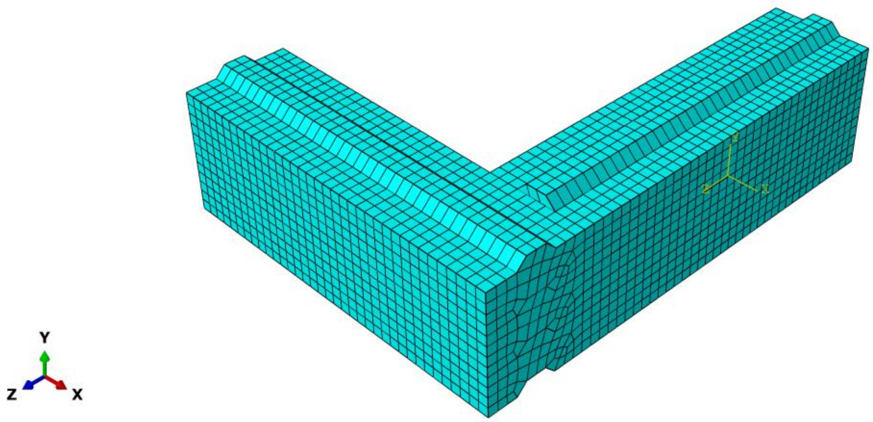


Figure 2.30 CAD Model of the proposed concept for bullet proofing (prototype)

CHAPTER 3

RESULTS AND DISCUSSION

3.1 FE Modeling Results

In this section finite element analysis results of JEFC plate, rubber and JEFRC sandwiches are explained.

3.1.1 Modeling Results of Composite Plate

Table 3.1 presents a bird's eye view of the results obtained from the analysis of JEFC plate, Rubber and JEFRC sandwiches. In this table, residual velocity, ballistic limit velocity and energy absorbed are listed for various thickness and projectile velocities.

It could be noticed from the tabulated results that ballistic limit increases with an increase in the thickness of the target. It is also evident form values that the rubber has a higher ballistic limit and absorbs larger energy. These could be attributed to the nature of damage sustained by JEFC and Rubber, which could be explained as below:

Table 3.1 Results of energy absorbed by JEFC, natural rubber and JEFRC

Jute Epoxy Fly ash Composite (JEFC)-Plate				
Thickness (mm)	Input Velocity (V_i) m/s	Residual Velocity (V_r) m/s	Ballistic Limit Velocity (V_b) m/s	Energy Absorbed (E_a) J
5	150	143.41	43.94	04.82
	250	243.43	56.07	07.86
	350	342.90	70.09	12.28
10	150	142.87	45.69	05.21
	250	242.07	62.43	09.74
	350	339.83	83.73	17.52
15	150	141.08	50.95	06.49
	250	239.16	84.85	13.25

	350	335.83	98.56	24.28
Natural Rubber				
5	150	130.60	73.78	13.60
	250	223.40	112.22	31.48
	350	310.90	160.75	64.60
10	150	120.40	89.46	19.80
	250	210.68	134.58	45.30
	350	280.35	209.53	109.80
15	150	098.40	113.21	32.00
	250	160.51	191.66	91.60
	350	220.87	279.33	184.28
Jute Epoxy Fly ash Rubber Composite (JEFRC)				
JEFRC Sandwich composite (5JEF+5Ru+5JEF)	150	108.4	103.67	26.87
	250	175.51	178.03	79.68
	350	240.88	208.82	161.2

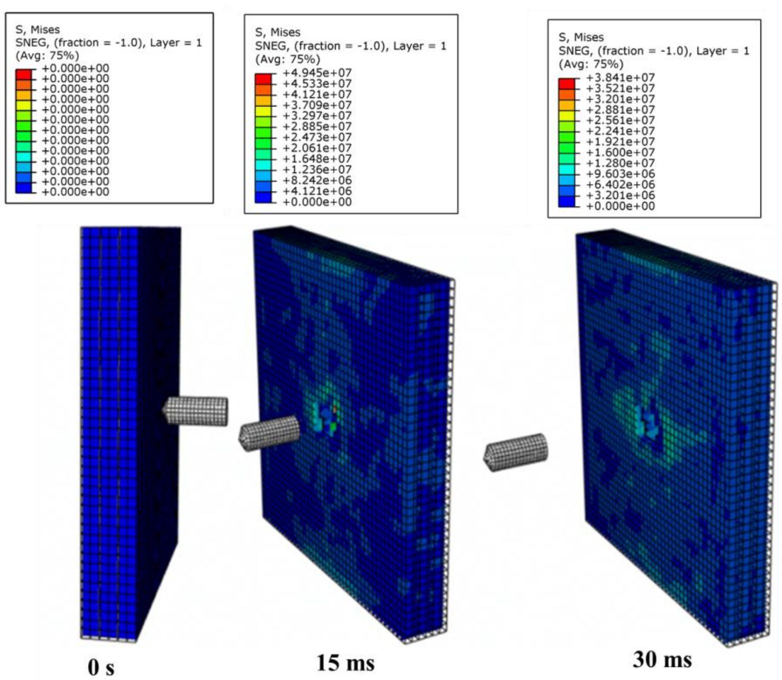


Figure 3.1 Damage behavior of 15 mm thick JEFC plate impacted with 350 m/s velocity
(Note: s-second, ms- millisecond)

Figure 3.1 shows the interaction of projectile with JEFC plate at time 0 second, 15 ms and 30 ms from the start of impact. It is observed from the JEFC target plate that, in the beginning, there are no stresses present in the materials as the projectile penetrates the target plate, stresses are developed. Once the stresses in the target plate reach above its maximum limit complete penetration of projectile occurs, and the plate fails with a clear hole. Predominantly, a brittle fracture of plates could be observed. It could be observed that stress values are relatively higher and concentrated in the small area around the damage of the plate. Figure 3.2 shows the damage in JEFC target plate representing damage at entry and exit side magnified. Similarly, Figure 3.3 and 3.4 show the progression of damage and its nature for rubber plate. It could be observed here that entry and exit damages are comparable but different from those observed from JEFC plate. Spread out of the damaged area is indicating stress relaxation local yielding of material. This could be attributed to lower residual velocity higher energy absorption and ductile nature of damage as represented in Figure 3.4. Progression of damage and its nature for JEFRC sandwich plate are shown in Figure 3.5 and 3.6 respectively. Where elastic yielding of the rubber core before tearing could be visualized from the extension of the mesh in the direction of impact. Thus, a dominant ductile failure of rubber, which encourages larger energy absorption, could be seen. The stress distributions are intermediary between JEF and rubber target JEFRC plates. The stresses are distributed through lager area of the target. It could be observed that energy absorbed in rubber is almost 10 times than that by JEFC plate.

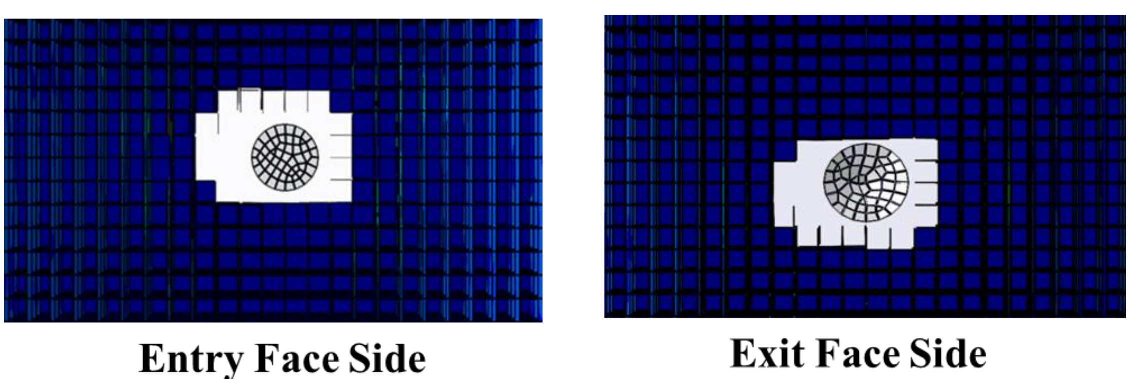


Figure 3.2 Damage in JEFC plate after penetration at 350 m/s with entry and exit magnified

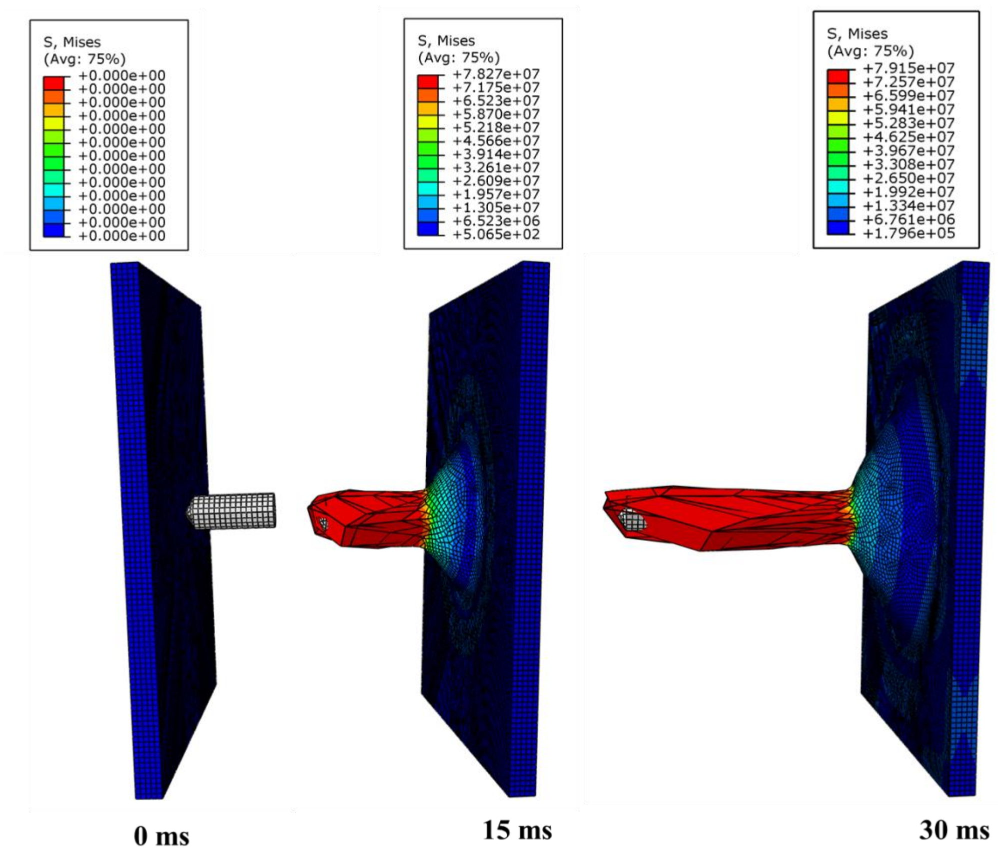


Figure 3.3 Damage behavior of rubber plate impacted with 350 m/s velocity

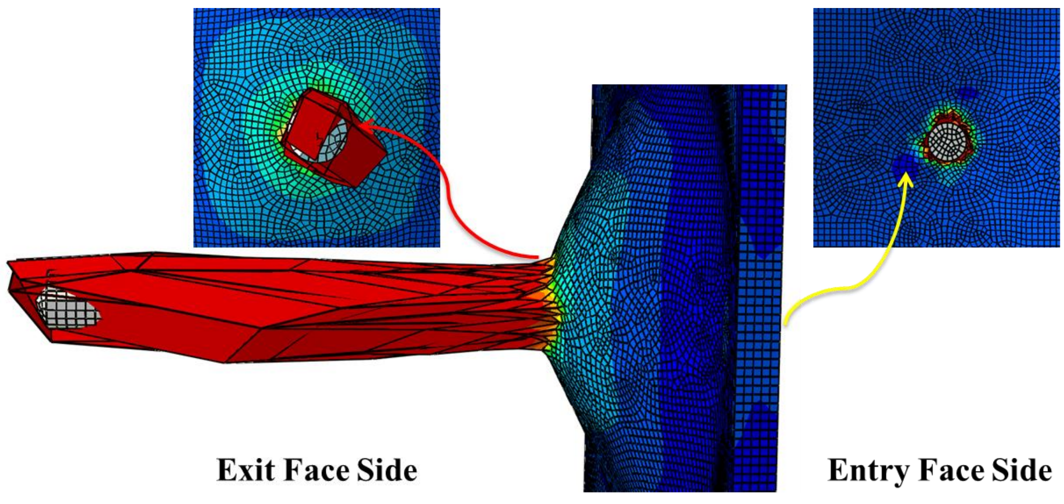


Figure 3.4 Damage in rubber plate after penetration 350 m/s with inset entry and exit damages magnified

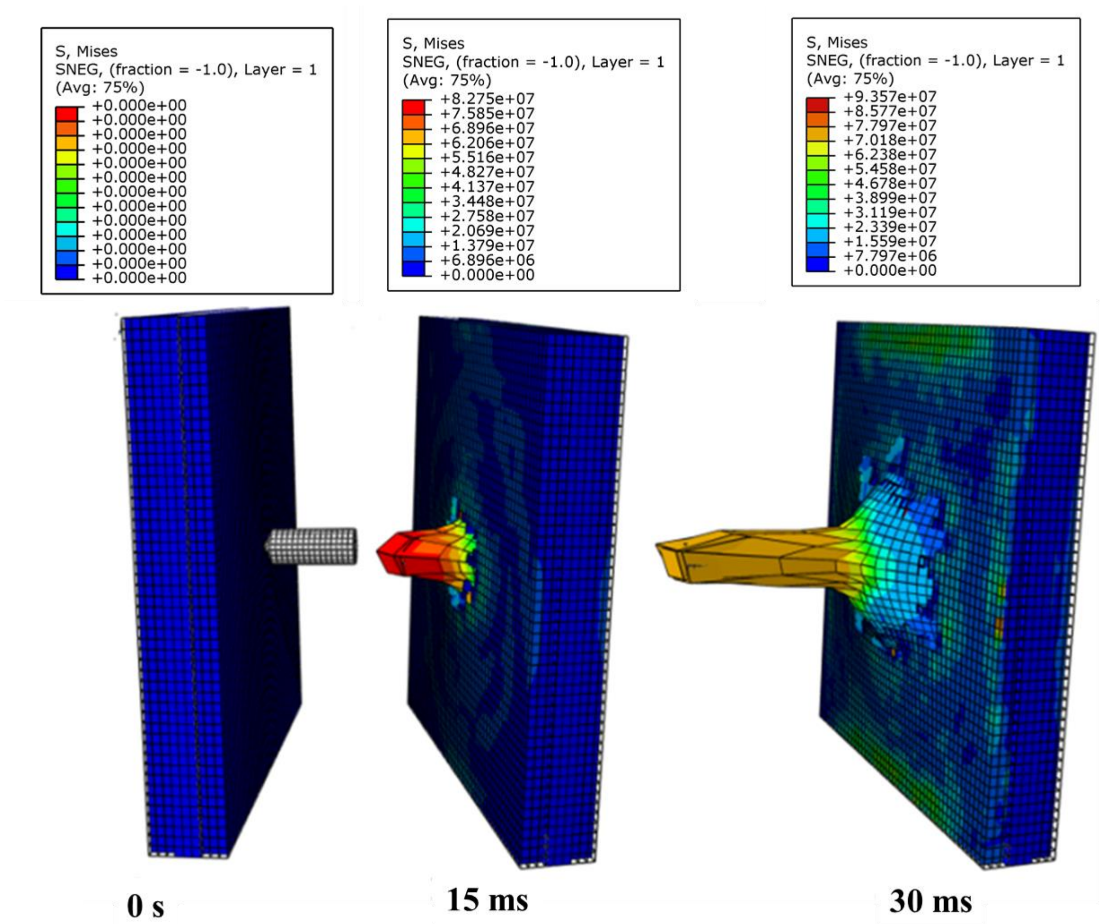


Figure 3.5 Damage behavior of JEFRC sandwich 15 mm plate impacted with 350m/s

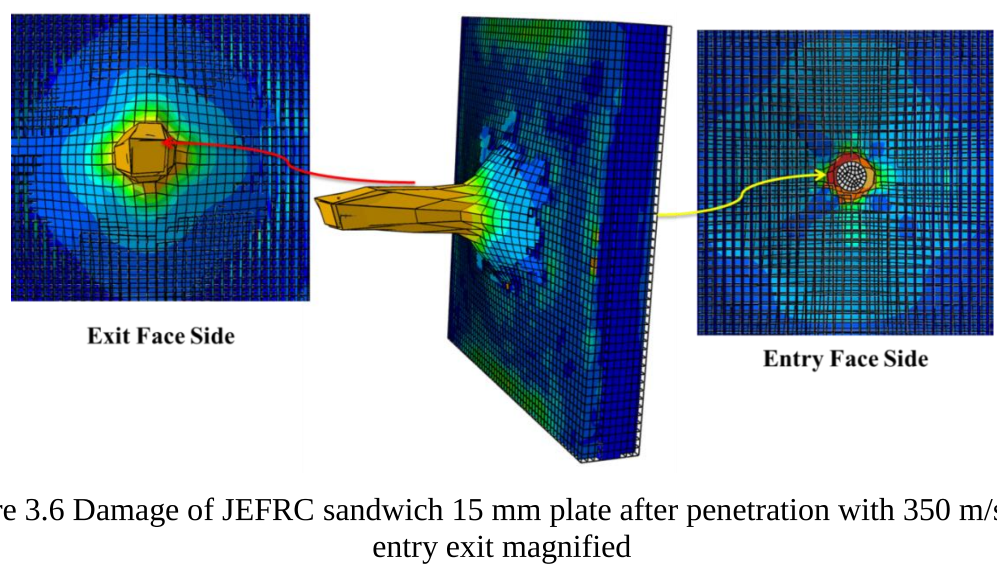


Figure 3.6 Damage of JEFRC sandwich 15 mm plate after penetration with 350 m/s with entry exit magnified

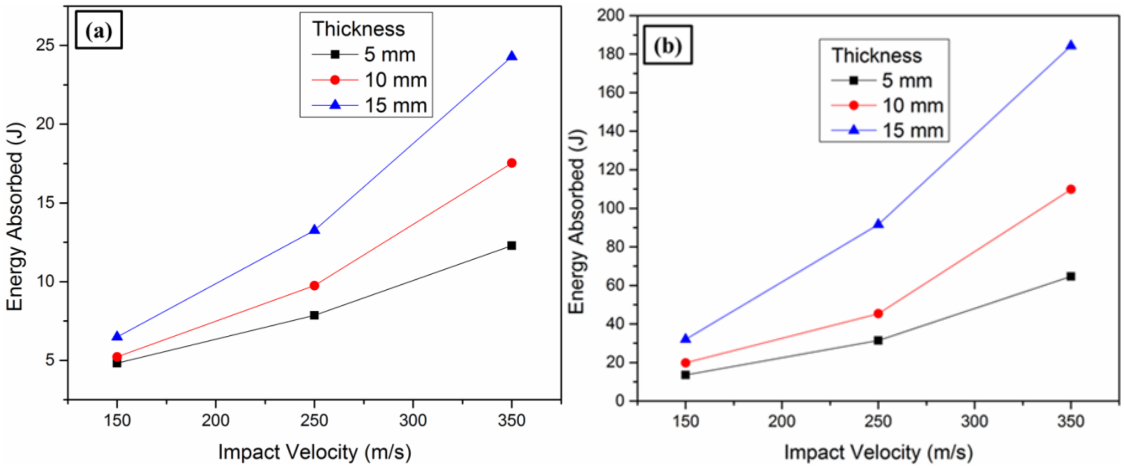


Figure 3.7 Plot of energy absorbed for different thicknesses of (a) jute epoxy fly ash composite, and (b) rubber plates

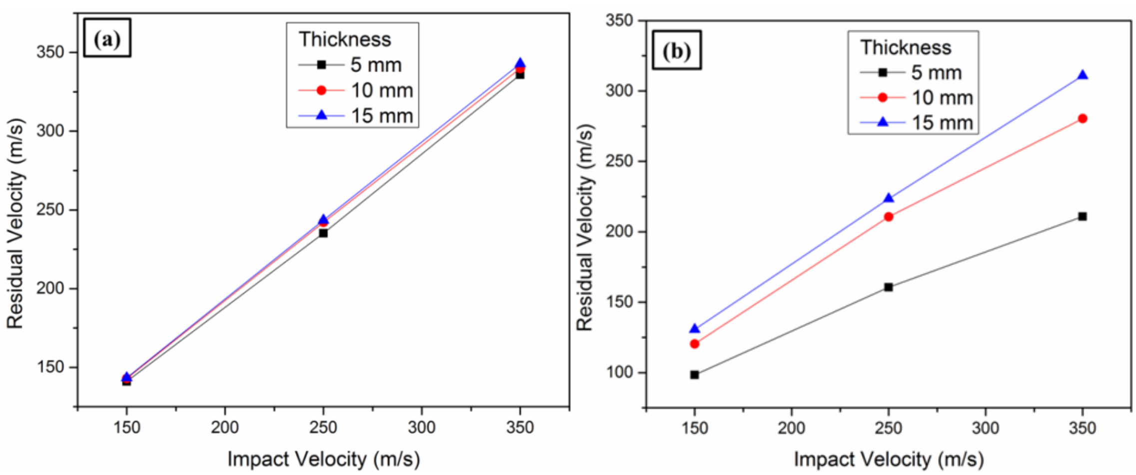


Figure 3.8 Plot of residual velocity for (a) jute epoxy fly ash composite, and (b) rubber impacted with 350m/s velocity

The aspect of higher energy absorption in rubber and lower energy absorption for JEFC was observed from plots shown in Figure 3.7 (b) and (a). Figure 3.8 (a) shows the linear relation between the impact and residual velocity for JEFC composites indicating sudden plug form of materials removal from composite, while in case of rubber as such no linear fit was observed are shown in Figure 3.8 (b) with thickness variation.

The results of JEFRC sandwich, JEFC plate and rubber plate are plotted in Figure 3.9 (a) and (b). The values of energy absorbed and the ballistic limit for the sandwich are closed to that of the rubber indicating mixed mode of damage with ductile rubber being dominant.

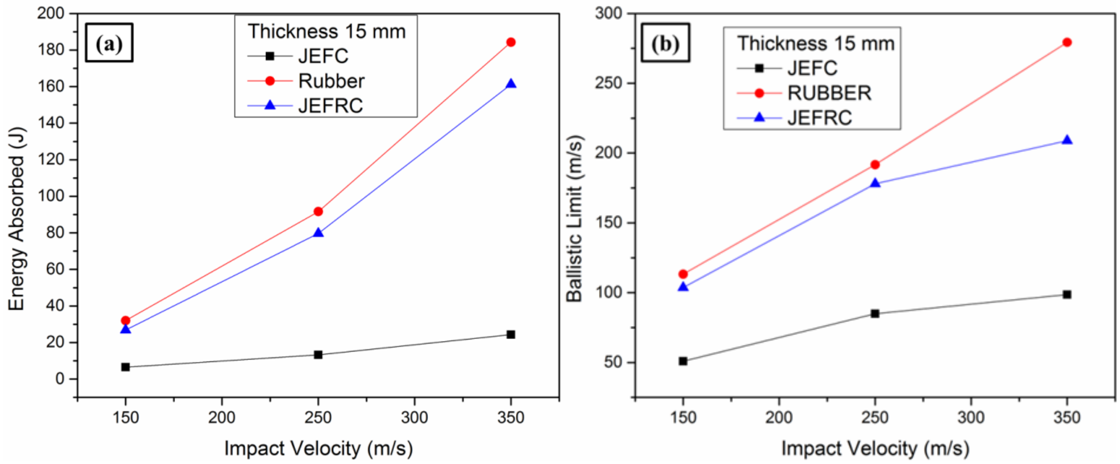


Figure 3.9 Plots of (a) energy absorbed, and (b) ballistic limit for JEFC, rubber and JEFRC sandwich

Hence proposed JEFRC sandwich is expected to provide better structural stability because of JEF and absorb large energy due to presence of rubber.

3.1.2 Modeling Results of Composite Sandwich Blocks

Table 3.2 presents a bird's eye view of the results obtained from the analysis of jute epoxy fly ash composite (JEFC) and jute rubber epoxy fly ash sandwich composites (JEFRC).

It can be noticed from the table that the ballistic limit increases with an increase in the thickness of the target. It is also evident from values that the rubber sandwich composite has a higher ballistic limit and absorbs larger energy. These could be attributed to the nature of damage sustained by JEFRC.

Table 3.2 Results of energy absorbed by JEFC and JEFRC

Material	Thickness (mm)	Input Velocity (V_i) m/s	Residual Velocity (V_r) m/s	Ballistic Limit Velocity (V_b) m/s	Energy Absorbed (E_a) J
JEFC	50	150	120	90	20
		250	190	162	66

		350	286	203	102
JEFRC	50	150	48	142	52
		250	98	230	132
		350	120	329	270
	75	150	22	148	55
		250	52	245	150
		350	78	341	291
	100	150	0	Arrested	Arrested
		250	0	Arrested	Arrested
		350	0	Arrested	Arrested
	150	150	0	Arrested	Arrested
		250	0	Arrested	Arrested
		350	0	Arrested	Arrested
	150	150	0	Arrested	Arrested
		250	0	Arrested	Arrested
		350	0	Arrested	Arrested

The residual velocity, energy absorption and ballistic limit are plotted against impact velocity in the Figure 3.10, 3.11 and 3.12 respectively. The residual velocity is highest for the case of JEFC, which in turn leads to lowest energy absorption. Residual velocity is lowest for the JEFRC sandwich, which in turn leads to higher energy absorption. The energy absorbed by JEFRC sandwich is almost 60% higher than JEFC.

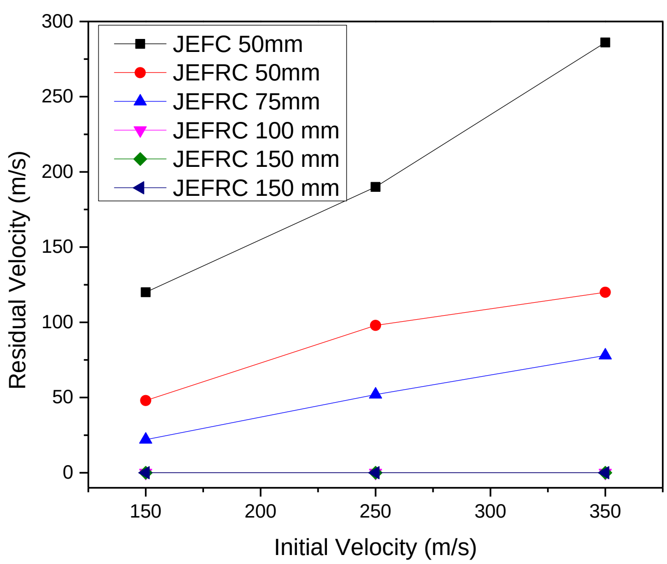


Figure 3.10 Plots of residual velocity variation with different thicknesses for JEFC and JEFRC sandwich

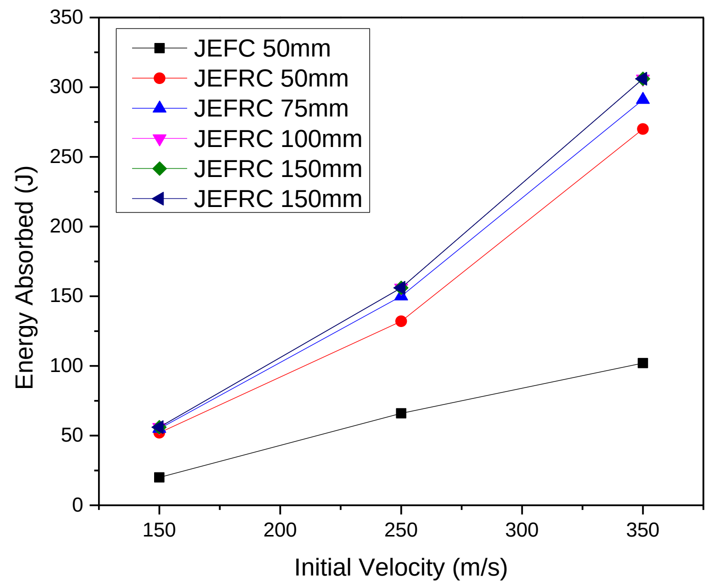


Figure 3.11 Plots of energy absorption variation with different thicknesses for JEFC and JEFRC sandwich

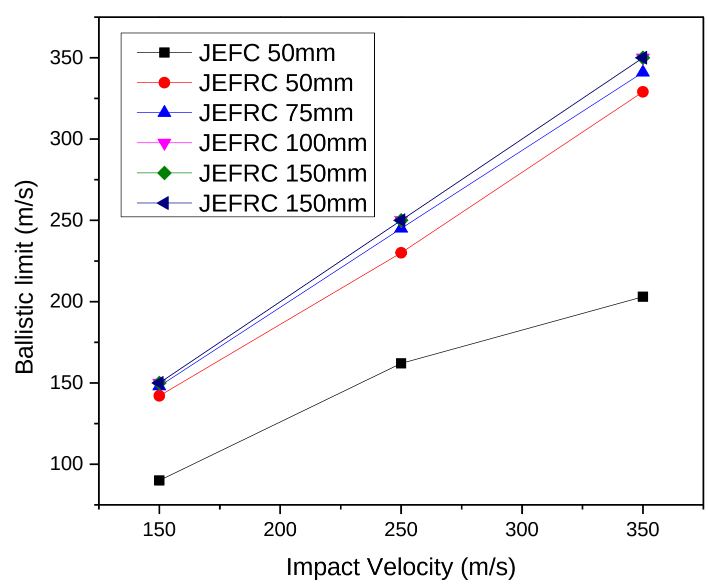


Figure 3.12 Plots of ballistic limit variation with different thicknesses for JEFC and JEFRC sandwich

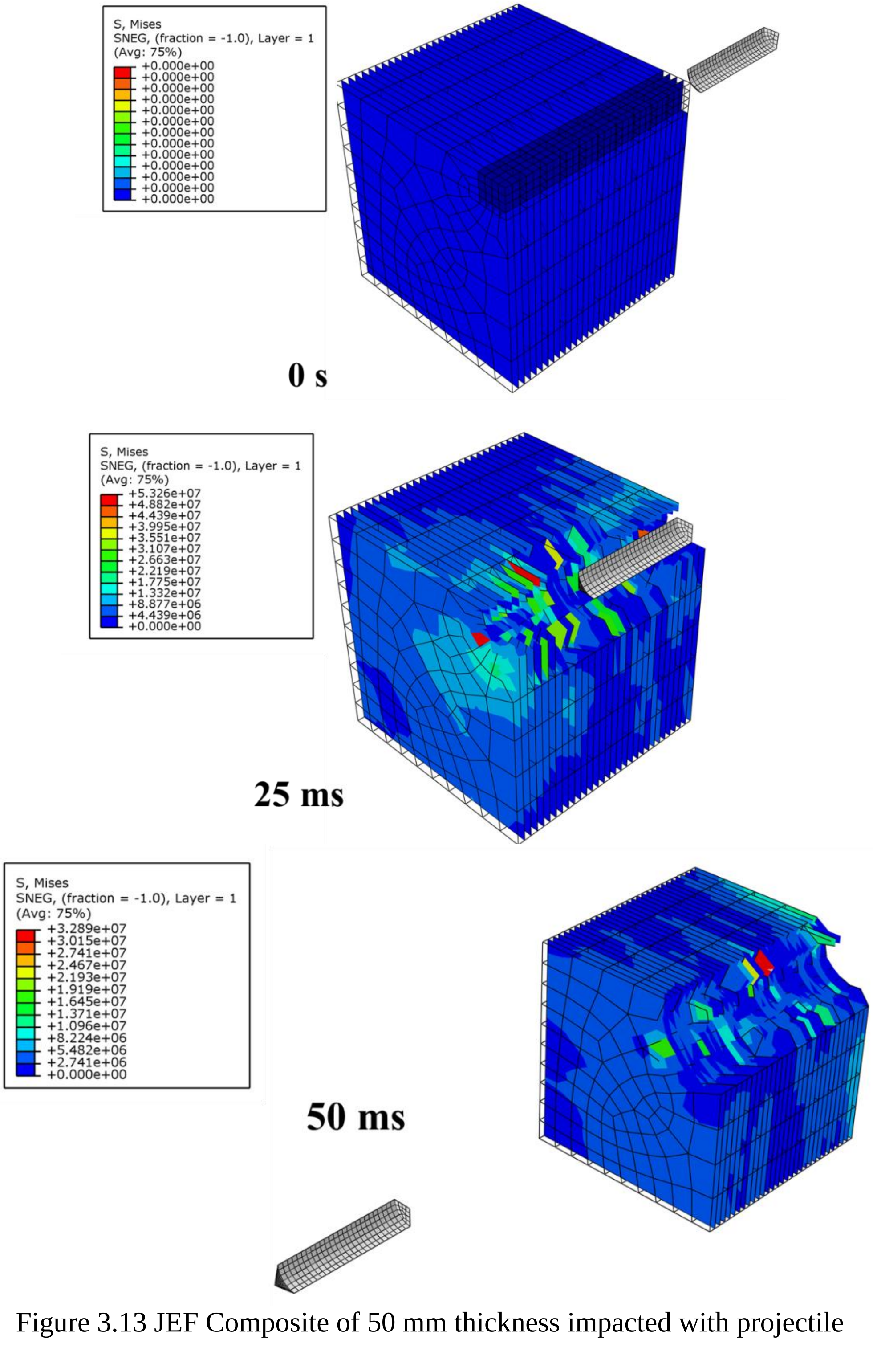


Figure 3.13 JEF Composite of 50 mm thickness impacted with projectile

(Note: s-second, ms- millisecond)

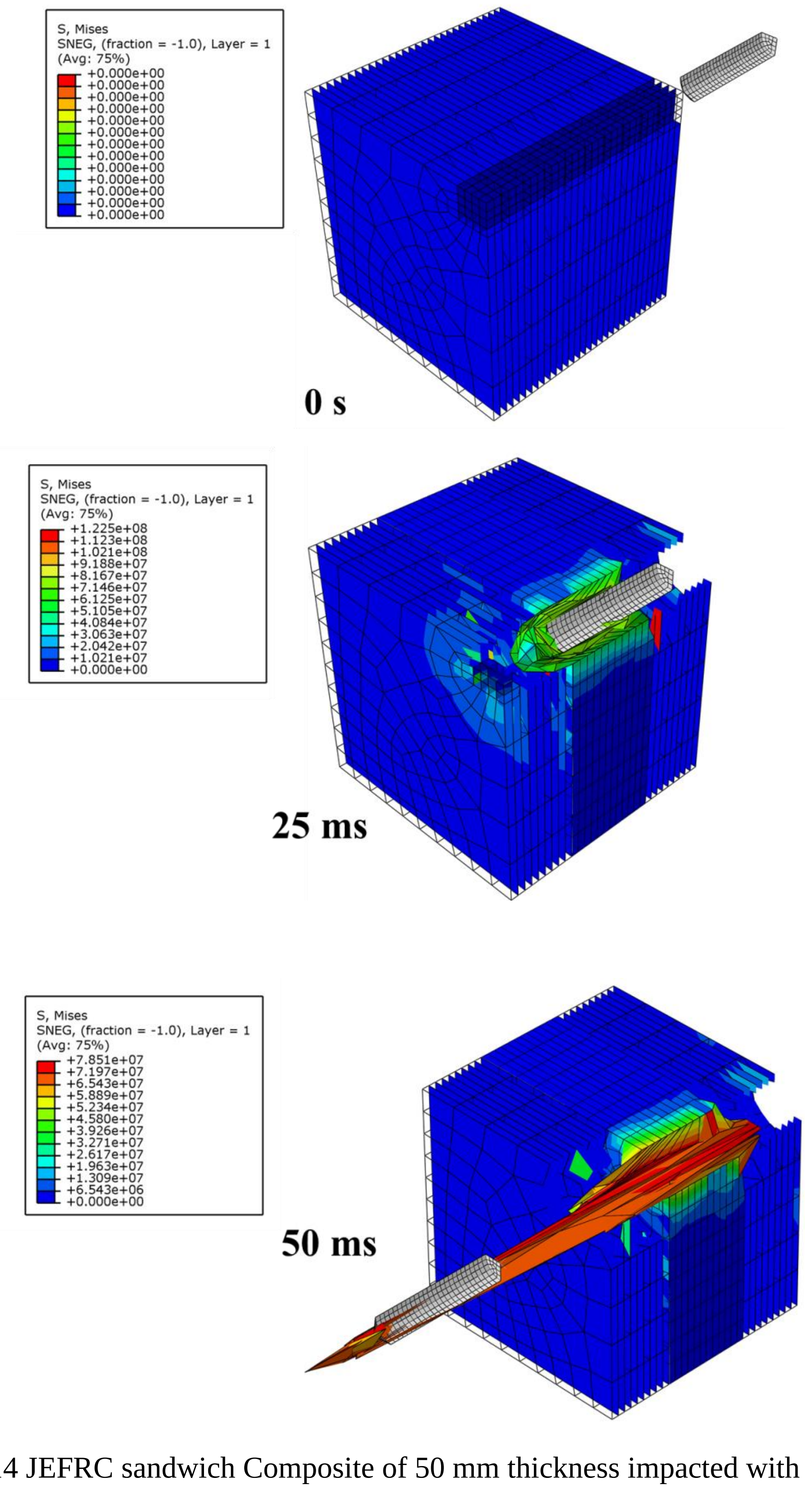


Figure 3.14 JEFRC sandwich Composite of 50 mm thickness impacted with projectile

For the JEFC configuration, the projectile advances quickly into the plate than those for the JEFRC configurations and composite fails by ejecting the material from the plate which could be seen from Figure 3.13. For JEFRC configuration, progressive-delamination is the common failure mode in high-velocity condition. Delamination between neighboring layers occurs, on the presence of shear stresses. In the delamination zone, projectile energy is absorbed which hinders the projectile movement and its propagation is prevented. Hence, the plate has still capacity to carry the further load until the fibers and rubber in the next layer fail in tension. Energy absorbed during delamination depends on the interlaminar shear fracture energy, the length of delamination and the number of delamination. Progressive delamination causes a ductile material behavior in the composite and significant amount of impact energy is absorbed. The nature of damage and delamination could be seen from Figure 3.14.

The results of the impact simulation carried out for various thicknesses (Figure 2.23) revealed that the sandwich with 100 mm thickness were able to arrest the projectile as shown in Figure 3.16. Whereas those which 50 mm and 75 mm thicknesses, were not able to arrest the projectile. Further simulation was carried out for 150 mm with two different configurations. One is sandwich block (50 mm JEF and 50 mm Rubber and 50 mm JEF) as shown in Figure 3.17 and second one is sandwich interlock block (alternate layers of JEF and Rubber) as shown in Figure 3.18. Both sandwich block and sandwich interlock block arrested the projectile. The length of penetration is less and damage obtained for the case of sandwich interlock block is small and hence sandwich interlock will be the best structure to withstand and arrest the projectile at a velocity of impact 350 m/s.

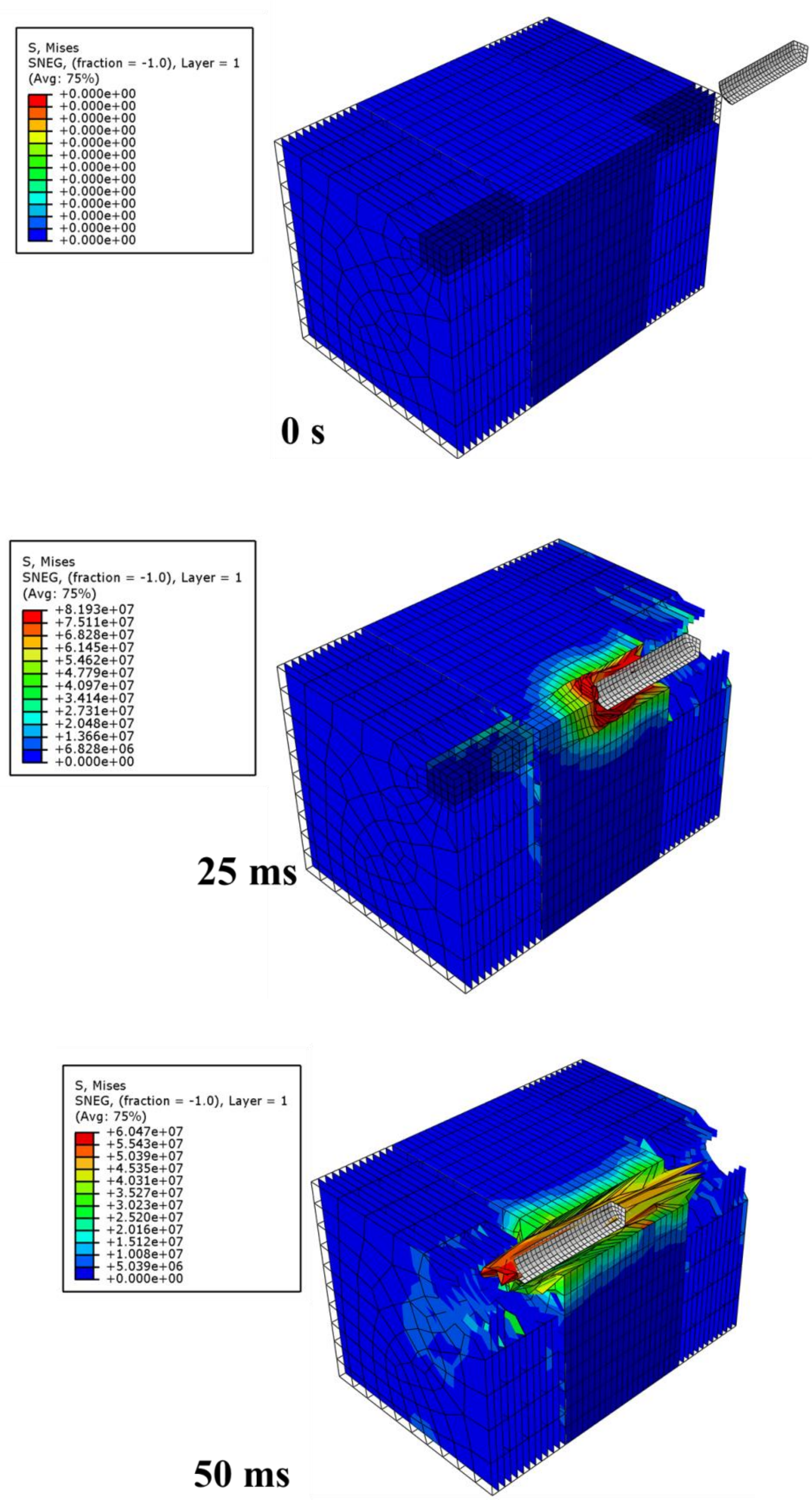


Figure 3.15 JEFRC sandwich of 75 mm thickness impacted with projectile

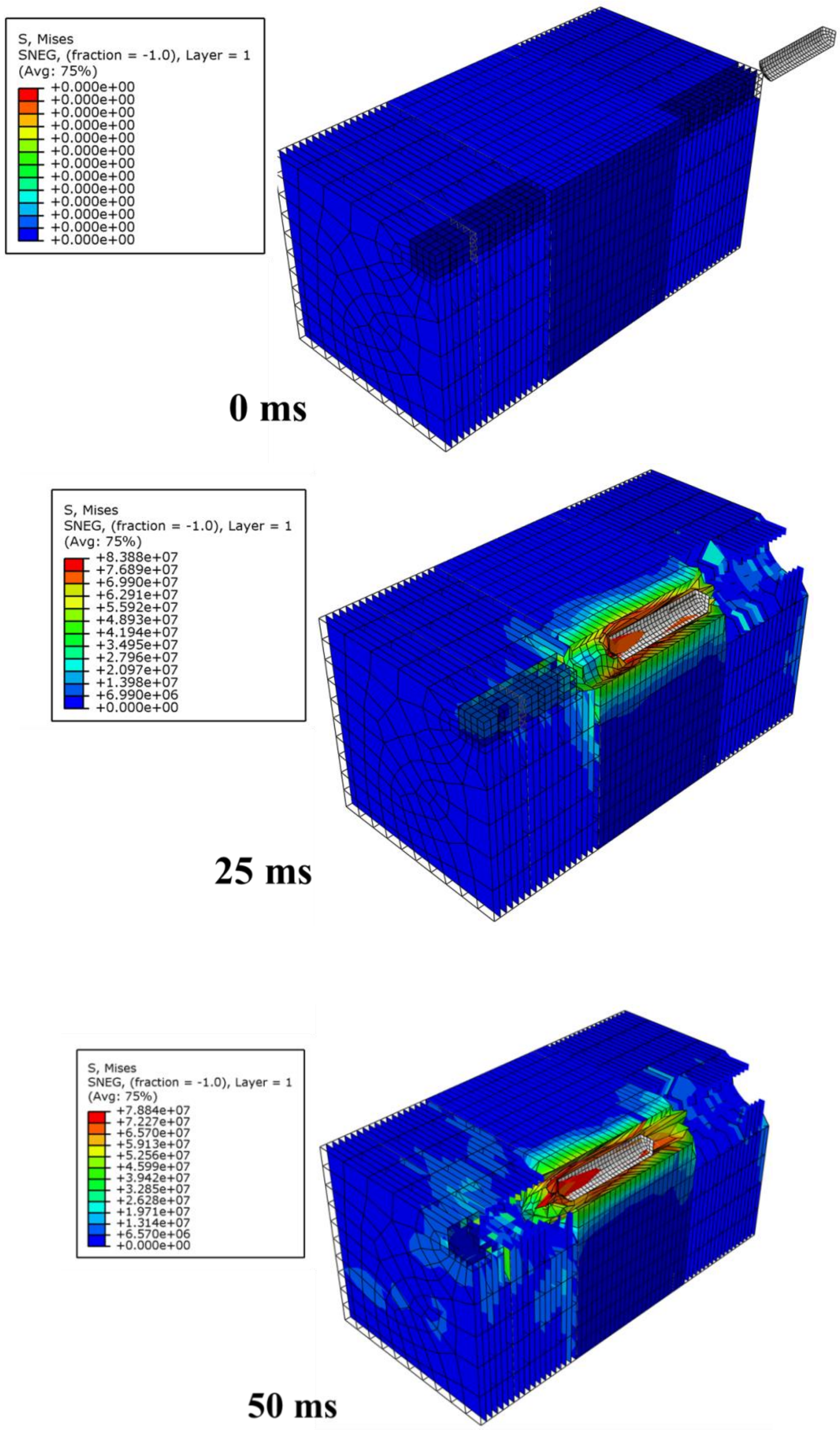


Figure 3.16 JEFRC sandwich of 100 mm thickness impacted with projectile

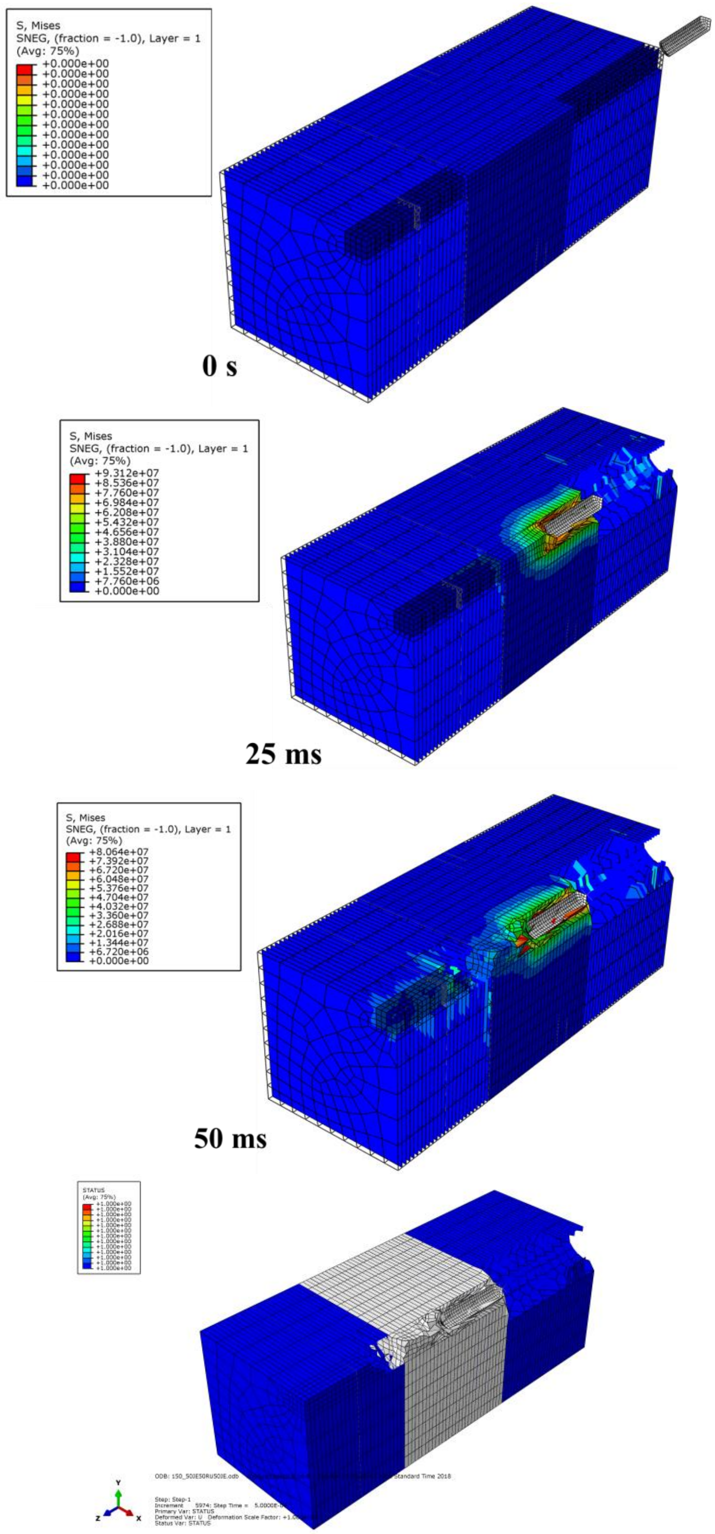
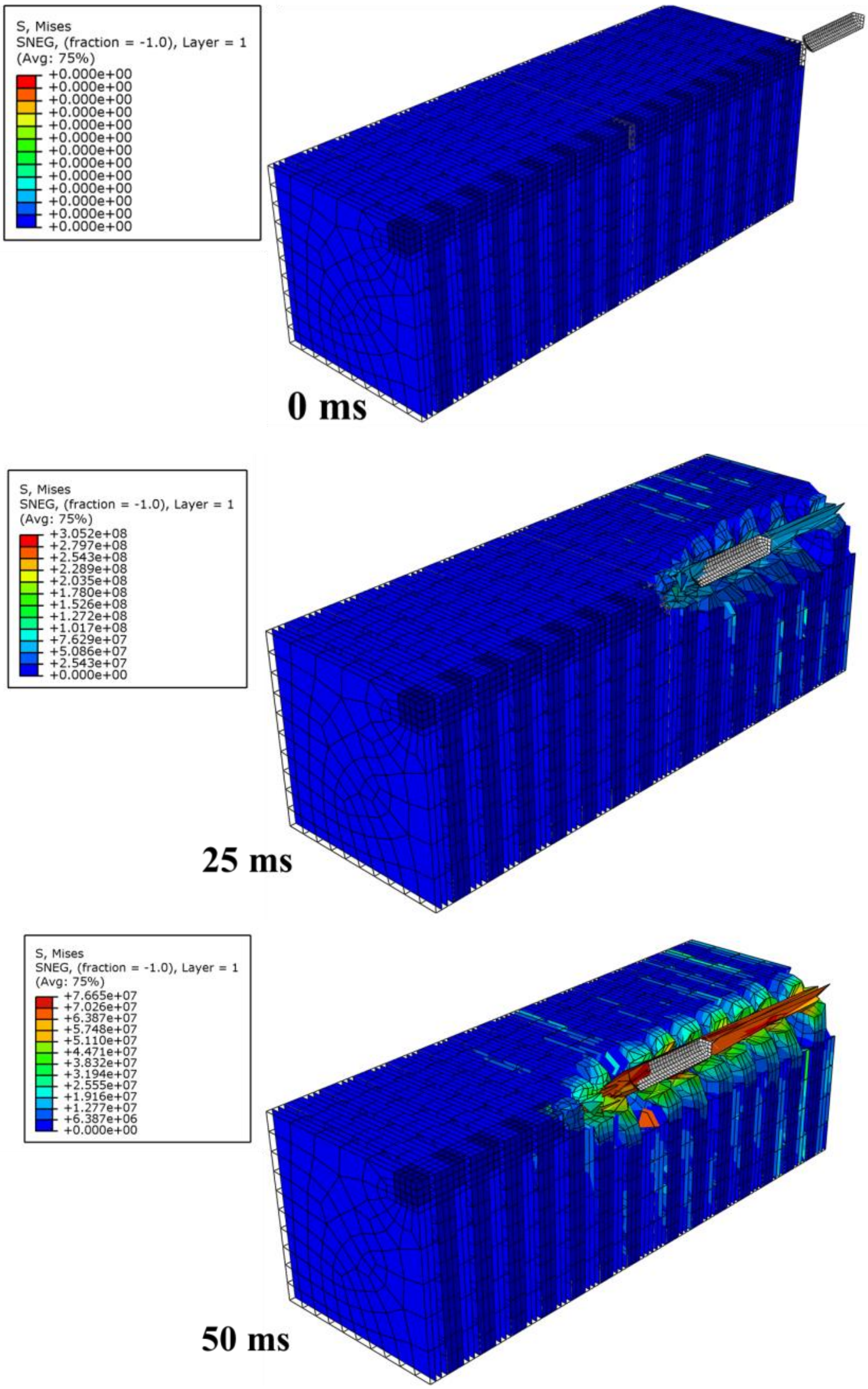


Figure 3.17 JEFRC sandwich of 150 mm thickness impacted with projectile


S, Mises
SNEG, (fraction = -1.0), Layer = 1
(Avg: 75%)
+0.000e+00
+0.000e+00
+0.000e+00
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+0.000e+00
+0.000e+00
+0.000e+00
+0.000e+00
+0.000e+00
+0.000e+00
+0.000e+00
+0.000e+00
+0.000e+00
0 ms
S, Mises
SNEG, (fraction = -1.0), Layer = 1
(Avg: 75%)
+3.052e+08
+2.797e+08
+2.543e+08
+2.289e+08
+2.035e+08
+1.780e+08
+1.526e+08
+1.272e+08
+1.017e+08
+7.629e+07
+5.086e+07
+2.543e+07
+0.000e+00
25 ms
S, Mises
SNEG, (fraction = -1.0), Layer = 1
(Avg: 75%)
+7.665e+07
+7.026e+07
+6.387e+07
+5.748e+07
+5.110e+07
+4.471e+07
+3.832e+07
+3.194e+07
+2.555e+07
+1.916e+07
+1.277e+07
+6.387e+06
+0.000e+00
50 ms

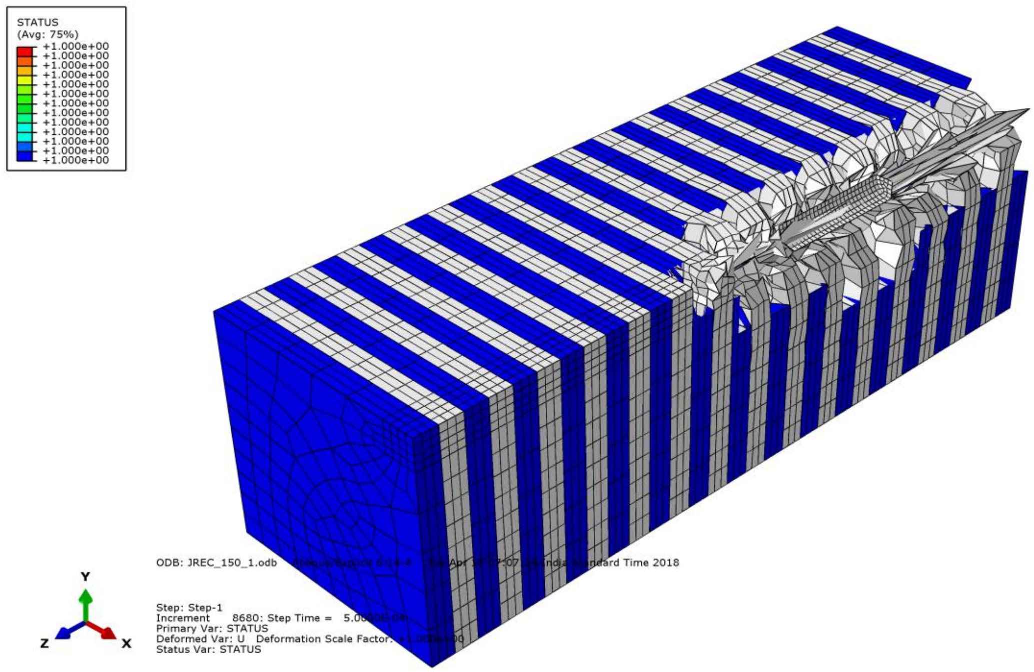


Figure 3.18 JEFRC sandwich of 150 mm thickness impacted with projectile

Throughout the analyses, various damage mechanisms were observed in the participating materials. To begin with, the JEF layer being highly brittle, JEF materials tend to shatter (or cracks) upon impact like ceramics. This tendency is mostly captured in the FE simulations. Due to the fact that ceramic materials are very weak in tension, the tensile waves that pass through the JEF layer can easily cause it to fail (like spallation) and such phenomena is also observed in the FE simulations. When the core material is rubber, it exhibits characteristic failure modes that composite materials have likely to fail by delamination and fiber breakage and these aspects are clearly observed in the FE simulations for all different configurations of the composites. The extent of delamination increases as rubber layers pushes the composite plate. When the tensile strength of the rubber is exceeded, rubber fails in tear mode (rubber breakage). Matrix cracking is another failure mode that was observed in all cases of sandwich and composites.

3.2 Mechanical and Physical Test Results of Composites

This section explains about results obtained from different mechanical and density test carried on fabricated composites.

3.2.1 Tensile Properties

The tensile test was carried out on the jute-epoxy-fly ash composite (JEFC) for which stress-strain plot is shown in Figure 3.19. The fractured composite test samples are shown in Figure 3.20.

Tensile load for a composite depends on the response of a composite to tensile loads and also on the strength properties of the reinforcement fiber since they are having high strength compared to that of the matrix system.

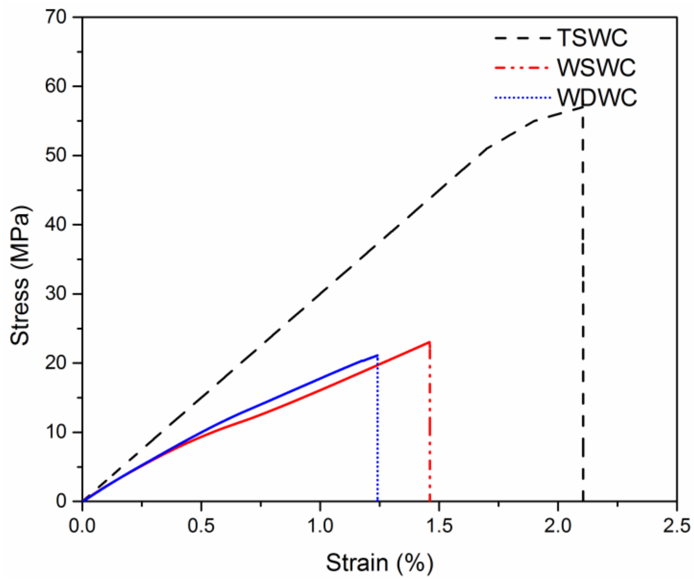


Figure 3.19 Stress-strain tensile test graphs for (a) tossa jute single woven composite (TSWC), (b) white jute single woven composite (WSWC), and (c) white jute double woven composite (WDWC)

It is also evident from Figure 3.19 that, the tensile strength of the composites is less in case of white JEF (SW-single woven /DW-double woven) composite, due to the poor adhesion between fiber and matrix. Poor adhesion is confirmed by the smooth surface observed in the SEM images as shown in Figure 3.22 (b). On the other hand, tossa jute has more surface roughness (Figure 3.22 (a)), resulting in good wettability, which in turn leads to good adhesion between fiber and matrix. Good adhesion increases the tensile strength of the tossa jute composite. The strength of tossa JEF (SW) composite was found to be 57% higher than white JEF (SW) and 60% higher than white JEF (DW) composites. The typical stress strain graph obtained for rubber material is shown in Figure 3.21 with elongation strain 200%.

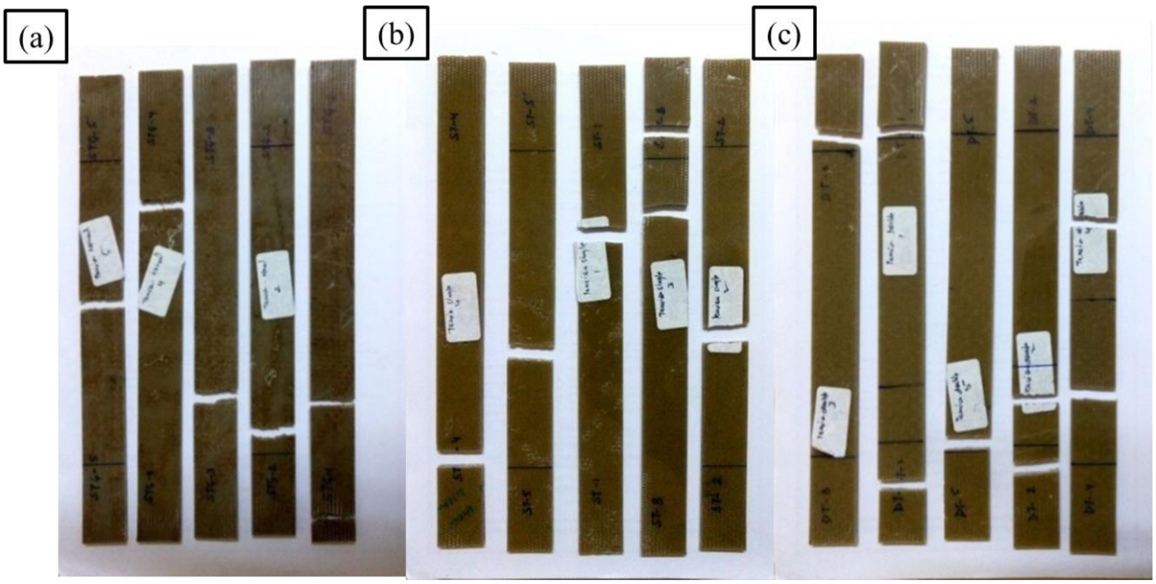


Figure 3.20 Tensile fractured samples for (a) tossa jute single woven composite (TSWC), (b) white jute single woven composite (WSWC), and (c) white jute double woven composite (WDWC)

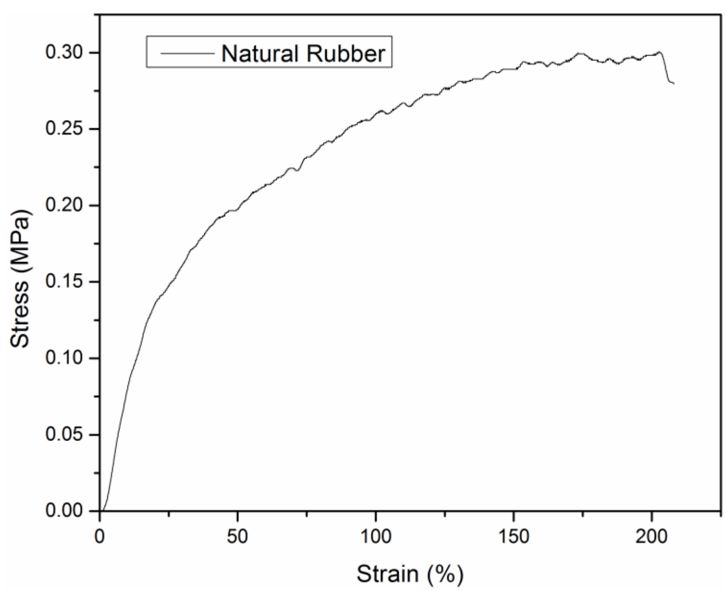


Figure 3.21 Tensile stress v/s strain graph for natural rubber material

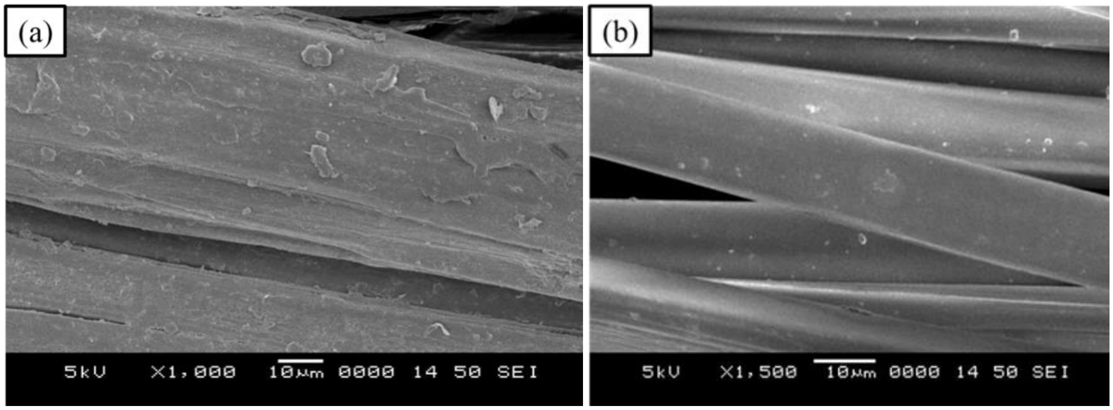
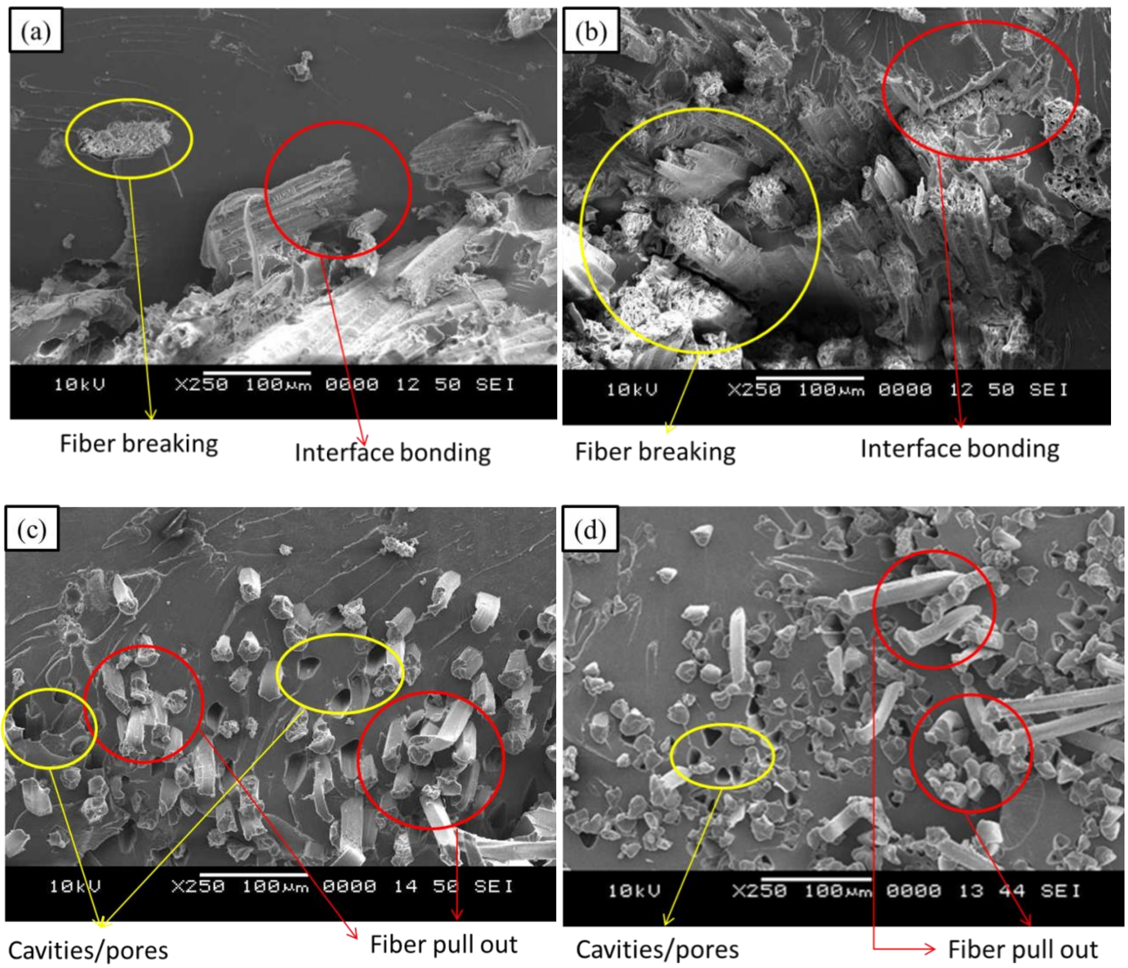


Figure 3.22 SEM images for (a) tossa jute fibre, and (b) white jute fiber



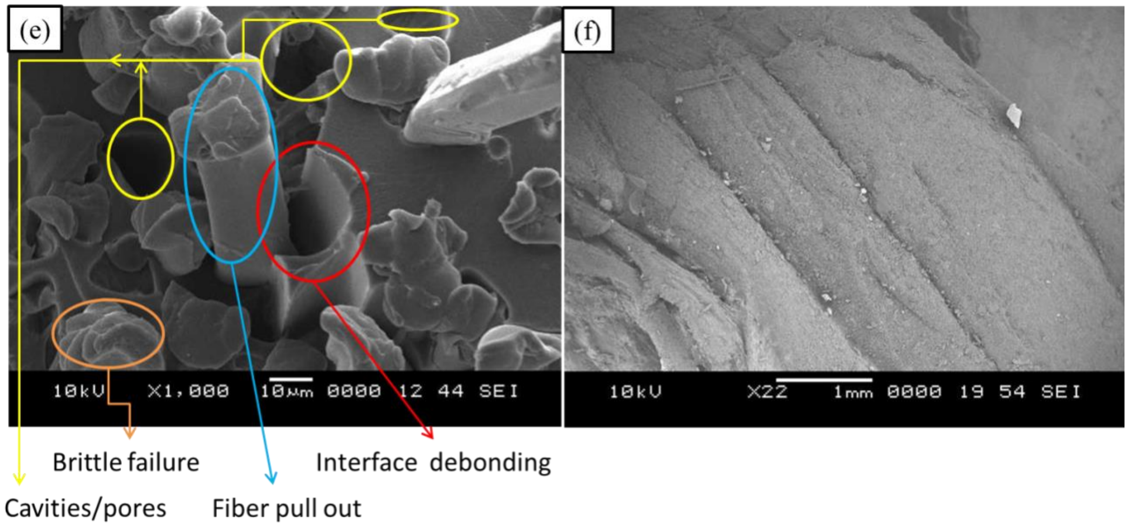


Figure 3.23 SEM images for different fiber JEF composites of (a) and (b) tossa jute fabric, (c), (d) and (e) white jute fabric, and (f) natural rubber

Figures 3.23 (a)-(e) are showing SEM images of failed JEF composite sample. In the case of tossa jute, no pull-out of fibers was observed since the complete load was taken only by the fibers which are clear from Figure 3.23 (a) and (b). Only breaking of fibers could be visualized from the above image, which implies a very good bonding exists between the fiber and matrix. This may lead to higher interfacial strength for tossa jute which could also be the reason for higher strength in tossa jute fiber composite whereas relatively large pull-out, existence of voids and weak interfacial bonding were observed for white jute composite [Figure 3.23 (c), (d) and (e)], which caused reduction in the strength of white jute fiber reinforced composite. Figure 3.23 (f) is showing the fractured surface of the rubber material.

3.2.2 Compression Properties

The composite which consists of tossa jute shows compressive strength of 75.61 MPa and composites which consist of white jute single woven gives 75.44 and 72.45 MPa for double woven jute fabric which is shown in Figure 3.24. This is due to the presence of more voids and cracks between the layers in white jute that might have resulted in failure, prior to that of tossa jute composites. As far as compression strength is concerned, there is no significant variation in strength observed for all the verities of jute fabric epoxy fly ash composites.

Initially, the compressive load applied longitudinally is taken by the matrix, which transfers load to the fibers oriented in that direction and loading continues through the defects i.e. micro-cracks and voids that gradually result in enlargement of cracks present in composite which resulted in the failure of the composite in the form of shear mode as shown in Figure 3.25.

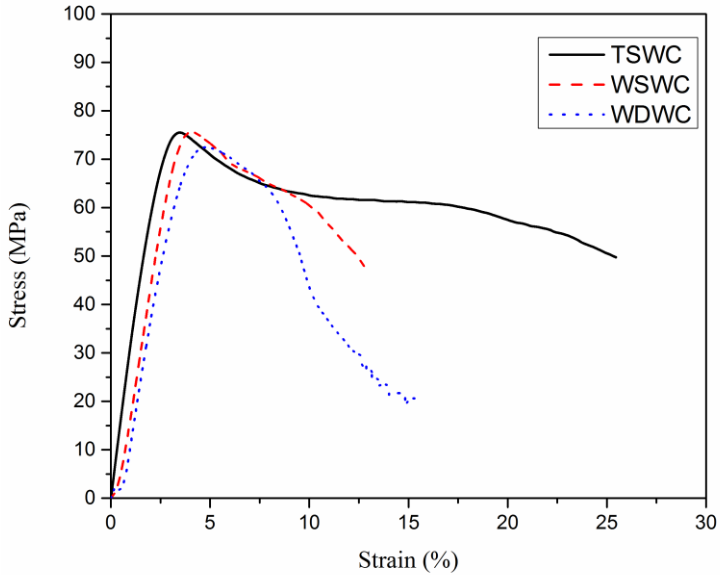


Figure 3.24 Stress-strain compressive test graphs for JEF composites: (a) tossa jute single woven composite (TSWC), (b) white jute single woven composite (WSWC), and (c) white jute double woven composite (WDWC)

Figure 3.25 JEF composites fractured failed samples by shear in compression (a) top view, and (b) side view

3.2.3 Flexural Properties

Figure 3.26 represents the stress-strain curve obtained from the flexural test. The bumps observed in all the stress-strain curves are the clear indications of the composite failing through multiple plastic phases. Composite consists of multiple layers and once the bottom layers fail to absorb the load; the load is transferred to the subsequent layers which are observed as a bump in the stress-strain curve. The stress-strain curve continues to behave in the same manner until the failure of the last layer.

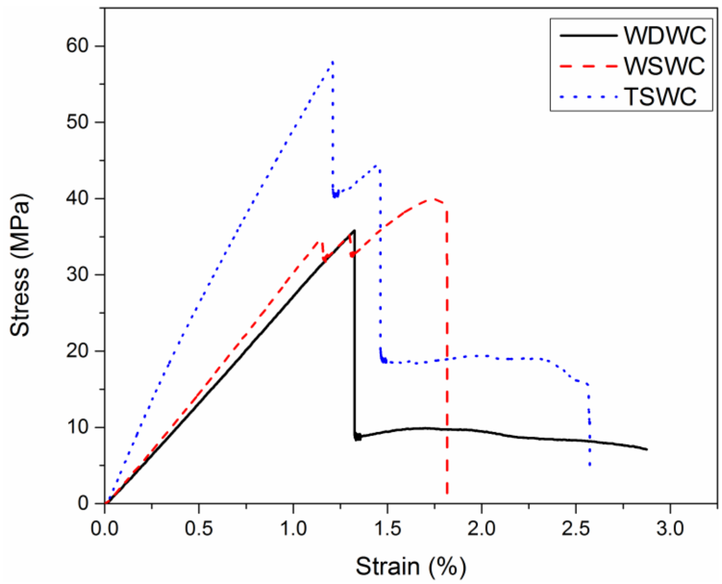


Figure 3.26 Stress-strain flexural test graphs for different fiber JEF composites: (a) tossa jute single woven composite (TSWC), (b) white jute single woven composite (WSWC), and (c) white jute double woven composite (WDWC)

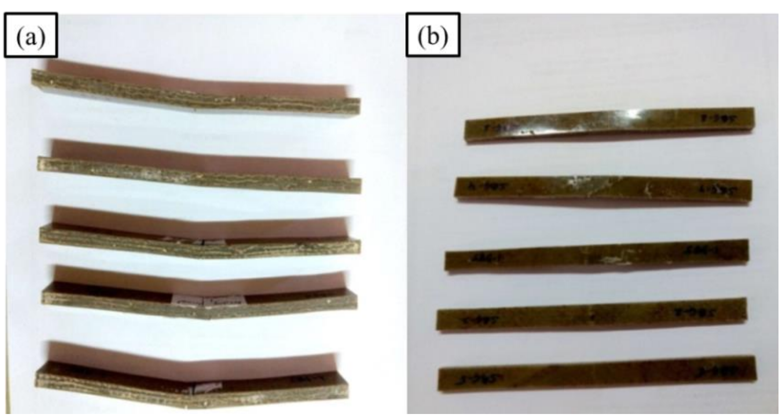


Figure 3.27 JEF composites typical flexural fractured samples for (a) front view, and (b) rear view

The maximum bending strength observed for tossa JEF composite was 57.88 MPa which is 30% higher than single woven has and 38% higher than double woven white jute composites. Tossa Jute epoxy has higher ultimate strength and strain to failure compared to the other two types of fiber reinforced composites as shown in Figure 3.26. This is attributed to better wettability of fiber and good adhesion between matrix and fiber. Failed samples during flexural tests are shown in Figure 3.27.

3.2.4 Hardness

Hardness test was carried out for all three varieties of composite samples using Shore D instrument. The variation in the hardness value was lying in the range of 88 to 90 durometer are given in Table 3.3, the possible reason for this consistency is that, during the processing stage, all composite samples were subjected to uniform constant pressure of 25 kg/cm^2 during compression molding, which resulted in even distribution of epoxy on the top surface which in turn resulted in the uniform epoxy layer thickness of the final composite.

Table 3.3 Hardness (SHORE D) for JEF composite

JEF Composite	Average
Tossa jute single woven fabric	89
White jute single woven fabric	88
White jute double woven fabric	89

3.2.5 Density

The tossa JEF composite shows lesser density than those of white JEF of both single woven (SW) and double woven (DW) composites. This could be due to the porous structure of tossa jute fiber which can be seen from cross-sectional SEM image [Figure 3.22 (a)]. Hence tossa JEF composite was found to be the better when compared to white JEF composite of SW and DW type. Table 3.4 indicates the density for JEF composites measured through density kit.

Table 3.4 Density for JEF composite

JEF Composite	Density(kg/m^3)
Tossa jute single woven fabric	1170
White jute single woven fabric	1210
White jute double woven fabric	1220

3.3 Results of Composite Plate for Ballistic Impact Test

The material used for producing composite plates for ballistic testing is tossa jute single woven fabric. The composite containing jute epoxy fly ash failed due to the penetration of the bullet through the laminate leaving behind a hole, indicating a small area of damage in the entry and large area at the exit which can be seen from Figure 3.28. This happens due to the compressive stresses in front face side and tensile stress waves at the rear side which leads to the removal of large material from the rear side. In Figure 3.28 - (1, 2, and 3 indicating the first, second and third hits on the composite plate)

This happens due to the compressive stresses in front face side and tensile stress waves at the back side which leads to the removal of large material from the back side. As in the material fly ash epoxy layer cracks which reach to the fiber, the fiber beaking takes place and finally reaches this action from the front portion to back portion and produces a hole on the specimen as shown in the Figures 3.28, 3.29, and 3.30.

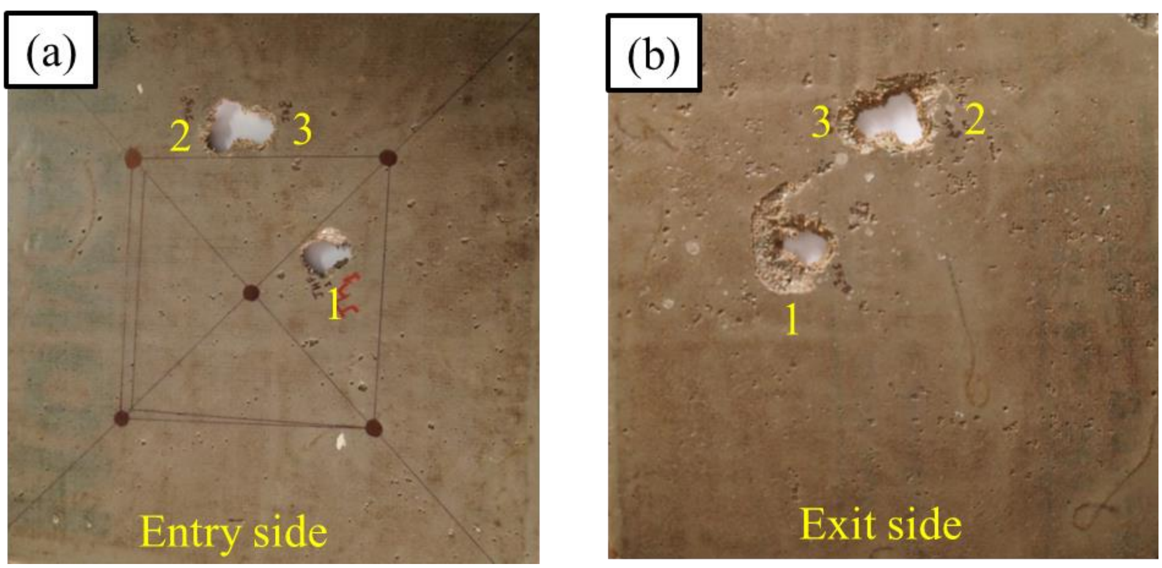


Figure 3.28 JEF composite after firing (a) front face, and (b) back face

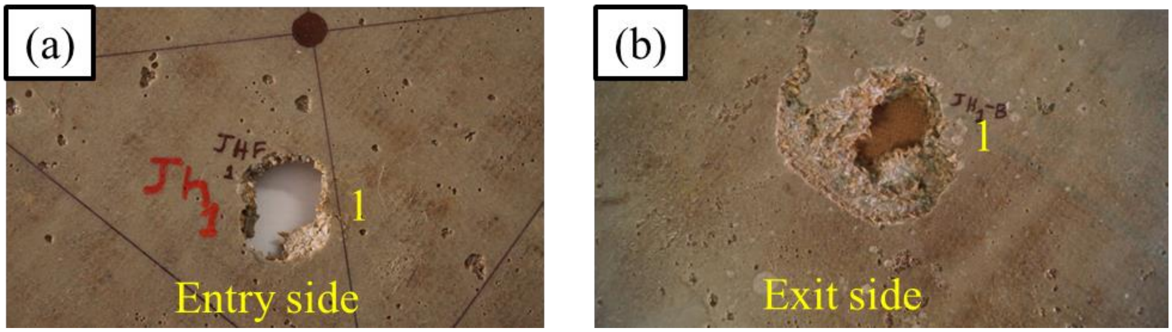


Figure 3.29 JEF composite after firing (a) front face, and (b) back face damage for first hit

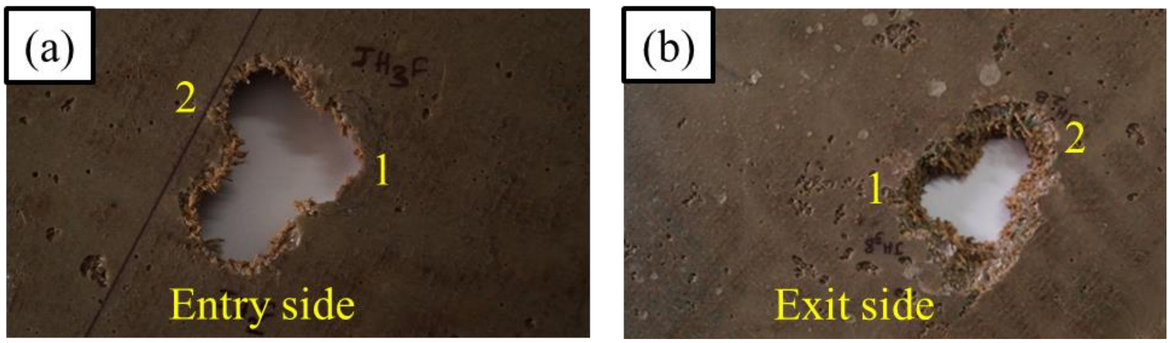


Figure 3.30 JEF composite after firing (a) front face, and (b) back face damage for second and third hit

In case of jute reinforced fly ash filled rubber interleaved epoxy composite, jute epoxy fly ash skin delaminates first and reaches to rubber core, rubber deforms by elongation and produces a small hole on rubber sheet and generates delamination at the rear portion of the JEFRC sandwich specimen which is shown in Figures 3.31, 3.32, and 3.33.

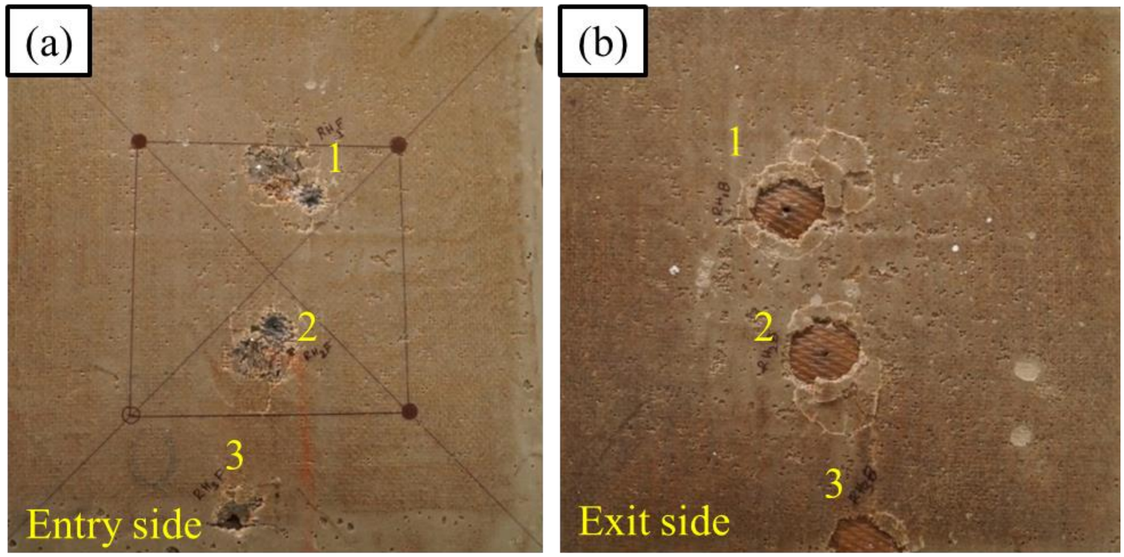


Figure 3.31 JEFR composite after firing (a) front face, and (b) back face damage

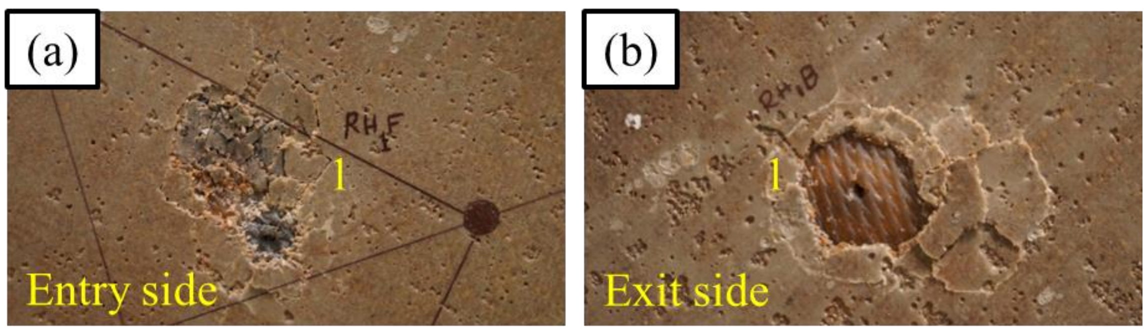


Figure 3.32 JEFR composite after firing (a) front face, and (b) back face damage for first hit

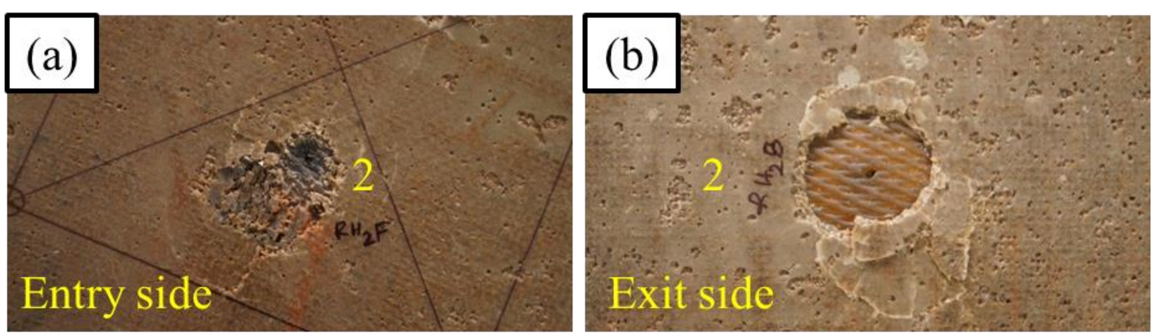


Figure 3.33 JEFR composite after firing (a) front face, and (b) back face damage to second hit

3.4 Results of Composite Sandwich Block and Interlock Block for Ballistic Impact Test

The composite containing jute epoxy fly ash fails as the bullet hits the specimen and makes a hole by producing a small area of damage in the front face side and a large area at the back side. This happens due to the compressive stresses in front face side and tensile stress waves at the back side which leads to the removal of large material from the back side. As in the material, fly ash epoxy layer cracks which reaches to the fiber. The fiber breaking takes place and finally reaches this action from the front portion to the back portion and produces a hole on the specimen. In case of jute reinforced fly ash filled rubber interleaved epoxy composite, jute epoxy fly ash skin delaminates first and reaches to rubber. Rubber deforms by elongation and produces a small hole on a rubber sheet and poduces delamination at the back portion of the JEFRC specimen which are shown in the Figures 3.34 to 3.37. Results of both FE simulated and field tested samples are given in the Table 3.6 which are in good agreement.

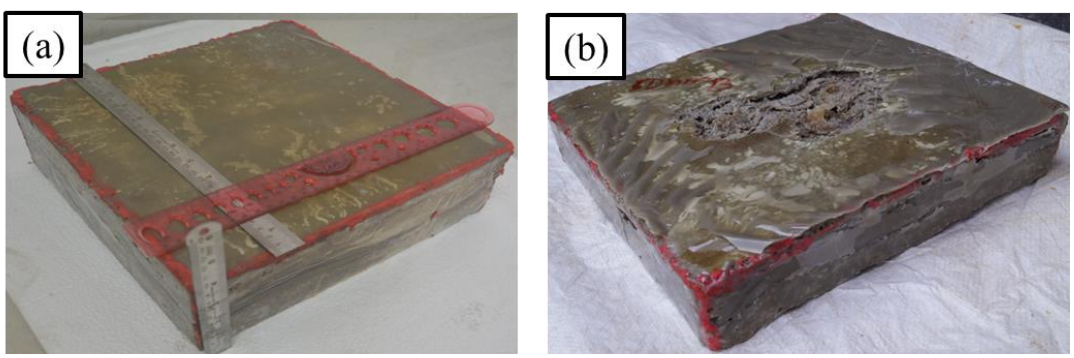


Figure 3.34 JEFRC sandwich of 50 mm (a) before, and (b) after impact

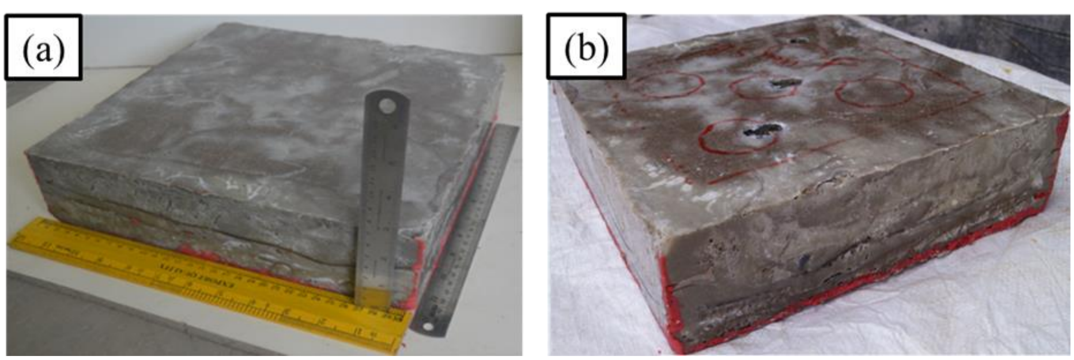


Figure 3.35 JEFRC sandwich of 75 mm (a) before, and (b) after impact

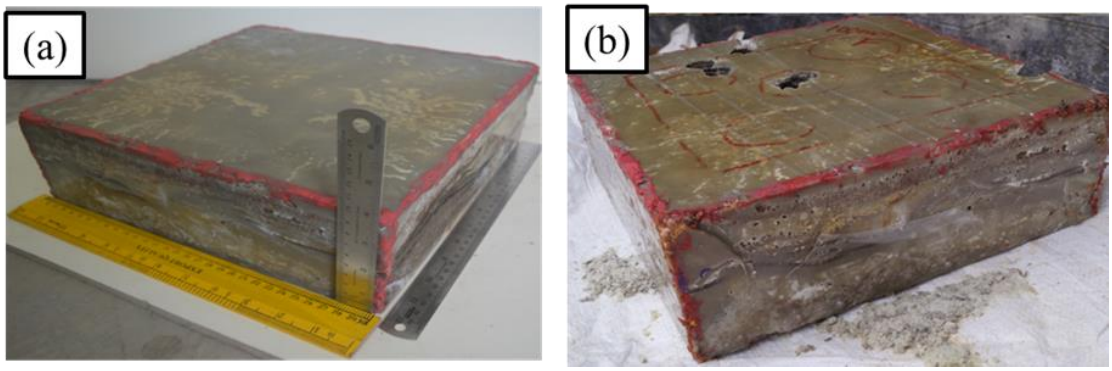


Figure 3.36 JEFRC sandwich of 100 mm (a) before, and (b) after impact

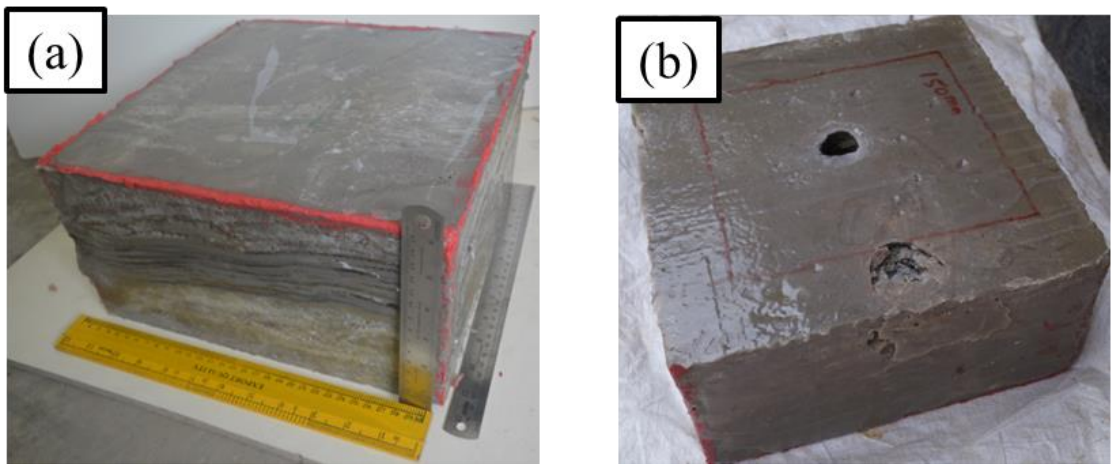


Figure 3.37 JEFR sandwich of 150 mm (a) before, and (b) after impact

Table 3.5 Comparative analysis of sandwich composite, FEA and ballistic impact field tests

Composite sandwich block (JEFRC) (Thickness in mm)			Total Thickness (mm)	Remarks (FEA)	Remarks (Ballistic impact Testing)
JEF	Ru	JEF			
15	20	15	50	Penetrated	Penetrated
20	35	20	75	Penetrated	Penetrated
30	40	30	100	Arrested	Arrested
50	50	50	150	Arrested	Arrested
Alternate JEF and Rubber (Interlock block)			150	Arrested	Arrested

Damage occurred on the sandwiches (JEFRC) are shown in the Figure 3.38 to 3.41 in the increasing order of their thickness [In images 1, 2, and 3 indicating the first, second and third bullet hits on the composite sandwich block]. From the damage analysis, it is clear that damage occurring on the entry side is small while the damage on the exit side is larger. Projectile before impact will be having very high kinetic energy (KE). After the impact KE transforms into heat and sound energy which in turn produces compressive deformation and vibrations in the target which leads to plug formation of the JEF front layers. This phenomenon will take place in a fraction of second, hence target will not be having time to react. The material behaves in a brittle manner on short scale time. JEF is stiffer than natural rubber and hence entry layers fail by making a small hole at the entry side. Once projectile reaches to rubber layers, debonding between rubber and JEF occur. Layers of rubber material undergo both compressive forces along direction of impact and tensile forces in the direction normal to impact which leads to large deformation of rubber materials and hence absorbs the greater energy from the projectile. This deformation of rubber leads to debonding of the JEF layer towards the exit side which in turn leads to spalling of JEF by creating a large area of damage at the exit side. From the Figure 3.41 it is clear that projectile has arrested within the JEFRC sandwich. Hence, damage existed at the entry side and there is no damage at the exit side.

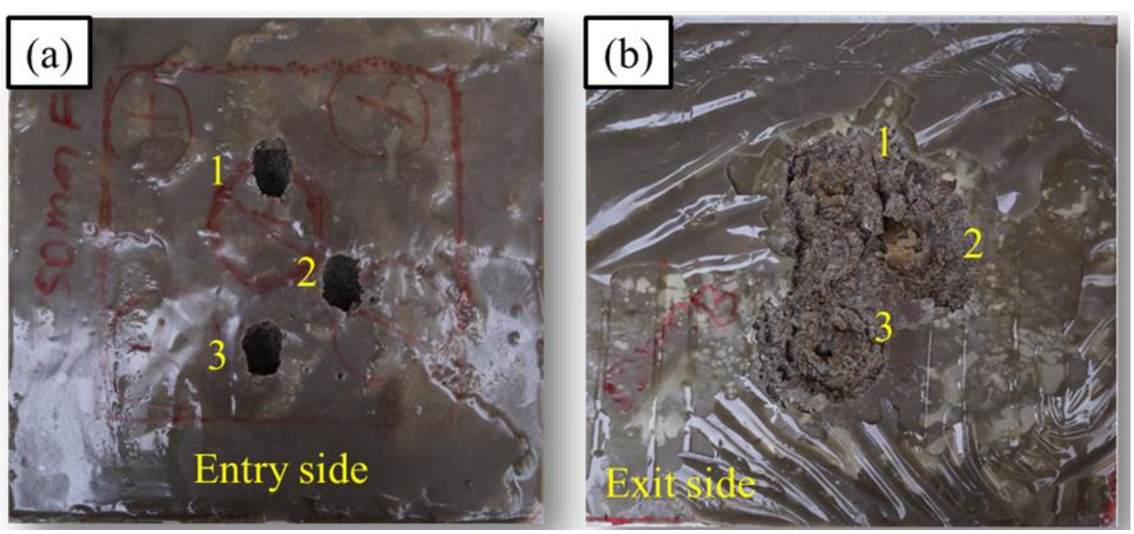


Figure 3.38 JEFRC sandwich 50 mm thick after firing (a) entry side, and (b) exit side damage

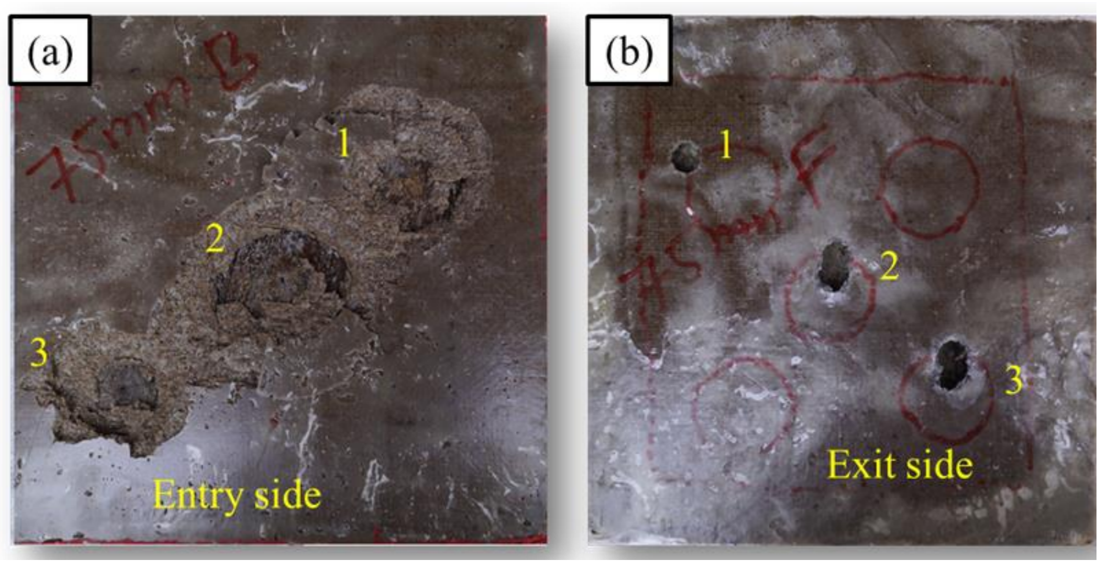


Figure 3.39 JEFRC sandwich 75mm thick impacted with projectile (a) entry side, and (b) exit side damage

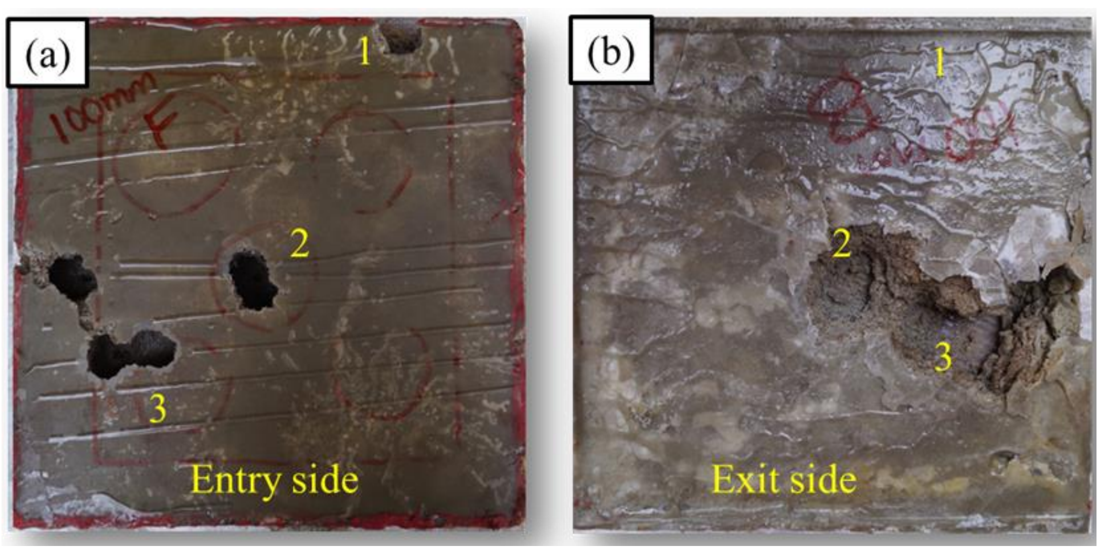


Figure 3.40 JEFRC sandwich 100 mm thick impacted with projectile (a) entry side, and (b) exit side damage

Ballistic tests were conducted in the sandwich block and sandwich interlock block of 150 mm thickness. Projectile failed to perforate the materials and the impact energy was dissipated inside the composite in association with a penetration depth in the sandwich, as shown in Figure 3.41.

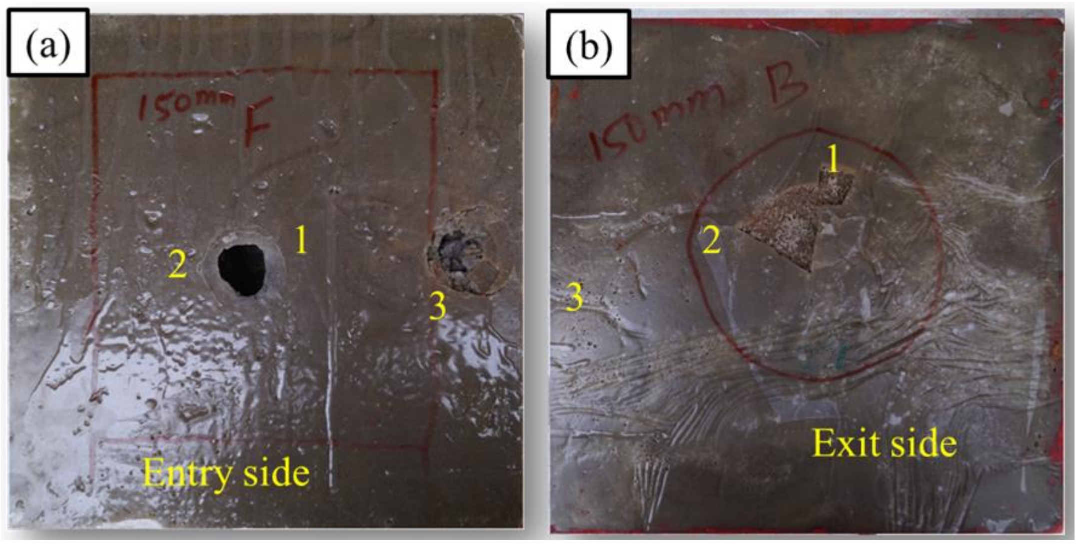


Figure 3.41 JEFRC sandwich 150 mm thick impacted with projectile (a) entry side, and (b) exit side damage

The average depth measured in the sandwich for the targets was investigated. Some points are worth discussing. The sandwich block composite showed a corresponding penetration depth below the 75±5 mm is shown in Figure 3.42 (a). For sandwich interlock block composite also arrested the projectile physical observation seems like a penetrated half way of its thickness (150 mm) is shown in Figure 3.42 (b). From both simulation and experiments, it revealed that projectile was arrested by sandwich composite.

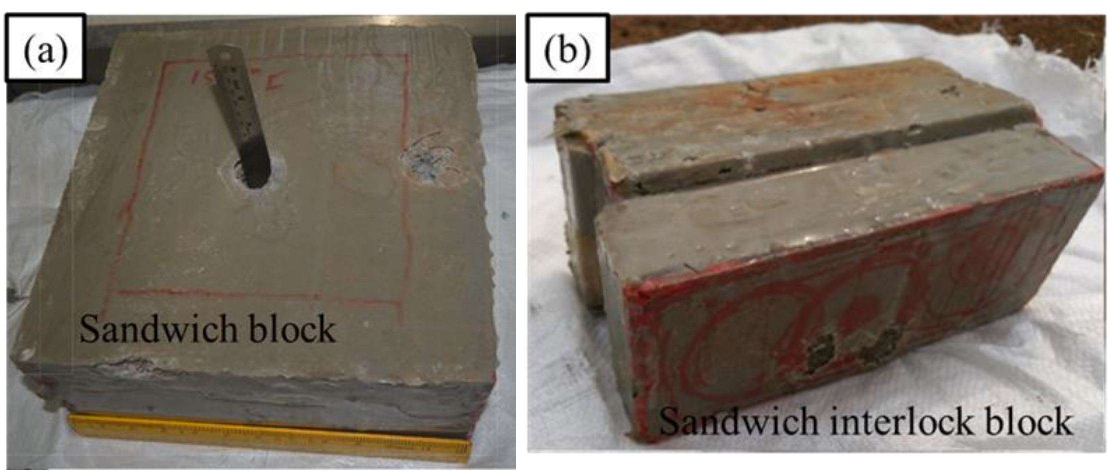


Figure 3. 42 JEFRC 150 mm thick impacted with projectile (a) sandwich block and (b) sandwich interlock block

3.5 SEM Analysis of Ballistic Impact Tested Composites

The morphology of the JEFRC composite due to ballistic impact is presented in Figures 3.43 to 3.45. After the impact spalling of composite occurs. From this spalled region, some small parts are taken for morphology study in which Figure 3.43 representing the failure of fly ash epoxy from the JEFRC composite. River band patterns, sudden cracks, failures could be observed.

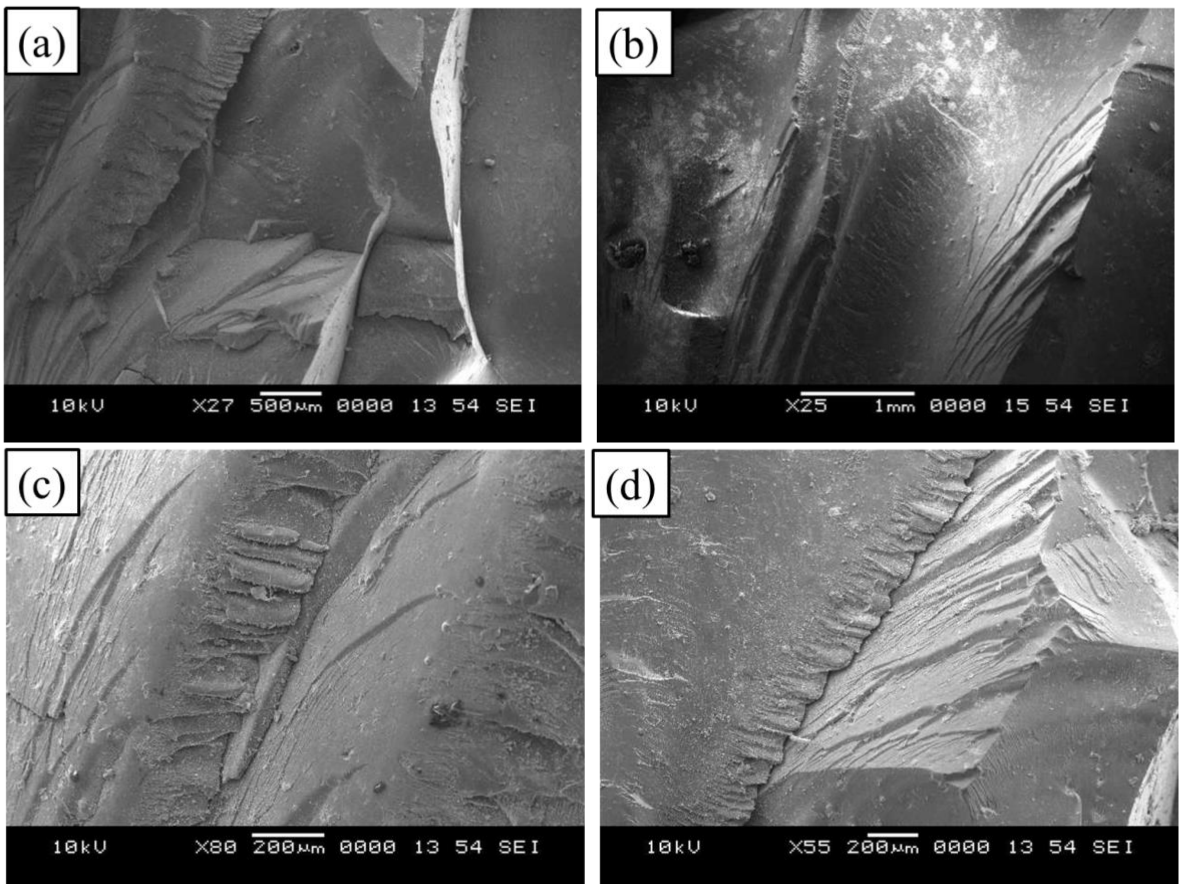


Figure 3.43 Fracture region of a JEF composite caused by fragments after the ballistic impact highlighting only fly ash epoxy composite

Figure 3.44 representing failure of JEF from the JEFRC, where jute fiber failed completely by fiber rupture and fiber breaking due to large tensile and compressive forces of the bullet impact. Fiber stretching also could be seen in some of the places. Fragmentation of JEF composite happens due to large forces applied during bullet impact which can be clearly seen from the 3.44 (b), (c), and (d).

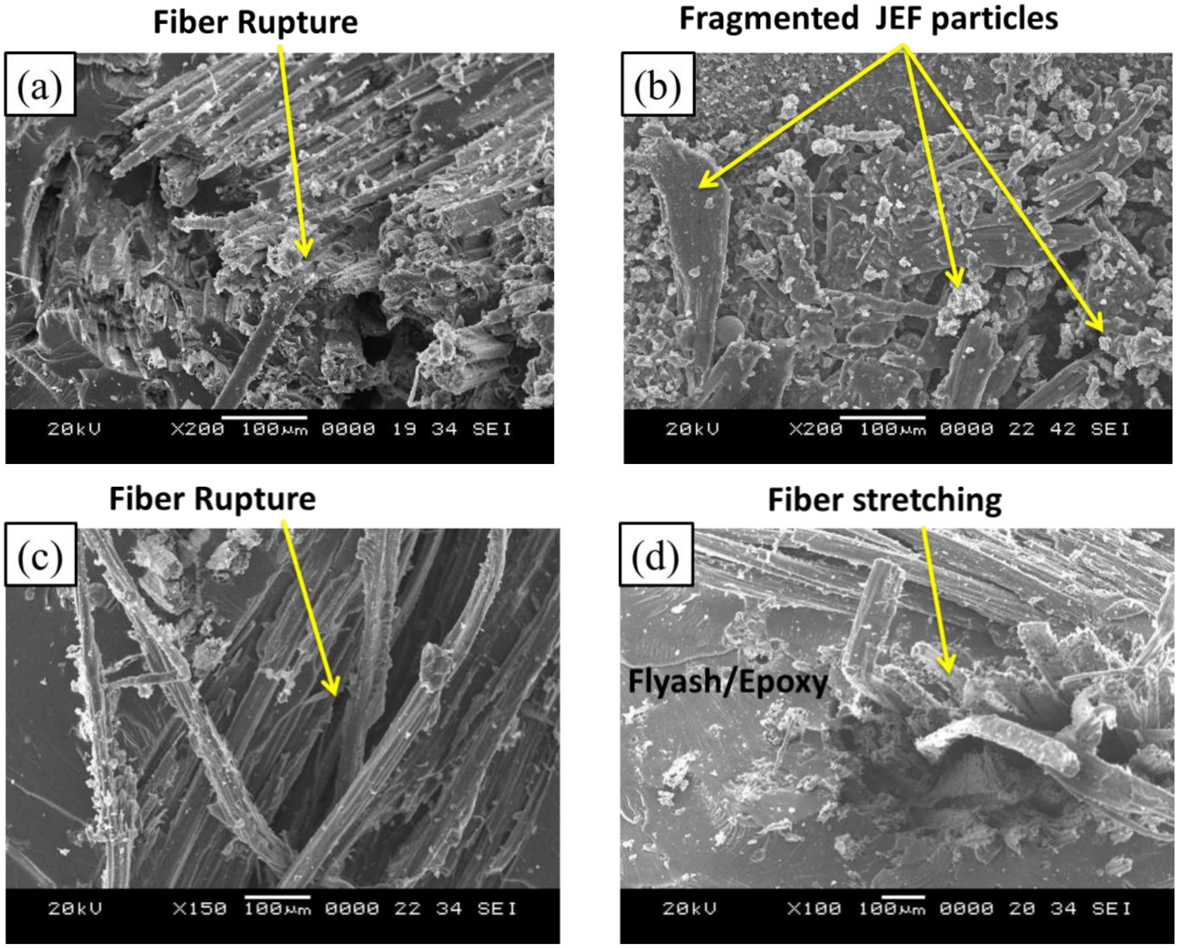


Figure 3.44 Fracture region of a JEF composite caused by fragments after the ballistic impact

Figure 3.45 is representing failure of rubber material from the JEFRC composite. Rubber material underwent wear due to impact of the bullet, as bullet punches and creates a small hole on rubber. After making a hole, it rubs against the rubber material and creates rough surfaces which are seen from Figure 3.45.

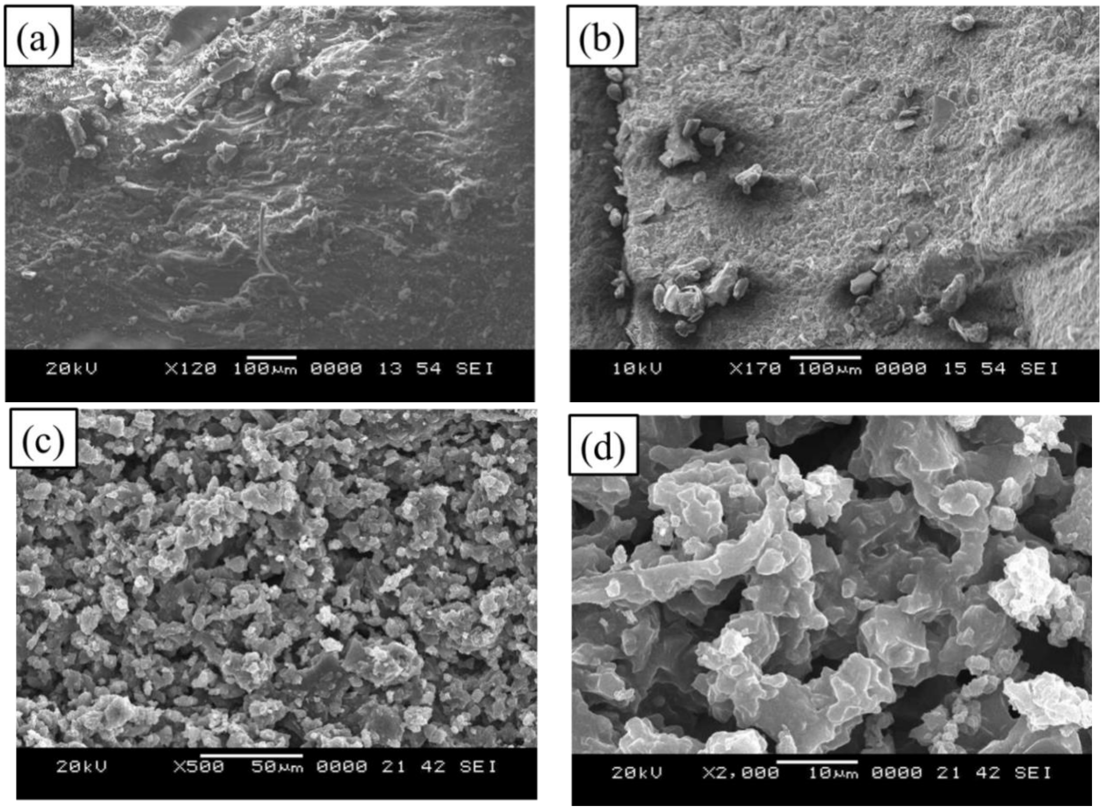


Figure 3.45 Fracture surface of natural rubber after the ballistic impact test

3.4.1. Comparative Damage Analysis on Experimental and FEA

Damages observed in FEA and experimentally tested samples of JEFC and JEFRC are presented in Figure. 3.46. Part (a) of the figure shows the entry and exit damages observed in JEFC plates. Damages on the entry side are smaller compared to the exit side. This could be due to the compressive stresses on the entry side and tensile stresses at the exit side leading to an increase in the extent of the damage. Distinctive through holes formed due to brittle fracture leading to the ejection of material in plug form can be noticed from Figure. 3.46 (a) in case of JEF composites. Similar damage observed in FEA contours can be seen in Figure. 3.46 (a).

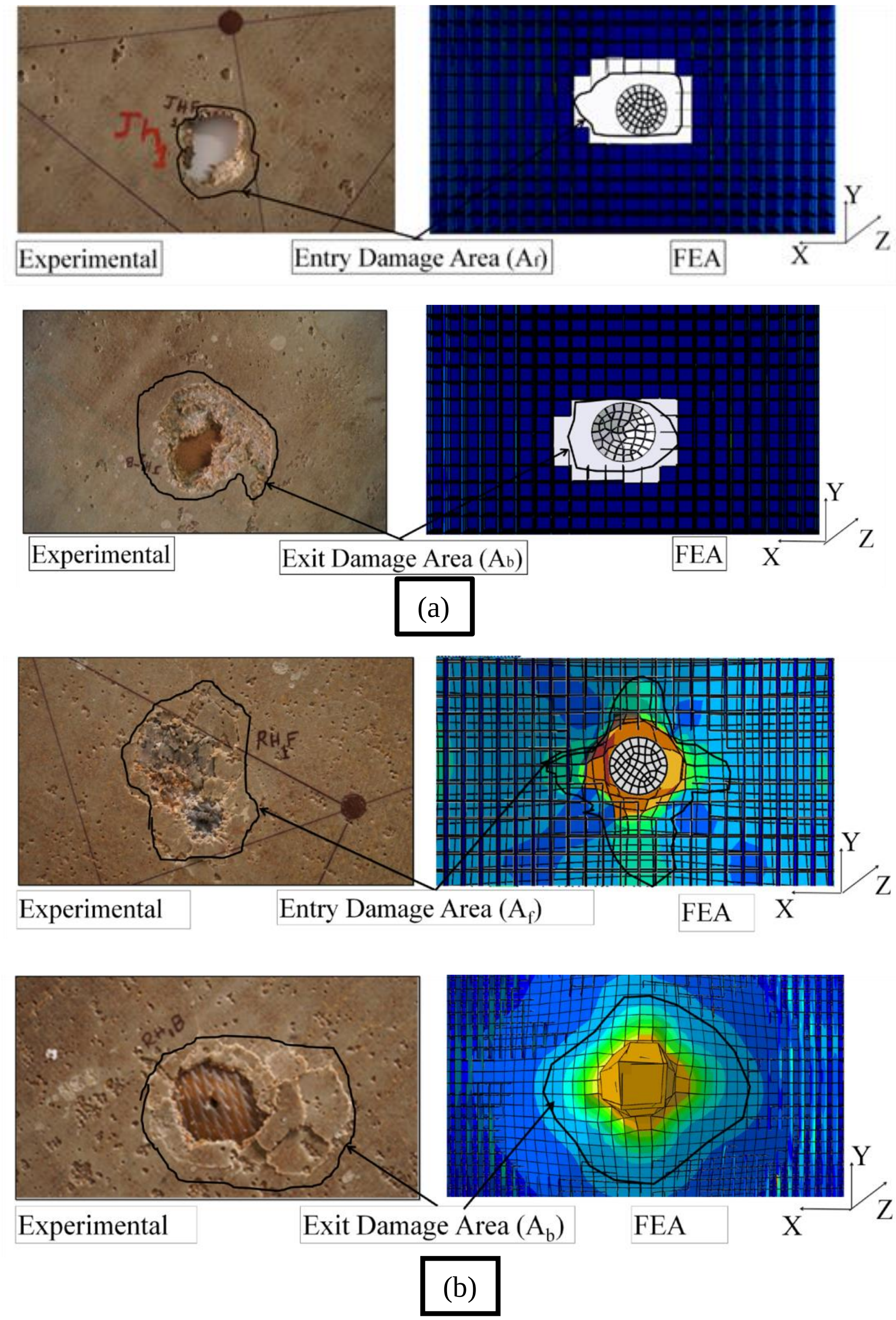


Figure 3.46 Composite after firing (a) JEFC entry and exit damaged surfaces, and (b) JEFRC entry and exit damage surfaces

In case of damages in JEFRC sandwich (Fig. 3.46 (b)), features of skin spalling could be seen along with elastic deformation of rubber core before tearing and final fracture. Small closing holes could be observed at the exit, supporting the above mechanism.

The ratio of areas at entry damage (A_f) to exit damage (A_b) (Mohan et al. 2007) was devised to assess the relationship of damages. This ratio (A_f/A_b) is found to be 0.5 in FEA and 0.54 in physical measurement for JEFC plates. Damage area ratio in case of JEFRC sandwich is 0.61 from FEA and 0.63 from the physical measurement. Thus, the appropriateness of FEA for analyzing the normal impact of a projectile on a composite/sandwich plates could be highlighted in the present work.

3.4.2 Proof of proposed concept

Final interlock block prototype produced for bullet proofing

Figure 3. 47 Protective interlock blocks for bullet proofing

The produced invention relates to portable, quick self-assembling composite interlock blocks for defence, particularly a bulletresistance retrievable fighting cum living bunker for providing protection to soldiers in defence, military and Police Departments in their respective areas engaged in counterinsurgency operations & fighting.

CHAPTER 4

CONCLUSION

The FE simulation was successfully developed using ABAQUS Explicit to predict the ballistic properties for composite. The optimum thickness required for sandwich composite to arrest the projectile was predicted from FE simulation and was also validated with the experimental field testing.

Tossa jute single woven composite (TSWC) showed better mechanical properties as compared to white jute single woven composite (WSWC) and white jute double woven composite (WDWC). Hence, tossa jute was used in ballistic FE simulation and ballistic testing.

The ballistic analysis of JEFC, natural rubber, and JEFRC sandwiches was carried out for different thickness ranging from 5 to 15 mm. It was found that JEFRC showed better ballistic performance than JEFC. The residual velocity in JEFC was higher, whereas the energy absorbed is low as compared to JEFRC. Also, brittle manner of damage was observed in JEFC. JEFRC absorbed 60 times more energy than JEFC and the nature of the damage was mixed mode followed by matrix cracking at initial stages, fiber stretching, compressing and delamination between the layers occurs.

FE simulation and experimental tests were conducted for different thickness from 50 mm to 150 mm. From this study, it can be stated that the sandwich block and sandwich interlock block composite, produced from compression molding technique with 150 mm thickness are capable of arresting the projectile with an impact velocity of 350 m/s. Thus, these sandwiches could be employed to provide required ballistic protection due to higher energy absorbed by the rubber and at the same time they provide better structural stability due to the presence of JEF. These composites can be used for replacing sand bags, military usage and to provide security for military personals in the remote places where they can be secured by using naturally available materials like a rubber sheet, jute, industrial waste fly ash and epoxy. This work can be extended for a different combination of materials and at higher velocity, there is also scope for hybrid composites could be explored for the present study.

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4. Sangamesh, Ravishankar, K. S., and S. M. Kulkarni. "Performance Study of Jute-Epoxy Composites/Sandwiches under Normal Ballistic Impact" Defence Technology Elsevier publishing.-Under Review
5. Sangamesh, Ravishankar K.S., S M Kulkarni "Impact Analysis of Natural Fiber and Synthetic Fiber Reinforced Polymer Composite" AIP Conference Proceedings 1953, 130003 may (2018); https://doi.org/10.1063/1.5033147 AIP publishing. (Scopus indexed)
6. Sangamesh Rajole, Ravishankar K.S., S M Kulkarni. "Study on Ballistic Energy Absorption Capability of Glass-Epoxy and Jute-Epoxy-Rubber Sandwich Composites", Materials Science Forum, Vol. 928, pp. 14-19, 2018. https://doi.org/10.4028/www.scientific.net/MSF.928.14. Trans Tech publishing. (Scopus indexed)

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10. Received "Young Scientist" DST SERB funding for attending 2018 9th International Conference on Manufacturing Science and Technology (ICMST 2018) at University of Malaya Malaysia under the scheme for Ph.D. scholars
11. Received "Young Scientist" CSIR funding for attending 2018 3rd International Conference on Composite Materials and Material Engineering (ICCMME2018) at NUS Singapore under scheme for Ph.D. scholars (http://csirhrdg.res.in/tg_sm_result.htm)
12. Best paper award to Sangamesh, Ravishankar K. S., S M Kulkarni in International Conference on Materials and Manufacturing Engineering (IMME17) held at NIT Trichy, during 10-12, March, 2017.(http://www.nitk.ac.in/news-announcments-tenders/best-paper-award-sangmesh-ravishankar-k-s-s-m-kulkarni-imme17)

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