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A Review on Multi-Layered Armour using Sugarcane Bagasse waste

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Abstract - *Monolithic metallic plates such as high strength steel has been the preferred choice for ballistic armour due to their high resistance against high-velocity projectiles. However due to their higher density, they are not suitable for practical applications. In such cases, multi-layered armours which are a combination of low-density materials with similar or superior ballistic resistance as that of monolithic metallic plates is used. Multilayered Armour Systems (MASs) with a front ceramic followed by synthetic fabric are currently used against high velocity ammunition. Researches are being conducted on the use of natural fibre composites, such as those made from sugarcane bagasse wastes , as the second layer in such Multi-layered armours. In this paper, we review the properties of sugarcane bagasse composite and the different materials used for fabricating a Multi-layered armour system.*

Key Words*: *Multi-layered armour, Sugarcane Bagasse, composites, ballistic plates, ballistic tests

1. INTRODUCTION

Sugarcane is one of the largest and most traditional plantation crops in our country. The main products from processing the juice extracted from sugarcane stalk are sugar for consumption and ethanol for transportation fuel. The spent roll-pressed stalk, is known as sugarcane bagasse or simply bagasse and has a fibrous structure consisting of cellulose, hemicellulose and lignin . India produces nearly 40 million metric tonnes (MMT) of bagasse and it is being minorly used as raw material in the paper industry, as domestic fuel for steam and power in the industrial mills or as fertilizer in sugarcane plantations. However, a significant amount of bagasse is either still disposed off as waste in open air piles which pose a risk to the environment or incinerated for production of electricity which release large amounts of CO_2 that contribute to global warming. Other alternatives are also being explored such as converting bagasse waste to useful charcoal [1], biogas and paper pulp [2]. An additional environment friendly application is the incorporation of bagasse waste into polymer composites [3]. Polymer matrix can be incorporated with either raw bagasse or with fibres extracted from the raw bagasse for reinforcement. The ultimate strength of a bagasse fiber was found to be around 200 MPa [4], which is higher than that of any other polymer. Another alternative application of bagasse waste is the use of composites made from Sugarcane Bagasse fibre as the secondary layer in Multi-Layered Armour. In this paper, we will review the multi-layered armour system, sugarcane bagasse composite and their ballistic properties.

2. SUGARCANE BAGASSE COMPOSITE

Bagasse is the fibrous residue or waste that remains after the juice is extracted from the sugarcane stalk. The performance of bagasse fiber reinforced polymer depends on several factors such as fibers chemical composition, cell dimensions, micro fibrillar angle, defects, structure, physical properties, mechanical properties, and also the interaction of a fiber with the polymer. In order to improve their performance, it is essential to know the fiber characteristics. Bagasse consists of around 50% cellulose and 25% of hemicellulose and lignin. Chemically, bagasse contains around 50% α-cellulose, 30% pentosans, and 2.4% ash. Because of its low ash content, bagasse offers numerous advantages for usage in microbial cultures when compared to other crop residues such as rice straw and wheat straw, which have 17.5% and 11.0% ash content respectively. Also bagasse is a rich solar energy reservoir due to its high yields and annual regeneration capacity.

Table 1: Mechanical properties of Bagasse fibre

Properties	Values
Tensile strength(MPa)	290
Young's modulus(GPa)	17
Density(g/cm^3)	1.25

2.1 Literature Survey

ER E.F. Cerqueira et al [5] had done evaluation on the mechanical properties of sugar-cane bagasse-polypropylene composites on the chemical modification. This is due to the incompatibility between natural fibres and polymer matrices and thus has the tendency to form aggregates during processing. It is also found that the composite has poor moisture resistance which reduces the use of natural fibre for reinforcement in polymers. Techniques like various methods of surface modifications are used to overcome this incompatibility. One of the methodologies of surface modification implemented in this study is chemical treatment. In this methodology the composite was pre-heated with 10% sulphuric acid solution then delignification with 1% sodium hydroxide solution. Fibres used consist of different volume fraction ranging from 5% to 20% with polypropylene in a thermokinetic mixer. 3-point bending and impact tests were conducted to evaluate the mechanical properties. Fraction analysis by Secondary Electrons Mode (SEM) was performed. Results obtained demonstrated improved flexural, tensile and impact strength of composite compared to pure polymer.

Gope P.C et al [6] did a study on a new composite developed using fly ash and bagasse. The microstructure of the composite was determined using SEM analysis. It was found from the microstructure analysis that there was a uniform distribution of bagasse and fly ash over the matrix. The matrix used was epoxy resin. The composite hence obtained was compared with ordinary bagasse fibre. The result found was that composite of fly ash-bagasse showed higher hardness than bagasse fibre composite.

Isiaka Oluwole Oladele et al [7] studied on the mechanical properties of sugar-cane bagasse fibre of different volume fraction. The study was conducted for 10%, 15%, and 20% volume fraction of sugar-cane bagasse with an unsaturated polyster resin and mechanical testing was conducted on the samples. The results demonstrated that 10wt% bagasse gave better results than the rest on various mechanical testing. The optimal wt% for bagasse was found out to be in the range 5-10 wt%

Punyapriya Mishra et al [8] studied the effect of impingement angle and particle velocity on bagasse fibre reinforced epoxy composite. The study was done on different volume fraction of the bagasse composite. Impingement angle is taken from 30^0 to 90^0 at velocities 48, 70, 82 and 109m/s. Silica sand is used as erodent whose size range from 150-250µm irregular in shape. The experiment was done on air jet erosion test machine. It was then found that the hardness value of the composite increases with increase in fibre content, even though the increment is marginal. Erosion also increases with increase in impact and impingement angle (maximum at 90^0). This indicates brittle behaviour of the composite. Fibre volume fraction also has a significant effect on erosion rate of composite.

N.Vijay Sai et al [9] did a study on the transverse vibration analysis of hybrid sisal-bagasse fabric reinforced epoxy composite. Frequency domain and frequency response function measurements obtained from the plate are used in this analysis. Fast Fourier based technique-based spectrum analyser is used for taking measurements. Damping factor and mode shapes of the composite is determined. Two types of composites were used in this experiment. One was hybrid sisal-bagasse fabric reinforced epoxy composite and other was ordinary sisal composite, both having same dimensions (300x300x3.5). After experimentation it was found that the average damping factor for fundamental frequency of hybrid composite was 1.15 times greater than the sisal composite. This means that the hybrid composite possesses higher damping factor than the sisal composite. Hence it can be used as vibration absorbing materials for certain applications like construction and automobiles.

Motaung and Anandjiwala et. al. [10] investigated the Effect of alkali and acid treatment on thermal degradation kinetics of sugar cane bagasse reinforced composite. It was found that the maximum values of thermal degradation were obtained by non-isothermal thermogravimetric investigation under nitrogen atmosphere for the alkali treated fabric samples. With the improved crystallinity of the fabric surface XRD and FTIR showed different functionalization. Acid treated samples showed lowest minimum thermal stability whereas NaOH treated sample showed the maximum.

Cerqueira, Baptistab, Mulinari et. al. [11] did a study on utilizing natural fibre as reinforcement on the composite material. The effect of chemical amendment on mechanical behaviour of bagasse fiber used as reinforcement in polypropylene based composites was evaluated. The Fibers were treated with 10% sulfuric acid solution and followed by delignification by 1% NaOH solution. The tensile, flexural (3 – point bending), and impact test were being studied of fabricated composites. Secondary Electrons Mode (SEM) was used for fracture analysis. The results of this composite were compared with pure composite and it was found that chemically modified bagasse has better properties than chemically untreated fibre particle reinforced composite.

Rodriguesa, Maiaa, and Mulinari et.al. [12] studied on the tensile strength of polyester resin reinforced sugarcane bagasse fibers modified by estherification. Impart property of chemical modification of bagasse hence was studied. This sugar-cane bagasse was used as reinforcement material in polyster matrix. X-ray diffractometer and Scanning Electron Microscope are used to analyse the modification in fibres. The bagasse fibres mixed with polyester resin and compression molding was used to fabricate the sample according to ASTMD-3039 standards for tensile tests. EMIC machine was used to carry out the tensile test.

Luz, A Gonc Alves, and Arco et. al. [13] did microstructural analysis of sugarcane bagasse fibers reinforced polypropylene composites and studied their mechanical behaviour. The composites were fabricated by compression and injection molding processes. The tensile and flexural properties were studied. Fracture surface was analysed using scanning electron microscope. The results demonstrated that mechanical properties did not have good adhesion between fibre and matrix.

Sun, Sun, Zhao, and Su et.al. [14] studied the isolation of cellulose from sugar-cane bagasse. The consecutive extractions of dewaxed sugar-cane bagasse in water with or without ultrasonic irradiation and different concentrations of alkali and alkaline peroxide yielded 44.7% and 45.9% cellulose preparations. 6% and 7.2% hemicelluloses, and 4.4% and 4.9% bound lignin was contained in it.

3. MULTI-LAYERED ARMOUR SYSTEM

Armoured shields usually consist of a monolithic high-strength metallic plate; however, multi-layered plate configurations are used nowadays because armour materials are not always manufactured to the required thickness, and multiple layers are necessary to fabricate shields that meet design specifications [15]. Also due to their higher density they are not comfortable to wear. Although there are a number of studies dealing with the ballistic behaviour of multi-layered plates, their scope is limited when compared to studies of monolithic plates [16-18]. Moreover, the study of multi-layered plates remains an open research topic since conclusive results of its effectiveness have not been obtained to date, as is remarked in recent investigations [17-18].

3.1 Literature Survey

Numerical study conducted by Zukas and Scheffler [15] found that 31.8 mm thick monolithic steel targets exhibited greater resistance when compared to multi-layered targets with equal thickness when impacted by a 65-mm long hemi-spherical nosed rods with a diameter of 13 mm and an initial velocity of 1164 m/s. The weakening of the multi-layered configuration was found to be due to the reduction of bending stiffness in the structure. Also, the reduction of resistance in multi-layered targets becomes more apparent when the number of plates is increased while keeping the total thickness constant [15], which has been observed experimentally [19-20].

Almohandes et al. [19] reported that monolithic steel plates were found to be more effective than multi-layered plates of the same thickness when impacted by a 7.62-mm projectile with an initial velocity of 826 m/s. An experiment conducted by Dey et al. [16] on the ballistic resistance of Weldox 700E steel in the sub-ordnance velocity range shows that 12 mm monolithic plate has better ballistic performance against projectiles when compared to double-layered plates with same thickness, while the opposite effect is observed when blunt projectiles were used. Borvik et al. [21] studied the same plate configurations using Weldox 700E steel against 7.62-mm APM2 projectiles and discovered that the ballistic limit velocities of monolithic and double-layered plates were identical. However, 12 mm monolithic plate had a slightly better performance for striking velocities above 850 m/s. An investigation by Teng et al. [17, 22] on the ballistic performance of monolithic and double-layered steel plates showed that the ballistic resistance depends on several factors, including nose shape of the projectile, mass of the projectile, impact velocity, configuration and material properties of the plates. Corran et al. [23] found that the failure mechanisms involved in the penetration process and consequently the ballistic performance are dependent upon the projectile nose shape and hardness. Hence they are very important factors to consider.

The above references show that the penetration process of multi-layered plates is a complex problem. For design purposes, several of the aforementioned factors should be considered to obtain optimum protection.

Selection of materials for armour against ballistic threats is crucial not only for the effective protection but also for weight reduction, which is very important from a design point of view. However, the selection of armour would depend on several factors including price, design, specific application, ballistic performance, maintenance and weight [21]. Even though high-strength steels are the primary candidates for protective structures, engineering aluminium alloys such as Al 7075 and 7017 may be attractive candidates due to their excellent strength-to-density ratio [24]. Although there are some experimental studies conducted on the ballistic behaviour of engineering aluminium alloys [25-28], they are limited and few numerical simulations have been performed to further understand these results.

MAS systems are divided into different types based on their constituent materials: non-metallic, metallic or a combination of both. According to Sadighi et al. [29]; Weerasinghe et al.[30] polymers, ceramics, fabrics and auxetics are some of the most commonly used non-metallic systems in ballistic mitigation applications.

Although these non-metallic systems have shown benefits such as high-performance bonds, enhanced energy absorption abilities and corrosion resistance, they have displayed vulnerability towards high temperatures and susceptibility towards brittle fractures (Cantwell and Morton,[31]; Gama et al.,[32]), which are less likely to occur in metals.

Difficulties in machining, low heat capacity, susceptibility to high temperatures and low structural rigidity can be considered as some of the drawbacks of polymers and auxetics (Patil et al.,[33]; Sadighi et al., [29]).

Moreover, ceramics undergo fragmentation, delamination and delocalization at the fracture zone upon impact, as they are weak in tension (Garshin et al.,[34]).

To overcome these weaknesses in non-metallic composites, there have been efforts to combine them with metals to enhance the ballistic resistance. Polyurea-coated aluminium (Mohotti et al., [35],[36]), Dyneema with aluminium (O'Masta et al., [37]), boron carbide with aluminium (Zhang et al., [38]), and alumina with steel (Sadanandan and Hetherington, [39]; Übeyli et al., [40]) are some examples of such systems. These systems have shown advantages such as low density, high specific strength, damage tolerance to fatigue crack growth and fire resistance (Gama et al., 2001; Sadighi et al., 2012). However they have a hight cost of fabrication, lower ductility and toughness.

Multi-layer composite structures are generally used to build the components of airplane and military vehicles. Several research works are being carried out to explore the suitability of the materials used in multi-layer composite structure. Woo et al. [41] proposed a six-layer hybrid multilayer composite structure consisted of S2-glass-1, CMC (ceramic matrix composite), EPDM rubber, Aluminum (Al 7039), Aluminum foam and S2- glass-2. In this structure, impact absorption energy was evaluated under high velocity impact load.

Tasdemirci and Hall [42] prepared a three-layer composite structure made of Alumina Ceramic in front layer, EPDM (ethylene propylene diene monomer) rubber in the mid- layer and glass/epoxy plate in the back layer of the structure. The behavior of this structure was studied at high strain rate.

Nayak et al. [43] conducted finite element analysis on a three layer composite structure to investigate the dynamic response (applied blast loading) of the structure. The bottom and top layer of the structure was composed of Graphite-Epoxy (GE) and interior layer was made up of PVC. Xue and Hutchinson [44] investigated the influence of blast loads on a three layer circular plate by finite element analysis.Two types of composite panels were prepared and compared by Karagiozova et al. [45]. One was made up of steel plates as facesheets and polystyrene core and the other one was built up of steel plates and aluminum honeycomb core. Librescu et al. [46] also conduct analysis to understand the linear and non-linear behavior of multi-layer composite flat panels in contact of blast loads.

Table 2: Depth of indentation as a NIJ standard ballistic performance of front ceramic multilayered armor systems (MAS) with natural fabric and fiber polymer composites. Same thickness of Kevlar laminate for comparison.

MAS natural fabric or fibre polymer composite	Depth of indentation (mm)	Reference
20 vol% fique fabric/polyester	15 ± 3	[47]
30 vol% jute fabric/polyester	17 ± 2	[48]
30 vol% sisal fiber/polyester	22 ± 3	[49]
30 vol% ramie fabric/epoxy	17 ± 1	[50]
30 vol% sugarcane bagassefiber/epoxy	21 ± 1	[51]
Kevlar®laminate	23 ± 3	[47]

3.2 Numerical Simulations

Numerical simulations have been used by several authors to predict the performance of multi-layered plates. Borvik et al. [21] used Lagrangian LS-DYNA simulations to model the impact of a 7.62-mm APM2 projectile on double-layered steel targets assuming axisymmetric conditions and reported that simulations and experiments were in good agreement. Dey et al. [16] also used axisymmetric Langrangian simulations in LS-DYNA to predict the behaviour of double-layered Weldox 700E plates impacted by an ogival projectile. They also reported that good agreement was observed between numerical simulations and experimental results. Borvik et al. [25] conducted impact simulations of an ogival projectile on Al 7075-T651 monolithic plate using both axisymmetric and solid formulations. They found that both the methods gave an overestimation of 30% of the ballistic limit. This was found to be due to the fact that numerical simulations were not able to fully capture the brittle fracture behaviour of the target and the extensive fragmentation observed experimentally. However, fractures modes in the simulation were found to be similar to those observed in the experiments. These studies show that numerical simulations can be a reliable tool to understand the ballistic behaviour of multi-layered armours.

Resnyansky and G.Katselis conducted Vulnerability Project Ballistic and Material Testing Procedures and Test Results for Composite Samples for the TIGER Helicopter A.D. A wide range of materials and geometry designs were developed using composite laminate materials for ballistic structural armors. In the study, a 100 cm^2 sample of a laminate plate consists of three different materials. Composite laminate structures with fiber-cement, Kevlar woven fabric, and steel layers were modeled with ANSYS simulation to investigate the technical feasibility of the armor design. Experimental analysis was done on samples for validation & result shows that a fiber-cement layer of 8 mm thickness, Kevlar 29 layer of 2.4 mm total thickness, and steel 1006 plate of 3 mm thickness can stop a 9 mm FMJ bullet with only slight deformation. Using the model, simulation can reduce expenses in the development process of ballistic armor as it can simulate the ballistic behavior and limitations of the design and can provide significant insights through product development process.[52]

The Brownian motion-based approach is a newly developed tool. Tahenti [53] analysed the performance of a model in relation to the hypothesis of the model's parameters constancy. It was noted that the results were in good agreement with the experimental results even under restrictive hypothesis. In addition, it was pointed out that better characterisation of the model parameters, indeed the impact velocity effect, can improve the quality of agreement between the experimental and simulated results. However, the inspection of the presently proposed inference method shows that its application imposes the need for a large experimental database.

As aforementioned, there are few studies dealing with the modelling of impact on multi-layered plates; however, numerical predictions of the ballistic performance of multi-layered plates made with layers of different materials have not been studied in detail. There is a huge scope for research in this area.

4. CONCLUSIONS

Natural fibers filled epoxy composites have great potential for armour applications due to their environmental suitability, technical feasibility and economic viability. A lot of effort and research has been put in this direction to generate these new composites, however, many technical and economic issues are yet to be addressed before they can be commercially used for armour applications. Kevlar armours, which are currently used by our military have the disadvantages of high cost, and high sensitivity to the environment, which can be reduced by using natural fibre composite. The main challenges for the near future are to further improve the durability and the mechanical performance of these composites by decreasing the costs of fabrication while developing an eco-friendly strategy. MAS with sugarcane bagasse fibres can be an economical solution to meet the needs of our country's defence forces.

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