Ballistic Impact analysis of 2D woven Kevlar/Basalt reinforced composite

K. KalaiThendral¹ and D. Abraham Antony²
¹PG Scholar, Department of Mechanical Engineering, Rajalakshmi Engineering College, Chennai
²Assistant Professor, Department of Mechanical Engineering, Rajalakshmi Engineering College, Chennai.

E-mail: kalai.thendral.555@gmail.com

Abstract: In defence industry, ballistic impact is common scenario occurs often. The materials used for making vests, automobile covering parts, aerospace parts affected due to impact of projectile. These materials should possess good impact strength and energy absorption for its damage resistance and providing safety for the industry. Usually Aramid fiber Kevlar used for its well-known impact strength [8]. Fiber alone creates expensive and usage the same under every condition subjected to less velocity impact can be diminished by Weaving Kevlar with Basalt. Thus, it is important to calculate its impact strength and energy absorption factor of reinforced composites. In this thesis, Kevlar is weaved with Basalt for its good resistance to impact and the ballistic impact test is carried out with structural steel projectile for studying its behaviour, impact strength and energy absorption. From the results, it is sufficient to conclude that usage of 2D woven Kevlar Basalt composite behaviour on the basis of woven pattern with impact of projectile.

1. Introduction
Composite materials are used as good replacement for almost any king of engineering and commercial industries due to their structural, adoptable and flexible property. In ballistic impact, a High velocity projectile is pressurized and made to hit on the mass object and involves studying damage incurred with help of energy absorption and impact energy. Kevlar, an aramid synthetic fiber available in fiber, mat forms possess good impact resistance property for impact as well as negative co-efficient of thermal expansion. The ballistic impact developed from high structural materials such as aluminium, steel and converged into usage of Kevlar at 1960. It started commercialized in 1965. As of now Kevlar are widely used in defence as cables, ropes, storage coating for ballistic projectiles, body armour etc.

Table 1. Literature review on research papers and proceedings.

| Authors         | Tests/Analysis | Inferences                                                                 |
|-----------------|----------------|---------------------------------------------------------------------------|
| J.D. Clayton[1] | Ballistic Analysis | Results from the experiments of two physical problems were related and it served the input model for ballistic impact problems. |
| Authors                                                                 | Test Type          | Description                                                                                                                                                                                                 |
|------------------------------------------------------------------------|--------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Subhan Ali Jogi, Muhammad Moazam, Ali Chandio, Iftikhar Ahamed Memon   | Fracture test      | Laminate of 9 layers 4 mm thick was fabricated with E-glass epoxy and E-glass Kevlar. A dart specimen done with ply angle orientation. 30°/60°, 0°/90° lay ups orientations does not possess good fracture toughness compared with 45°/45°. |
| Md. Milon Hossain, M A Khan, Md. Abu Bakar, Siddiquee, R A Khan, Tauhidul Islam | Tensile strength, Tensile modulus, Elongation at break, Bending strength, Bending modulus, Impact strength | Thermoset and thermoplastic reinforcement matrices used for fabrication of woven carbon and Kevlar out of which the CK/PP showed less mechanical properties. |
| Elias Randjbaran, Rizal, Zahari, Dayang Laila Abang Abdul Majid, and Nawal Aswan Abdul Jalil | Impact test        | 6 hybrids were woven and impact test carried out showed that the hybrid 2 (Glass Carbon Kevlar Carbon Kevlar Glass) has better absorption energy of 95.17 J. hybrid 2 and 4 has 95.17 J and 95.15 J respectively. Use of carbon and glass on central layer is most efficient and carbon at last layer strictly not recommended. |
| V. Narayanamurthy, C. Lakshmana Rao, and B.N. Rao                       | Impact analysis    | ANSYS LS-DYNA with two different bullet velocities (1000m/s and 500 m/s). Plate experience bending and crack tends to propagate in four mutually perpendicular directions. |
| K.K. Herbert Yeung and K.P. Rao                                        | Uniaxial tensile test, Compression test, Three point flexural strength | All the three tests are experimentally determined and compared with theoretical value which are of 90% equal values. |
| S. Manigandan                                                          | Impact analysis    | K-49 and K-149 elemental fibers chosen for comparative study. K-149 has better resistance to impact compared with K-49 in defense and impact applications. |
Hassan M. El-Dessouky and Mohamed N. Saleh[8]  
**Stress Analysis**  
Based on binder path three types of composite woven in 3D architecture and tested. Results showed that the LTL plain has low mechanical properties. Satin and Twill LTL weaves were similar and cross over points defined the stress intensity.

Brenda L. Buitrago Carlos Navarro, Enrique Barbero, Carlos Santiuste, Sonia Sanchez-Saez. [9]  
**Energy absorption**  
The front and back skin were the important for absorption of energy by the impact. The honeycomb structure absorption is comparatively lower.

Aswani Kumar Bandaru, Yogesh, Sachan, R. Alagirusamy, Shivdayal Patel, Naresh Bhatnagar [10]  
**Tensile and compression test**  
Hybrids of Kevlar and basalt were reinforced and the specimen varied on change of resins PP, Epoxy undergone tensile and compression test. The same is simulated with ABAQUS.

From literature survey, Importance of ballistic impact matters a good procedure for defence industry to understand the behaviour of materials that withstand the impact of projectile. Tensile strength of woven fabrics discussed in material selection, weave patterns offers property flexibility in specimens initiates the basic idea to do ballistic impact. Weave patterns available for only minimum materials since the weaving process consumes time and use of natural fiber less compared with carbon and E-glass. In this thesis Kevlar basalt 2D woven composite subjected to ballistic impact test to find the energy absorption and impact strength of composite using orientation changes and the weave pattern changes, weave patterns behaviour change need to be tested and comparison establishes way to impact test with orientation change.

2. **Material Selection**

Ballistic application widely uses Kevlar as the basic material in fibre woven in matt form, the material reinforcements mixed with Kevlar fibbers showed variation in material property as well as cost efficient since Kevlar is expensive [1]. Material reinforcement process used for production of laminate of Kevlar composite are hand lay-up process, vacuum bag moulding, compression moulding etc. the process chosen based on cost efficient and productivity cycle time reduction. In this thesis basalt fibre chosen as reinforcement for its better strength and stiffness to withstand impact loads, main reason to choose basalt over carbon, similar tensile property with reduced cost. Epoxy resin gives better adhesion property for Kevlar with other reinforcements. The fibres subjected to form laminate woven against each other in three weave patterns and 2D woven laminate fabricated.

2.1. **Kevlar**

Kevlar is an aramid synthetic fiber that possess good heat resistance and impact strength. It was found as polymeric compound by Stephanie Kwolek. Due to its high impact strength and tensile strength to weight ratio, that used in racing bicycling tires to defense industry for making storage of impact projectiles, aerospace parts, ropes, wires and vests. The chemical name of Kevlar is Poly-paraphenylene terephthalamide synthesized by condensation reaction and the process is expensive since it is produced from concentrated sulfuric acid and maintaining the water-insoluble polymer in
solution during its synthesis. Based on applications, Kevlar is available in grades such as K-29, K-49, K-149, K-100, K-119, K-129 etc.

**Table 2. Kevlar properties.**

| S.no | Grade     | Density (g/cm$^3$) | Tensile modulus (GPa) | Tensile strength (GPa) | Tensile elongation (GPa) |
|------|-----------|--------------------|-----------------------|------------------------|--------------------------|
| 1    | Kevlar 29 | 1.44               | 83                    | 3.6                    | 4.0                      |
| 2    | Kevlar 49 | 1.44               | 131                   | 3.6-4.1                | 2.8                      |
| 3    | Kevlar 149| 1.47               | 179                   | 3.4                    | 2.0                      |

2.2. Basalt
Basalt is a fiber naturally occurring inert material and the fibers are easy to extract by one stage process homogenization and extraction of fibers. It consists of olivine, minerals plagioclase and pyroxene. Cheaper than carbon and has better property than fiber glass so used as fiber material reinforcement which reduces cost to the composite material and develops new material for using under various applications such as aerospace, automotive and fireproof textiles. Woven fabric are highly useful in construction industry as asbestos substitute for their better specific strength three times greater than steel.

**Table 3. Basalt properties.**

| S.no | Properties       | Value             |
|------|------------------|-------------------|
| 1    | Density          | 2.7 g/cm$^3$      |
| 2    | Tensile strength | 4.84 GPa          |
| 3    | Elastic modulus  | 89 GPa            |
| 4    | Elongation at break | 3.15 %          |

3. Tensile test
Kevlar and basalt were subjected to tensile test computationally for determine their tensile stress range. If the range does not have much variance then they both can be made together as a composite. ASTM-E-646-98 standard specimen is modelled in solid works and imported to ANSYS Workbench. Kevlar and basalt properties were installed manually in engineering data column. One end of the specimen is fixed and the Degrees of freedom are constrained in all the directions and a load of 20 KN is applied on the other face. The results were not of much difference between Kevlar and basalt.

![Figure 1. Tensile model for analysis (ASTM-E-646-98).](image-url)
3.1. Tensile test results

The results obtained from ANSYS solver output. The static structural analysis of tensile models does not show much variance in equivalent stress and deformation. From the results furnished, it shows here is greater possibility of usage of Kevlar and basalt together.

![Figure 2. Tensile Stress Analysis. (a) Kevlar Equivalent stress. (b) Kevlar Total Deformation (c) Basalt Equivalent stress. (d) Basalt Total Deformation.](image)

4. Explicit Dynamics

Low velocity impact tests were computationally simulated with ANSYS workbench. This uses AUTO-DYN module to solve the problem and can be used for any type of impact on plate or any other objects subjected to projectile impacts. In this paper Explicit Dynamics analysis used to study the deformation of Kevlar and Basalt whether they can withstand structural steel bullet projectile impact. The procedure follows as same as the tensile test modelling the plate and bullet in solid works and importing in Workbench. Dimensions of the plate were not actual dimensions of plate fabricated since ANSYS Workbench takes too long for solving smaller dimensional models and the computational analysis is only for the study of deformation and equivalent stress that the plate can withstand. Three cases were chosen based on the velocities 70000 mm/s, 72000 mm/s, 74000 mm/s.
Figure 3. Explicit Dynamics: (a) Equivalent stress of Kevlar at 70 m/s. (b) Equivalent stress of Basalt at 70 m/s. (c) Equivalent stress of Kevlar at 72 m/s. (d) Equivalent stress of Basalt at 72 m/s. (e) Equivalent stress of Kevlar at 74 m/s. (f) Equivalent stress of Basalt at 74 m/s.
The Dimensions of the plate is 500×500 with 3 mm thickness. The results showed that the velocity increases and decreases within these three velocity ranges.

5. Results
The results showed that the Kevlar has good impact resistance and basalt is comparatively lower than Kevlar. Tensile results were almost of equal range whereas Explicit Dynamics has great difference between Kevlar and Basalt. So that we can use Kevlar and basalt for 2D woven structure. Important characteristics should be taken in amount such that the basalt should be woven as warp and the Kevlar as weft. This is due to lower impact strength obtained in Basalt. If Kevlar is woven as weft the maximum area covers in the structure would be Kevlar and the material is safer as much as possible.

| Velocity (m/s) | Equivalent stress (MPa) | Deformation (mm) | Equivalent stress ×10^2 (MPa) | Deformation (mm) |
|---------------|-------------------------|------------------|------------------------------|------------------|
| 70            | 175.08                  | 16.875           | 160.25                       | 136.65           |
| 72            | 281.68                  | 16.884           | 161.83                       | 137.01           |
| 74            | 209.68                  | 16.88            | 163.41                       | 137.34           |

Figure 4. Kevlar Explicit Dynamics Graph.
6. Inference
From the obtained results, it clearly shows that the deformation is higher at the area of impact. The Stress distributed along the four sides of the plate from the centre portion. Structural steel experiences the maximum stress in case of Kevlar whereas in case of basalt, deformation is higher in the plate. Use of Kevlar and Basalt can be effective for low impact applications. The important feature to be carried out that the basalt should be woven in warp direction because of its lower impact strength perhaps adaptation of Nano-particles improve impact resistance. Equivalent stress has the deviations increasing and decreasing at greater extent, basalt does not show much variation.

7. Conclusion
The computational tests were adopted to use of fabrication of 2D woven plates. Kevlar plate showed highest stress of 281.68 MPa at velocity 72 m/s. Basalt showed maximum of 163.41 MPa at velocity of 74 m/s. Fabrication of 2D woven Kevlar/basalt was completed which will be subjected to ballistic impact tests and impact energy will be calculated. The virtual results will be compared with computational results on the deformation. This gives a detailed study in 2D woven composites.
8. References

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