Kaunas University of Technology

Faculty of Mechanical Engineering and Design

Design and Comparative Analysis of Composite Intrusion Beams in Passenger Car's Side Door

Master's Final Degree Project

Gopi Kompelli

Project author

Prof. Dr. Lukosevicius Vaidas

Supervisor

Kaunas, 2020

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Reviewer

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Declaration of Academic Integrity

I confirm that the final project of mine, Gopi Kompelli, on the topic „Design and Comparative Analysis of Composite Intrusion Beams in Passenger Car’s Side Door“ is written completely by myself; all the provided data and research results are correct and have been obtained honestly. None of the parts of this thesis have been plagiarised from any printed, Internet-based or otherwise recorded sources. All direct and indirect quotations from external resources are indicated in the list of references. No monetary funds (unless required by Law) have been paid to anyone for any contribution to this project.

I fully and completely understand that any discovery of any manifestations/case/facts of dishonesty inevitably results in me incurring a penalty according to the procedure(s) effective at Kaunas University of Technology.

______________________________ _______________

(name and surname filled in by hand) (signature)

Kaunas University of Technology

Faculty of Mechanical Engineering and Design

Study programme: Vehicle Engineering (6211EX021)

Design and Comparative Analysis of Composite Intrusion Beams in Passenger Car's Side Door

Given to the student: Gopi Kompelli

1. Title of the Project:

Design and Comparative Analysis of Composite Intrusion Beams in Passenger Car's Side Door
Lengvųjų automobilių šoninių durų kompozitinių apsauginių sijų projektavimas ir lyginamoji analizė

2. Aim of the Project:

To design the different types of intrusion beams and apply different materials such as metal alloys and composite materials. Analyze them in implicit and explicit dynamics conditions using CAE software. Compare the output results of metal alloy intrusion beams and composite material intrusion beams.

3. Tasks of the Project:

- Design the five different intrusion beam profiles with different materials such as AA 1060, AISI 1018, AISI 1060, AISI 1080, Steel 20 GOST, Carbon fiber, E-glass and S-glass
- Analyze these beams under implicit and explicit dynamics conditions using Ansys Workbench to find out the displacement, force reaction, the internal energy absorption of the beams.
- Compare the results by plotting the graphs to find out the effective beam under such conditions.

4. Structure of the Text Part:

- Introduction of the importance of the Intrusion beams.
- Different safety standards for the examination of the side impact on the car's side door.
- Literature reviews on the side impact or intrusion beams
- The theoretical background of the side impact beams
- Material properties and its importance in manufacturing an effective intrusion beam.

- Problems identified in the design and analysis of the intrusion beams from the previous research works.
- Designed the five different types of intrusion beams in Solidworks.
- Tested the intrusion beams in the three-point bending setup in implicit and explicit conditions using Ansys
- The results were discussed between different beams with different materials

5. Structure of the Graphical Part:

- The results were discussed by plotting graphs of force reaction v/s displacement and internal energy absorption v/s time of the different intrusion beams with different materials.

6. Consultants of the Project:

Author of the Final Degree Project	Gopi Kompelli *(abbreviation of the position, name, surname, signature, date)*
Supervisor of the Final Degree Project	prof. Dr. Lukosevicius Vaidas *(abbreviation of the position, name, surname, signature, date)*
Head of Study Programmes	prof. Artūras Keršys *(abbreviation of the position, name, surname, signature, date)*

Gopi Kompelli. Design and Comparative Analysis of Composite Intrusion Beams in Passenger Car's Side Door. Master's Final Degree Project / Prof. Dr. Lukosevicius Vaidas; Faculty of Mechanical Engineering and Design, Kaunas University of Technology.
Study field and area (study field group): Transport Engineering (E12), Engineering Science.

Keywords: Intrusion beams, Solidworks, Ansys, three-point bending, metal alloys, composite materials, displacement, force reaction, internal energy absorption, time.

Kaunas, 2020. 61 pages.

Summary

Side impact collisions are the second most crashes happening after the frontal crashes in the world. Side-impact collisions are more dangerous than the frontal crashes as there is little space between the impact region(side door) and the passenger. So the car side doors need to be strong enough to withstand during the collision by absorbing the impact forces. The intrusion beams are placed inside the car side door to increase the stiffness, strength, and energy absorption capacity during the side-impact collision. And the weight of the automobile components (intrusion beam) is also the main criteria to increase fuel efficiency and reduce gas emissions.

So in this research project, different types of intrusion beam profiles are designed in Solidworks. Two categories of materials were used like metal alloys and composite materials. The composite material beams are further designed in Ansys ACP Pre to give the number of layers with different orientations according to the polar properties of the material to increase its overall performance. And these beams are analyzed in static structural (implicit) conditions by using AnsysWorkbench to find the displacement, force rection to know the strength and stiffness. And in explicit dynamics conditions by using AnsysWorkbench LS-DYNA to find internal energy absorption to know energy absorption characteristics. Based on results graphs were plotted and compared to find efficient beams.

Gopi Kompelli. Lengvųjų automobilių šoninių durų kompozitinių apsauginių sijų projektavimas ir lyginamoji analizė. Magistro baigiamasis projektas / Prof. Dr. Lukosevicius Vaidas; Kauno technologijos universitetas, Mechanikos inžinerijos ir dizaino fakultetas fakultetas.

Studijų kryptis ir sritis (studijų krypčių grupė): Transporto inžinerija (E12), Inžinerijos mokslai.

Reikšminiai žodžiai: Įsibrovimo sijos, Solidworks, Ansys, trijų taškų lenkimas, metalų lydiniai, kompozicinės medžiagos, poslinkis, jėgos reakcija, vidinė energija, laikas.

Kaunas, 2020. 61 sk. p.

Santrauka

Šoniniai susidūrimai yra antra avarijų priežastis, vykstanti po priekinio susidūrimo. Šoniniai susidūrimai yra pavojingesni nei priekiniai susidūrimai, nes tarp smūgio vietos (šoninių durų) ir keleivio yra mažai vietos. Taigi automobilio šoninės durys turi būti pakankamai stiprios, kad galėtų atlaikyti apkrovas susidūrimo metu, sugerti smūgio jėgas. Apsauginės sijos montuojamos į automobilio šoninių durų vidų, kad padidėtų šoninių durų standumas, stiprumas ir energijos sugertis. Automobilių komponentų masė taip pat yra pagrindinis kriterijus, siekiant padidinti degalų efektyvumą.

Taigi šiame tyrimų projekte „Ansys Workbench“ montuojami skirtingi apsauginių sijį profilių tipai. Buvo naudojamos dviejų kategorijų medžiagos, metalų lydiniai ir kompozicinės medžiagos. Kompozicinės medžiagos pluoštai toliau projektuojami Ansys ACP Pre programoje, kad būtų pateiktas skirtingų sluoksnių skaičius atsižvelgiant į medžiagos polines savybes, kad būtų padidintos visos medžiagos savybės. Toliau sijos analizuojamos statinėmis sąlygomis, naudojant AnsysWorkbench, kad būtų galima sužinoti poslinkį, jėgos pasipriešinimą, kad būtų galima sužinoti jėgą ir standumą. O aiškių dinaminių sąlygų sąlygomis naudojant „AnsysWorkbench LS-DYNA“, norėdami sužinoti vidinę energijos absorbciją, tam kad nustatyti energijos sugerties savybes. Remiantis gautais rezultatais, buvo nubraižyti ir palyginti grafikai, rastos efektyvios pluoštinių medžiagų savybės.

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Abbreviations:

Assoc. prof. – associate professor;

Lect. – lecturer;

Prof. – professor.

AA – aluminum alloy

AISI – American Iron and Steel Institute

E-glass – electric grade glass

S-glass – strength glass

FEA – finite element analysis

CAE – computer-aided engineering

CAD – computer-aided design

FEM – finite element method

NHTSA – National Highway Traffic Safety Administration

IIHS – Insurance Institute for Highway Safety

CAFE– Corporate Average Fuel Economy

FMVSS– Federal Motor Vehicle Safety Standards

MDB– moving deformable barrier

Euro-NCAP– Euro New Car Assessment Program

HIC– Human head injury criteria

AISC– Automotive Industry Standards Committee

FRP– fiber-reinforced polymer

ACP– Ansys Composite PrepPost

CTP– Composite test procedure

D (Y) – Displacement in Y-direction

FR – Force Reaction

IEA – Internal Energy Absorption

SAE – Specific Energy Absorption

Terms:

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1. Introduction

In a modern-day world, accidents are happening in every corner and every hour. In many accidents, the occupants are injuring severely and sometimes losing lives. There are different types of accidents, which are happening daily, like frontal, side-impact, rollover, and rear impact, etc. Side impact collisions are too dangerous as there is no space for the more deformation of the side structures when compared with frontal collisions. Side impact collision is the second most type of collision happening after frontal collisions (as shown in fig. 1). Fatalities by accidents in the USA, in 2008, are 23,888 out of that 5,265 were happened just because of side-impact collisions[1].

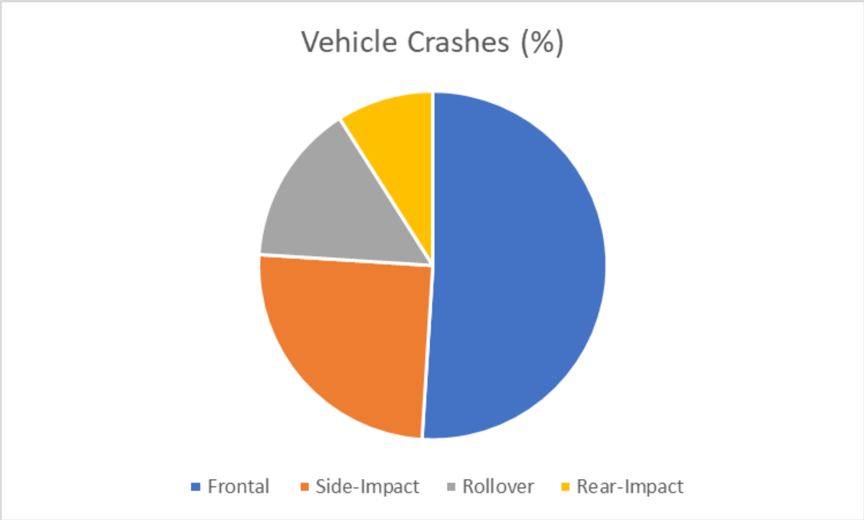

Fig. 1. Vehicles crash percentages at various impacts[1]

At an extreme level, the research is going on to increase the safety of vehicles by decreasing the effectiveness of collisions. With time, there are successful results in safeguarding the occupants from severe injuries during collisions. In the past two decades, the percentage of vehicle crash injuries in frontal crashes has been decreased as a result of researches, but the percentage of vehicle crash injuries in side-impact raised (as shown in fig. 2). So, to reduce the effectiveness of side-impact crashes, we need much research and development in this area.

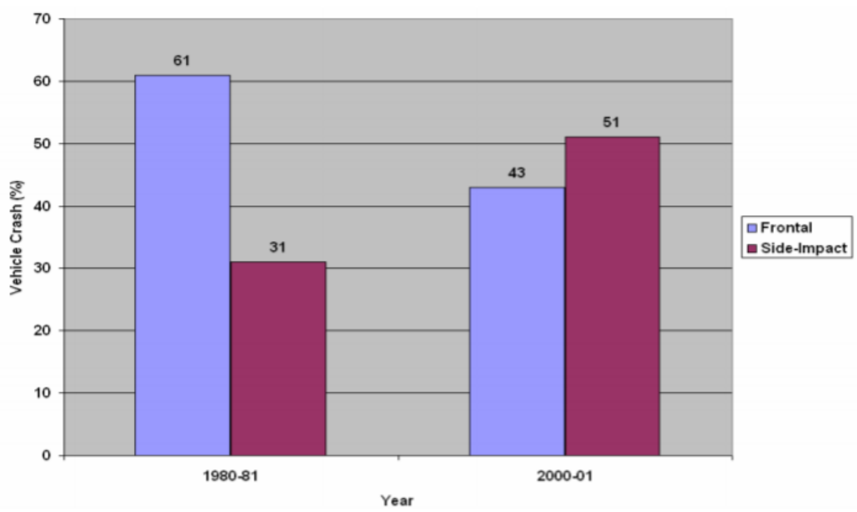

Fig. 2. Comparison of a frontal and side-impact crash[1]

Intrusion beams are mainly designed as a feature in car doors for the security of the driver and passenger during the side-impact collision. Its purpose is to absorb and withstand the impact loads, which are developed during the side-impact collision. The deformation level cannot provide space for the side airbag to deploy.

Automobile gas emissions are one of the bothering issues right now. The world is facing a huge issue because of the emissions released by vehicles. the environment deteriorating day by day because of greenhouse gases like carbon monoxide, sulfur dioxide, methane, carbon, etc. All these gases are emitted by the vehicles. They are creating smog in the atmosphere, which became a huge issue in the world, the climate is changing drastically. It causes health issues for the people, moreover, it is affecting the ecosystem. Which is not considered in the long run.

The smog is created mainly because of the gas emissions from vehicles in large cities. Massachusetts Institute of Technology (MIT) researched these gas emissions released by the vehicles in 2003, mind-blowing facts were out, because of these vehicle emissions in the USA, nearly 53000 deaths were caused per year. According to other university studies, traffic pollution is causing 5000 deaths per year in the UK [2].

The emissions from the vehicles can be reduced in two ways, one is the proper design of the vehicle engine and body. Secondly the reduction of vehicle weight. Weight reduction plays a major role in fuel efficiency of the vehicle, which also leads to less emission of exhaust gases as less fuel is combusted.

So in this project, an initiation is taken forward to increase the safety of the vehicle and also to reduce the weight of the vehicle components, which directly affects the vehicle emissions in percentage. The composite materials are lightweight materials and strong when compared with the metals. because of its less density and more yield strength. Composite materials are expensive, but because of the new technologies, the price is reducing day by day, which is a good sign. The composite is mainly using in aerospace and racing cars. But the introduction of the composites to the passengers' cars is so beneficial regarding safety and fuel efficiency. There are many types of research are going on to produce cheap and efficient composite components.

1.1. Crashworthiness

The term “Crashworthiness” is firstly used in the aerospace industry. Crashworthiness indicates the capacity of the vehicle structure to deform plastically to avoid the driver and passenger injuries at the time of survivable crashes by providing enough space. Severe injuries and fatalities can be decreased by extra protection like occupant packaging and restraint system. A vehicle as to be designed in a manner that, at higher speeds, the occupants in the vehicle should not experience net declaration more than 20g. it can be categories into three areas such as 1)material engineering and design, 2) combustion and fire, and 3) medical engineering (biomechanics). It covers different types of applications related to automotive, marine, aerospace, and military. Here we concentrate on the automotive sector. Crashworthiness features include seat belts, airbags, side-impact protection, crumple zones, headrests, and interior padding. These features are getting updated from time to time with innovations for better safety and new design. Crashworthiness assessment is done by various tests and analytical methods[3].

1.2. Standards for the safety of the vehicle

1.2.1. NHTSA standards

The National Highway Traffic Safety Administration is the part of the Department of Transportation under the US Federal Government. NHSTA was formed on December 31st, 1970, as a preceding agency of the National Highway Safety Bureau. The mottos of the NHTSA are to reduce vehicle crashes, prevent injuries, and save lives.

The NHTSA aims to prevent a greater number of injuries, deaths, and reducing economic losses in vehicle accidents. This is achieved by setting and implementing safety execution standards for motor vehicle manufacturers and through a permit to governments to empower them to conduct successful highway safety programs locally.

NHSTA is also enforcing the regulations for vehicle theft resistance and fuel economy by being part of the corporate average fuel economy (CAFE). It will provide licenses for manufacturers and importers of vehicles, and it regulates the import of vehicles and vehicle parts, control the vehicle ID number system (VIN), human dummies are developed for the usage in US safety testing, test protocols for testing, and cost data for vehicle insurance. Continuously there will be ongoing research and investigation on safety standards for the betterment of motor vehicles to decrease the injuries during accidents[3].

One of the activities of the NHTSA is to enforce the Federal Motor Vehicle Safety Standards (FMVSS)

1.2.1.1. Federal Motor Vehicle Safety Standards (FMVSS)

Federal Motor Vehicle Safety Standards (FMVSS) are federal regulations of the US specifying design, construction, performance, and durability requirements for vehicles and regulated to vehicle safety-related design, automotive parts, and systems [3].

It was divided into three sections

- 100(series) Crash avoidance
- 200(series) crashworthiness
- 300(series) Post-crash survivability

1.2.1.2. Federal Motor Vehicle Safety Standards (FMVSS) 214

Federal Motor Vehicle Safety Standards (FMVSS) 214 came into existence in 1990 to secure occupants during the dynamic test, which is simulated at the right angle crash. It is the significant and assuring safety standards enforced by the National Highway Traffic Safety Administration (NHTSA).

During 1994-97, FMVSS was introduced into new model passenger cars. The occurrence of death to the occupants of passenger cars was 33% in 1993. It’s been the significant research of FMVSS to reduce the impact of collisions on car door side occupants when it was hit by another vehicle during the collision[4].

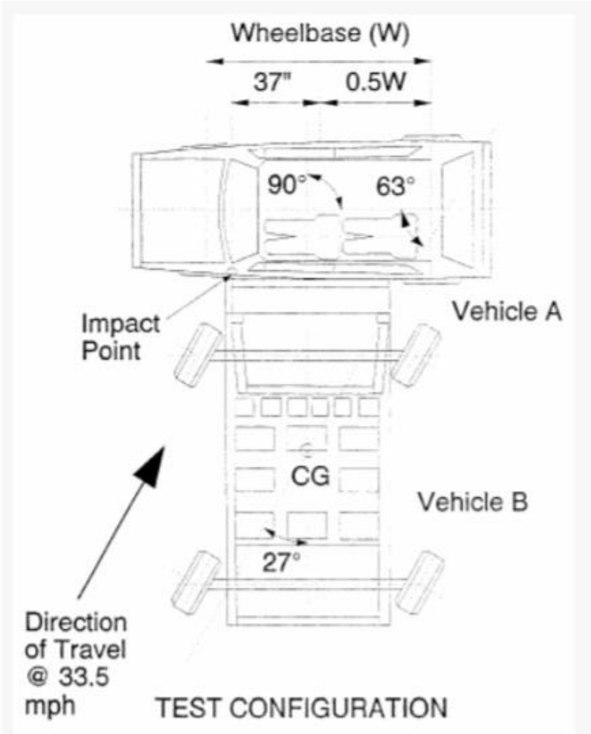

Fig. 3. FMVSS 214 Test Configuration[4]

A moving deformable barrier (MBD) travels at a speed of 33.5 mph and strikes a car(specimen), which is perpendicular to each other. All wheels of MBD are inclined at a 27° angle. Honeycomb barrier made up of aluminum is fixed in the Infront of the MBD at the height of the bumper. And the dummies are placed inside the car to measure the severity of injuries.

1.2.2. Insurance Institute for Highway Safety (IIHS), side-impact test protocol

In 2003 Insurance Institute for Highway Safety started a side-impact vehicle crash test. It is a severe test for the vehicles, which can injure the occupants severely. However, by providing appropriate side impact protection to the occupants, the level of injuries can be minimized during the collision.

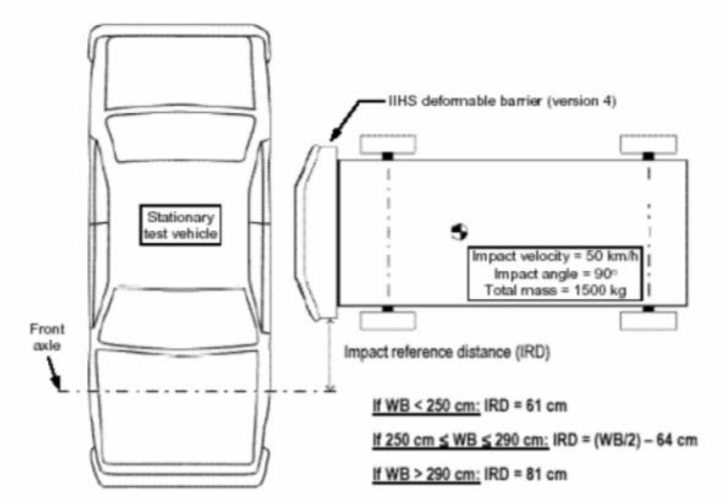

Fig. 4. IIHS Test Configuration[5]

This crash test likely the Federal Vehicle Safety Standard (FMVSS 214), but there is variation in wheels alignment of moving deformable barrier (MDB), which are in 0˚ degree to the cart's longitudinal axis to collide the vehicle perpendicularly at 50 Kmph speed. The MDB is with 1500 kgs mass, and with 50 Kmph velocity colliding, the vehicle perpendicularly can cause severe injuries to the occupants[5].

1.2.3. Euro NCAP

In Euro NCAP's test, a trolley mounted with a deformable barrier (with frontal part of aluminum foam) of 950 kg mass with 50km/h speed drove into the side of the test vehicle which is stationary at right angles. Average male side impact dummies are placed in the driver's seat and the rear seats, the child dummies are placed with the help of child restraint systems.

The test guarantees that there is enough assurance of the critical body regions. This has driven the reinforcing the structures of vehicles around the B-column, the fitment of side effect or airbags in vehicles and also the advancement of more subtle vitality retaining structures in seats and door panels. The greatest possible protection can be achieved when the airbags are deployed in time [6].

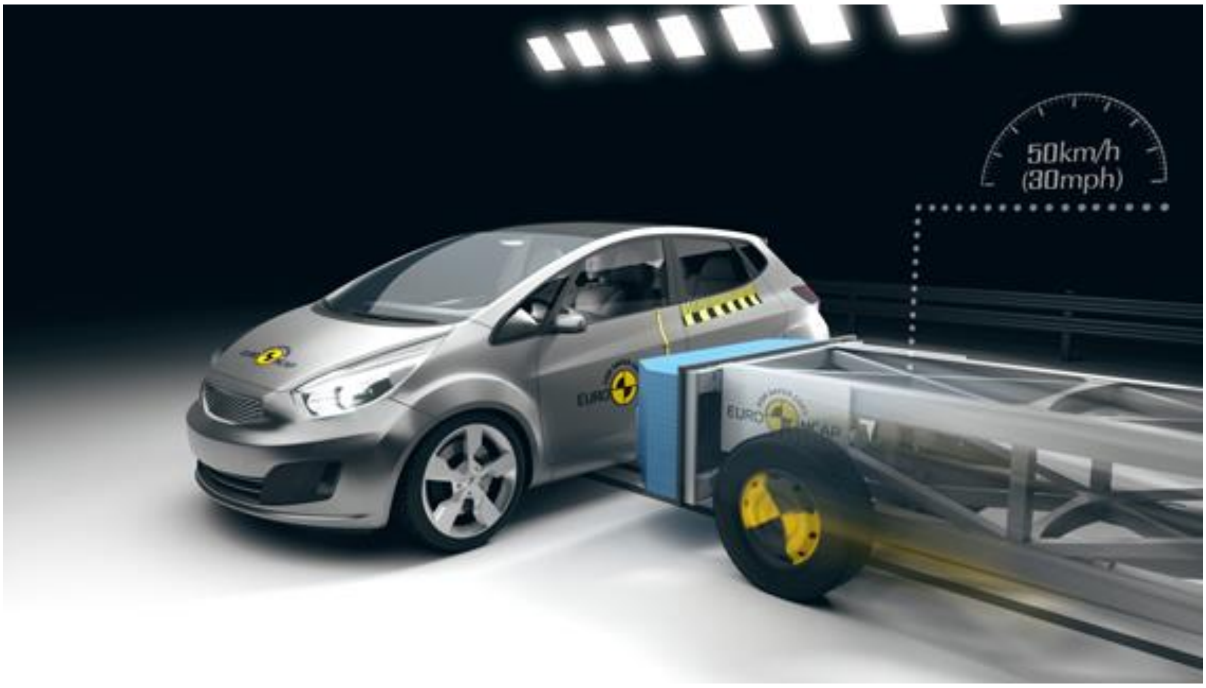

Fig. 5. Side mobile barrier impact test[6]

As per the Euro New Car Assessment Program (Euro-NCAP) in side-impact against a pole. A car is rigidly fixed on to a specially designed carriage, and it is pushed at a speed of 29kmph towards the fixed pole. Driver dummy is directed towards the pole, so that pole and driver's head were in one plane. The pole diameter is 254 mm during the impact, and it intrudes into the cabin of the car. For the Human head injury criteria (HIC) is measured.

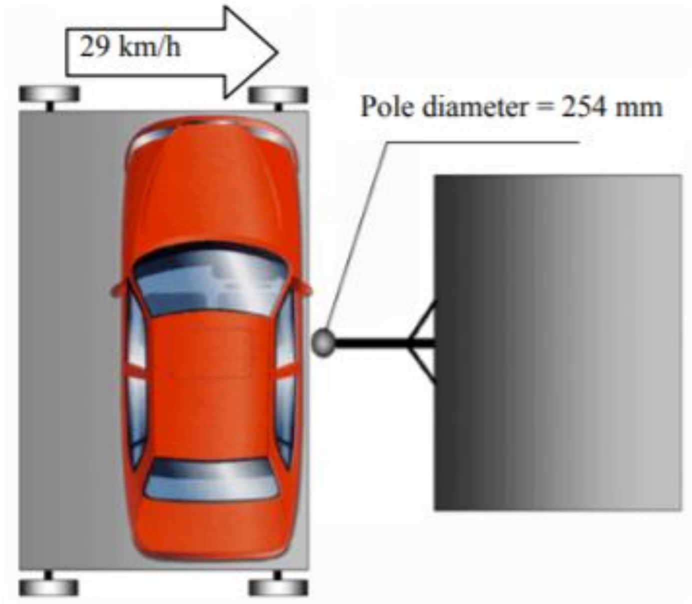

Fig. 6. Side Impact Test to the Pole as per EURO-NCAP standards[7]

1.2.4. AIS-099

The government of India has constituted the Automotive Industry Standards Committee (AISC) on September 15th, 1997, to maintain standards for the safety of vehicles and the development of test facilities. Under this, AIS-099 is the test procedure for a side impact of the vehicles under collision. The procedure is the same as the Insurance Institute for Highway Safety (II-HS) side impact test procedure[8].

1.1 Crash Data

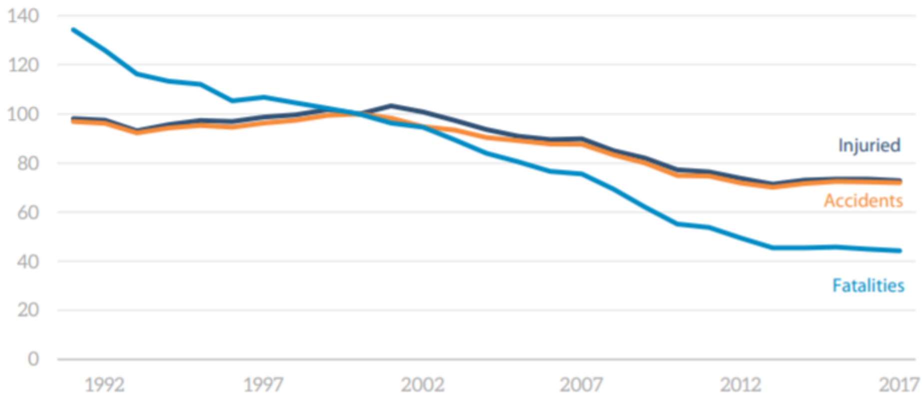

Fig. 7. Evolution of fatalities, accidents, and injuries in the EU.[9]

Between 1991 and 2017, and especially after 2000, the EU witnessed substantial improvements in terms of road safety, there was a drastic improvement in vehicle safety in EU when it was measured in terms of percentage of injuries or accidents and fatalities. in a short span from 2001 to 2010, the percentage of fatalities was decreased by 43% and around 20 % more since 2010[9].

2. Literature review

From time to time, there are many types of research going on to improve the safety of cars by using different techniques in design. The side-impact crash is also one of the main problems in-car safety. So, to increase the safety in a side-impact crash, the Intrusion beam is inserted inside the side doors. To increase the efficiency in high specific strength, high specific stiffness, damping, high impact load energy absorbing capacities, and for weight reduction of the component different types of materials and designs are used.

Mohd Fadzli Abdollah, Rafidah Hassan, has investigated on "Preliminary Design of Side Door Impact beam for Passenger Cars Using Aluminium Alloy" to reduce the weight of the component to increase fuel efficiency, because of its higher strength in weight ratio than that of the conventional steel beams. Firstly, he did a study on structural modification of the beam using finite element analysis for the cross-section. By using the Charpy test, the energy absorption characteristics of the aluminum alloy and conventional steel are investigated. After the impact test, the fracture and surface counters are observed from the preliminary results, from that Square hollow cross-section found to be having yield at high bending load. Both exhibit fractures and surface counters differently after impact and found be aluminum alloy experiences ductile fracture and high impact energy absorption than the conventional steel [10].

Seong Sik Cheon, Dai GilLee, Kwang SeopJeong researched a project known as "composite side door impact beams for passenger cars" to increase the fuel efficiency and to regulate gas emissions, and they used glass fiber reinforced composite material instead of metals, as they have low capacity to impact absorption at minimal temperatures. By using static tests, optimum stacking sequences and cross-sectional thickness were determined for weight saving ratios than to the high strength steel.

At various temperatures, dynamic tests are done by using a pneumatic impact tester at 30kmps speed. To find the composite beam's dynamic impact characteristics. Finite element analysis is also performed by using Abaqus. Experimental and FEA results are compared and found to be similar satisfactory [11].

"Taguchi Based Design Optimization of Side Impact Beam for Energy Absorption" by Radha Krishna Nemani, Dr. Rachayya ArakerimathIn. In this research study, three different side impacts beams are designed with different cross-sections. During side-impact collisions, severe injuries and deaths occur. So side-impact beams are used to reduce the impact forces on the vehicle doors as well as to reduce the intrusion of the side door interior to protect the occupant. In a test, the vehicle's side door has collided against a pole and the total door assembly is assessed. Finally, the side impact beams have a major advantage in the safety of the total door assembly.

In this case, FEM models are used to develop the three-point load test and the diameter of the rigid punch is 450mm and applied displacement is 100mm to find minimal energy absorption. these processes are performed in the LS-DYNA to find energy absorption of different beams with the Taguchi method. [12].

"Modeling, Analysis and Comparative Study of Side Impact Beam" by Harijono Djojodihardjo, Soo Lin Khai. The main objective of this research work is an effective impact beam for the door panel of a passenger car. which gives more safety for passengers regarding side impact.

In this research, firstly the vertical displacement and stresses in the steel were found out in refinement element method, beam theory, Matlab program, and Nastran&Patran, and the results from all the methods were compared. the solution was analyzed to find the best method to continue in this research.

Nastran&Patran results found to be reasonable. The specimen beam is designed in Catia with specific dimensions and the model is imported into MSC/PATRAN to transform the model into the finite element model. The material glass-fiber-reinforced polymer is used with Epoxy resin and simulation is carried out in static and dynamic conditions. And the results of the beam were compared with different materials. From the results, the glass-fiber-reinforced polymer has high stiffness and strength in static analysis and high impact energy absorption capacity in dynamic conditions [13].

Analysis of FRP side-door impact beam by S Eržen, Z Ren, and I Anžel. In this research, they designed different types of side impact beam with composite material known as fiber-reinforced plastics made up of Twintex with multiple layers and orientations to reduce the weight of the beam. due to the reduction of weight, it can improve fuel efficiency and emission reductions. They found the highest possible strain energy by changing the number of layers, orientation, and thickness and compared the results with a standard steel impact beam. They used a Finite element method (FEM) for computational analysis with European standard ECE-R 95 to find the behavior of the impact beam under loading to get the impact energy absorption. Because of the Twintex composite, the overall thickness as increased but still the 10 % weight reduction achieved, when compared with the standard steel impact beam [14].

“Investigation of anti-intrusion Beams in vehicle side doors” research project by E. Černiauskas, A. Keršys, V. Lukoševičius, and J. Sapragonas. In this paper, the new anti-intrusion beam was designed under FMVSS 214 regulation standard.

The anti-intrusion beams were designed with different cross-sections and different steel grade standard material. Firstly, the experimental and numerical methods were done and compared to find the effective beam with high strength. The rigid closed profile beams at different materials and in open profile beams have minimum stiffness requirements. The side door Intrusion beams are designed in the CAD model to evaluate the structure stiffness during the collision against the obstacle. Analyzed the side vehicle impact beam against the obstacle developed from FE models of the force-power characteristics of non-isolated beams and dynamic investigation of the beams. Calculation of the experimental beam and FEM results of the open profile side door beams with a different cross-section and different materials of the mechanical properties. The results are depending on the mechanical properties of the material, which is used to perform in mechanical testing of the side impact beams [7].

Divakara H Basavaraju researched “Design and analysis of a composite beam for side-impact protection of occupants in a sedan”. The main aim of the project is to build an efficient beam to reduce the injuries to the passenger during sid impact collision nad also to reduce the weight of the beam. So the designed a composite side impact beam using Carbon/Expoxy AS4/3051-6.

A Ford Taurus car‘s and Moving Deformable Body‘s finite element models developed by the National Crash Analysis Center were taken and used in this research. The side impact is designed with different thicknesses, layers, and orientations in Catia and MSC/PATRAN. The beam in the FEA models is replaced with a newly designed composite model and simulation was carried out in different conditions to total energy absorption energy. And the simulation is carried for the steel beam. Both the results were compared . and proposed that the composite beam is more efficient and 65% weight reduction [15].

Avinash P. Pawar researched on “Crashworthiness Evaluation of Low Weight Recyclable Intrusion beam for Side Impact” project by Avinash P. Pawar, the main aim of the research project is to design a lightweight and efficient intrusion beam to protect the passengers during a side-impact collision. Thermoplastic glass epoxy fiber is used as a material. The intrusion beam is designed and analyzed using FEA software. The results were verified under the Federal Motor Vehicle Safety Standards (FMVSS)-214. And the experiments were also carried out using the Universal Testing Machine (UTM). Both the FEA and experimental results were compared.

1. FEA results are varied by 23.2 % with experimental results.
2. The rectangular cross-section composite intrusion beam has high strength when compared with other beams.
3. The glass epoxy fiber intrusion beam has 41.4% weight than the high strength steel intrusion beam[1].

Yogesh K. Nicht, Prof. Arun. K. Battu researched on “Development of Side Door Intrusion Beam of Passenger Car for Maximum Bending Load” project. In this research work, they developed different cross-sections in CAD software to make a three-point bending test by using the LS-DYNA. Different parameters are improved to measure the maximum load bending capacity in the I-shape, square shape. C beam and circular sections to compare the bending force. This paper concluded I-shape and square shape beams require the high bending force as compared with conventional circular cross-sections beams and I-shape requires maximum bending force than others. I section is the replacement for circular beam because the reduced part weight is 17% and load capacity is increased by 34%. The square beam can replace a circular beam and also reduce the weight by 10% and increases the load capacity by 24% [16].

K. Veeraswamy, V. VenkataSudheerBabu researched on “Design and Analysis of a composite beam for side impact protection” project. The aim is to design a composite beam to reduce the weight of a side impact beam and to increase the safety and fuel efficiency of the car. Decreasing the weight of the beam without compromising in safety is the main criteria of the project. Which also results in a decrease in the emission of gases. They designed a composite beam with Carbon/epoxy AS4/3051-6 material, which as high stiffness, strength, and energy absorption characteristics. Car doors and Moving block‘s finite element models are used to do analysis. The new beam is designed in the Catia software and replaced the existing side impact with it. The simulation is carried out to find the total energy absorption of the beam. And the results are evaluated according to the FMVSS-214 side-impact safety standards. The total energy absorption results of the composite beam and steel beam are compared. Concluded that there is a 65% weight reduction in the beam weight. If the steel beam is replaced with a composite beam, and also the composite beam has a high energy absorption capacity. But the composite beam is failed in buckling during the impact loading, but it can be rectified by proper changes in design, fabric orientations, and layers[4].

Pedro Mota Rebelo researched on “Design Study of a Side Intrusion Beam for Automotive Safety” project. The project aims to build a side intrusion beam to absorb the high impact energy through a phenomenon called elastoplastic deformation. Designed the beams with different thicknesses to evaluate the energy absorption capacity and bending performances.

The analysis is carried out in two types of approaches, experimental analysis, and FEA. firstly the beams are analyzed in 3-point bending in a laboratory and the bending performance results were taken and they are analyzed in the CAE software by placing the side intrusion beam in the car FEA model. In the end, the results were compared and concluded that the increase in thickness and also material selection plays a major role because the yield strength of the material also results in the increasing un the bending performance of the beam and also energy absorption capacities of the beam [17].

3. Theoretical background

When compared with the frontal crash injuries, the side impact vehicle crash injuries are severe. The occupants are directly affected by the vehicle structures as there is no enough space for the structure of the vehicle to deform during a collision. So, to minimize the impact of the collision on the occupant, the vehicle structure (side impact beam) should absorb the maximum crash impact forces. The maximum strength of the side impact will reduce the crash effect on the occupants and save them from injuries in severe accidents.

3.1. Side impact beam

A side impact beam is a passive safety device. It is installed in the car side doors. The main purpose of the beam is to strengthen the door and to observe the impact loads during the side-impact crash. Side impacts are very dangerous for two reasons 1) the impact of the collision is very near to the occupant, who can be immediately affected by the impact vehicle 2) in most of the cases the impact vehicles are larger, heavier, taller or structural stiffer than the stuck vehicle.

Fig. 8. Car side door with an Intrusion beam[7].

3.1.1. Requirements of the side impact beam

Federal Motor Vehicle Safety Standards (FMVSS) No. 214 builds up the minimum strength requirements for passenger cars' side doors. The side doors should be capable enough to withstand a crush resistance of 2,250 pounds initially after deformation of 6 inches. 3,500 pounds and 4,375 pounds of intermediate crush resistance without and with seats installed after deformation of 12 inches, respectively. Nearly it should withstand the maximum crush resistance, which is two times the car‘s weight or without seats is 7,000 pounds installed and 3-1/2 times the car‘s weight or with seats installed is 12,000 pounds after the deformation of 18 inches [18].

3.2. Test methodologies for crash test

There are different methodologies in crash tests.

3.2.1. Impact testing

In this test, the velocity of the impact test reduces from an initial condition to zero at the end as the energy was observed by a specimen.

Advantages of impact testing:

- It's an actual crash simulation because the Stress rate sensitivity of materials comes into account during the crash simulation.

The major disadvantage of impact testing:

- In Impact testing, Infractionn of seconds the crushing process took place. So, its recommended to use a highspeed camera to study the process [19].

3.2.2. Quasi-static testing

In quasi-static testing, the specimen is subjected to crash under the constant velocity. But it's not the actual condition of crash simulation. Because in the actual crash condition, the velocity of crushing gradually decreases from an initial impact velocity to the zero at the end.

Advantages in quasi-static testing:

- The tests are simple to do and control.
- When compared with the impact test, the equipment is not much expensive, and also the process doesn't occur in a split second. Here we can study the composites' mechanical failures with the desired speed.

Major disadvantages:

- It may not be like actual crash simulation conditions because certain materials are strain-rate sensitive [19].

3.2.3. Dynamic collision test (FMVSS 214)

In this test, a moving deformable barrier (MBD) travels at a speed of 33.5 mph and strikes a car(specimen), which are perpendicular to each other. All wheels of MBD are inclined at a 27° angle. An aluminum honeycomb barrier is fixed in the Infront of the MBD at the bumper‘s height. And the US side impact dummies are placed inside the car to measure the severity of injuries [20].

3.2.4. Composite test procedure (CTP)

A fully equipped vehicle or body in white, with all relevant components for lateral impact fitted, can be used in the test, allowing the safety characteristics of the vehicle to be evaluated at an early stage.

The CTP does not use a mechanical dummy. The loads to which occupants are subjected are calculated with the help of a simulated(mathematical) occupant. As the characteristics of this occupant are not subject to scatter, the CTP offers superior overall test repeatability.

Everything indicates that a mathematical occupant is better suited than a mechanical dummy to simulate human behavior because an increased level of sophistication can be incorporated, which relates much more accurately to actual human characteristics. Besides, less time and money is required to modify a mathematical occupant as new biomechanical findings emerge, which is not the case for a mechanical dummy.

The CTP offers deeper insight into the collision process. It is, therefore, not only suitable as a test procedure but can also be used as a development tool. As in the case of fullscale tests, the designer is free to select the countermeasures he wants. He can exploit the options in terms of structure as well as padding to protect the occupants.

Although the CTP results are a development from a specified collision speed and vehicle barrier mass, the results for other speed and masses can, within certain limits, be derived from the same test. Thus other accident situations can be evaluated from a single test[21].

3.3. Injury pattern in side-impact

side-impact collision mainly affects the chest, stomach, and pelvis of the passenger beside the door. Mainly the injuries occur because of the intrusion of the door panel. So the safety standards mainly concentrate on the severity of the impact of collision of these body parts.

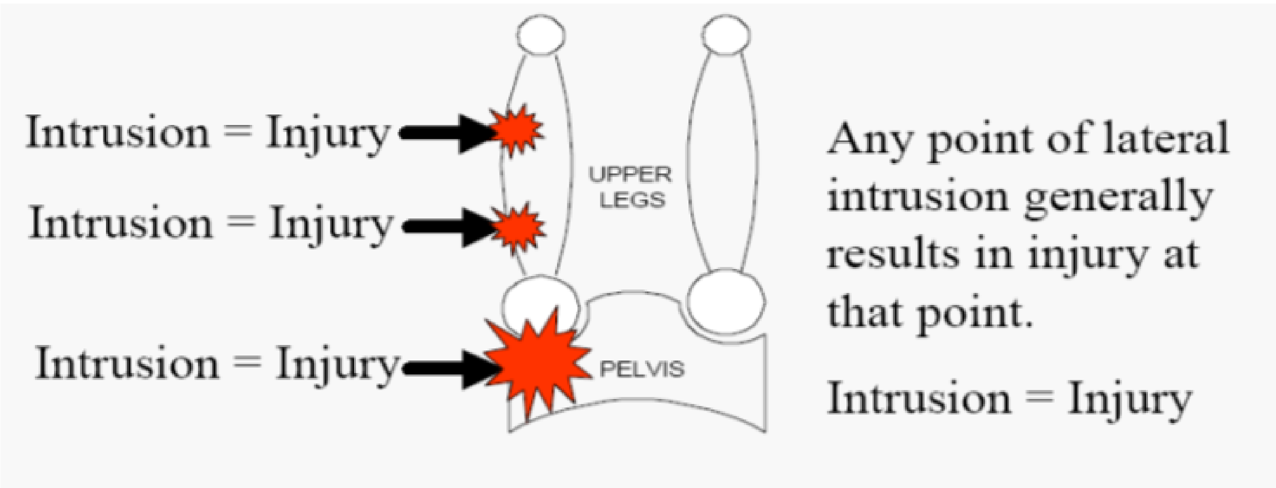

Fig. 9. Side impact injury pattern[15]

3.4. Numerical formulas for energy absorption

3.4.1. Energy absorbed per unit mass

Energy absorbed per unit mass is the ratio of the energy observed by crushing (E) to the deformed structures unit mass.

$$E_S = \frac{E}{\rho\delta A_{mat}} = \int_0^{\delta} \frac{F\,dx}{\rho\delta A_{mat}}$$

(3.3.1.1)

For simplified analysis the equation 1. can be written using average collapse load ($\bar{F}$)or average collapse stress ($\bar{\sigma}$) as

$$E_S \approx \frac{\bar{F}}{\rho A_{mat}} = \frac{\bar{\sigma}}{\rho}$$

(3.3.1.2)

Specific energy absorption is significantly useful to calculate and compare the energy absorption capability for various structural materials where weight is considered a majoraspect[4].

3.4.2. Energy absorbed per unit volume

When the deformation zone is restricted for energy absorption during the crash, then in those situations, Energy absorbed per unit volume has appeared. It might be suitable when components other than the parent material‘s deformation contribute fundamentally to a structure’s general capability of energy absorption [4].

3.4.3. Energy absorbed per unit length

It is the ratio of the energy absorbed per unit to the distance of deformation. This can express as

$$E_L = \frac{E}{\delta}$$

(3.3.3.1)

It gives an accessible and easy way to measure the structure crashworthiness, where the collapse is limited to a well-defined crash zone.

For a given circumstance, the energy absorption parameters will rely upon the type of material and crushed structure’s geometry and the type of application under consideration[4].

3.5. Material properties of Intrusion beams.

3.5.1. Elasticity

if the stresses induced in a material are less than the limit of yield strength than the material will recover fully to its original shape without any break in the chemical bonds between its atoms. Only the atomic bonds will stretch because of the elasticity in between them.

Elastic behavior of metals is described by Hooke's law

$$\sigma = E\varepsilon$$

(3.5.1)

3.5.2. Plasticity

If the stresses induced in a material is beyond the limit of yield strength than the material will deform permanently.

– Materials failing because of small deformation are brittle.
– The ductile response is safer for the beams as it elongates instead of breaking.

Hardening rules are two types of Hardenings[22].

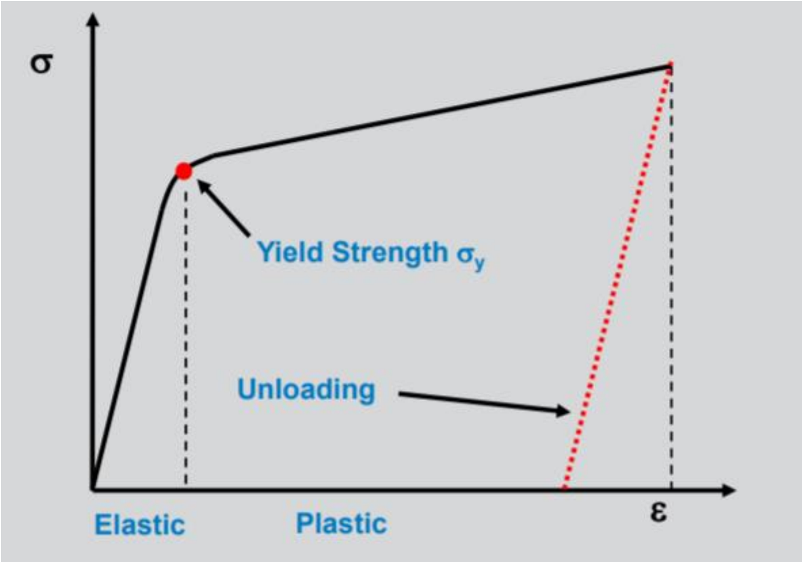

Fig. 10. Stress v/s Strain curve[22].

3.5.2.1. Kinematic hardening

The yield surface translates in the direction of yields and remains constant in size. isotropic material initially experiences kinematic hardening and no longer isotropic after it yields. In every large strain simulation, because of the Bauschinger effect, the linear kinematic hardening model can become inappropriate. It is generally used for small strain and cyclic loading applications [22].

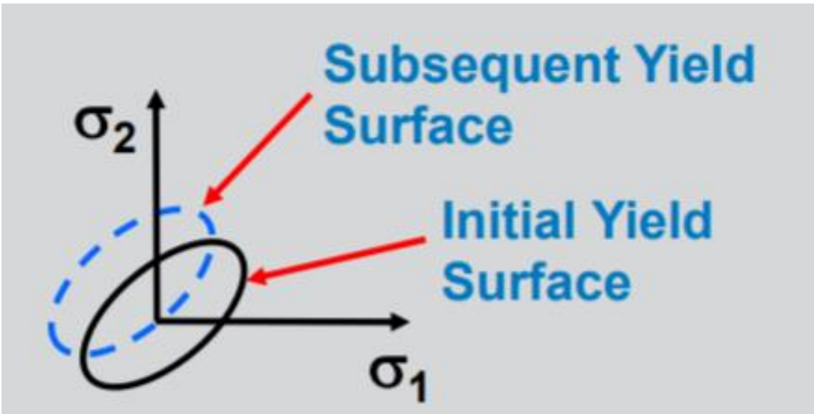

Fig. 11. Kinematic hardening[22].

3.5.2.2. Isotropic hardening

The yield surface enlarges uniformly with the plastic flow in all directions. It raises the uniform dilation of the yield surface and it is dissimilar from an ’isotropic‘ yield criterion(ie., material orientation). The succeeding yield in compression and the high-rise stress attained are equal during the tensile phase. It is mostly used for higher strain and corresponding loading simulations. It is usually not applicable to fo cyclic loading [22].

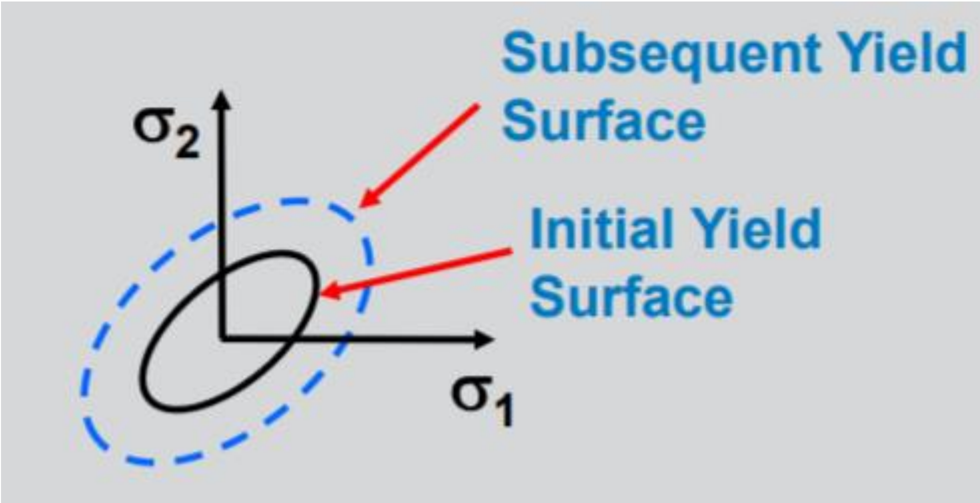

Fig. 12. Isotropic hardening [22].

There are two types of stress and strain curves representations possible in the Ansys Engineering database.

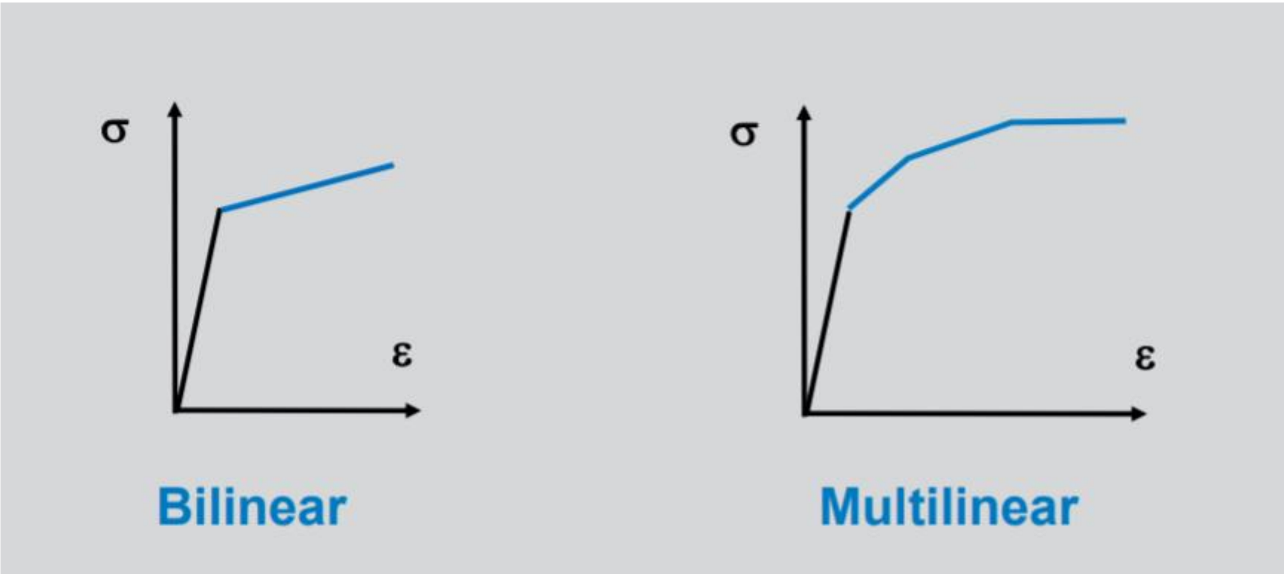

Fig. 13. Stress-Strain curve types[22].

4. Research methodology

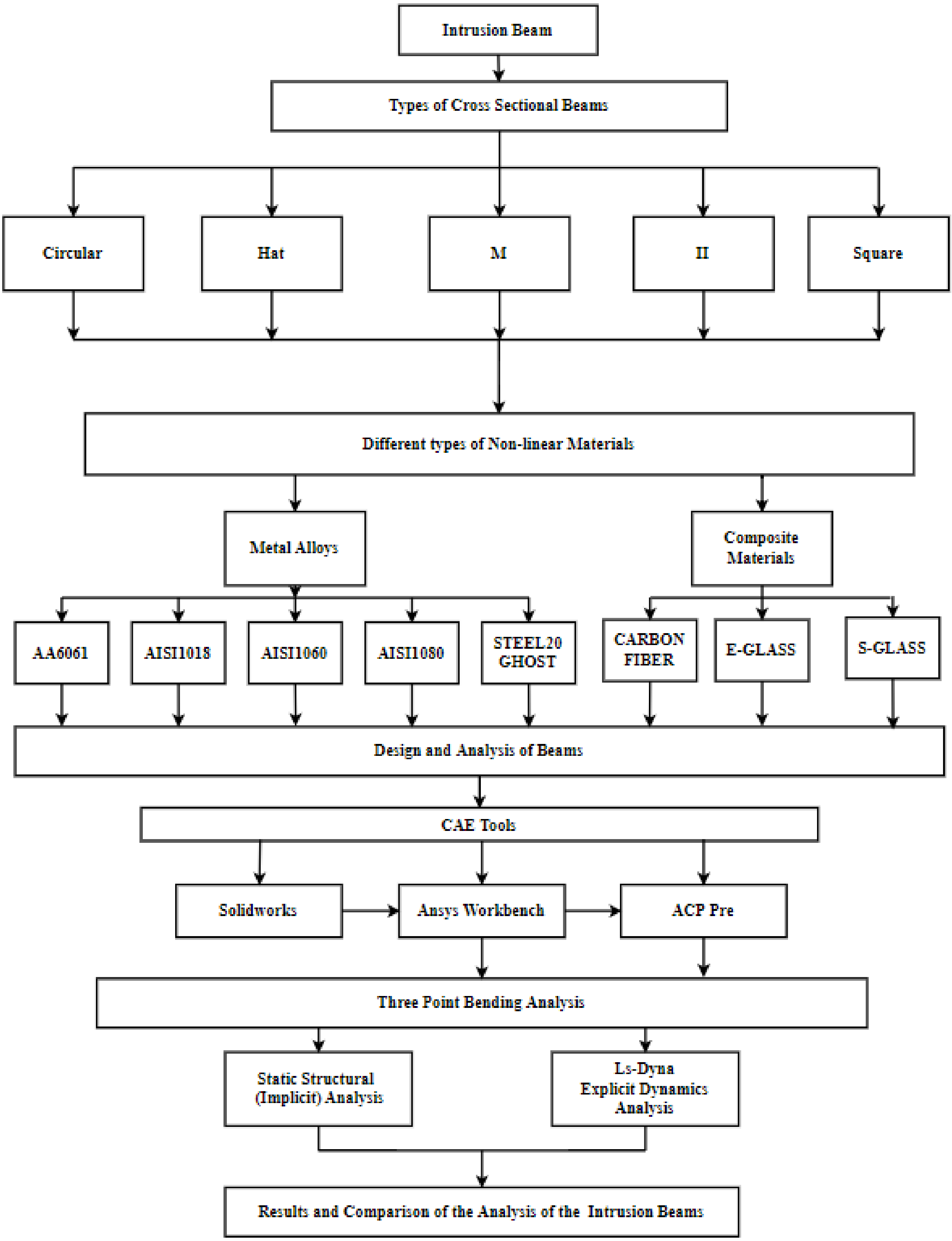

Fig. 14. Flow chart of Research Methodology

The methodology of this research is to design and analysis of the different cross-sectional Intrusional beams with different materials, such as metal alloys and composites. These Intrusion beams are fitted in the side doors of a passenger car to protect the passenger during a collision. When compared with the severity of the injuries, the side-impact collision will have a five times greater impact on the passenger than the frontal collision, as there is very little space between the door and the passenger. So we need the Intrusion beams with high strength, stiffness, and energy absorptions.

But the weight is also one of the main criteria in manufacturing passenger cars concerning fuel efficiency. So metal alloys and composites beams are used, which are having less density when compared with steel and aluminum.

- Design of five different cross-sectional Intrusion beams with different materials.
- Analyzed these different cross-sections in implicit structural analysis in ANSYS Workbench to find out the Force reactions and Displacements.
- Later on, Analyzed them in explicit dynamics analysis in ANSYS Workbench Ls-Dyna to find the internal energy absorption.

By using the ACP Pre, composite beams with the number of plies with different orientations are designed. And did implicit and explicit analysis in ANSYS Workbench and ANSYS Workbench Ls-Dyna respectively to find out the Force reactions, Displacements, and Internal energy absorption for comparison

4.1. Problem identification

This research is based on many literature reviews, which are about the side impact beams or Intrusion beams. The main aim of all the previous researches is to find an effective and efficient beam to withstand during a collision. But few problems are identified from them such as

- Many of the side impact beams are made up of steel, where the density is high. Which means the weight is increased. It is not a good sign in modern vehicles, as fuel efficiency is also of the main criteria.
- Many of the beams are not able to withstand high deformation and have a low energy absorption rate.
- There are only a few 3-point bending analysis types of research. But it’s one of the cost-effective analysis.
- Much of researches are did in safety standards to NHTSA and II-HS, which are time-consuming and high-cost research.
- In previous researches, there is no comparative analysis on beams made up of metal alloys and composites materials under Implicit and Explicit conditions.
- The cross-section of the beam should be in a manner to withstand high deformation values and to absorb high impact forces. There only a few such types of beams.
- So, the Intrusion beam has to be made up of nonlinear materials to have high strength and energy absorption during impact forces with low density to reduce the weight.

4.2. Design of intrusion beams

4.2.1. Different types of cross-sections of intrusion beams designed in Solidworks

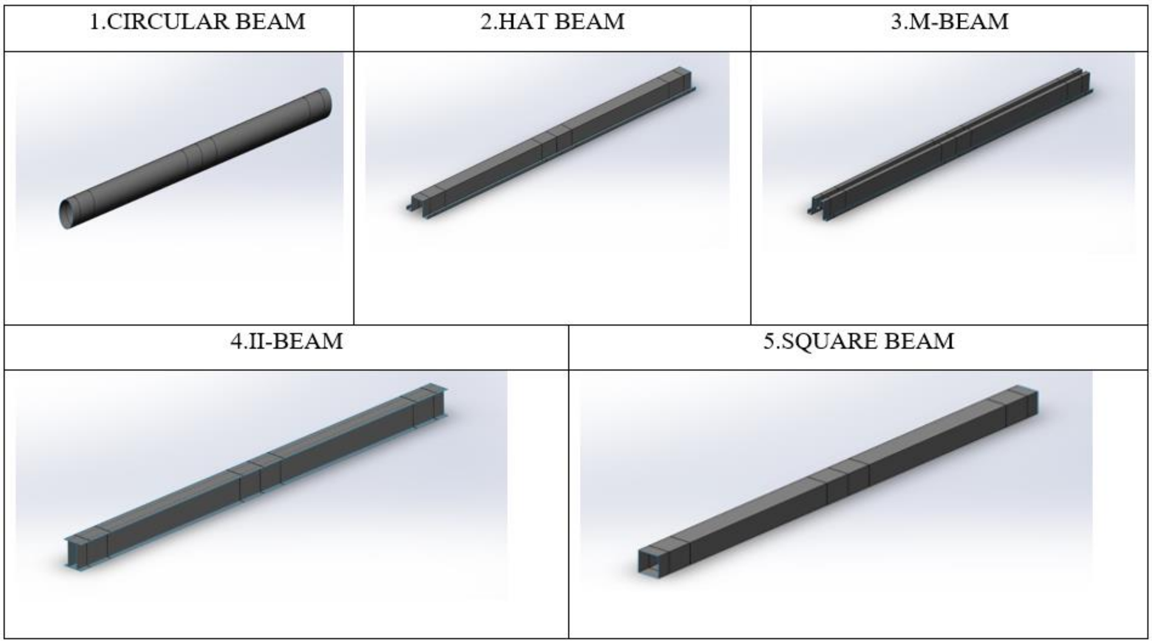

Fig. 15. Different types of Cross-sections of Intrusion beams

These beam profiles are designed by CAE software called Solidworks. These are shell models with a length of 1000 mm.

4.2.2. Dimensions of the Intrusion beams

Table 1.Dimensions of the different cross-sectional Intrusion beam profiles

S.no.	Cross-sections of beam profiles	Thickness (mm)	Distance between supports (mm)
1	Circular beams	2 mm	900 mm
2	Hat-type beams	2 mm	900 mm
3	M-type beams	2 mm	900 mm
4	II--type beams	2 mm	900 mm
5	Square beams	2 mm	900 mm

4.3. Material Description

The two different categories of materials are used in this research metal (steel and aluminum) alloys and composite materials.

Steel and aluminum alloys are AA6061, AISI 1080, AISI 1060, AISI 1018 and Steel 20 GOST

Composite materials are Carbon fiber, E-Glass, and S-Glass.

Table 2. Material properties of metal alloys[7]

Mechanical Properties	Metal Alloys				
	AA 6061	**AISI 1080**	**AISI 1060**	**AISI 1018**	**Steel 20 GOST**
Young's Modulus, (Pa)	69E+10	205 E+10	205 E+10	205 E+10	205 E+10
Poisson's Ratio	0.33	0.28	0.28	0.29	0.3
Density, (kg/m^3)	2700	7860	7860	7865	7860
Tangent Modulus, (Pa)	675E+8	5669E+8	1468E+8	763E+8	110E+8
Yield Strength, (Pa)	262E+8	869E+8	430E+8	315E+8	210E+8

4.3.1. Carbon fiber

It is made up of carbon crystals, which are aligned in the long-axis as ribbons. The crystals aligned in ribbons make the fibers strong enough to withstand loads. These ribbons are arranged within the fibers. The stiffness of the carbon fiber depends upon Young's modulus. It is an orthotropic elastic material.

Carbon fibers have great properties:

- High strength to weight ratio.
- Rigidity.
- Fatigue resistance.
- Good tensile strength but brittle.
- High thermal conductivity.

Fig. 16. Carbon fiber material[23]

Table 3. Material Properties of Carbon Fiber

Material Properties		Carbon Fiber
Density (kg/m^3)		1800
Orthotropic Elasticity	Young‘s Modulus in X directions (Pa)	2.3E+11
	Young‘s Modulus in Y directions (Pa)	2.3E+11
	Young‘s Modulus in Z directions (Pa)	2.3E+10
	Poisson’s Ratio XY	0.2
	Poisson’s Ratio YZ	0.4
	Poisson’s Ratio XZ	0.2
	Shear Modulus XY (Pa)	9E+09
	Shear Modolous YZ (Pa)	8.21E+09
	Shear Modolous XZ (Pa)	9E+09

Fig. 17. E-glass composite material[24]

Table 4. Material Properties of E-Glass, S-Glass and Resin Epoxy

Material Properties		**E-Glass**	**S-Glass**	**Resin Epoxy**
Density (kg/m^3)		2600	2500	1160
Isotropic Elasticity	Young‘s Modulus (Pa)	7.3E+10	9E+10	3.78e+09
	Poisson‘s Ratio	0.22	0.22	0.35
	Bulk Modulus (Pa)	4.345E+10	5.37E+10	4.2e+09
	Shear Modulus (Pa)	2.99E+10	3.688E+10	5.4e+07

5. Model setup and analysis

The Intrusion beams are firstly designed in the Solidworks as shell models, and then they are imported into the Ansys Workbench to do implicit and Explicit dynamics analysis. To find the deformation and force reaction, the static structural analysis is used. And to find the internal energy absorption, the Workbench Ls-Dyna is used. The different materials are added to the Engineering database.

5.1. Model setup in Static Structural and Workbench Ls-Dyna

The different shell models are imported from the Solidworks into Static Structural and Explicit Dynamics of Ansys Workbench. The different materials are selected from Engineering Data. The beams are simply supported on the fixed supports at both ends with a certain distance from the end. A rigid punch is placed on top of the beam in the middle.

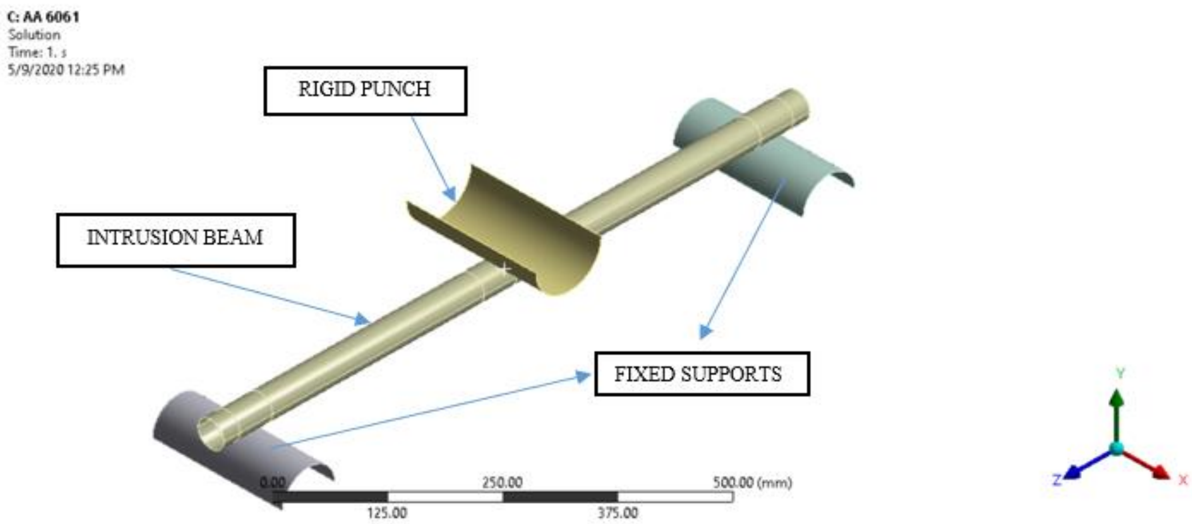

Fig. 18. Model Setup in Ansys Workbench's Static Structural and Workbench Ls-Dyna

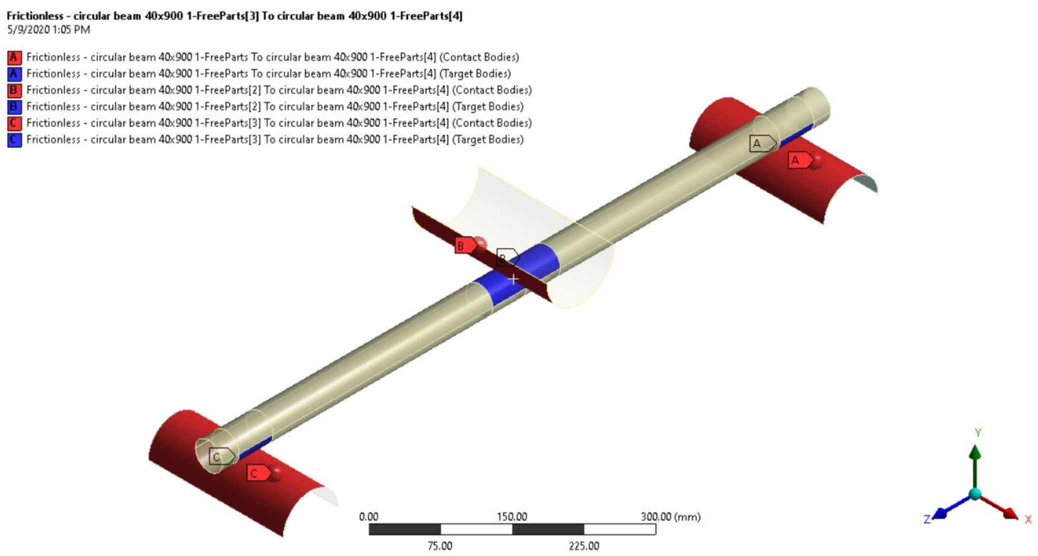

Fig. 19. Types of connections between beam, fixed support, and rigid body.

The connection between the beam and the fixed supports‘ surface is frictionless. And also, the connection between the beam and rigid punch is frictionless. During the connections, a command is inserted to apply thickness to the beams. Command: "keyopt,cid,11,1"

5.1.1. Static Structural Analysis and Workbench Ls-Dyna (explicit dynamics)

Mesh details

The accuracy of the Finite Element Analysis depends upon the type of meshing.

Table 5. Mesh Parameters

Mesh Parameters	**Implicit analysis**	**Explicit analysis**
Element Size	8 mm	6 mm
Physical Preference	Mechanical	Explicit
Size function	Uniform	Uniform
Behavior	Smooth	Smooth
Methods	Quadrilateral	Quadrilateral
Number of nodes	2597	3254
Number of elements	2488	3108

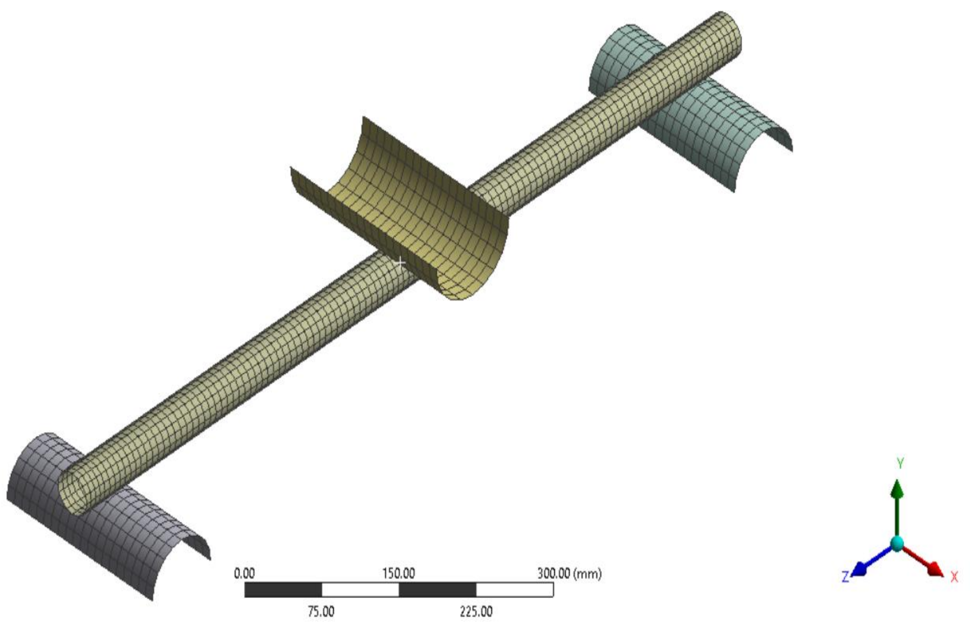

Fig. 20. Meshed

In Static Structural analysis, the displacement of -150 mm is applied to the surface of the rigid punch in Y-direction.

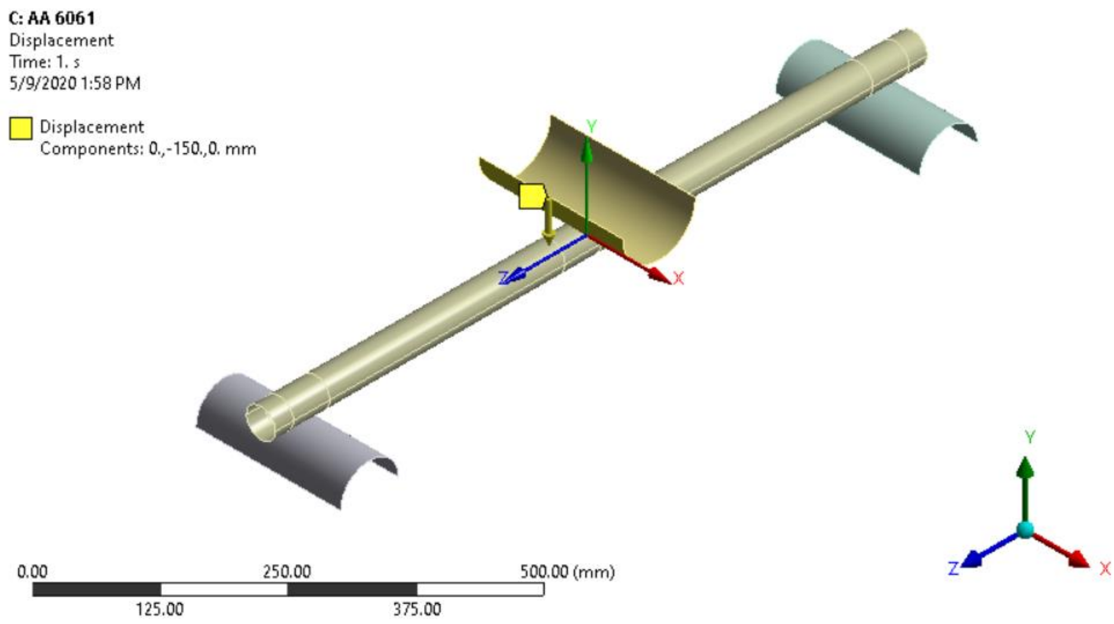

Fig. 21. Displacement applied in Y-direction to the Rigid Punch

Table 6. Displacement of Rigid Punch

Axis	**Displacement (mm)**	**Velocity (mm/s)**
X	0	0
Y	-150	-10,000
Z	0	0

The weight of the rigid punch is 50 kgs and the material applied for fixed supports and rigid punch is a structural steel with high density.

5.1.2. ACP Pre

Composite materials are designed using ACP Pre. These are created by stacking up the layers with different thicknesses, material, and orientation. It is designed to be lightweight and strong. Composites are more flexible in designing different complex shapes. The composite materials used are Carbon Fiber, E-Glass, and S-Glass.

Number of layers = 10

The thickness of each layer = 0.2 mm

The thickness of the composite beam = 2 mm

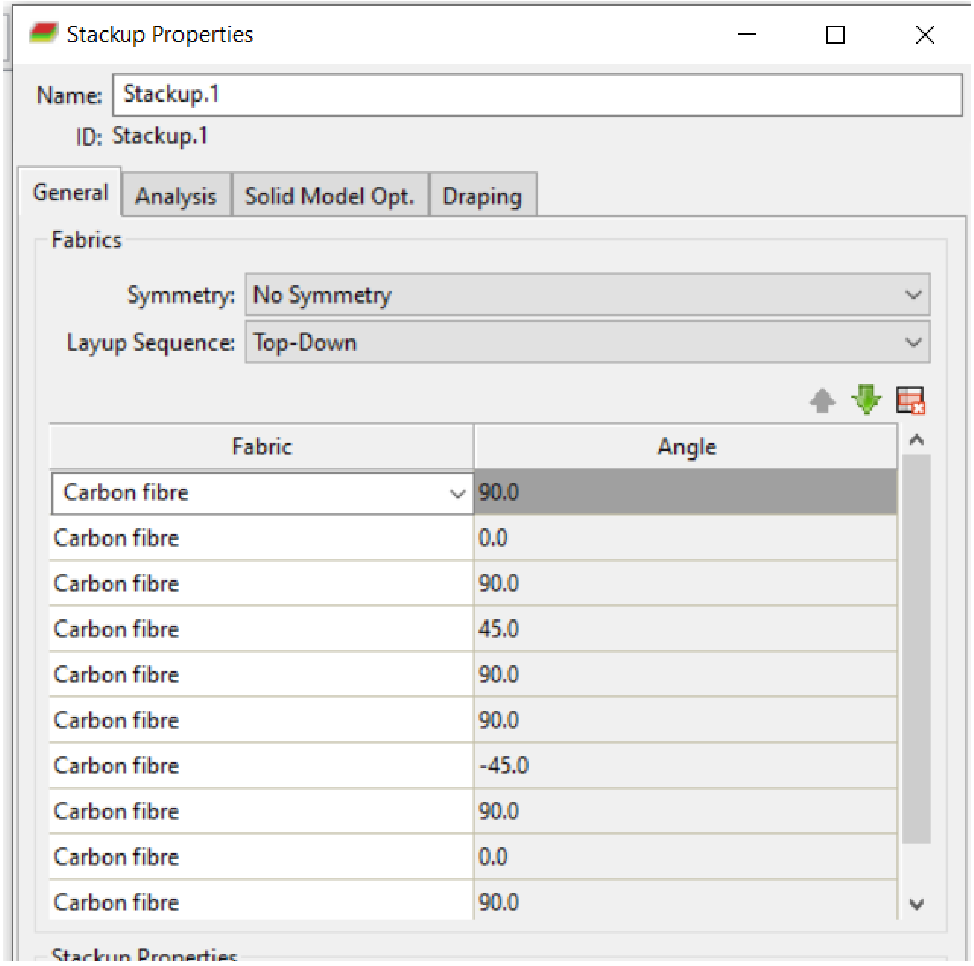

Fig. 22. Stackup of 10 layers in different orientations.

The arrangement of layers in a specified orientation (90/0/90/45/90/90/-45/90/0/90)

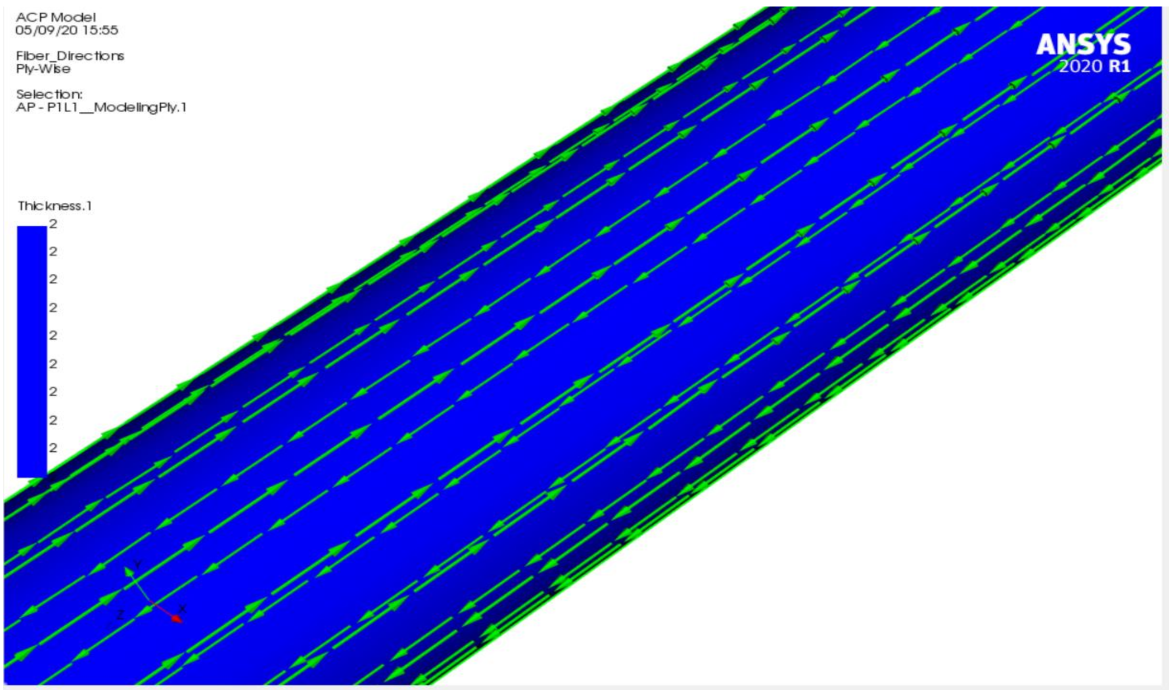

Fig. 23. Orientation (90°) of one layer in the ACP Pre.

- Each layer in stack up is oriented in different degrees to increase the mechanical properties of the beam.
- The composite beams are stack up by ten layers or laminates with different orientations, as mentioned below.
- The orientation is the direction of the laminates. Composite materials will have different properties in different directions.

The polar plot exhibits (E1, E2, and G12) rotated by 0 to 360 degrees are laminate engineering constants. This plot summit laminate's anisotropy of the and the orientation influence [25].

E1, E2 determines the stiffness of the laminate, and G12 determines the shear stiffness of the laminate.

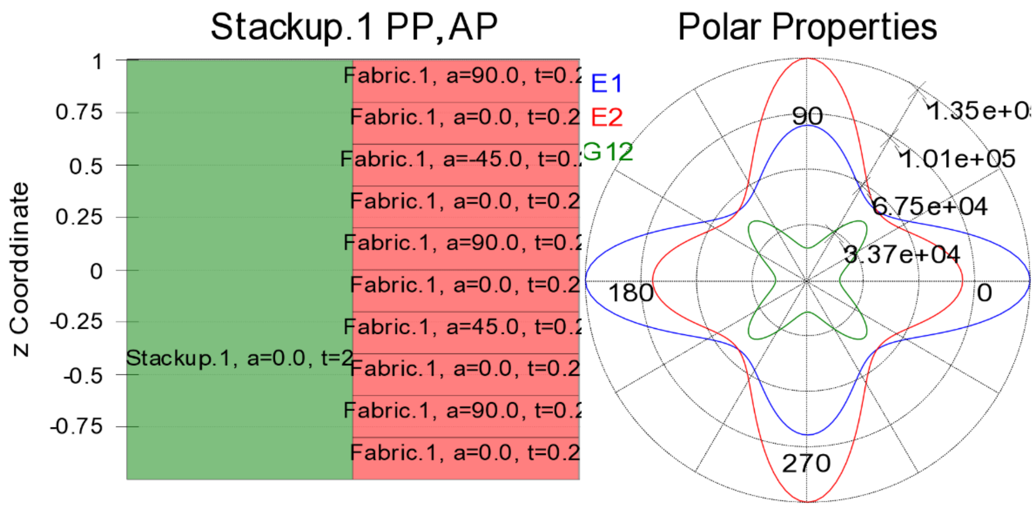

Fig. 24. Polar properties of the Carbon fiber material

The carbon fiber is an orthotropic material. It means that it exhibits different properties in different directions. The carbon fiber laminates exhibit high stiffness in 0 and 90 degrees as per the polar diagram. This is the desired property to design the intrusion beams.

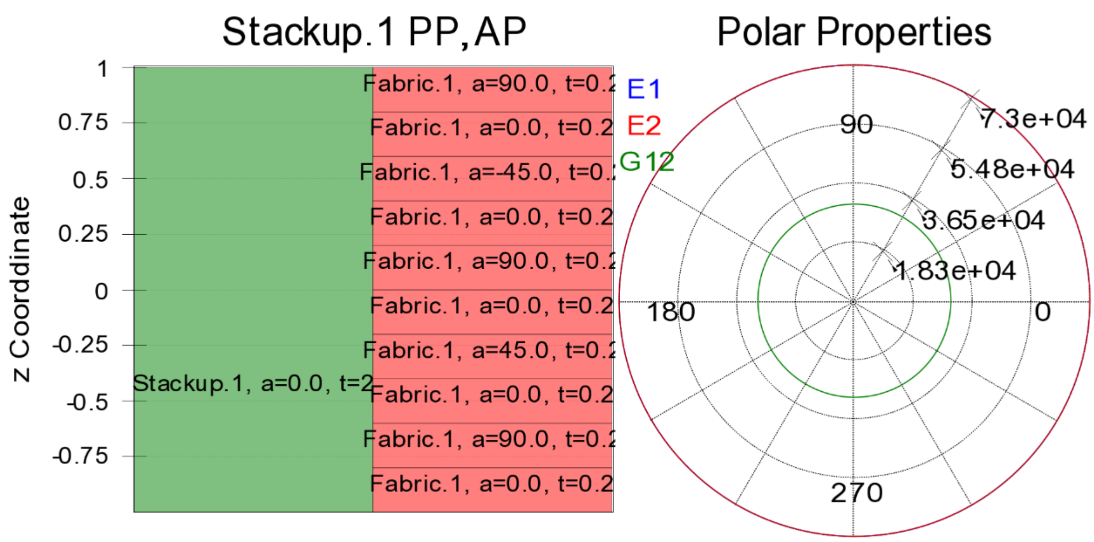

Fig. 25. Polar properties of the E-glass material

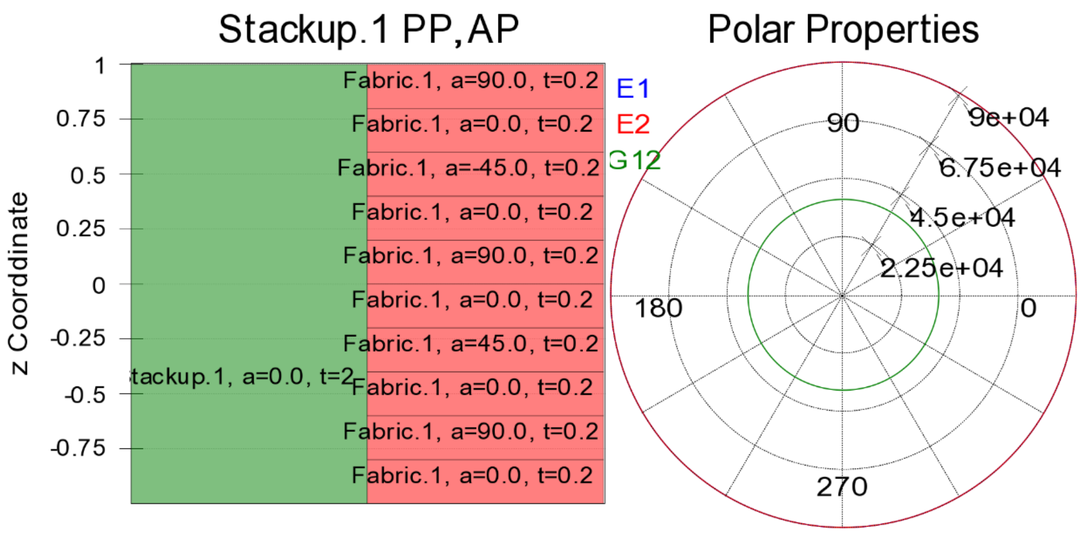

Fig. 26. Polar properties of the S-glass material

E-glass and S-glass are anisotropic materials. It means they exhibit the same properties in all directions. The E-glass and S-glass laminates exhibit the same stiffness in 0 to 360 degrees as per the polar diagram. It can withstand when the load is applied in any directions

6. Results and Discussions

The Intrusion beams with metal alloys and composite materials are tested in Static Structural to find the deformation and force reaction. And also tested in Ls-Dyna Explicit Dynamics to find the internal energy of the beam.

6.1. Metal alloy beams

6.1.1. Static Structural Implicit Analysis

The five different beams are analyzed with five different materials like AA6061, AISI 1016, AISI 1060, AISI 1080, and Steel 20 GOST to find out the directional deformation or displacement in Y-direction and force reaction.

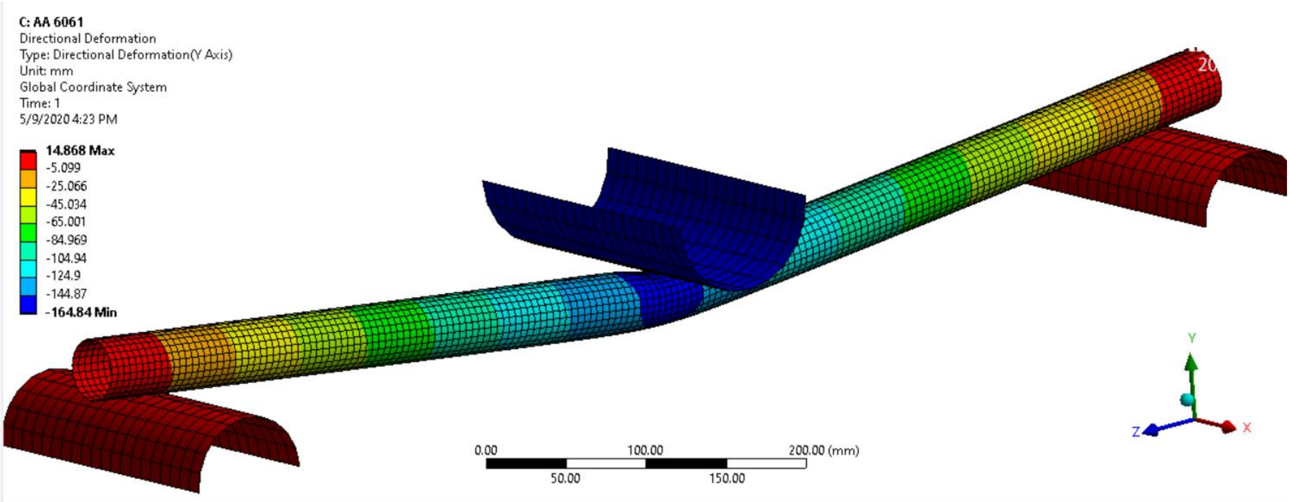

Fig. 27. Deformation of Circular beam in Y-direction

The Circular beam with AA6061 material deformation in Y-direction is -164.84 mm under a rigid punch‘s displacement of -150 mm in Y-direction.

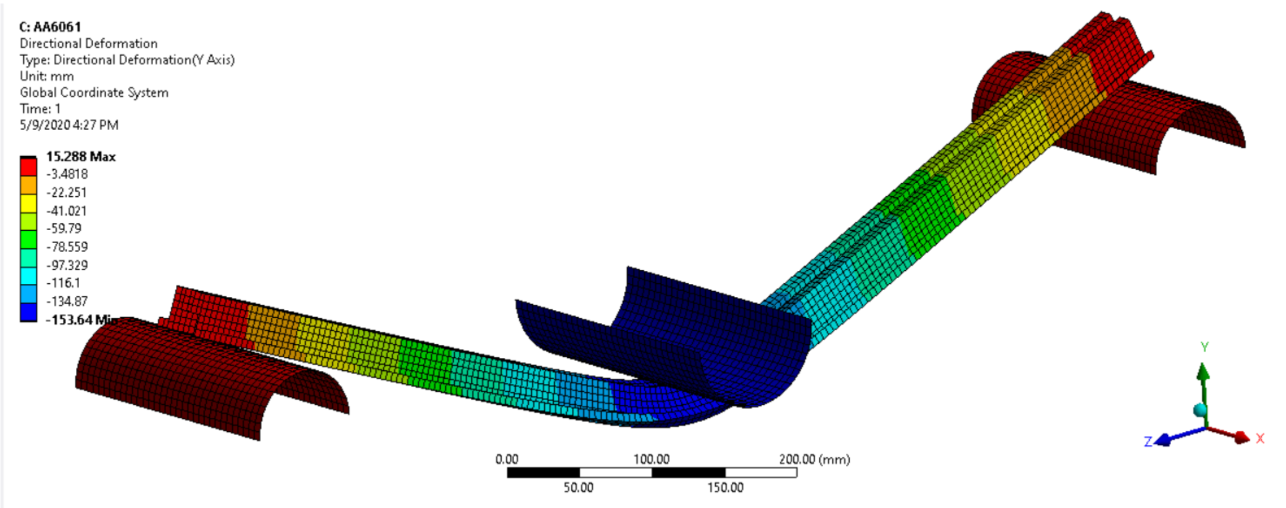

Fig. 28. Deformation of M-beam in Y-direction

The M-beam with AA6061 material deformation in Y-direction is -153.64 mm under a rigid punch's displacement of -150 mm in Y-direction.

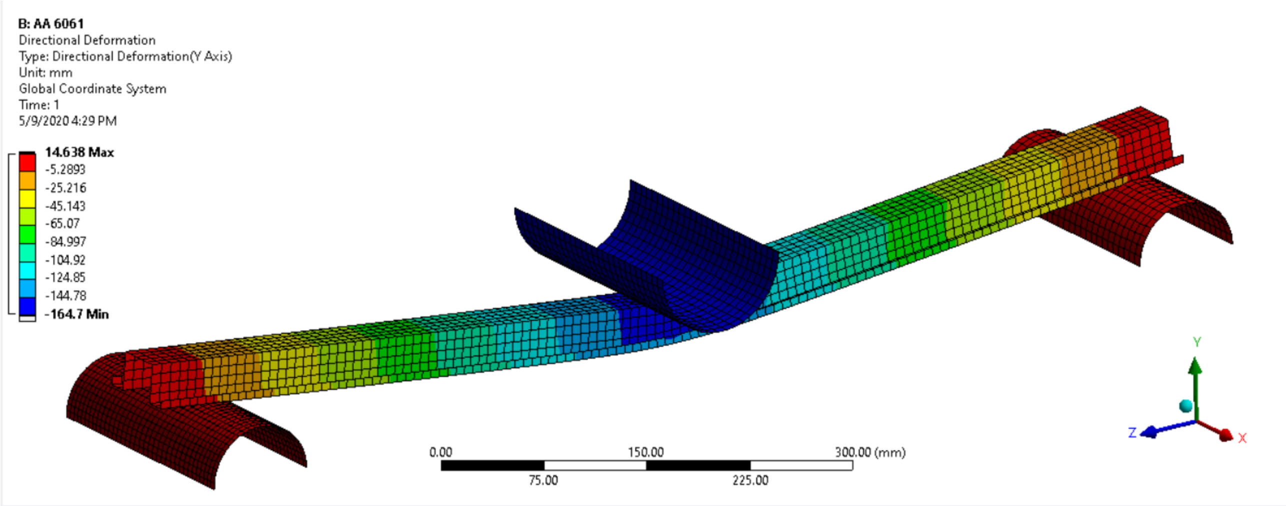

Fig. 29. Deformation of Hat-beam in Y-direction

The Hat-beam with AA6061 material deformation in Y-direction is -164.7 mm under a rigid punch's displacement of -150 mm in Y-direction.

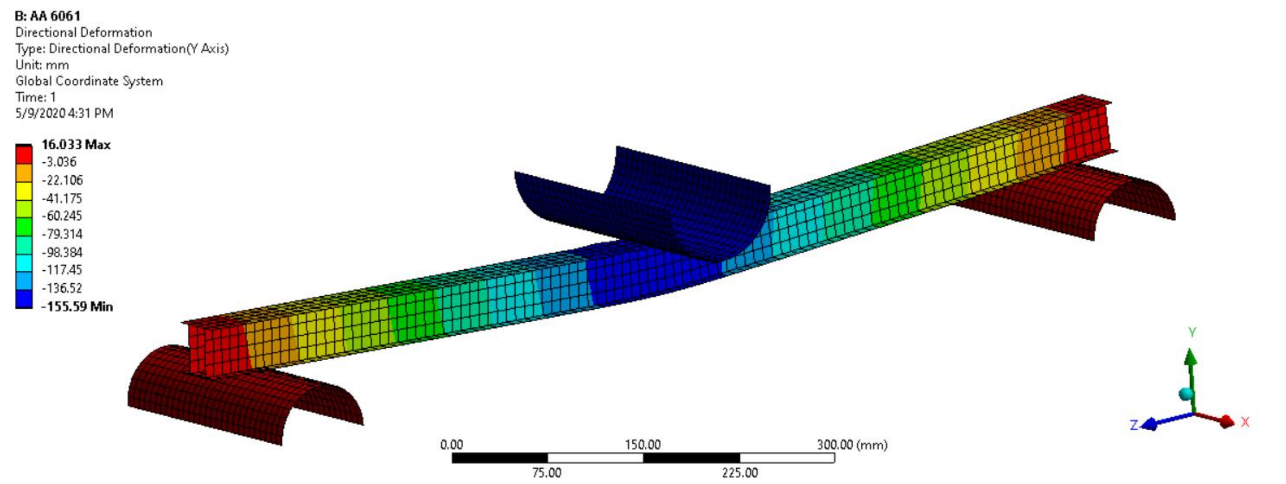

Fig. 30. Deformation of II-beam in Y-direction

The II-beam with AA6061 material deformation in Y-direction is -155.59 mm under a rigid punch's displacement of -150 mm in Y-direction.

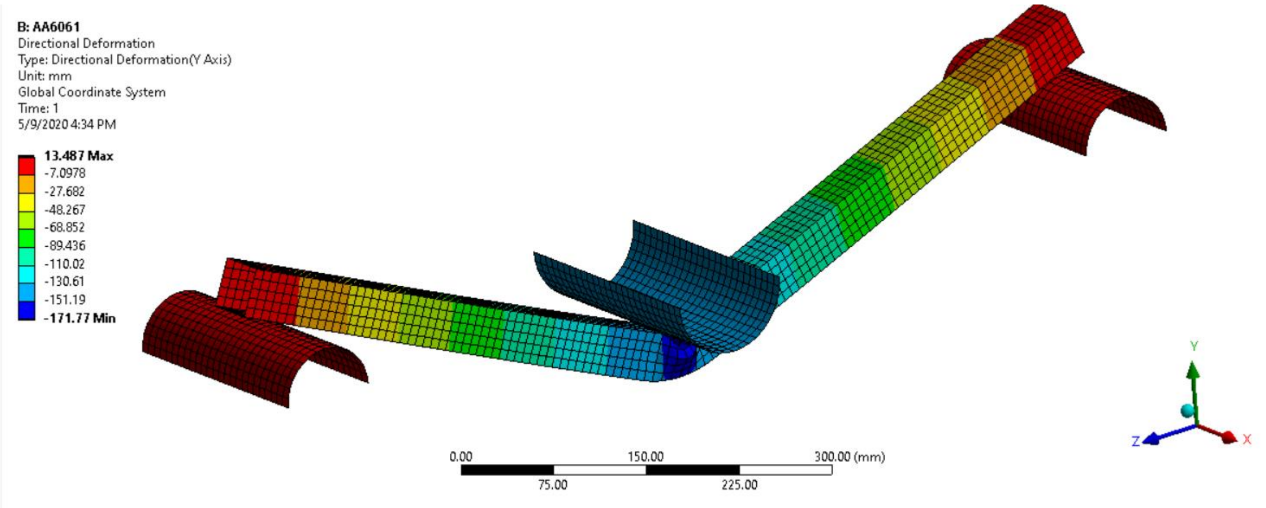

Fig. 31. Deformation of Square beam in Y-direction

The Square beam with AA6061 material deformation in Y-direction is -171.77 mm under a rigid punch's displacement of -150 mm in Y-direction.

6.1.1.1. Displacement v/s Force reaction

Every beam is tested with different metal alloy materials to find out the different deformations and force reactions. And the graphs were plotted Displacement (Y) (mm) v/s Force reaction (N) for each beam with different materials. To find an efficient beam with efficient material.

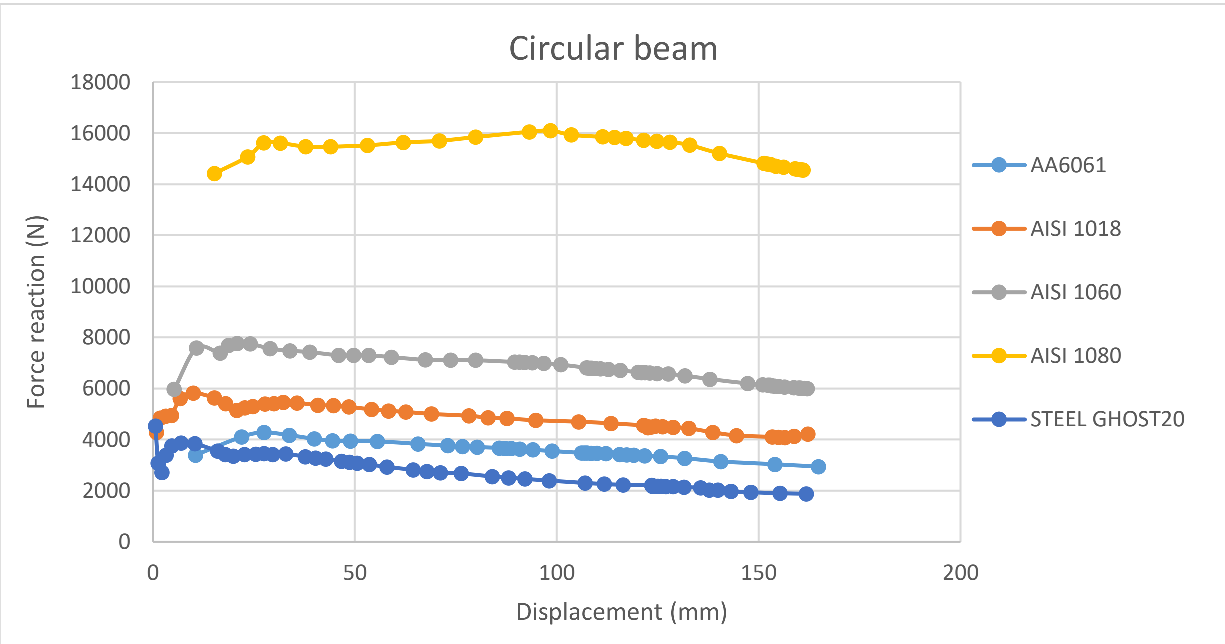

Fig. 32. Comparison of Circular beam with different materials

In the Circular beam, the curves look a little stable from starting to the ending. The material AISI 1080 has a high force reaction value and low displacement, which means it has high strength and stiffness than other materials. Followed by AISI 1060, AISI 1018, AA6061 and the last Steel 20 GOST, which has low force reaction and displacement, it means it has low strength and stiffness.

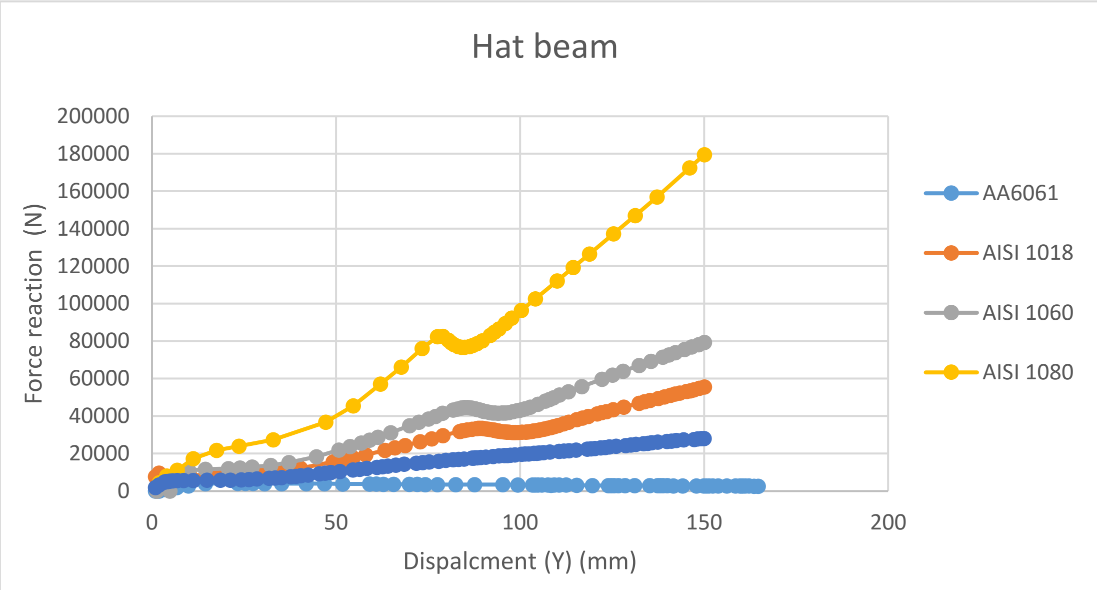

Fig. 33. Comparison of Hat beam with different materials

In the Hat beam, the values are raised in a similar pattern starting from low values. The material AISI 1080 has a high force reaction value and low displacement, which means it has high strength and stiffness than other materials. Followed by AISI 1060, AISI 1018, Steel 20 GOST, and the lastly AA6061, which has low force reaction and displacement, it means it has low strength and stiffness.

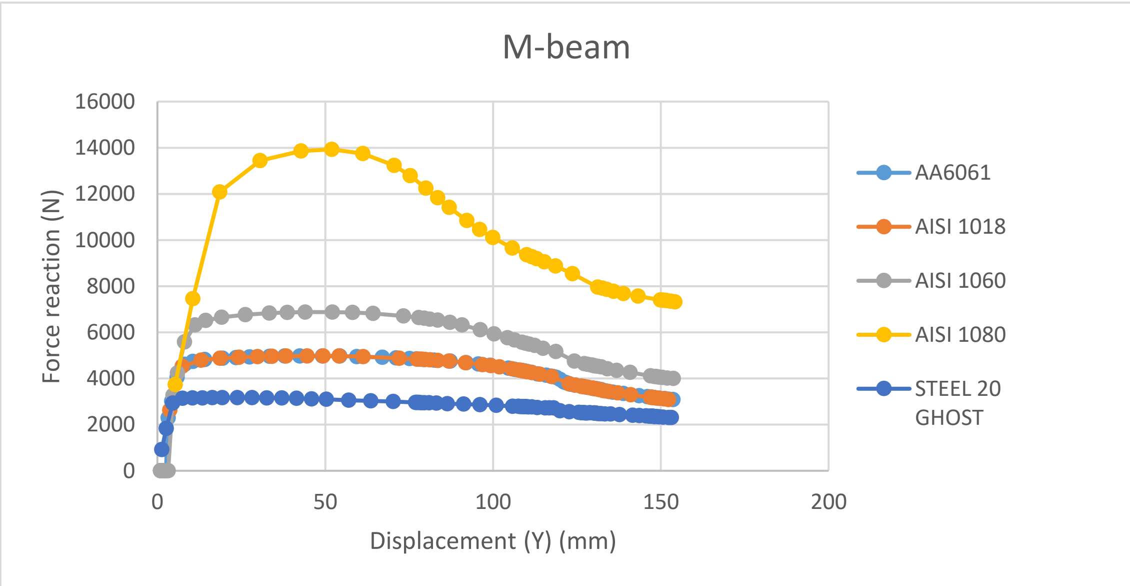

Fig. 34. Comparison of M-beam with different materials

In the M-beam, the values are raised in a starting and then look stable until the end. The material AISI 1080 has risen higher and reduced in the end. It has a high force reaction value and low displacement, which means it has high strength and stiffness than other materials followed by AISI 1060. AA6061 and AISI 1018 are similar from starting to the end. lastly, Steel 20 GOST, which has low force reaction and displacement, it means it has low strength and stiffness.

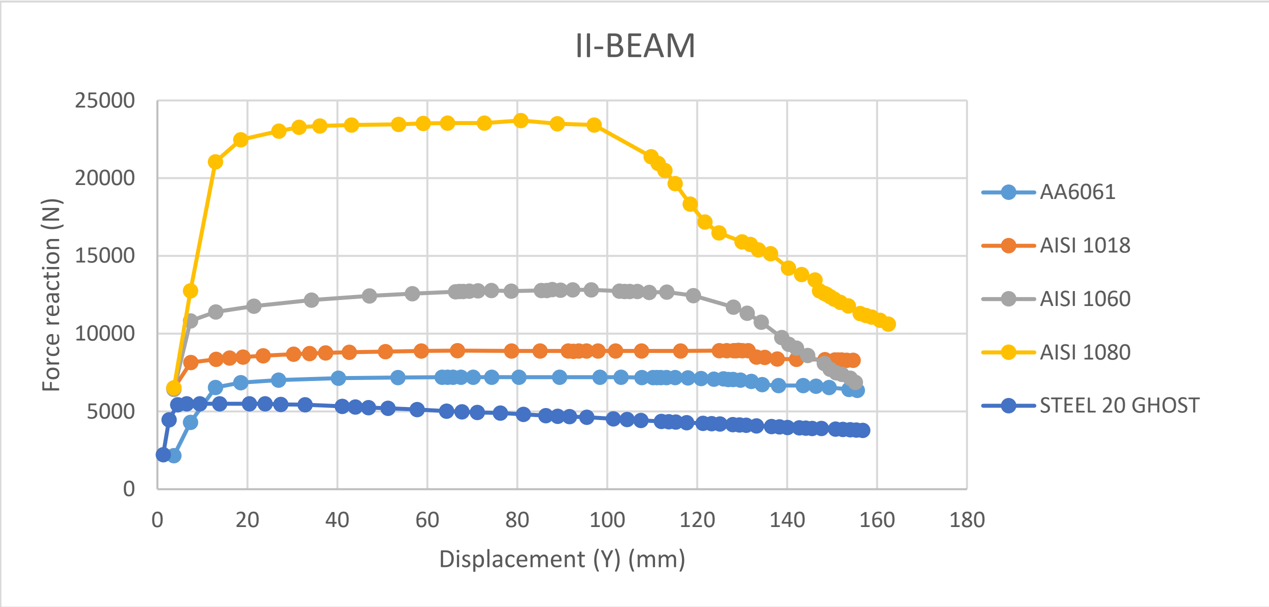

Fig. 35. Comparison of II--Beam with different materials

In II-beam, the values are raised in a starting and then looks stable until the end. But the material AISI 1080 has risen higher and reduced in the end. It has high force reaction value and displacement, which means it has high strength and stiffness than other materials followed by AISI 1060, AA6061 and AISI 1018. lastly, Steel 20 GOST, which has low force reaction and displacement, it means it has low strength and stiffness.

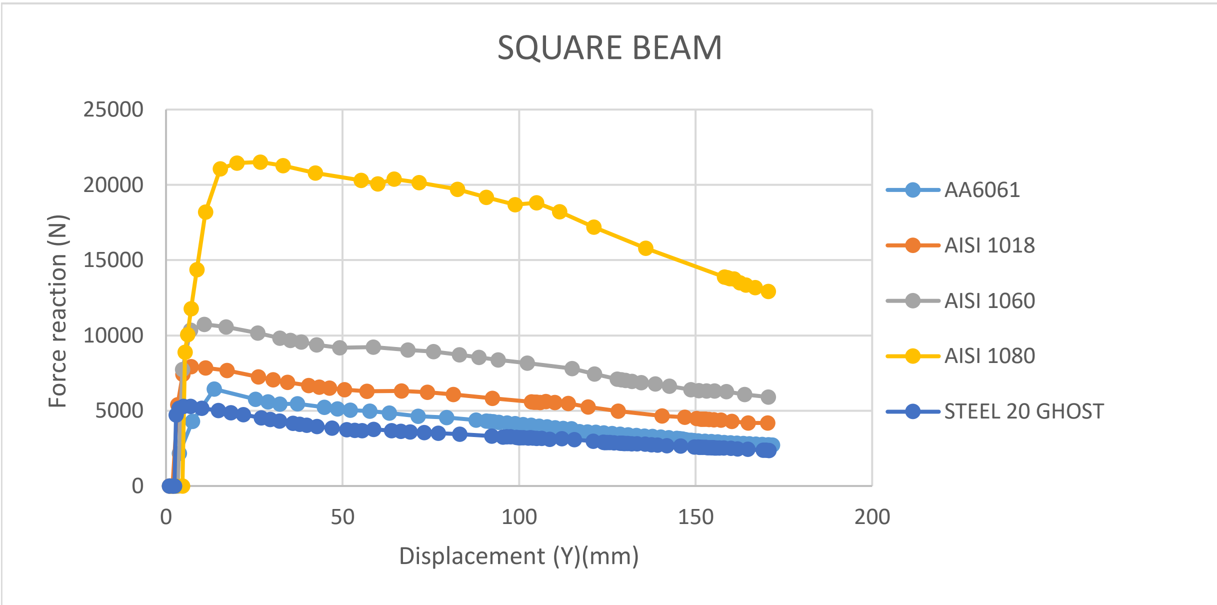

Fig. 36. Comparison of Square beam with different materials

In Square beam, the curves look stable and similar from starting to the ending except AISI 1080. The material AISI 1080 has a high force reaction value and displacement, which means it has high strength and stiffness than other materials. Followed by AISI 1060, AISI 1018, AA6061 and the last Steel 20 GOST, which has low force reaction and displacement, it means it has low strength and stiffness.

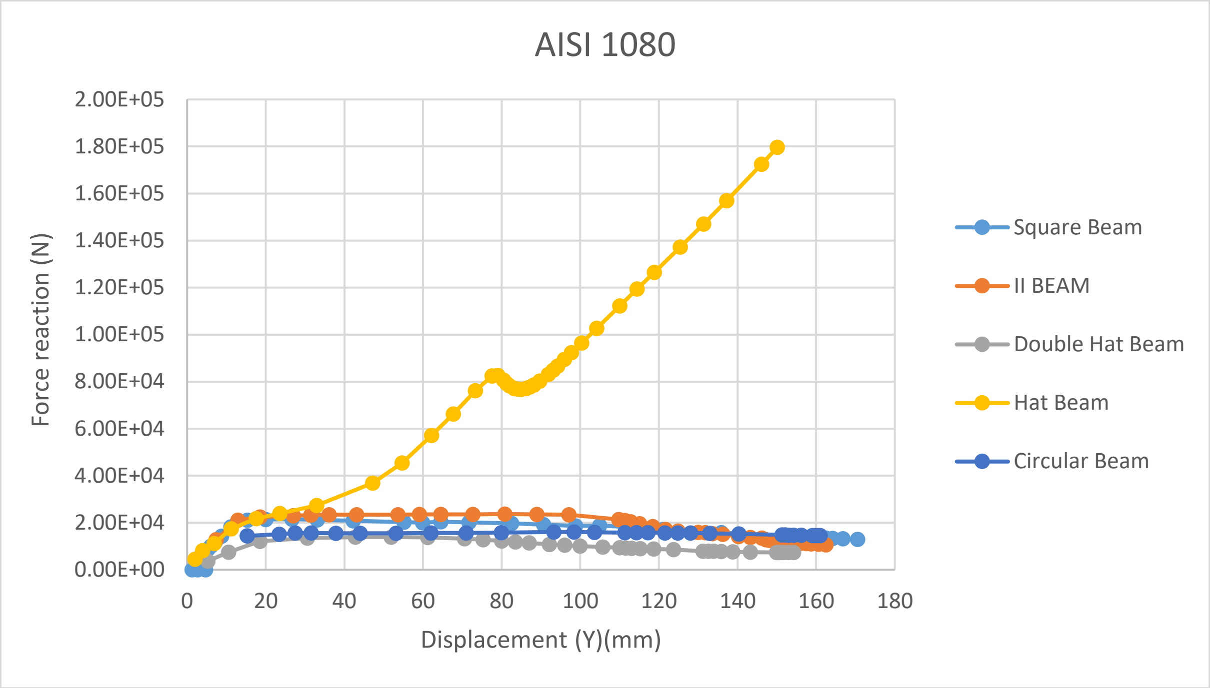

Fig. 37. Comparison of different beams with AISI 1080 material

In all the materials, the material AISI 1080 has the highest force reaction for all the beams. In that, the Hat beam has the highest force reaction. It means Hat beam has high stability and stiffness. Hat beam with different materials also has a high force reaction (**Fig. 37**.).

6.1.2. Workbench Ls-Dyna (explicit dynamics) analysis

The five different beams are analyzed with five different materials like AA6061, AISI 1016, AISI 1060, AISI 1080, and Steel 20 GOST to find out the internal energies of the beams.

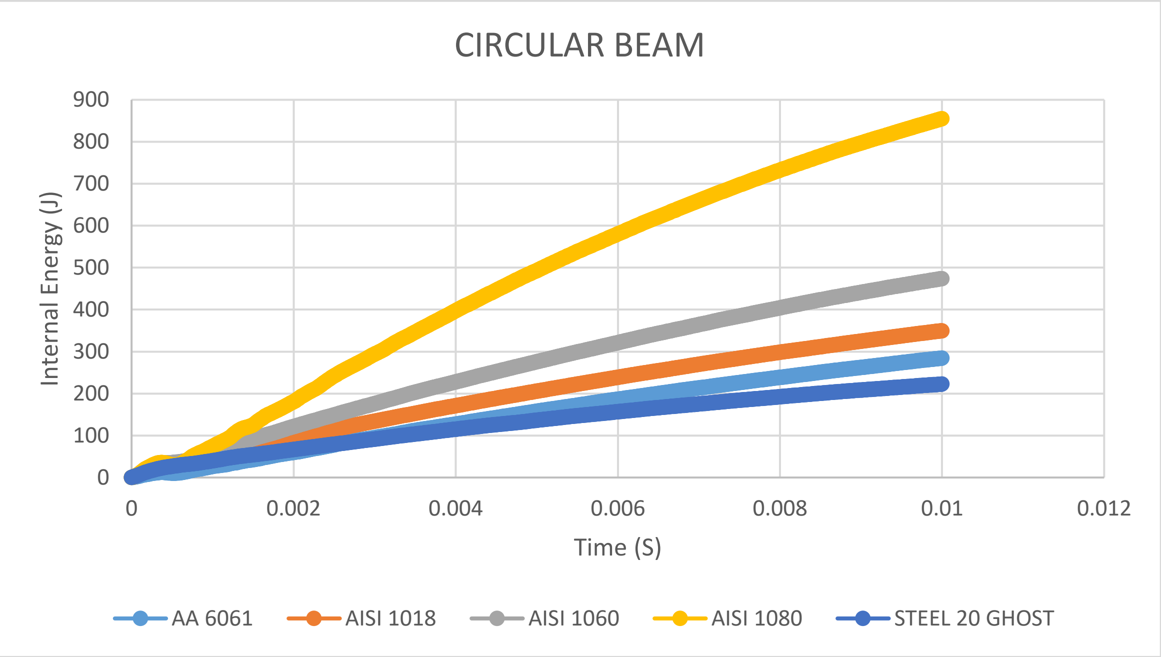

Fig. 38. Comparison of Circular beam's Internal energies with different materials

Circular beam with AISI 1080 has the highest internal energy absorption rate than other types of beams.

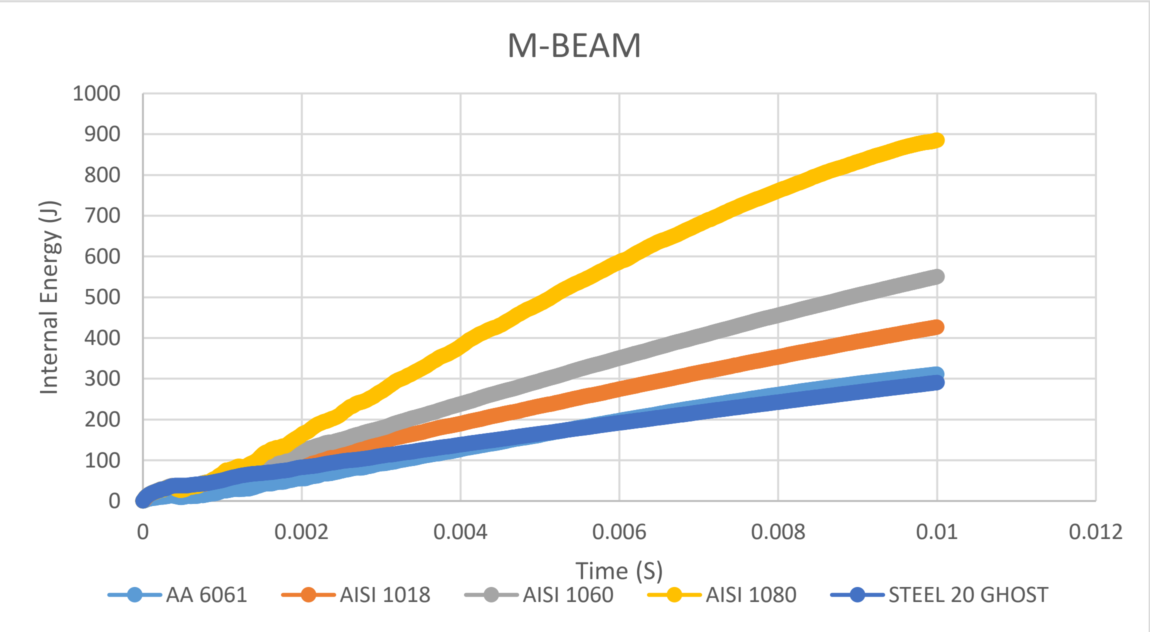

Fig. 39. Comparison of M-beam's Internal energies with different materials

M- beam with AISI 1080 has the highest internal energy absorption rate than other types of beams.

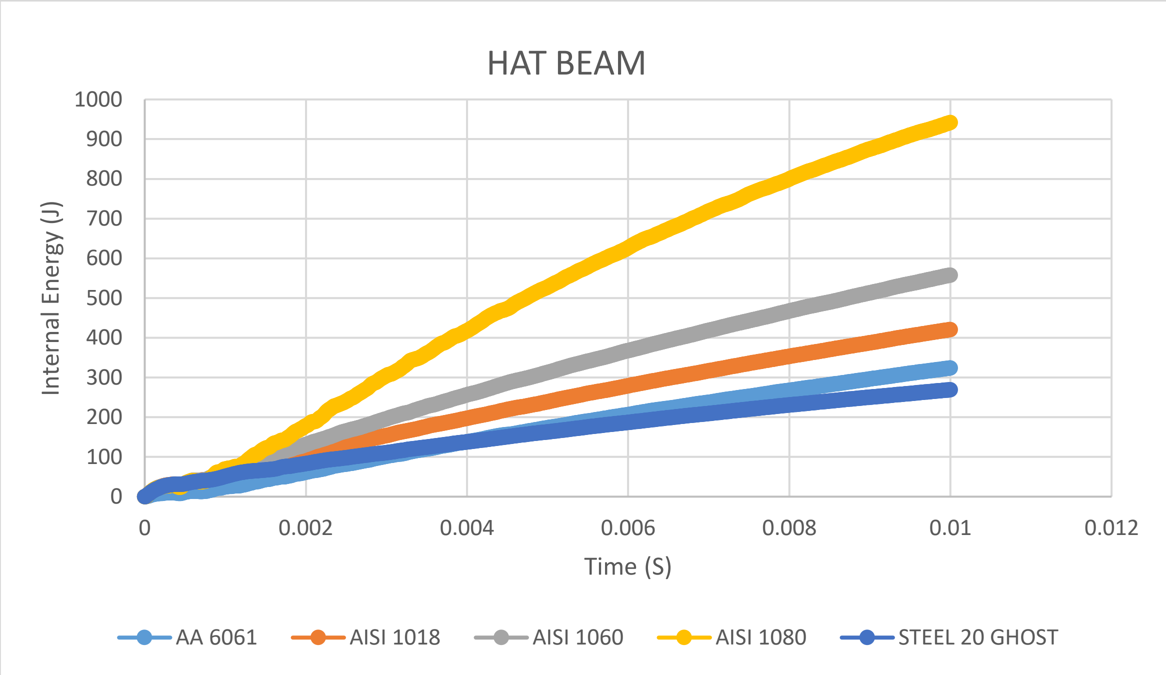

Fig. 40. Comparison of Hat beam‘s Internal energies with different materials

Hat beam with AISI 1080 has the highest internal energy absorption rate than other types of beams.

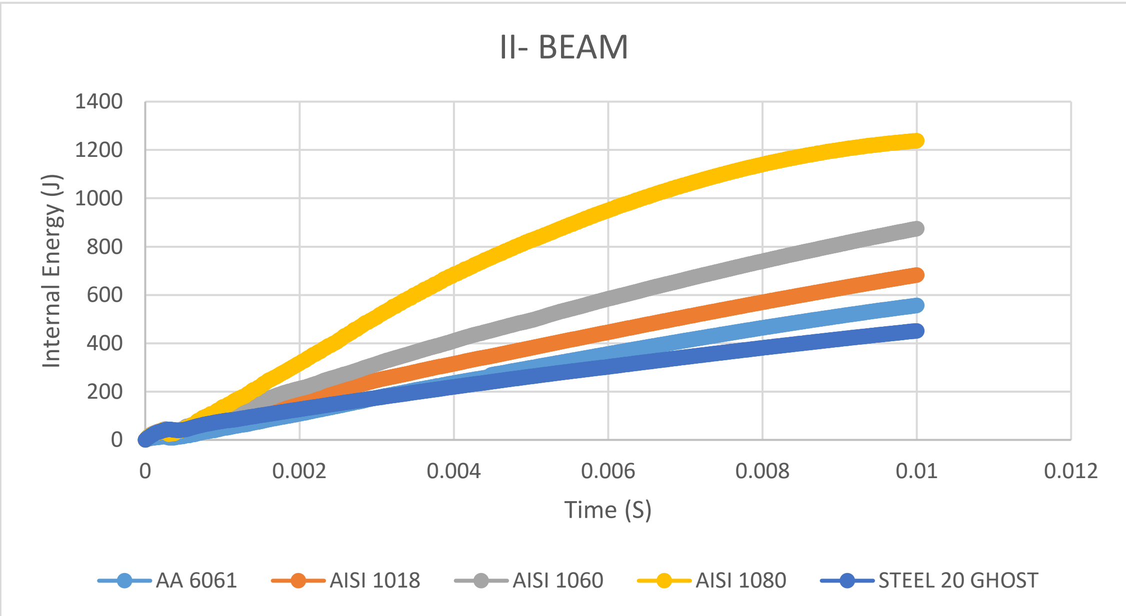

Fig. 41. Comparison of II-beam‘s Internal energies with different materials

II- beam with AISI 1080 has the highest internal energy absorption rate than other types of beams.

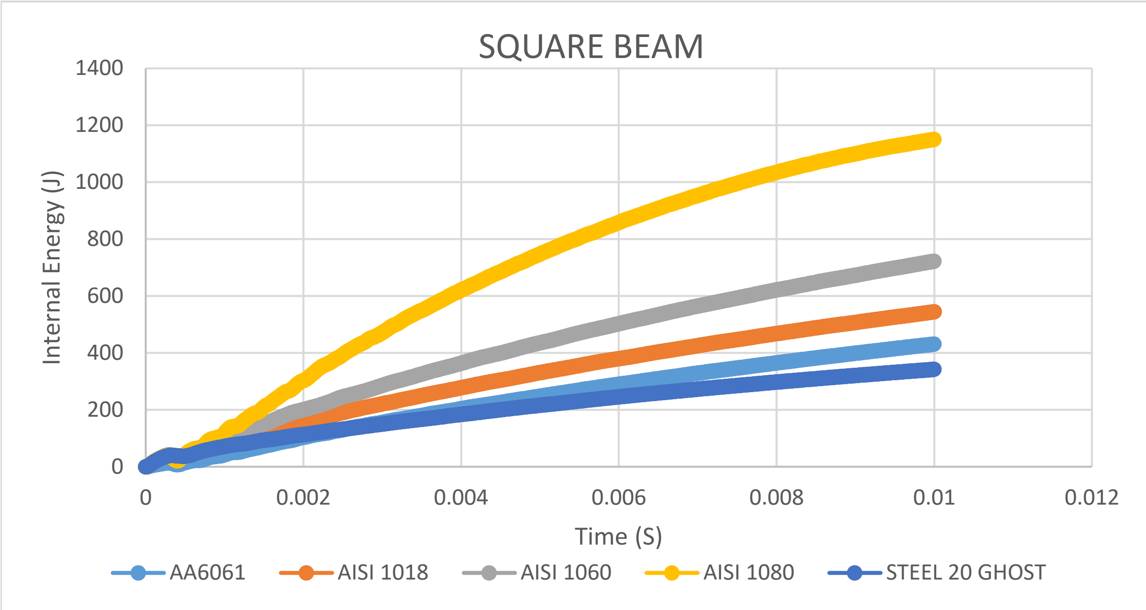

Fig. 42. Comparison of Square beam's Internal energies with different materials

Square beam with AISI 1080 has the highest energy absorption rate than other types of beams.

In all the beams, the material AISI 1080 has the highest internal energy.

6.2. Composite beams

6.2.1. Static Structural Implicit Analysis (ACP Pre)

Static structural Implicit Analysis for five different Beams with Carbon fiber, E-Glass, and S-Glass is doing to find out the displacement and force reaction under displacement of the rigid punch in Y-direction.

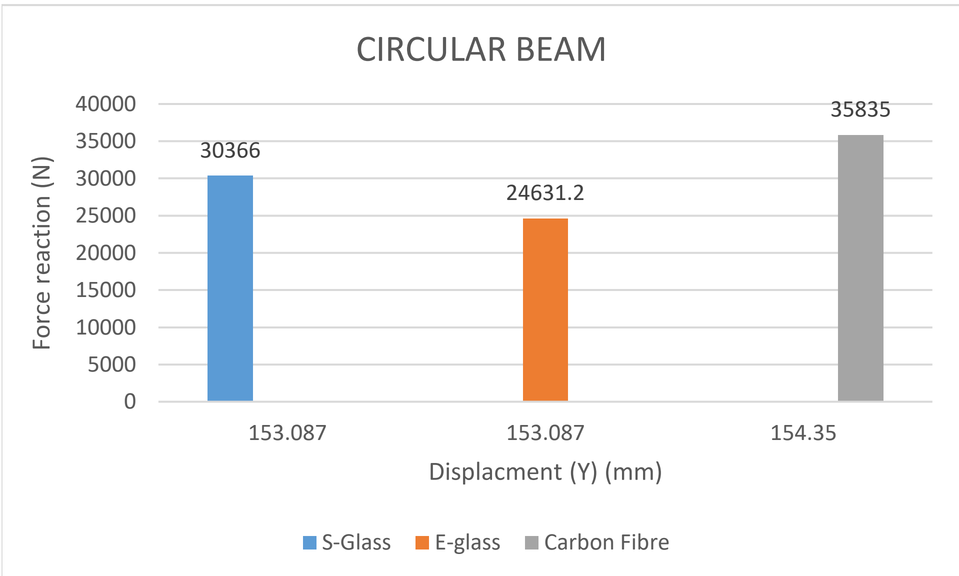

Fig. 43. Comparison of Circular beam with different composite materials

Circular composite beam with Carbon fiber material has the highest force reaction and displacement. It means it has high strength and stiffness and followed by S-Glass and E-Glass.

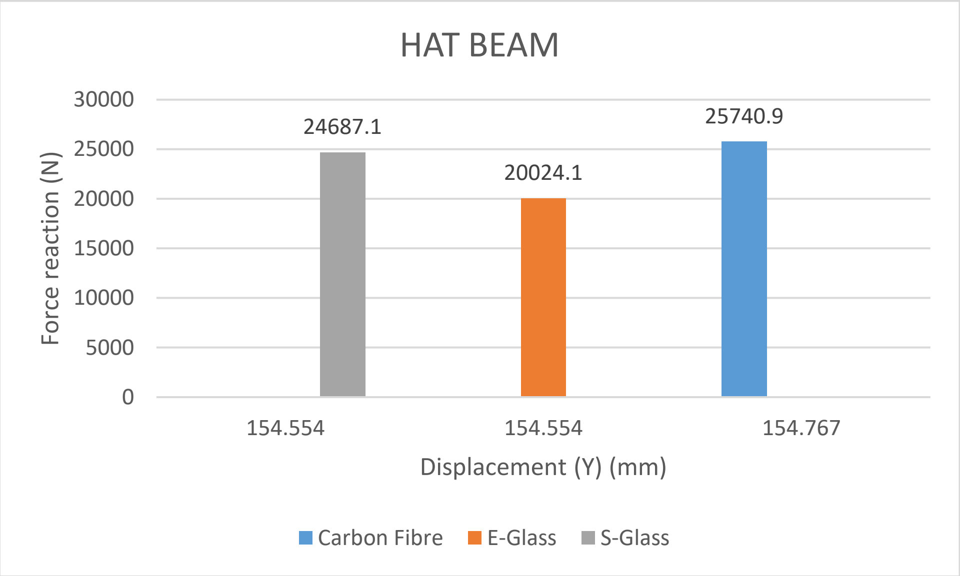

Fig. 44. Comparison of Circular beam with different composite materials

In Hat composite beam with Carbon fiber material have the highest force reaction and displacement. It means it has high strength and stiffness and followed by S-Glass and E-Glass.

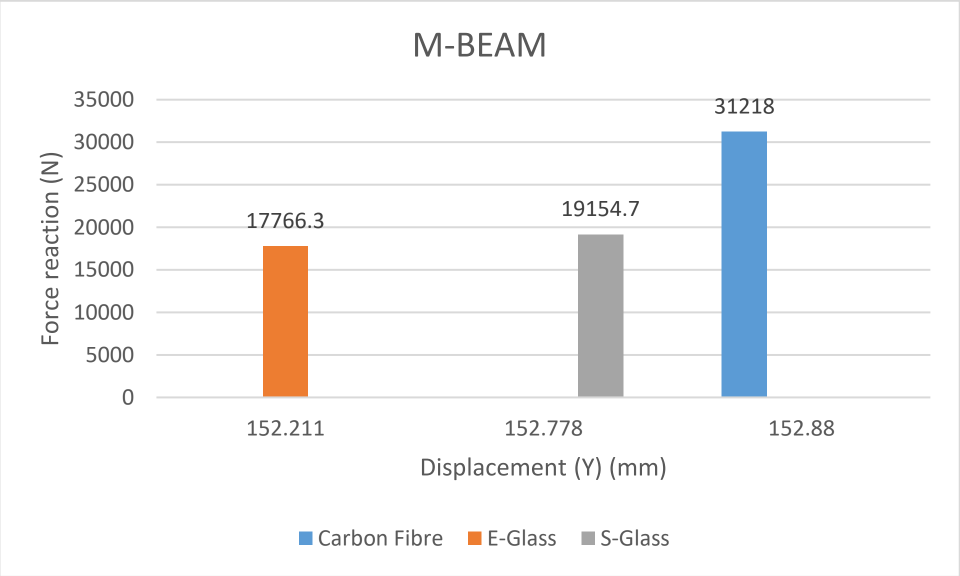

Fig. 45. Comparison of M-beam with different composite materials

M-beam with Carbon fiber material has the highest force reaction and displacement. It means it has high strength and stiffness and followed by S-Glass and E-Glass.

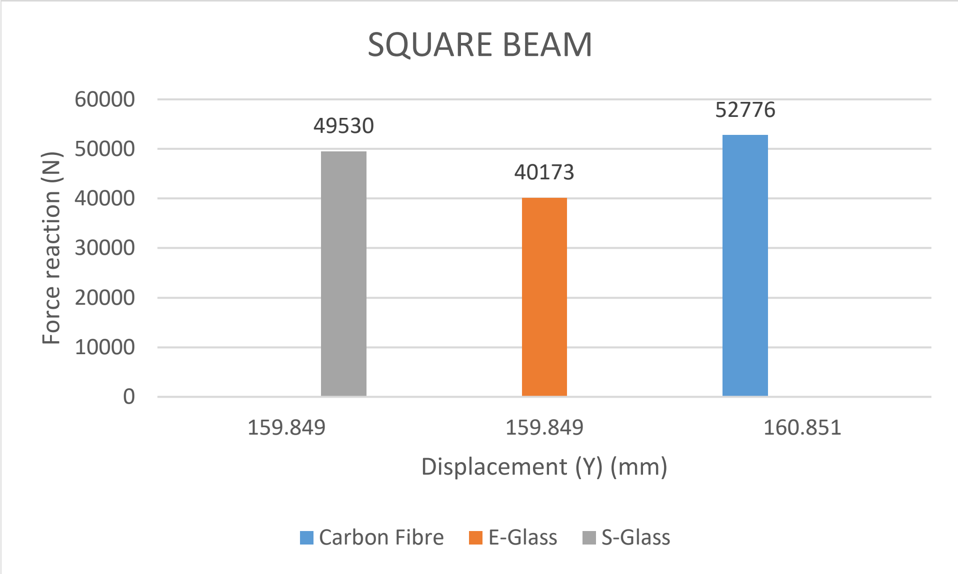

Fig. 46. Comparison of Square beam with different composite materials

In Square beam with Carbon fiber material have the highest force reaction and displacement. It means it has high strength and stiffness and followed by S-Glass and E-Glass.

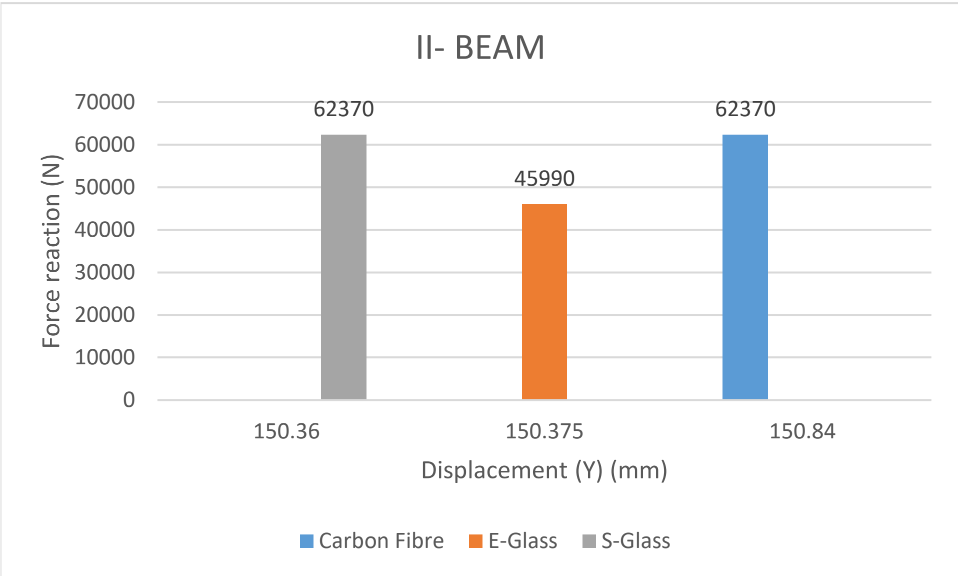

Fig. 47. Comparison of II--beam with different composite materials

In II-beam with Carbon fiber material and S-Glass have the same and highest force reaction and displacement. Even it has the highest force reaction when compared with all other beams. It means those have high strength and stiffness and followed by E-Glass.

6.2.2. Workbench Ls-Dyna (Explicit Dynamics) Analysis (ACP Pre)

Explicit Dynamics analysis is done on five different composite beams with Carbon fiber, E-Glass, and S-Glass materials to find the Internal energies of the beam.

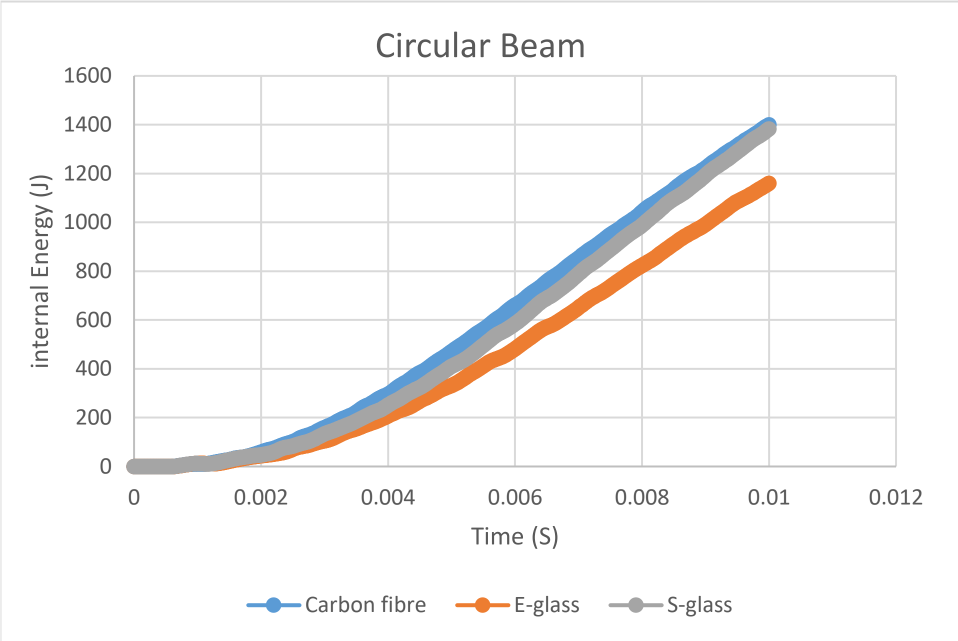

Fig. 48. Comparison of Internal energies of Circular beam with different composite materials

Circular beam with Carbon fiber has a high internal energy absorption capacity. The internal energy absorption of the Circular beam with Carbon fiber and S-Glass material is approximately equal. But the Circular beam with E-Glass has less internal energy absorption capacity.

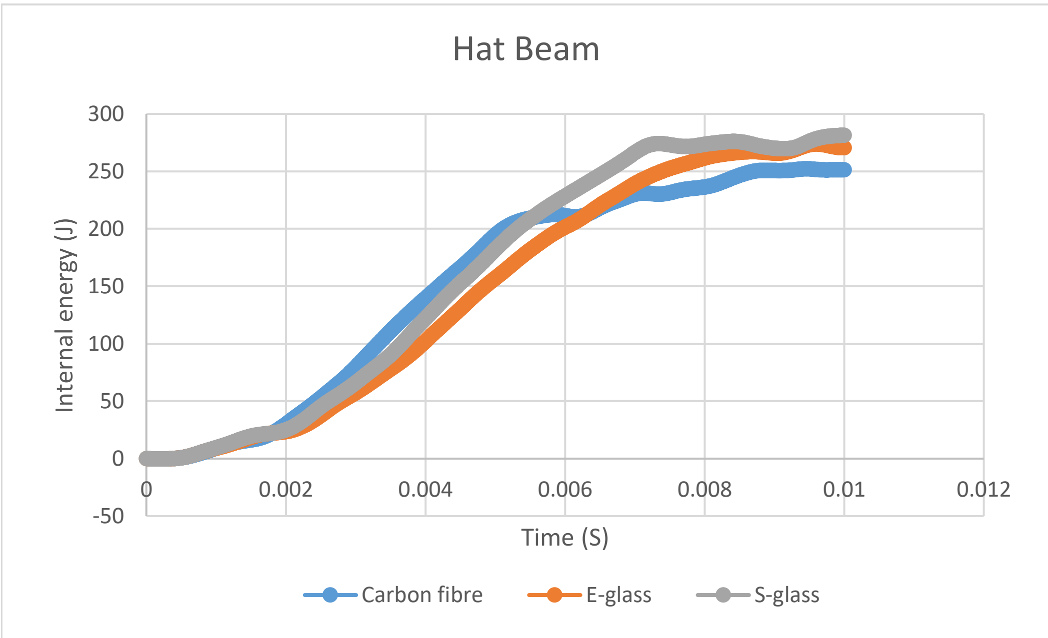

Fig. 49. Comparison of Internal energies of Hat beam with different composite materials

Hat beam with S-Glass material has a high internal energy absorption capacity. Hat beam with E-Glass also has the internal energy absorption approximately to the internal energy absorption of the Circular beam with S-Glass material. But the Hat beam with Carbon fiber has less internal absorption capacity.

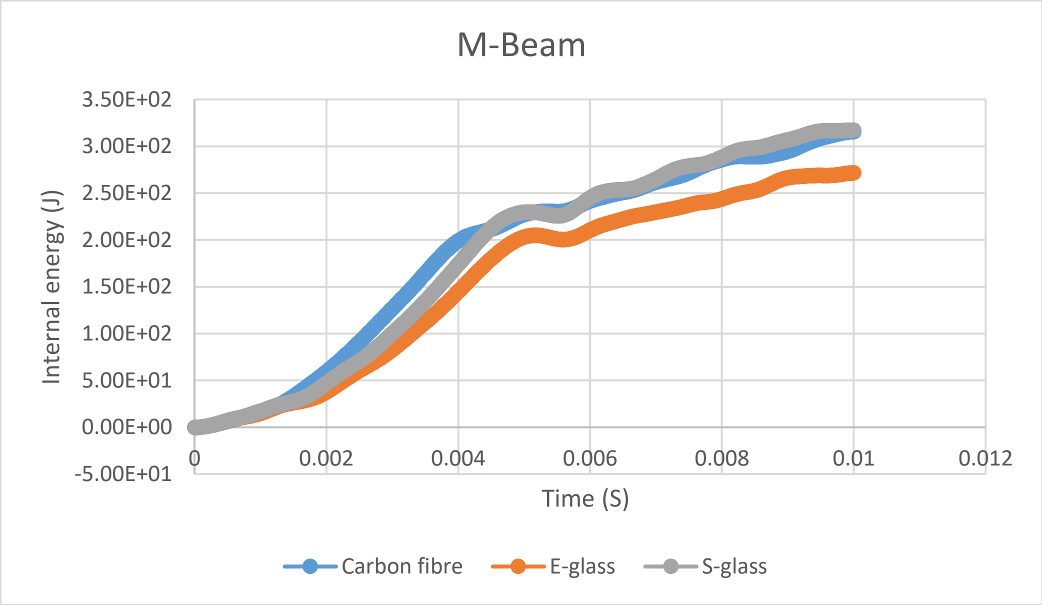

Fig. 50. Comparison of Internal energies of M-beam with different composite materials

Both the curves of M-beam with Carbon fiber material and with S-Glass material has the same and high internal energy absorption capacity. Hat beam with E- Glass has less internal energy absorption capacity.

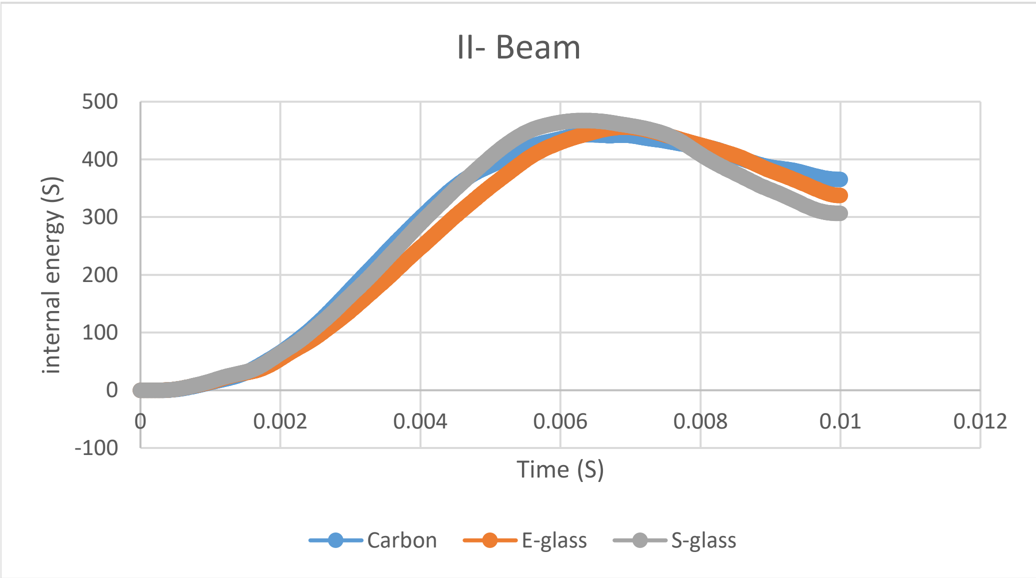

Fig. 51. Comparison of Internal energies of II-beam with different composite materials

In II-beam, all curves risen to a certain level and then reduced with the time. They look similar. But in that, S-Glass has high internal energy absorption followed by E-Glass and Carbon fiber.

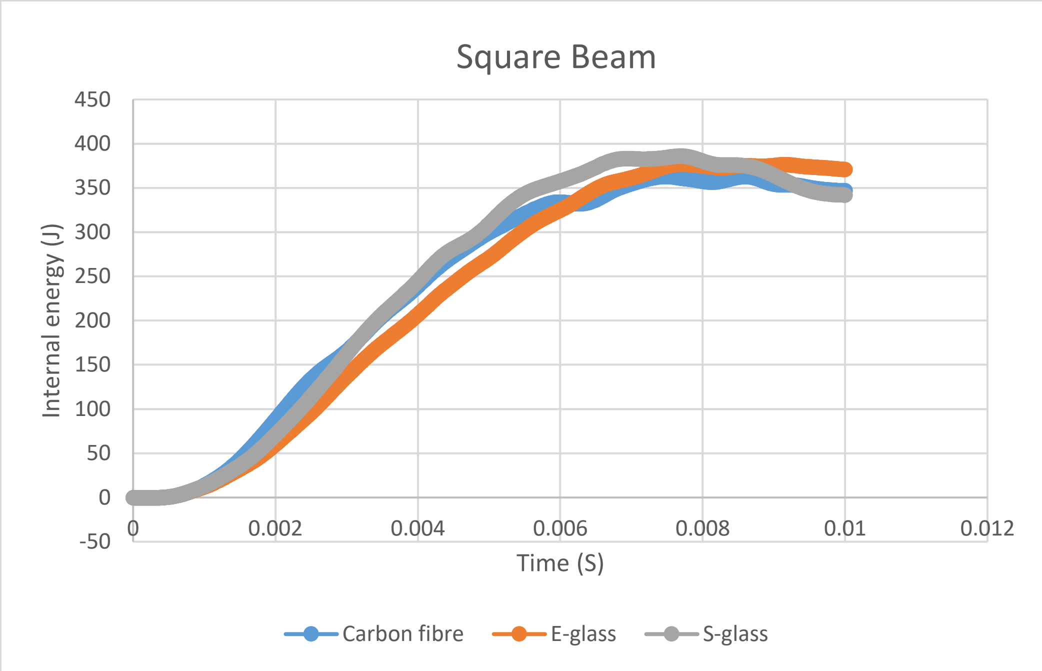

Fig. 52. Comparison of Internal energies of Square beam with different composite materials

In II-beam, all curves are looks similar. But in that, S-Glass has high internal energy absorption followed by E-Glass and Carbon fiber.

6.3. Discussions

In this, the five different bemas are designed and analyzed with two different categories of materials, such as Metal alloys and composite materials in CAE software.

- Using Static structural analysis, the force reaction and directional deformation of the Intrusion beams were found out.
- Using Workbench Ls-Dyna (Explicit Dynamics), the internal energy absorptions of the Intrusion beams were found out.

6.3.1. Comparison table of Implicit analysis results- Directional Deformation and Explicit Dynamics results- Internal energy absorption of five beams with different metals.

Table 7. Comparison of Implicit and Explicit results of different beam profiles with different materials.

		Metal alloys					**Composite materials**		
Beam profiles	**Results**	AA 6061	AISI 1018	AISI1060	AIS I1080	STEEL 20 GOST	CARBON FIBRE	E-GLASS	S-GLASS
Circular beam	D (Y) (mm)	164.84	162.24	162.04	161.02	161.85	154.35	153.087	153.087
	FR (N)	2941.2	4220.4	6002.2	14564	1879.1	35835	24631.2	30366
	IEA (J)	284.16	349.55	473.87	854.92	222.33	1400.02	1159.9	1383.174
	SEA (J/kg)	466.60	196.92	266.96	481.64	125.25	3444.08	1976.0	2450.26
Hat beam	D (Y) (mm)	164.7	160.19	160.18	150.12	150.05	154.767	154.554	154.554
	FR (N)	2711.9	55572	79348	179610	28135	25740.9	20024.1	24687.1
	IEA (J)	324.34	420.95	558.24	942.12	269.37	281.38	270.42	251.45
	SEA (J/kg)	483.65	215.60	285.92	482.54	137.96	562.40	419.25	453.10
M-beam	D (Y) (mm)	153.64	152.33	153.7	151.23	153.14	152.88	152.778	152.211
	FR (N)	3078.5	3089.7	4000.2	7320.5	2301.3	31218	17766.3	19154.7
	IEA (J)	311.17	426.6	550.35	885.57	290.53	315.72	271.71	317.41
	SEA (J/kg)	421.22	198.37	255.91	482.54	137.96	641.18	381.99	464.04
II-beam	D (Y) (mm)	155.59	154.68	155.18	162.48	156.8	150.36	150.375	150.84
	FR (N)	6350.9	8300.5	6876.8	10630	3794.7	62370	45990	62370
	IEA (J)	556.56	682.61	874.65	1238.3	451.59	442.74	445.73	471.78
	SEA (J/kg)	716.29	302.03	387.01	561.61	199.81	847.162	608.480	648.13
Square beam	D (Y) (mm)	171.77	170.61	170.68	170.57	170.72	160.851	159.849	159.849
	FR (N)	2722.1	4186.8	5900.4	12923	2362.4	52776	40173	49530
	IEA (J)	431.18	544.6	722.53	1150.4	342.54	363.09	376.76	386.02
	SEA (J/kg)	554.92	240.97	319.70	509.02	151.56	698.53	501.85	532.18

D (Y) – Displacement in Y-direction (mm)
FR – Force Reaction (N)
IEA – Internal Energy Absorption (J)
SAE – Specific Energy Absorption (J/kg)

6.3.2. Static analysis

By using static structural analysis, the displacement and force reactions of all five beams with different materials are found out and compared the results by plotting graphs for effective beam in metal alloys and composite material category.

Table 8. Comparison of effective metal alloy beam and composite beam in static structural analysis

Beam profile	Type of material	Displacement (mm)	Force reactions (N)	Mass (Kg)
Hat-beam	AISI 1080	150.12	179610	1.9524
II-beam	Carbon fiber	150.84	62370	0.5184

From the results, both the beams are having decent displacement when they are subjected to 150 mm displacement through rigid punch. But the force reaction is high for AISI 1080 Hat beam when compared with the Carbon fiber II-beam. This means the AISI 1080 Hat beam has high stiffness and strength than all other beams in this research. But the mass of the AISI 1080 Hat beam is 3.7 times more than the mass of the carbon fiber II-beam, which is to be considered regarding the impact on fuel efficiency.

6.3.3. Explicit analysis

By using the explicit dynamics, the internal energies of all five beams with different materials are found out, and the results were compared by plotting graphs to find the effective beam in metal alloys and composite materials category.

Table 9. Comparison of effective metal alloy beam and composite beam in explicit dynamics analysis

Beam profile	Type of material	Internal energy absorption (J)	Mass (Kg)	Specific Energy Absorption (J/kg)
II-beam	AISI 1080	1238.3	2.2637	561.61
	AA 6061	556.56	0.6097	716.29
Circular beam	Carbon fiber	1400.02	0.4065	3444.08

The Circular beam with carbon fiber is having high internal energy absorption when it is subjected to the velocity of 10,000 m/s through rigid punch when compared with AISI 1080 II-beam. The carbon fiber Circular beam has high specific energy absorption characteristics than all other beams in this research. Circular beam with carbon fiber has 4.8 times more specific energy absorption than II-beam with AA 6061 and 6.1 times more than II-beam with AISI 1080. The mass of the carbon fiber Circular beam is 1.49 times lesser than the mass of the II-beam with AISI 1080 and 3.7 times lesser than the II-beam with AISI 1080. which is to be considered regarding the impact on fuel efficiency.

Conclusion

4. In metal alloys, Hat-beam with AISI 1080 has the highest force reaction of 179610 N and the lowest displacement of 150.12 mm than other intrusion beams. This means it has high strength and stiffness.
5. In composite materials, II-beam with carbon fiber material has the highest force reaction of 62370 N and the displacement of 150.84 mm than other intrusion beams. This means it has high strength and stiffness.
6. Here the Hat beam mass is 3.7 times more than the mass of the II-beam. Even both the beams are of the same thickness. So the composite II-beam is useful to reduce the mass impact on the fuel efficiency in passengers‘ cars.
7. In metal alloys, II-beam with AA 6061 has a high specific energy absorption of 716.29 J/kg than all other metal alloy beams. This means it has high energy absorption characteristics during impact.
8. In composite materials, a Circular beam with carbon fiber material has a high specific energy absorption of 3444.08 J/kg. This means it has high energy absorption characteristics during impact.
9. The Circular beam with carbon fiber has 4.8 times more specific energy absorption than II-beam with AA 6061 material.
10. Here the mass of II-beam with AA 6061 material is 1.49 times more than the mass of the Circular beam with Carbon fiber material. So the Circular composite beam is best for energy absorption conditions, and also the mass reduction is useful to increase the fuel efficiency of the passengers‘ cars.
11. AISI 1080 material is the best metal alloy material for intrusion beams in this research. It has the highest Young‘s modulus of 869E+8 Pa and Tangent modulus of 869E+8 Pa than all other beams. So it means that Young’s modulus and Tangent modulus plays a major role in increasing the strength and stiffness of the beams.
12. Carbon fiber has orthogonal elasticity properties. It has higher Young‘s modulus in all three directions. In X-direction is 2.3E+11 Pa, Y- direction is 2.3e+11Pa and Z- direction is 2.3e+10 Pa. So these properties play a major role in increasing higher energy absorption characteristics during impact.
13. The density places a major role in reducing the mass of any component. Here the carbon fiber density is 1800 kg/m3, which is 4.3 times less than the density of the AISI 1080 is 7860 kg/m3.so the composite intrusion beams are lighter than metal alloy intrusion beams.
14. TRIP, high-strength, super-strength, ultra-strength, 3rd generation steels are used in the automotive industry because aluminum alloys and composites are not yet technologically advanced in mass production. Energy absorption depends on strength, so better to use super strong steel such as AISI 1080.

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