REPUBLIC OF TURKEY
ADANA ALPARSLAN TÜRKEŞ SCIENCE AND TECHNOLOGY UNIVERSITY

INSTITUTE OF GRADUATE SCHOOL
AERONAUTICAL AND SPACE SCIENCES

BALLISTIC MODELING OF HYBRID COMPOSITES MATERIALS

SERCAN ALBAYRAK

M.Sc.

ADANA 2024

REPUBLIC OF TURKEY
ADANA ALPARSLAN TÜRKEŞ SCIENCE AND TECHNOLOGY UNIVERSITY

GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
DEPARTMENT OF AEROSPACE ENGINEERING

BALLISTIC MODELING OF HYBRID COMPOSITES MATERIALS

SERCAN ALBAYRAK

M.Sc.

SUPERVISOR
ASSOC. PROF. DR. AHMET REFAH TORUN

ADANA 2024

DECLARATION OF CONFORMITY

In this thesis study, which was prepared following the thesis writing rules of Adana Alparslan Türkeş Science and Technology University Institute of Graduate School, I declare that I provide all the information, documents, evaluations and results in accordance with scientific ethics and moral codes without resorting to any means or assistance that would be contrary to scientific ethics and traditions. I also declare that I refer to all of the articles I used in this study with appropriate references and accept all moral and legal consequences if a situation is found contrary to my statement regarding my work.

ÖZET

HİBRİT KOMPOZİT MALZEMELERİN BALİSTİK MODELLEMESİ

Sercan ALBAYRAK
Yüksek Lisans, Havacılık ve Uzay MühendisliğiAnabilim Dalı
Danışman: Doç. Dr. Ahmet Refah TORUN
Ağustos 2024, 53 sayfa

Hibrit kompozitler, günümüz endüstrisinde gelişmiş ve karmaşık uygulamalar için temel ve son derece önemli mühendislik malzemelerinden biri haline gelmiştir. Bu çalışmada, katman sayısı aynı kalmak şartıyla, katman tipi ve katman diziliminin, aynı balistik etki altında kompozit malzemelerin davranışları deneysel olarak incelenmiştir. Laboratuvarda vakum infüzyon üretim yöntemi ile 10 adet reçine destekli cam elyaf ve karbon katkılı hibrit kompozit numune elde edilmiştir. Vakum infüzyon üretim yöntemi kullanılarak kompozit malzemelerin üretimi için 200 g/m2 twill cam elyaf kumaş kullanılmıştır. Üretilen kompozitlerin balistik etkilerini incelemek amacıyla STANAG 2920 standartlarına uygun olarak poligonda atış gerçekleştirilmiştir. Belirlenen bu atış testleri sonucunda, merminin kompozit malzemeler üzerinde oluşturduğu hasarlar analiz edilmiştir. Ayrıca, malzemedeki katman düzeni ve katman tipinin mermi hızını nasıl etkilediği analiz edilmiştir.

Anahtar Kelimeler: Hibrit Kompozit, Balistik, Cam Elyaf, Karbon, Vakum İnfuzyon Yöntemi

ABSTRACT

BALLISTIC MODELING OF HYBRID COMPOSITES MATERIALS

Sercan ALBAYRAK
M.Sc., Department of Aeronautical and Space Sciences

Supervisor: Assoc. Prof. Dr. Ahmet Refah TORUN
August 2024, 53 pages

Hybrid composites have become one of the essential and highly important engineering materials for advanced and complex applications in today's industry. In this study, the behaviours of composite materials under the same ballistic effect of layer type and layer arrangement were investigated experimentally, provided that the number of layers remained the same. . In the laboratory, 10 resin-supported glass fibre and carbon doped hybrid composite samples were obtained by vacuum infusion production method. In order to examine the ballistic effects of the produced composites, shooting was carried out in the polygon in accordance with STANAG 2920 standards. As a result of these specified firing tests, the damages caused by the projectile on composite materials were analysed. In addition, it was analysed how the layer order and layer type in the material affect the projectile velocity.

Keywords: Hybrid Composite, Ballistic, Glass Fibre, Carbon, Vacuum Infusion Method

Dedication

ACKNOWLEDGEMENTS

I am proud to share the excitement and happiness of finishing my master's thesis, which is the biggest step I took to complete my master's degree.
I would like to express my gratitude to Assoc.Prof.Dr. Ahmet Refah TORUN, who has always supported me on this path. He guided me and answered my questions with great understanding in this challenging process.

I am happy to dedicate my graduation thesis to my closest friends and family.

Sercan ALBAYRAK

Adana, 2024

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

Si	:Silicon
Ti	:Titanium
Mg	:Magnesium
Al	:Aluminum
Ni	:Nickel
Bi	:Bismuth
Cu	:Copper
Fe	:Iron(Ferrum)
Co	:Cobalt
Mo	:Molybdenum
C	:Carbon
SiC	:Silicon carbide
Al_2O_3	:Aluminum oxide
B_4C	:Boron carbide
Si_3N_4	:Silicon nitride
PVC	:Polyvinyl Chloride

1. INTRODUCTION

As a definition in the dictionary, composite is the combination of at least two different or more types of materials to form a new material. Despite the broad scope of composite materials, they can be broadly defined as a class of materials that are generated at the interface through the combination of chemically and physically distinct materials, exhibiting resistance to chemical dissolution and guaranteeing that each material utilized preserves its original structure. [41]

Numerous studies have shown that the materials used to build buildings in earlier eras when people were transitioning to established lives were a type of composite material. blocks made from straw, adobe, clay, and mud reinforcement that are used to build houses as shelter. These kinds of constructions are easily cited as instances of conventional composite construction.Fibre-reinforced composite materials, which started to be used in electrical materials in 1942, have only started to be used in aerospace, automotive industry, sports equipment such as swimming shoes, golf clubs, snow skis and biomedical industry in the late 1970s [46].

In the last century, difficult economic processes, depleted natural resources and rapidly increasing pollution in the world, coupled with ever-advancing technology and simplifying production techniques, environmentally friendly, lightweight, easy-to-produce and easy-to-assemble designs have made engineering studies a kind of compulsory focal point [42].

The use of composite materials, which have become widespread and almost mandatory in order to reduce fuel consumption in the aviation and automotive sector, has led to a focus on hybrid materials due to the fact that composite materials are used together with metal and polymer materials, which are frequently used in designs due to their structural strength. The development of hybrid composites started in the mid-20th century.

Materials classed as ceramic, metallic, and polymer-based are those that do not interact chemically when combined. In today's technologically advanced world, it is regrettably exceedingly challenging to get all the essential mechanical qualities in a single material type. At this point, multiphase composites can help to solve such difficulties. For example, the ductility of a hardened low carbon steel can only be achieved if hardness is sacrificed, or, to give another example, if we want to combine carbon fibre and glass fibre in a matrix phase to form a composite, the advantage at this point is in favour of carbon fibre. Because it contains high strength values and low cost elements due to glass fibre.

Therefore, modelling a combined design by combining the desired properties (hardness, toughness, ductility, compression, tensile, impact, tensile strength, dissolution resistance in reactive media, abrasion resistance, fracture resistance, delimitation and puncture resistance, etc.) and producing composite materials offers the ability to produce the material we need with high efficiency.

In addition, composites stand out in the aerospace sector thanks to their superior qualities such as lightness and robustness. The main purpose of aerospace and aviation is to consume less fuel and provide higher speed and efficiency[25].

1.1. Composites

A composite material is one that has had two or more different materials combined at a macro level to combine their greatest qualities or to produce a new feature. The qualities of composite materials are determined by four fundamental components. These qualities are those of the matrix, fiber, interface, and microstructure. A continuous fiber and a matrix substance typically make up the composite material. The fiber/matrix materials that are created by combining different combinations of matrix and fiber components are the basis for the nomenclature of compositmaterials[1].

The structural elements of composite materials do not melt into one another. Nonetheless, some dissolution, even at modest rates, and interfacial interactions between components can be seen, particularly in metallic systems, and can have an impact on the characteristics of the composite[2].

Depending on the use, engineering materials must possess specific characteristics. These include physical properties, chemical properties like stability and corrosion resistance, and mechanical properties like tensile, compression, bending, yield, friction, fatigue strength, hardness, toughness, rigidity, abrasion resistance, electrical conductivity, insulativity, thermal conductivity-insulativity, magnetic properties, density, etc. The engineering community and operators always take into account additional factors, such as the material's unit cost, required tonnage, easy availability, processability, and shaping, in addition to these properties, which are significant in the choice of material and design and can be measured using a variety of techniques.

The main factors that have drawn so much attention to composites and made them an increasingly common replacement for metal and other materials are: - They are far stronger than materials of the same weight; - Composites have a greater tensile strength than other materials, - Composites have a greater specific modulus, which is the product of a material's hardness and density; - higher fatigue strength limitations - Composites have a larger impact absorption energy than other materials, Because of the greater flexibility of their designs, they have the ability to provide the needed qualities in the preferred direction. - The risk of rusting is minimal. - Unlike other kinds of material, composites don't require fasteners like bolts, rivets, etc., therefore these components do not contribute to any problems with structure.

Composite components don't alter chemically. If the aggregate includes particles at the nanoscale level, these composites are known as nanocomposites. It is possible to construct a composite material with all the necessary properties. Consequently, it is hard to evaluate the properties of the composite material with any degree of certainty. inversely, the application of composite materials is widespread due to a number of features[3].

- High strength/density ratio (Specific Strength)
- High stiffness/density ratio (Specific Stiffness)
- Lightness
- High Dielectric Resistance
- High Corrosion resistance
- Diversity
- Easy molding
- Color variety
- Transparency Feature
- Non-combustibility
- Thermal resistance
- Reparability
- Flexibility
- Impermeability

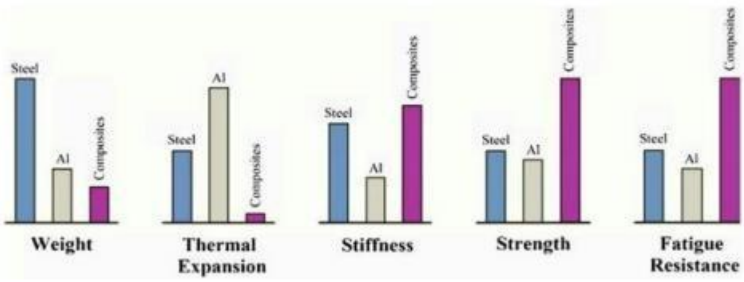


Figure 1. The comparison of conventional and composite materials [45]

1.1.2 Classification Based on Matrix Composites

The adhesive and adhesive qualities are present in matrix materials. In a composite structure, the matrix serves to both hold the fibers together and transfer applied load amongst them.

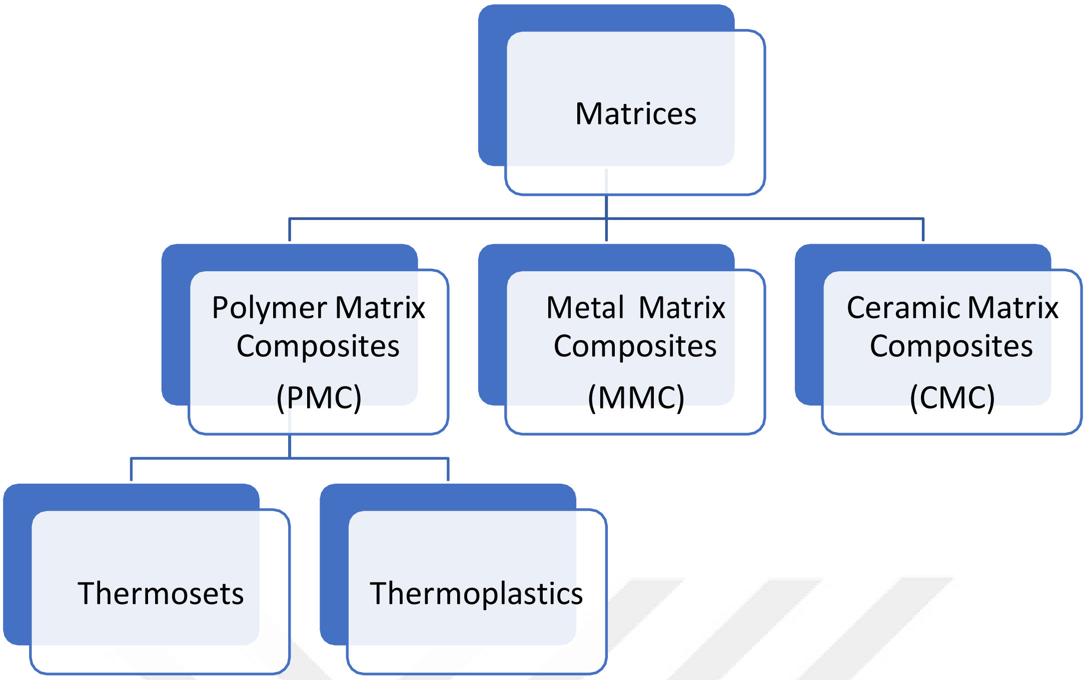


Figure 2. Classification composite materials based on Matrix Materials

1.1.2.1 Metal Matrices

The increasing use of metal matrix composites in many areas has necessitated improvement and development processes on these materials.Metal matrices are frequently utilized in parts because they are intended to function at extremely high temperatures and have very high strength qualities. Metal matrices made of copper and aluminum oxide might be used as an example. Strength and thermal stresses are also considered in metal matrix structures[6-48-49]. Because of their high ductility and enough strength, metals and alloys including Al, Ti, Mg, Cu, Fe, Co, Mo, and Ni are among the most favored matrix materials. Metal matrices are reinforced with either carbon or silicon carbides[23-14-24-49].

They are typically employed in materials that are anticipated to have high wear and fatigue resistance. Compared to other matrix materials, they have more efficient recycling qualities. Apart from their advantageous characteristics, these composites are less widely used than other matrix material composites because of their expensive production processes[6].

1.1.2.2 Ceramic Matrix Composites

Because of their chemical bond architectures, ceramics—which are primarily ionic or covalent hybrids—have strong chemical stability, a high melting temperature, and minimal atomic

mobility. On the other hand, ceramics are hard and brittle materials that can be used under very high temperature conditions without deteriorating their structure. [50-51].
These are types of composites that usually incorporate ceramic materials including silicon nitride, carbon,boron carbide, silicon carbide, and aluminum oxide(C,SiC, Al_2O_3, B_4C, Si_3N_4). To lessen the delicate nature of the monolithic ceramic structure, they include strands of fiber incorporated into the structure itself.Composites made from polymer matrix have particular characteristics necessary for applications that involve high temperatures. Despite their sensitivity to flaws, ceramic matrix composites are widely used in the aerospace and defense industries. They have been utilized for structural applications such as cracking. Their low fracture toughness constitutes by far their biggest drawback.
The undersides of space shuttles silica-based ceramic composite plates, which are favored for their light weight and heat resistance, are resistant to the heat increasing during atmospheric entry. It is an excellent representation of the field in which ceramic matrix composites are used.

1.1.2.3 Polymer Matrix Composites

Composites termed polymer matrix composites are composed of thermoplastic or thermosetting plastic matrices and are reinforced with metal, glass, carbon, or kevlar fibers. A combination of their high durability and adaptability to higher temperatures, thermosets are used more frequently in compositions[8].

They can withstand chemicals with ease. Epoxy resin, polyester resin, and phenolic resin are three thermoset solutions that are frequently seen on the market. Their superior temperature resistance and cost-effectiveness over thermoplastics make them stand out. Polypropylene, polyamide, and polyethylene are notable thermoplastics.

1.1.2.3.1 Thermosets

Strong Vander Waals bonds in three dimensions bind the molecules together. They are hence inflexible structures. When created, the thermosets prevent the material from softening or changing shape in dependence on temperature. The most widely used thermosetting resins are silicone, polyester, vinyl ester, epoxy, and phenolic.

Small monomer molecules undergo chemical reactions to generate lengthy polymer molecules with strong links between them, which is how they are formed. They solidify after first gelling during application. You cannot reheat them to make them softer. This category includes polyesters, epoxy resins, and amino resins. Because of their covalent 3D connections, they are highly stiff. The initial thermoset materials were used to create polymer matrix composites. In comparison with thermoplastics, they are stronger and more brittle[9].

1.1.2.3.2 Thermoplastics

The molecules are connected by a weak Vander Waals connection. These materials are softer than thermoplastics as a result. Heat has the ability to change their shape. Polypropylene, polyethylene, polyether ether ketone, and polycarbonate are examples of common thermoplastic resins. Compared to thermosets, they require more complicated and challenging manufacturing techniques. Their use temperatures are lower than thermosets because they revert to softness when heated. These materials include acrylics, polyesters, Teflon, ABS, polyethylene, polypropylene, PVC(polyvinyl chloride), and polyamides. Thermoplastics provide excellent resistance to chemicals, the environment, and petroleum-derived materials. They can also be utilized extensively because they are mostly recyclable. offered.

Table 1. Comparison of thermoplastics and thermoset [44]

Thermoplastics	Thermoset
Soften on heating and pressure, and thus easy to repair	Decompose on heating
High strains to failure	Low strains to failure
Indefinite shelf life	Definite shelf life
Can be reprocessed	Cannot be reprocessed
Not tacky and easy to handle	Tacky
Short cure cycles	Long cure cycles
Higher fabrication temperature and viscosities have made it difficult to process	Lower fabrication temperature
Excellent solvent resistance	Fair solvent resistance

1.1.2.4 Composites by Reinforcement Type

1.1.2.4.1 Structural Composites

The thermoset composites that are typically made using the casting method are reinforced with glass. This class includes high-strength composites made of unsaturated resin and long fiber strands. They are typically employed in situations where minimal weight and strong strength are required. Based on the molding expertise, they can also be utilized in fittings and sub-assemblies[7].

1.1.2.4.2 Particule Composites

The term suggests that the reinforcing is particle-based (platelets are also a component of this class). It is essentially equiaxed, but it could be spherical, cubic, tetragonal, platelet-shaped, or of another regular or irregular shape. Particles generally have little effect on increasing fracture resistance, despite they can somewhat increase the composite's rigidity. Particle fillers are commonly employed to enhance matrix materials' mechanical and electrical conductivities, raise performance at high temperatures, decrease friction, boost abrasion and wear resistance, increase machinability, raise surface hardness, and decrease shrinkage.

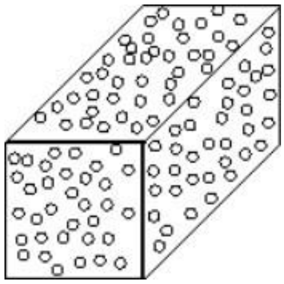


Figure 3. Particles as the reinforcement (Particulate composites) [10]

1.1.2.4.3 Fibrous Composites

Popular composites known as "fiber reinforced composites" are made of synthetic fibers like glass, carbon, basalt, kevlar, etc. These fibers give the composites mechanical qualities that give them advantages like high strength, stiffness, and chemical resistance. Their heightened impact resistance and fatigue strength are only a few of their advantageous qualities; their ability to biodegrade gives them a plethora of industrial uses.

In spite of their small cross-sectional dimensions, man-made filaments or fibers formed of non-polymeric materials have considerably better strength along their length than huge defects that may be present in the bulk material. High strength and stiffness are the consequence of the molecular structure's orientation in polymeric materials[10].

Up until a certain point, the strength of the material in fiber-reinforced composites is directly correlated with the amount of fiber in the composition. Increasing the fiber ratio, nevertheless causes the strength to drop after a certain point. A reduction in polymer content in the composite is the cause of this. The matrix loses its ability to hold the fiber mesh together as the proportion of polymer drops dramatically.

Additionally, the toughness of the fiber weave is determined directly by the strand thickness. To properly disperse this load while operation under load, the material prefers thinner fibers exposed to more matrix material rather than thicker strands[7].
Common fiber types for fiber-reinforced composites;

- Glass Fibers
- Carbon Fibers
- Aramid Fibers

Table 2. Some important properties of fibre materials [43]

Fiber	Density (g/cm^3)	Elongation (%)	Tensile Strength (MPa)	Young's Modulus (GPa)
Aramid	1.4	3.3–3.7	3000–3150	63–67
E-glass	2.5	2.5–3	2000–3500	70
S-glass	2.5	2.8	4570	86
Cotton	1.5–1.6	3–10	287–597	5.5–12.6
Hemp	1.48	1.6	550–900	70
Jute	1.3–1.46	1.5–1.8	393–800	10–30
Flax	1.4–1.5	1.2–3.2	345–1500	27.6–80
Ramie	1.5	2–3.8	220–938	44–128
Sisal	1.33–1.5	2–14	400–700	9–38
Coir	1.2	15–30	175–220	4–6
Kenaf	0.6–1.5	1.6–4.3	223–1191	11–60
Bamboo	1.2–1.5	1.9–3.2	500–575	27–40
Oil palm	0.7–1.6	4–8	50–400	0.6–9
Betel nut	0.2–0.4	22–24	120–166	1.3–2.6
Sugarcane bagasse	1.1–1.6	6.3–7.9	170–350	5.1–6.2

1.1.2.4.4 Hybrid Composites

Hybrid composites are a group of materials with high strength and high resistance to impact loads obtained from the mixture of at least two or more different fibre reinforcements.The advancement of technology and evolving human demands have led to a greater demand for ergonomic materials with a wider range of characteristics. The performance, structure, and qualities of composite materials need to be enhanced in light of the rising demand for them in recent years[13].

Due to their varied applications, composite materials are subject to effects which shorten their lifespan. Because of this, how composite materials behave when subjected to impact at low or high speeds is crucial. The mixture of multiple reinforced parts with a matrix to create a new material with improved qualities is known as hybrid composite materials.

The most commonly used hybrid composite is carbon and glass fiber reinforced polymeric resin, which exhibits a superior combination of qualities compared to a single fiber composite. A different approach kind of composite structure that was created to combine the smooth surface creation of microfill composites with the robust mechanical and physical qualities of traditional composites is the hybrid composite.

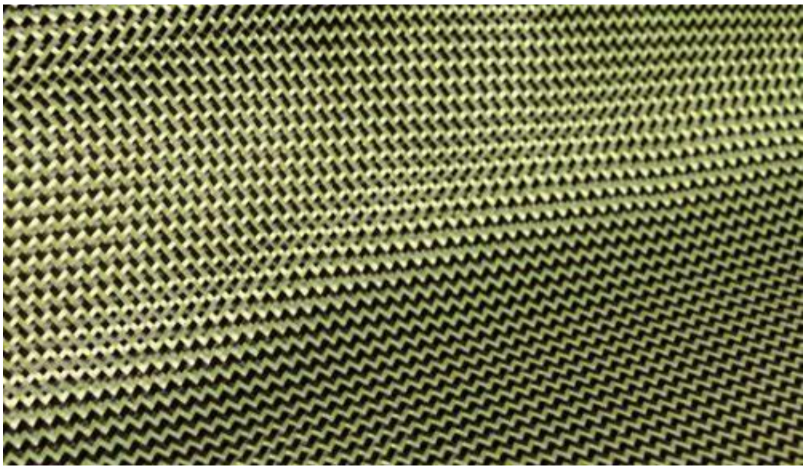


Figure 4. Carbon-aramid hybrid [40]

1.2 Ballistics Concept

1.2.1 Ballistics

The apparatus called "ballistia"—which is intended to shoot long arrows—is the source of the name "ballistics".The Greek word ballein, which meaning to toss, is where the word ballistia first appeared. The word ballistics, which derives from the French word balistique, is now defined as the science that examines the movements of items propelled into space, or mainly bullets, both inside and outside the weapon, that is, their movements and their effect on the target[30-52].

Furthermore, the analysis focuses on the motion of projectiles, rockets, artillery shells, and their interactions, effects, and flight paths as well as their velocities and accelerations. Ballistics also includes studies on the effects of firearms and the analysis of crime scenes.

1.2.1.1 Internal Ballistics

In actuality, the introduction of gunpowder marked the beginning of the notion and adventure of ballistics. Gunpowder was standardized to include 75% saltpeter, 15% charcoal, and 10% sulfur toward the end of the 18th and beginning of the 19th centuries after many years of experimentation with many varieties[29].

From the moment the trigger is pulled until the bullet exits the barrel, internal ballistics are in effect. For large projectiles, internal ballistics estimates are mathematically more dependable than for tiny projectiles. Internal ballistics covers topics including the cartridge chamber, barrel size, pressure, bullet core velocity, rifling, rifling numbers, degrees of rotation, the firing of the capsule, the rate of combustion, gunpowders, and rifling.

In general, for any weapon system to have high efficiency, the concept of internal ballistics must be well understood in order to minimise energy losses as much as possible and to define the design parameters correctly [53].

1.2.1.2 External Ballistics

Thanks to the work of the renowned Italian scientist Galileo Galilei (1562–1642), external ballistics is now recognized as an exact science. It analyzes the state of the bullet core from the moment it exits the barrel of the barrel until it reaches the target. The field of external ballistics includes air resistance, the impact of gravity on the bullet core, the bullet core's descent to the ground, its drift, and its balance[29].

In external ballistics, projectile dynamics and stability, predicted flight path, flight time and angle of impact, velocity and its location is important.It also investigates how thrown things move and interact with their surroundings. External ballistics includes, for instance, the trajectory of a rocket or projectile in the atmosphere, the impact of gravity, aerodynamic forces, target accuracy, and other elements. Consequently, analysis is also done on the objects' flight courses, ranges, impact energy, and other performance parameters [54].

1.2.1.3 Intermediate Ballistics

‘Intermediate ballistics’, which fills the gap between internal and external ballistics, covers the 1-2 milliseconds before and after the bullet core leaves the rifle or pistol barrel.To put it briefly, it is the field of ballistics that examines actions that take place near a rifle's or other weapon's muzzle. While internal and intermediate ballistics are similar, the distinction between the two lies in the process of moving from internal to external ballistics. Accurate results can be obtained by accounting for the bullet's initial movement as it exits the muzzle. Intermediate ballistics examines muzzle swirls and blast pressure, muzzle flame, muzzle smoke and muzzle sound[31].

1.2.1.4 Target Ballistics

Target ballistics studies the effects of bullets on targets from the time the bullet core enters the target until it exits, including the transfer of the bullet's energy and penetrating power to the target's object. Of course, impacts like blast, illumination, penetration of armored targets, fire, fragment, fog, toxic gas, radioactive, and germ effects may all be seen clearly on the target[55]. Not all of these effects can be produced by a single model bullet. Therefore, various types of projectiles should be applied to the target according to the desired effect[32].The study of ballistics makes a substantial contribution to target analysis by helping to comprehend how a projectile or rocket affects a target and how much energy it can transmit while penetrating it. Additionally, it advances the development of defense plans, weapon systems, and efficient shooting methods. Target ballistics examines the effects of projectiles on personal protective armour, but also the effects of explosives on different types of targets, such as a building, helicopter, military vehicle or tank[56].

1.2.1.5 Ballistic Limit

When a projectile impacts and loses all of its velocity due to material penetration, it reaches the ballistic limit, which is also known as the critical velocity or kinetic energy level. This definition is computed by averaging two impact velocities, one of which should be the greatest velocity producing a partial effect and the other of which should be the lowest velocity producing a full effect.

Making sure the difference in velocity between the two is less than 50 feet (15.24 meters) per second is crucial for figuring out the ballistic limit. The ballistic limit velocity notion can be used to velocities below this velocity, which is the velocity at which the bullet cannot entirely contact the item or object put on the target. Variations in the parameters employed to define the perforation event are the reason for the discrepancies between these methods[33].

1.2.2 Target

An object that a projectile, rocket, or other ballistic object interacts with is called a target. Typically, a target is an object chosen with a specific intent and meant to be struck or otherwise impacted. Every kind of target is unique. Targets in military ballistics may include opposing soldiers, vehicles, or buildings. Targets in ballistics utilized by law enforcement or security personnel are typically threats or criminals. Targets are target boards or targets that the shooter aims at or attempts to strike in ballistic shooting training.

Every ballistic event has a potential consequence that targets can affect. There are several possible outcomes when a projectile or rocket strikes or interacts with a target. These may involve the target's penetration, destruction, impact, damage, or destruction.

1.2.3 Penetration

It describes how any object can penetrate or be penetrated by another object into an obstruction. Ballistic objects, such as bullets, rockets, or other projectiles, have a better chance of penetrating their targets out of all the options. When a ballistic object reaches its target, penetration describes how it advances through it. This indicates that the ballistic object crosses the target's surface and enters its interior during penetration operations. The ballistic object must possess the necessary kinetic energy, geometry, and structural strength to successfully pierce the target in order for the defined penetration to be accomplished.

The structural properties of the ballistic object and the target's resistance are connected to penetration capacity. High strength, high density, high hardness, and unique design elements are required in ballistic materials. Ballistic armor steels and ballistic ceramics are two examples of materials that are used to boost and enhance projectile and rocket penetration capabilities in order to deliver these qualities.In the domains of security, defense, and the military, penetration capacity is crucial. Penetration capability is directly related to the ability of a tank shell to penetrate enemy armor or the ability of an armor-piercing projectile or rocket to penetrate the target vehicle's armor. For ballistic materials and systems to be improved, enhanced, and evaluated for efficacy, penetration analysis and testing are crucial.

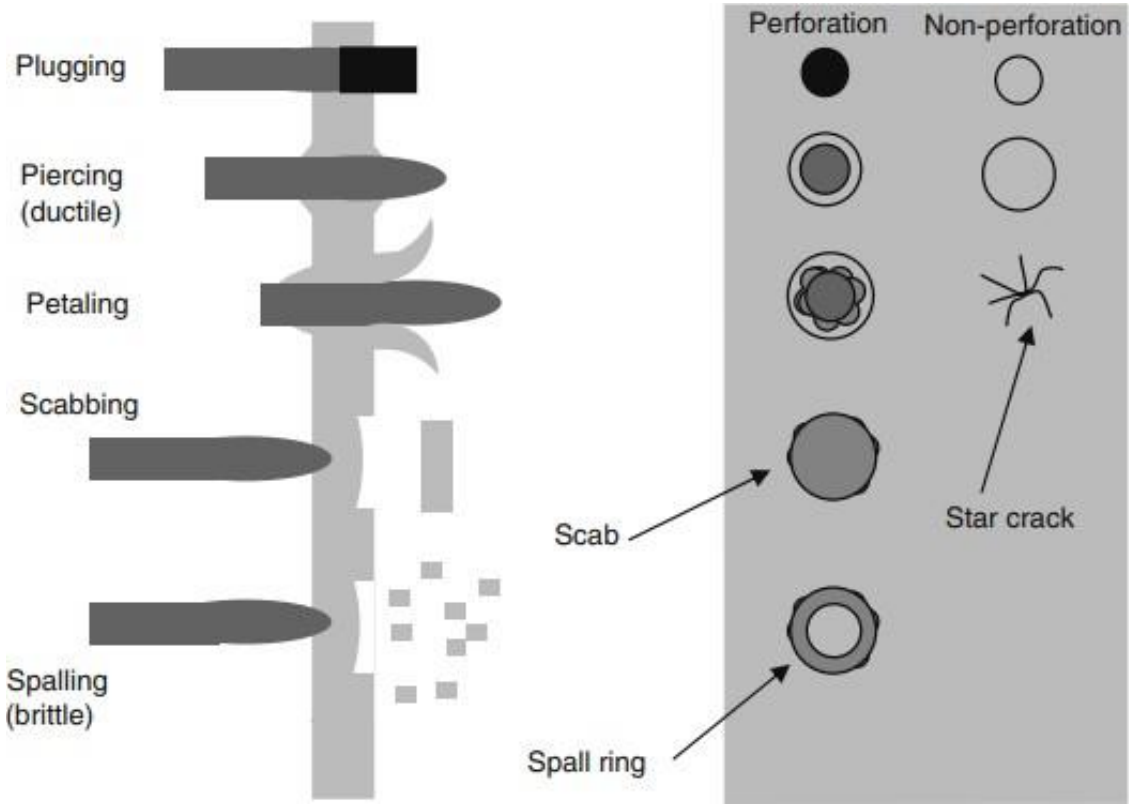


Figure 5. Target failure modes [54].

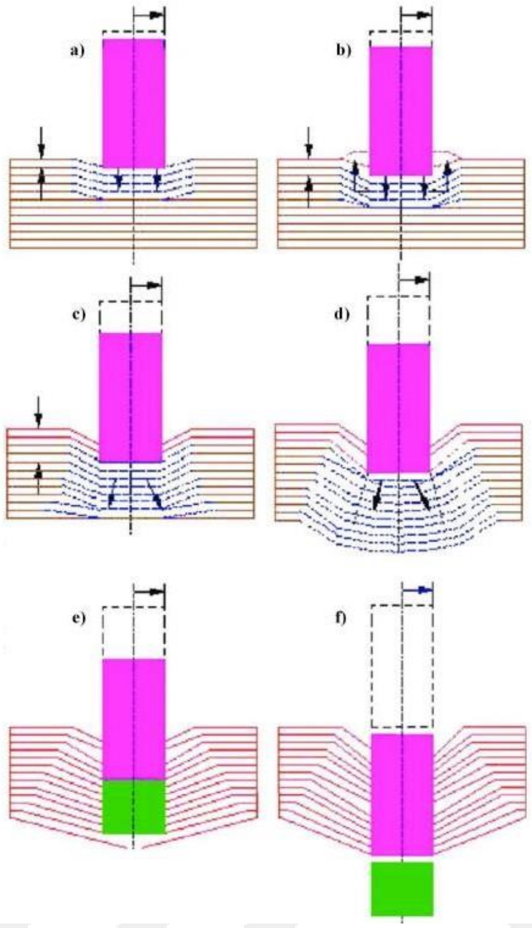


Figure 6. Penetration and perforation stages of 2D woven fabric composite target during ballistic impact [57].

1.2.4 Perforation

The act of creating holes in the surface of the targeted object is known as a perforation. Generally speaking, the term "perforation" describes actions like the piercing of projectiles, rockets, or other ballistic items. The process by which a ballistic object punctures a target, either permanently or temporarily, when it strikes it is sometimes referred to as perforation. A ballistic object's kinetic energy, geometry, target object resistance, and other independent elements determine how easily it can pierce a target.

Understanding how a ballistic object affects a target object can be accomplished effectively with the use of perforation analysis. It assesses a variety of factors, including the energy transmission, perforation depth, and hole characteristics of ballistic materials or objects. The design of armor, material selection, and the creation of efficient protection systems all benefit greatly from penetration testing.

1.2.5 Bullets

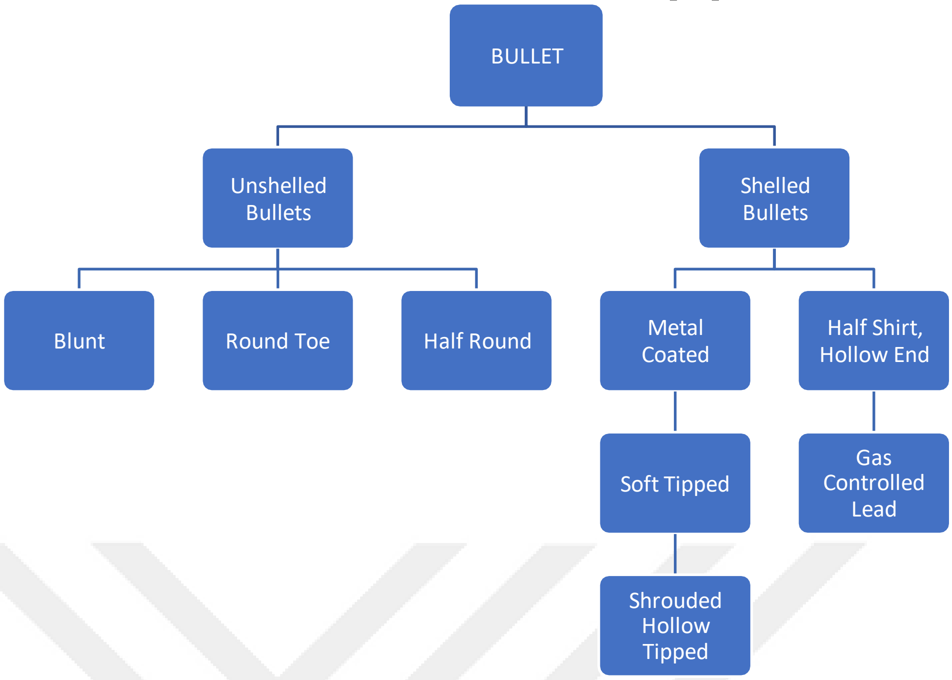
Bullet refers to a sharp, explosive, highly destructive material that can only be discharged by firearms. Three components make into the bullet structure of weapons. The bullet core is located at the end of the bullet. This is where the component that propels the bullet core toward the target is placed when the weapon is discharged. The section containing the propelling powder is the second one. Here, the pressure created by the burning propellant forces the bullet out of the barrel. The shell casing is located in the third part. Inside the shell casing, which has the form of a closed metal cylinder, is where the propelling powder is hidden. The powder can be shot simultaneously by pulling the trigger as soon as the capsule behind the cartridge casing fires.

The capsule ignites the gunpowder in the barrel when it fires, either by impacting the firing pin or by the action of an electric current. The bullet core is pushed forward and begins to travel toward the target at a very high speed as the gunpowder begins to burn and the hot gas pressure in the surroundings heats up.

In automatic weapons, reverse pressure is applied to reload the weapon using the same propellant that ejects the round from the barrel. When it comes to the energy contained in the bullet, the kind and amount of gunpowder employed have a significant impact on its starting velocity[2].

Propelling powder is a material made of nitrocellulose. This substance is mixed with a variety of chemicals to regulate the rate and heat of combustion. Single base gunpowder is defined as gunpowder that is made exclusively of nitrocellulose. Double base gunpowder is the term for gunpowders that have an initial velocity and energy significantly higher than single base gunpowder and include 70–80% nitroglycerin[2].

Table 3. Classification of Bullets [35]



Shelled and unshelled bullets are the two different kinds of bullets. Unshelled bullets are those with a lead core only, whereas shelled bullets contain a lead core and are coated with any substance.
Shells can be made of brass, nickel, copper-coated steel, nickel-plated steel, and tombak (tombak is 90% copper and 10% zinc)[2].The penetration and deformation of the projectile can be determined according to the structural features, tip geometry, velocity, core material and coating properties of the projectile[47].

Figure 7. Types of Bullets [2]

1.2.5.1 Bullet Kinetics

As we know from physics, kinetic energy is directly related to the mass and speed of matter.The study of bullet kinetics has a close connection to the concepts of motion and energy[35].
The quantity of energy left on the bullet after shooting, following the loss in the barrel, is known as the muzzle energy or kinetic energy of the bullet. This energy is directly related to the product of the bullet's mass and squared velocity[36].

Muzzle velocity is the most significant component of muzzle energy. In contrast, the effective potential of the bullet in a handgun is referred to as muzzle energy, and variables like aerodynamics and gravity are disregarded. The muzzle energy and its potential for damage increase when the bullet is moving at its fastest possible speed and most heavily. In contrast, one of the reasons why bullets pose a significant risk to life even if their weight is quite modest is because of the momentum force that gives them a high speed[37].

1.2.6 Ballistic Related Standarts

Ballistic protection guidelines have been produced by the National Institute of Justice (NIJ) and the North Atlantic Treaty Organization (NATO). The Turkish Standards Institute has additionally created a standard.

NIJ and German standards are utilized to define various protection levels, which take into consideration the projectile's type, weight, speed, and caliber. The NATO publication STANAG 2920 quantifies the degree of ballistic protection by fragment. STANAG 2920 is a NATO specific ballistic test standard for armour materials and combat clothing. It is widely known in military specifications throughout NATO, and is the authorised test standard for military personal protective equipment, but is also used to complement other test protocols[58].
Ballistic performance is usually determined by the ballistic limit speed of the material used. Ballistic limit speed is an important parameter in understanding the dynamic damage behaviour in order to design any composite structure and to effectively use the designed composite material as a protective structure[59].

Ballistic property is investigated by the amount of potential energy absorbed, controlling the velocity of the projectile and the depth of indentation. Some of the many factors that improve ballistic performance in composites include hybridisation of natural and synthetic fibres, combination of low and high tensile fibres and weaving architectures[60].

Table 4. Ballistic Protection Standards in the World

STANDARD NO	STANDARD NAME
MIL-A-46103 C	Light Weight, Ceramic Faced Composite Armor Procedure Requirements
MIL-B-44053 A	Fragmentation Protective Body Armor, Vest Ground Trops
MIL-STD-662 F	Department Of Defense Test Method Standart V50 Ballistic Test For Armor
NIJ-STD-0101.04	Balistic Resistance of Personel Body Armor
NIJ-STD-0108.04	Balistic Resistance Protective Materials
STANAG 2920	Balistic Test Method For Personel Armor
UK/SC/4697	The Balistic Testing of Fragment Protective Personel Armors
TS 11164	Ballistic Protective Vest

PPAA STD-1989-05	Personel Protective Armor Assosiation Testing Standards For Balistic Resistance of Personel Body Armors
UL 752	Balistic Resistance Equipment
MIL-B-44194 A	Body Armor Fragmantation Protective Undergarment C.V.Crevmens
MIL-P-46199	Aluminium Oxide Ceramic (For Use In Armor Composite)
pR EN ISO 14876-2	Protective Clothing-Body Armor-Part-2:Bullet Resistance-Requirements and Methods

Table 5. Ballistic test criteria according to NIJ Standard-0101.04 [38].

Test Variables					Performance Requirements						
Armor Type	Test Round	Test Bullet	Bullet Weight	Reference Velocity (± 30 ft/s)	Hits Per Armor Part at 0° Angle of Incidence	BFS Depth Maximum	Hits Per Armor Part at 30° Angle of Incidence	Shots Per Panel	Shots Per Sample	Shots Per Threat	Total Shots Req'd
I	1	22 caliber LR LRN	2.6 g 40 gr.	329 m/s (1080 ft/s)	4	44 mm (1.73 in)	2	6	12	24	48
	2	380 ACP FMJ RN	6.2 g 95 gr.	322 m/s (1055 ft/s)	4	44mm (1.73 in)	2	6	12	24	
IIA	1	9 mm FMJ RN	8.0 g 124 gr.	341 m/s (1120 ft/s)	4	44 mm (1.73 in)	2	6	12	24	48
	2	40 S&W FMJ	11.7 g 180 gr.	322 m/s (1055 ft/s)	4	44 mm (1.73 in)	2	6	12	24	
II	1	9 mm FMJ RN	8.0 g 124 gr.	367 m/s (1205 ft/s)	4	44 mm (1.73 in)	2	6	12	24	48
	2	357 Mag JSP	10.2 g 158 gr.	436 m/s (1430 ft/s)	4	44 mm (1.73 in)	2	6	12	24	
IIIA	1	9 mm FMJ RN	8.2 g 124 gr.	436 m/s (1430 ft/s)	4	44 mm (1.73 in)	2	6	12	24	48
	2	44 Mag JHP	15.6 g 240 gr.	436 m/s (1430 ft/s)	4	44 mm (1.73 in)	2	6	12	24	
III	1	7.62 mm NATO FMJ	9.6 g 148 gr.	838 m/s (2780 ft/s)	6	44 mm (1.73 in)	0	6	12	12	12
IV	1	30 caliber M2 AP	10.8 g 166 gr.	869 m/s (2880 ft/s)	1	44 mm (1.73 in)	0	1	2	2	2
Special	*	*	*	*	*	44 mm (1.73 in)	*	*	*	*	*

2. LITERATURE REVIEW

2.1 Production Methods of Composites Materials

When it comes to producing composites, there are numerous production techniques available to suit various requirements. There are several benefits to each of these approaches. With this benefit, the best production technique must be used for the material in order to give the composite the appropriate shape and ultimately produce a product of the desired quality.

Depending on the type of matrix used in the composite material, these production techniques are separated into two groups: metal matrix composites and polymer matrix composites.

2.1.1 Metal Matrix Composites Production Methods

- Hot pressing
- Powder metallurgy
- Liquid metal impregnation
- Electrolysis method
- Vapor precipitation
- Rolling [14-15].

2.1.2 Polymer Matrix Composites Production Methods

- Hand deposit method
- Spraying method
- Resin transfer molding method
- Helical winding method
- Vacuum bagging method
- Pultrusion method [16].

2.1.2.1 Hand Deposit Method

A common process for creating glass fiber reinforced composites is hand lay-up. This technique is employed in a wide range of applications, including body panels for automobiles, trucks, and boats, as well as in the construction industry for things like ventilation system ducts, storage tank bodies, and swimming pools[15-14].This process of open molding is used to create polymer matrix composites. This method's low cost is a result of the inexpensive tools that were employed in its creation. The best option that can be chosen is the hand lay-up approach if there is no mass production, that is, no creation of prototypes or models[17].

The hand lay-up approach offers a wide range of benefits. These include minimal mold prices, no restrictions on the size of the parts to be manufactured, and the possibility to build molds in a range of shapes. Different is a highly favored method due to its many benefits. Of course, there are drawbacks to this approach in addition to its benefits. These drawbacks could include a variety of deviations in the dimensions of the composite that is produced, variations in thickness where the resin is not distributed evenly or where the fiber distribution is uneven, and modifications that will significantly affect the mechanical properties of the material owing to air bubbles that remain after the process and improper settling of the fibers during laying, depending on how professionally the hand lay-up method is applied.

Materials including silicon, mineral oils, polyvinyl alcohol, and waxes are employed in this technique to keep the resin from adhering to the mold surface, facilitating a simple removal of the composite material from the mold[15].

Applying the hand laying method is done as Figure 4 illustrates. Here, the fiber is laid out and the resin is applied using a roller-shaped brush to ensure that there are no air bubbles left after the mold release material has been applied. Applying fiber and glue in successive layers until the required thickness is reached completes the procedure[20-17-18-19-15-14-16].

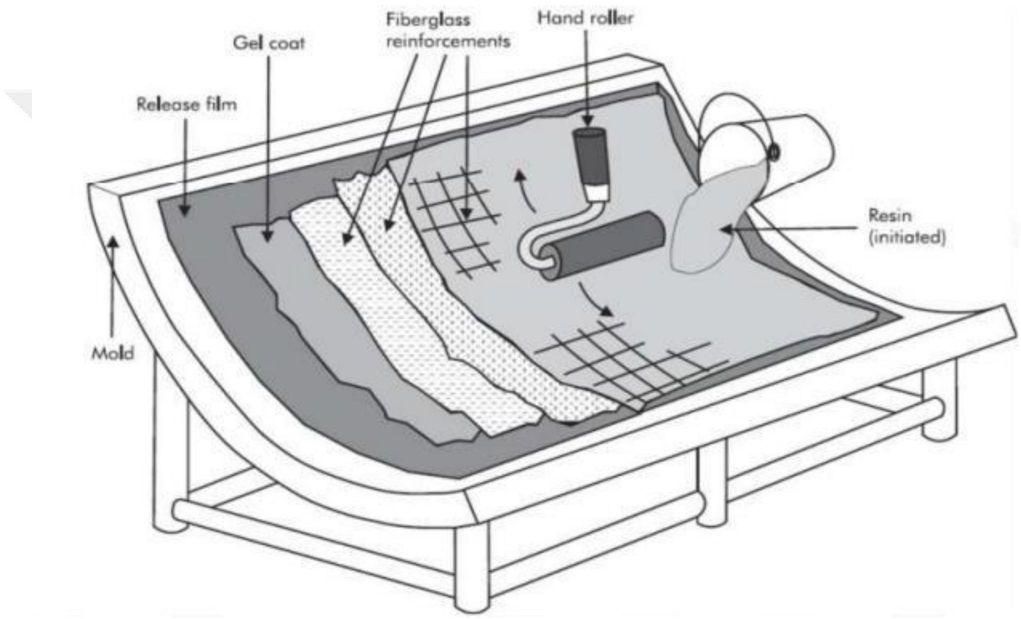


Figure 8. The hand lay-up methods [21-22].

2.1.2.2 Spraying Method

The spraying method is a production technique utilized in fields like boats, car bodywork, boats, and tanks where the reinforcing material used in the content is used in cropped form, even if it shares certain general similarities with the hand lay-up method[17-20-24].

Using a specialized cannon, continuous fibers that have been chopped into small pieces are sprayed into the mold at the right speed along with the resin and hardener mixture in the spraying process. When the required thickness is achieved, the spraying process is stopped. A roller is also used in this procedure to eliminate any potential air bubbles[15].

As a result, the pace at which the resin wets the fibers rises. It's a good approach since it can make complicated shaped parts and has minimal labor costs and inexpensive tools and materials. It also does not have any size restrictions on the parts that may be made[16-15].

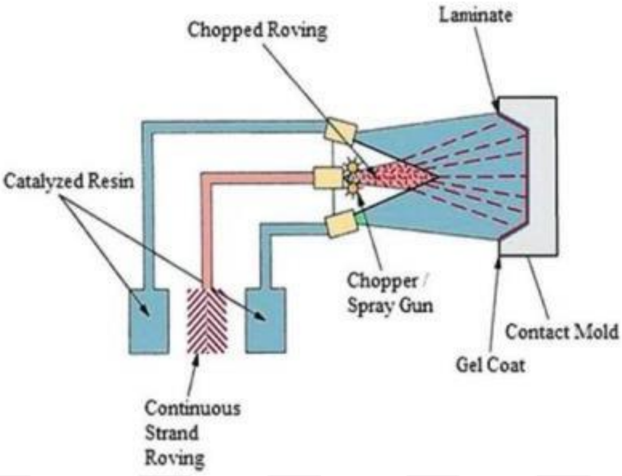


Figure 9. The spray-up methods [22].

2.1.2.3 Resin Transfer Molding Method

The top and lower molds of a closed molding technique called resin transfer molding are used. Two-part molds are utilized combined in this production method, which is quicker and more durable than the manual lay-up method. When pieces need to be smooth on both surfaces, this approach is usually chosen. Dry felt, fabric, or a combination of these two materials is utilized as reinforcing material. The mold is first closed after the reinforcing material has been inserted to fill the mold cavity. Subsequently, the resin is forced into the mold. It takes longer to complete this process. Containers up to 80°C can be used for matrix injection, whether they are cold, warm, or hot[17-19-25].

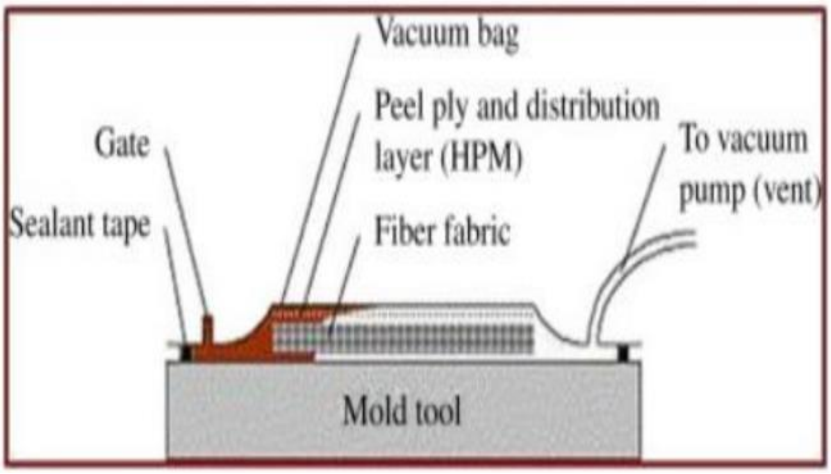


Figure 10. The resin transfer molding methods[26].

2.1.2.4 Helical Winding Method

An open mold technique called helical winding is used to make cylindrical parts like masts, pipes, pressure tanks, and rocket bodies. Usually, this technique makes use of a steel shaft that rotates. Flexible shafts that may be inflated and deflated at the end of production can be employed for certain particular purposes. With this method, continuous fibers that have been passed through a resin reservoir are wound on the shaft by adjusting them to the desired angles. A tool that moves back and forth along the shaft aids in the winding process until the desired thickness is reached at a particular tension. The result is taken out of the shaft and the procedure is finished once the resin has solidified[19-24-16].

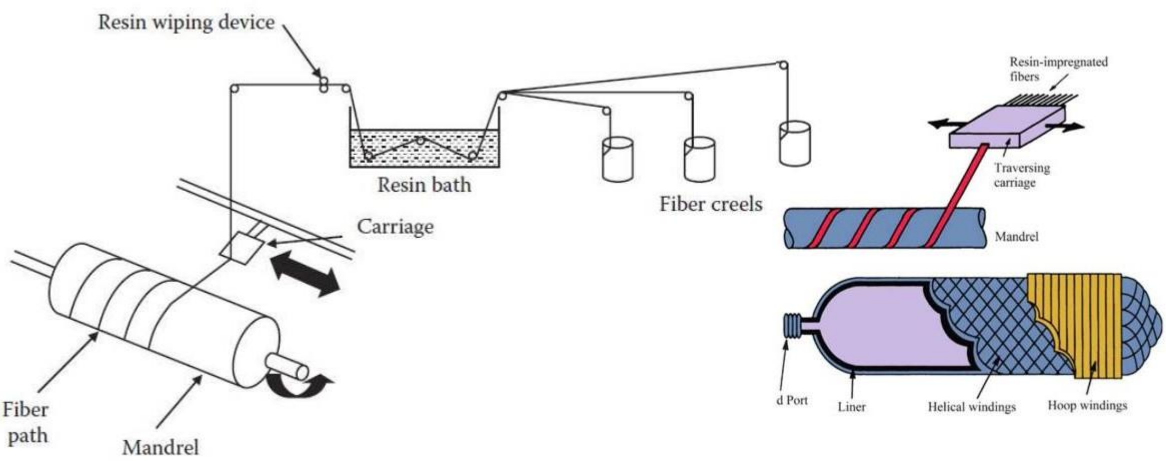


Figure 11. Helical winding method[27].

2.1.2.5 Vacuum Bagging Method

Similar to the hand lay-up method, this technique covers the mold with a vacuum bag after the resin is applied to the reinforcement element inserted into the mold. The edges of the vacuum bag are then secured with specific tapes to provide sealing. The vacuum system then removes the air from the bag, allowing the resin to more effectively enter the reinforcing element due to the external atmospheric pressure. Similar to previous techniques, the vacuum process is stopped and the product is taken out of the mold when hardening takes place. It is possible to produce items with improved mechanical qualities using this technology[23-29-19].

2.1.2.6 Pultrusion Method

Continuous fixed section composite profile products can be made using this low-cost mass production technology. The continuous reinforcing material is run through a resin bath during the process. For hardening, and it is subsequently put into a forming mold that is heated to between 120 and 150°C. Bright steel molds that have been chrome-plated are typically used. Extremely high mechanical strength is achieved in the direction of reinforcement because continuous fiber is used. The formed product is finished and cut into specific lengths once it has been brought to the right size in the design unit. Because of its broad applicability and cheap initial expenditure, this method is commonly employed.[29-19].

3. MATERIALS AND METHOD

3.1. Materials

Fibre, matrix and primary variables (fibre type, resin) that define our current field of study and variable parameters affecting the interfaces are taken into account in the design and production process of composite materials and the production process has started. Table 6 shows the components of the composite materials produced.

Table 6. Composite Material Components Used in the Study.

Component Type	Features
Fibre	Glass Fibre (200 g/m2)
Resin	Epoxy, HEXION MGS L160/H160 System
Production Method	Vacuum Assisted Resin Transfer Method

3.1.1. Glass Woven Fabric

In this study, epoxy was used as matrix and glass fibre was used as reinforcing element. Glass fibre is widely preferred and used in composite construction due to its lower cost compared to carbon fibre and also due to its chemical resistance. Glass fibre fabrics used in this thesis were obtained from Kompozit Pazarı A.Ş.

200 gr/m² plain woven glass fiber fabric was chosen for this thesis because it is employed in delicate applications such as electronic circuit boards, varnish coating applications in the maritime industry, and sensitive applications in the civil aviation sector where weight calculations are done extremely accurately. In the composites industry, 200 gr/m² plain glass fiber woven fabrics are the most favored materials in terms of price-performance ratio. It is well known that glass fiber performs better than felt in terms of structural characteristics [39].Glass fibre plain 200 gr/m² fabric has a compatible performance with polyester, vinylester and epoxy resins and the resin consumption is proportional to the weight of the fabric. When calculating

the amount of resin needed, it is necessary to take into account the amount that will remain on the brush and in the mixing container [39].

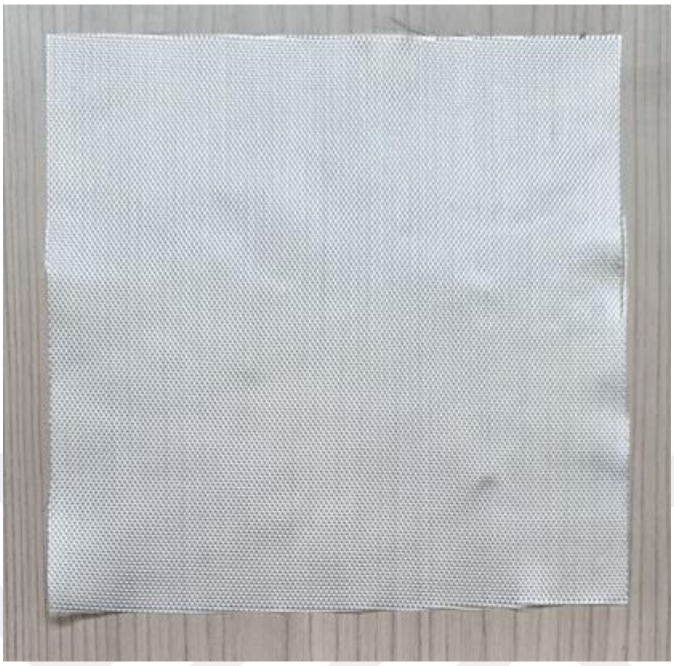


Figure 12. Glass fibre used in production.

3.1.2. Resin and Hardener

The epoxy system employed in this study was HEXION MGS L160/H160. Aerospace, automotive, maritime, wind turbine, and the defense industry are among the industries that use the MGS L160 lamination system. Compact infusion applications benefit from the comfort that the MGS L160 system offers. Parts that satisfy civil aviation standards can be obtained by following the proper procedures once it has cured at the optimal temperature, which is room temperature [41].

Table 7. Properties of the laminating resin MGS L160.

Density (g/cm^3)	1,13-1,17
Visocosity (mPas)	700-900
Epoxy equivalent gr/equivalent	166-182
Epoxy value equivalent/100g	0,55-0,60
Measurement Conditions	25℃

Table 8. Properties of MGS H160 hardener.

Density (g/cm³)	0,96-1,00
Visocosity (mPas)	10-50
Amine value (mg KOH/gr)	550-650
Refractor index	1,5200-1,5210
Measurement Conditions	25°C

3.2 Production Method

3.2.1 Composite Material Design

Within the scope of this study, the composite material was produced by vacuum infusion by using only glass fabric in some, carbon in some and glass fabric and carbon together in some as previously mentioned. Before the parts were produced, the sheet sizes to be produced were determined according to the number of samples to be used in the tests to be performed. The number of laminae and the amount of resin were calculated according to these plate sizes.

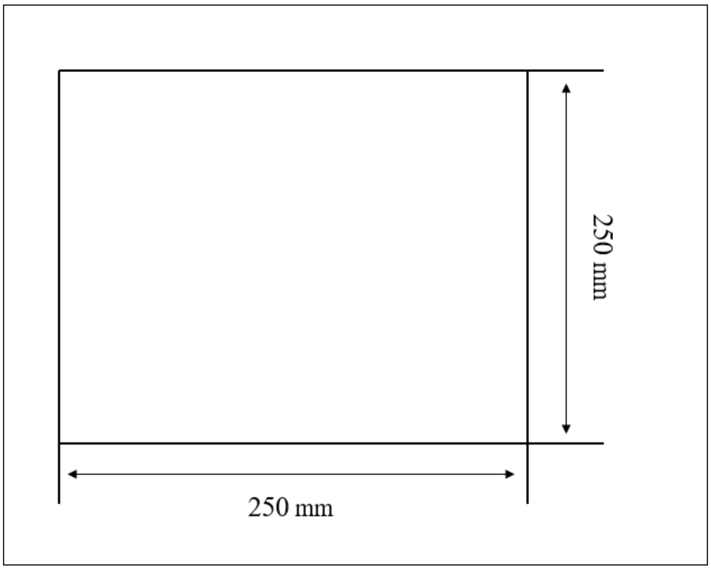


Figure 13. Size of the Prepared Composite Material.

Plate Total Area : Width x Length

:250mm x250mm $\cong 62500(mm)^2 \cong$ 0,0625 m2

Glass Fabric Weight : 200 g/m2

10 plates were produced in various forms. Sample representations of these plates are as shown in Figure 14.

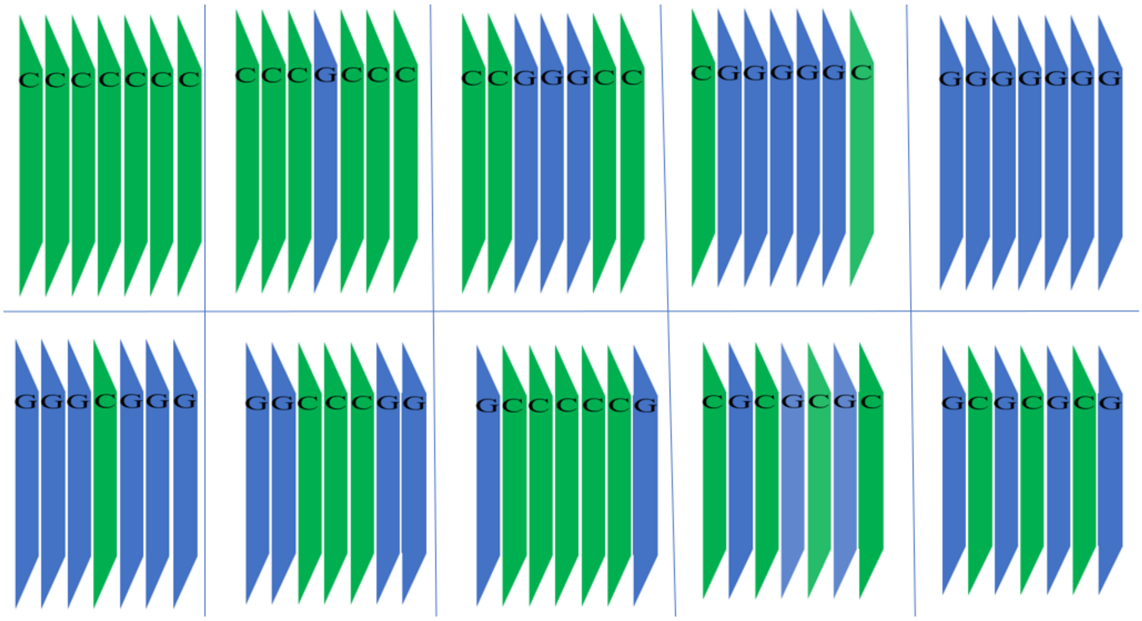


Figure 14. Produced Composite Material Layer Arrangement(C: Carbon - G: Glass)

The produced plates were cut in 250mmx250mm dimensions and made ready for firing.Table 9 shows the weight and thickness values of 10 composite materials produced.

Table 9. Weight and thickness of the samples(C: Carbon - G: Glass)

Samples	Thickness(mm)	Weights(g)
CGCGCGC	1,5	155,06
CCCCCCC	1,5	131,66
GCGCGCG	1,5	151,18
GCCCCCG	1,5	148,40
CGGGGGC	1,5	147,23
CCGGGCC	1,35	146,55
GGCCCGG	1,35	149,08
GGGCGGG	1,1	153,58
CCCGCCC	1,35	148,02
GGGGGGG	1,0	139,11

3.2.2 Production of Composite Materials

Within the scope of this study, vacuum for composite production infusion production method was preferred. The produced plates were cut in accordance with the standards and mechanical tests were carried out. In this section, the vacuum infusion method and production stages of the designed composite material are listed below:

i) Firstly, the glass surface where the production will be carried out was cleaned well with a wet cloth, then wiped with a dry cloth and dried.
ii) The fabrics were cut in 250mmx250 mm dimensions by cutting 1-1,5 mm more than the sheet dimensions to be produced.
iii) Paper tapes were adhered around an area at least 50 mm wider than their dimensions, and the designed and cut fabrics were positioned to cover the composite area. These tapes made it possible to apply the mold releasing agent in the precise location that was needed.
iv) Two coats of mould release compound were applied to this band area. After each application, a waiting time of five minutes was given and allowed to dry.
v) The fabrics are laid on top of each other according to the composite design to be applied.
vi) The paper tapes were removed and sealing tape was applied to the clean surfaces.
vii) The purpose of the peeling mesh is to create a texture on the composite and to easily separate the flow mesh from the produced part with a vacuum bag. Therefore, the peeling net is laid on top of the laid fabric to cover the fabric.
viii) After the peeling mesh was laid, a resin line was installed to ensure the flow of resin from the resin tank. Spiral hose and normal transparent hose were used for the resin line. The transparent hose was connected to the spiral hose at one end with a T-connection. The spiral hose was wrapped with a flow net and glued with paper tape to prevent unravelling.
ix) The flow net was cut to be larger than the fabric dimensions and laid on top of the peeling net. The spiral hose wrapped with the flow net was left in contact with the topmost flow net and secured with paper tapes.
x) On the other side was installed the vacuum line, which is equally crucial. With the use of clips, transparent hoses were fastened to each line. To keep air from coming into contact with the resin and from entering, it was folded and shattered.
xi) The finalised system is sealed very carefully and carefully with a vacuum bag.
xii) The homogenised epoxy resin and hardener were gently mixed for 10 minutes.
xiii) The vacuum pump was started and the empty air on the fabric was vacuumed and checked for air leakage. The pressure gauge in the vacuum pump was checked for the change in the engine sound and the vacuum bag not sticking and the pressure

values were ensured to be at the desired value (-760 mm Hg value) by taking appropriate measures.

xiv) The resin is given to the system with the help of a transparent hose. Here, the resin flows into the system thanks to the vacuum, while the resin flows into the system during this flow. Care was taken not to remove the hose from the resin in order to prevent suction of the air together. After the resin was finished, the hose was folded in half and clamped with a clip.

xv) The vacuum pump was operated for 3 hours while the resin progress was kept under observation.

xvi) The vacuum pump was switched off at the end of this period and the vacuum line The transparent tube is folded in half and clamped with a clip.

xvii) The system was left in this state and the resin impregnated fabric was left to cure in a vacuum closed system for 24 hours.

Figures 15-16-17 show the sequential representation of composite specimens produced by vacuum infusion manufacturing method.

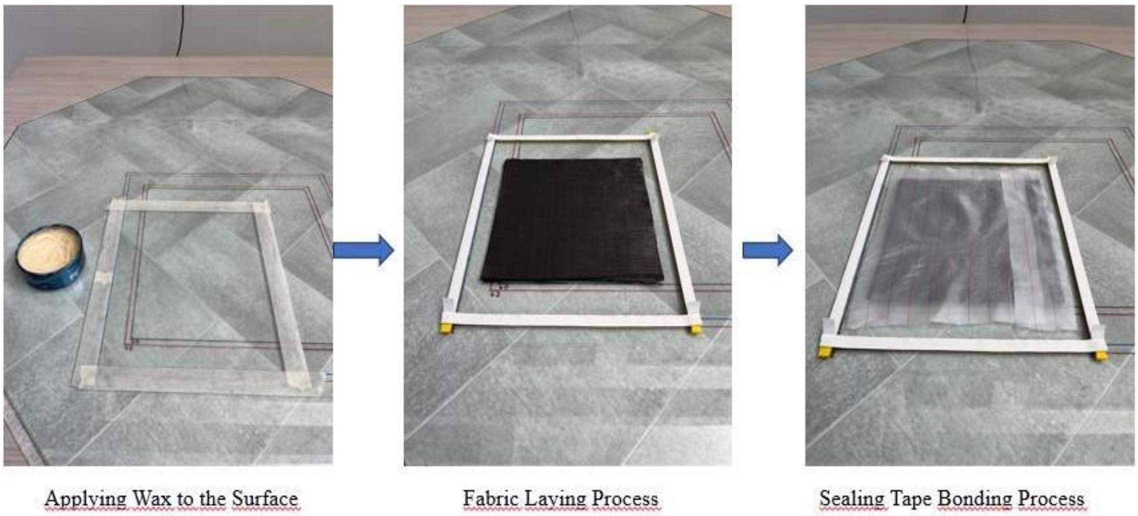
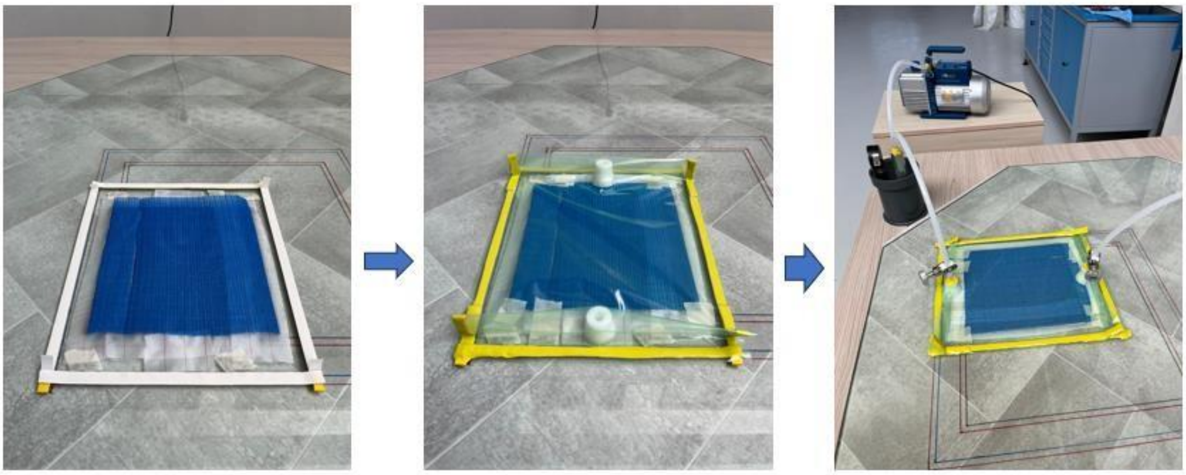


Figure 15. Illustration of the production stages of composite material by vacuum infusion method(a)

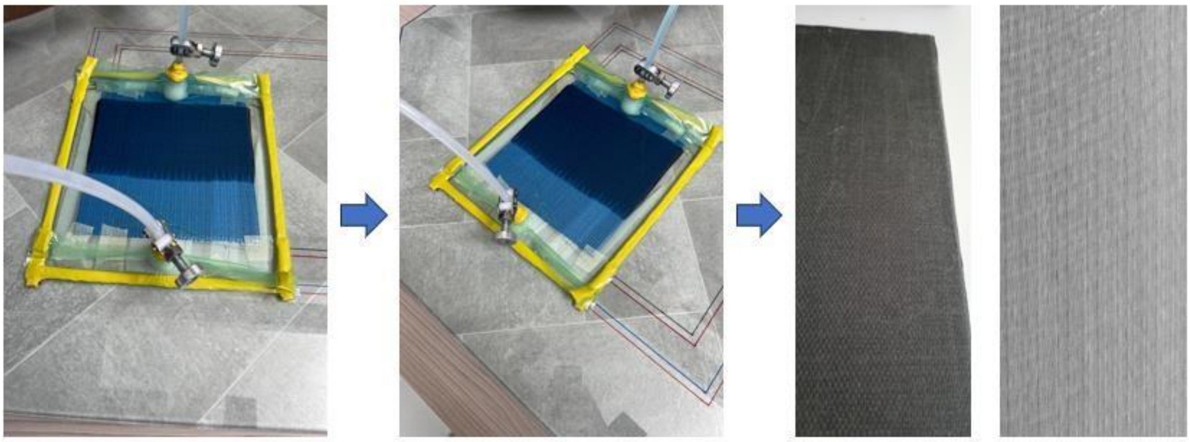


Mould Release Mesh

Flow Mesh

Vacuum Circle and Vacuum Pump Connections

Figure 16. Illustration of the production stages of composite material by vacuum infusion method(b)



Resin Starts to ProgressUnder Vacuum

The Resin ends its progress under vacuum and remains under vacuum for 24 hours

Glass and Carbon Fibre Reinforced Hybrid Composite

Figure 17. Illustration of the production stages of composite material by vacuum infusion method(c)

4. ANALYSIS AND DISCUSSION

Two 'PRECISION BALLISTIC CHRONOGRAPH BULLET SPEED MEASURING DEVICE ' tools were placed on 3 wooden blocks with 4 legs, with an average height of one metre, at the beginning and at the end. In the middle part, the composite samples were fixed to the wooden block with fixing clamps (provided that a different sample was used for each shot).

Then, each sample was shot once with a 36 calibre rifle at a distance of 3 metres. The entry and exit velocity of the bullet was measured separately for each sample with 'PRECISION BALLISTIC CHRONOGRAPH BULLET SPEED MEASURING DEVICE'.

Figure 18. PRECISION BALLISTIC CHRONOGRAPH BULLET SPEED MEASURING DEVICE

Figure 19. Experimental setup1(a)

Figure 20. Experimental setup1(b)

Table 10. shows the bullet entry and exit velocities of 10 different samples produced using glass and carbon.

Table 10. Entry and exit velocities of lead into and out of the samples (C: Carbon - G: Glass)

Samples	Enterance Velocity(m/s)	Exit Velocity(m/s)
CGCGCGC	507,4	466
CCCCCCC	520	410
GCGCGCG	508	486
GCCCCCG	514,6	476,3
CGGGGGC	514	466,1
CCGGGCC	509	476,4
GGCCCGG	514,6	465,3
GGGCGGG	516	476
CCCGCCC	516,7	466,4
GGGGGGG	516,3	476,4

The images of the bullet entry-exit damages on the front and back faces of 10 composite samples produced by vacuum infusion method in accordance with the standards after a single shot are clearly shown in Figures 21-22.

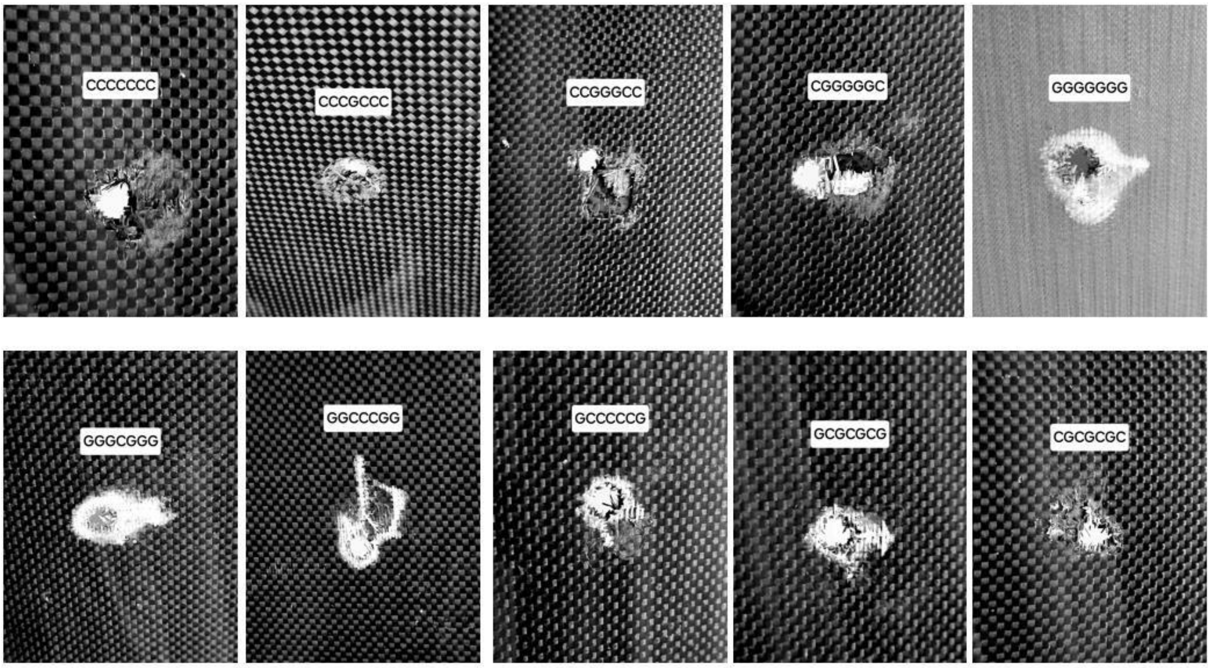


Figure 21. Bullet entry damage on the sample surface

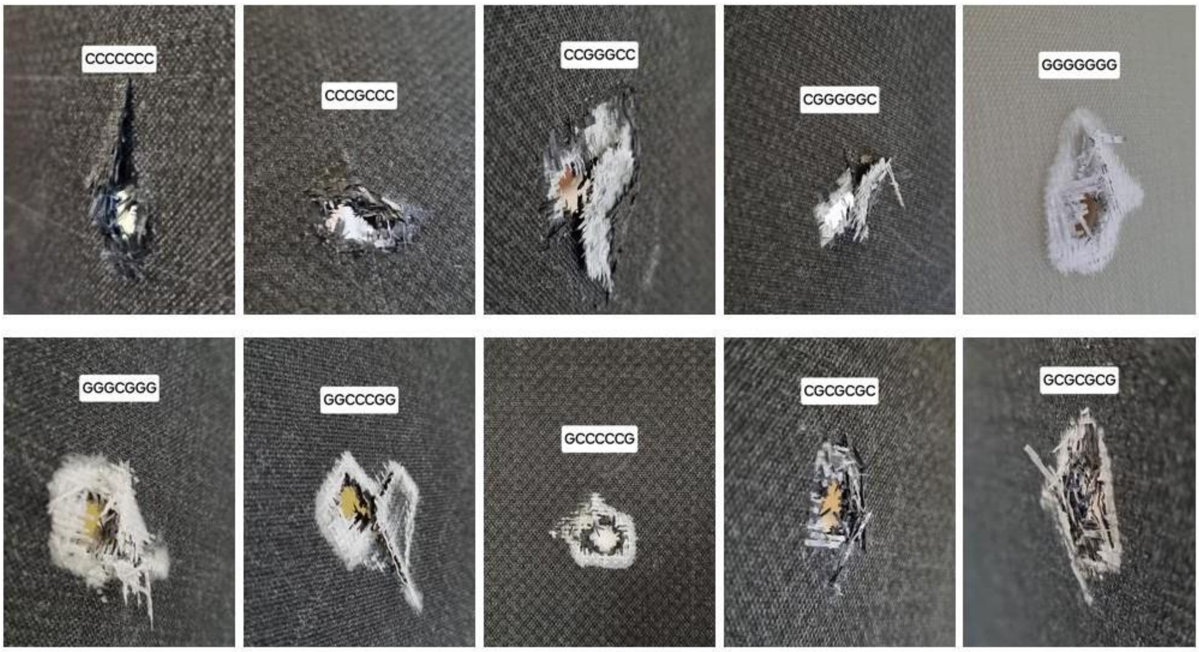


Figure 22. Bullet exit damage on the sample surface

The graph showing the bullet entry and exit velocities for the shots fired on 10 composite materials prepared in different forms used in this study is as shown in Figure 23.

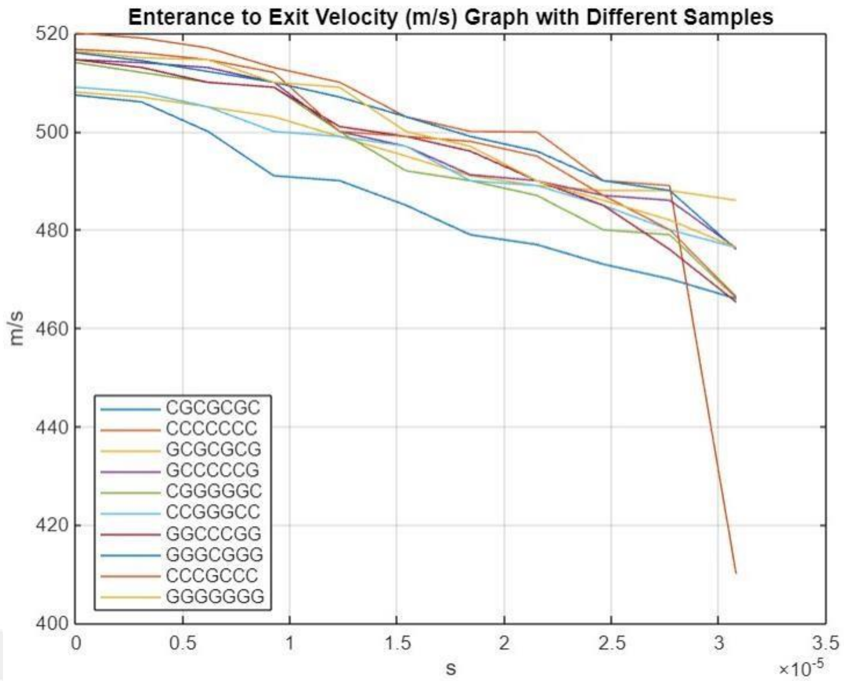


Figure 23. Bullet entry and exit velocities for selected samples

The material supported by carbon is the one that absorbs the most of the projectile's kinetic energy, as this illustration shows. Many elements, of course, influence the bullet velocity (wind, relative humidity, air resistance, gravitational acceleration, material thickness, proportion of glass or carbon in the material, shooting angle, etc.), but it is presumed that these aspects are not considered. Because all of these assumptions were made in the same environment under the same conditions. Based on this supposition, the sample that had carbon throughout was the one that took up the greatest amount of the kinetic energy of the bullet in the shots fired with a 36 caliber rifle.

5. CONCLUSIONS

At the end of 10 different shots for 10 different samples, it was realised that the order of glass and carbon used in the samples was not important. In other words, it was observed that if the type of material used in the sample is not the same, the layer order does not cause a significant change in the projectile exit velocity. The sample made with just carbon absorbed the maximum projectile kinetic energy out of the ten samples made with seven layers utilizing glass and carbon in varying sequences. The study concluded that bullets fired from a 36-caliber rifle absorb the most kinetic energy when striking materials with higher carbon content. Despite potential influences on bullet velocity such as wind, humidity and material thickness, these factors were controlled by ensuring consistent test conditions. Therefore, the material with the highest carbon content proved to be the most effective in absorbing the kinetic energy of the projectile.

REFERENCES

[1] Taşgetiren S. (1999). Kompozit Malzemelere Giriş Ders Notları, Afyon Kocatepe Üniversitesi, Teknik Eğitim Fakültesi, S: 2-3.

[2] Çalık, M. (2004). Zırh Tasarımında Kullanılan Farklı Geometriye Sahip Kompozit Kabukların Balistik Özellikleri. Yüksek Lisans Tezi, Afyon Kocatepe Üniversitesi, Fen Bilimleri Enstitüsü, Afyonkarahisar.

[3] Zor, M. (2017). Lecture Notes of Composite Materials, Izmir, Dokuz Eylül University.

[4] Kalemtaş, A. (2015). "Seramik Matrisli Kompozit Malzemeler." Bursa: Putech and Composites.

[5] Aztekin, K. (2010). Termoset Polyester Matrisli Kompozitlerin İşlenebilirliğinin AISI 1050 İle Karşılaştırmalı Olarak Araştırılması, Doktora Tezi, Balıkesir Üniversitesi Fen Bilimleri Enstitüsü, Balıkesir.

[6] Kalemtaş, A. (2014). "Metal matrisli kompozitlere genel bir bakış." Putech & Composites, Vol. 22, pp. 18-30.

[7] Dipen, K.R., Pagar, D. D., Kumar, R. ve Pruncu, C. I. (2019). "Recent progress of reinforcement materials: A comprehensive overview of composite materials." Journal of Materials Research and Technology, Vol. 8(6), pp. 6354-6374.

[8] Gülmez, S. (2018). Otomotiv Endüstrisinde Kullanılan Polimer Matrisli Kompozit Malzemeler, Yüksek Lisans Tezi, Pamukkale Üniversitesi Fen Bilimleri Enstitüsü, Denizli.

[9] Aztekin, K. (2010). Termoset Polyester Matrisli Kompozitlerin İşlenebilirliğinin AISI 1050 İle Karşılaştırmalı Olarak Araştırılması, Doktora Tezi, Balıkesir Üniversitesi Fen Bilimleri Enstitüsü, Balıkesir.

[10] Mishra, P. (2011). Development and Characterization of Low Cost Composite from Sugarcane Bagasse Waste. PhD Thesis, National Institute of Technology Rourkela, India

[11] Shokrieh, M. M., & Javadpour, G. H. (2008). Penetration analysis of a projectile in ceramic composite armor. Composite Structures, 82, 269–276

[12] Wang, R., Zheng, S., & Zheng, Y. (2011). Polymer Matrix Composites and Technology. Beijing: Woodhead Publishing

[13] Jenq, Syh-Tsang ve Mo, JJ. (1996). Ballistic impact response for two-step braided threedimensional textile composites. Aiaa Journal- AIAA J. 34. 375-384. 10.2514/3.13074. Thyssenkrupp Steel Europe, Secure 500 ürün AçIklaması, Https://www.Thyssenkruppsteel.Com/Media/Content_1/Publikationen/Grobblech_ Migration/Secure/Werkstoffblaet Ter_4/Secure_500_Wbl_1943_Englisch.Pdf (01.2016).

[14] Deniz, M.E., 2005, "Kompozit malzemelerin üretim yöntemleri ve ısıl işlemle presleme tekniğini kullanarak kompozit malzeme üretecek bir düzeneğin tasarım ve imalatı", Yüksek Lisans Tezi, Harran Üniversitesi Fen Bilimleri Enstİtüsü, Şanlıurfa,4, 32-47.

[15] Özer, H., 2015, "Sürekli cam elyaf takviyeli termoplastik kompozit malzemelerin geliştirilmesi ve mekanik özelliklerinin deneysel olarak belirlenmesi", Yüksek Lisans Tezi, Uludağ Üniversitesi Fen Bilimleri Enstitüsü, Bursa, 10-37.

[16] Şahin, Y., 2006, "Kompozit Malzemelere Giriş, 2. Baskı", Seçkin Yayınevi, Ankara, 27-139.

[17] İnançer, G., 2015, "Farklı takviye malzemeli plastik kompozitlerin darbe davranışına çevrenin etkisi", Yüksek Lisans Tezi, Dokuz Eylül Üniversitesi Fen Bilimleri Enstitüsü, İzmir,13-25.

[18] Mıstık, S.Ü., 2009, "Bor lifi takviyesinin polimer esaslı kompozit yüzeylerin mekanik özelliklerine etkileri", Doktora Tezi, Marmara Üniversitesi Fen Bilimleri Enstitüsü, İstanbul, 6-8, 43.

[19] Barbero, E. J., 2018, "Introduction to Composite Materials Design, Third edition", CRC Press Taylor & Francis Group , New York, 37-102.

[20] Chawla, K.K., 2011, "Composite Materials Science and Engineering, Third Edition" Springer , New York, USA, 11-140.

[21] Direk, E., "PRODUCTION OF COMPOSITE WITH ADDITIVES BY HAND LAY-UP PROCESS", Istanbul Commerce University Department of Mechatronics Engineering, İstanbul, 16-46, (2022).

[22] Bartın University. 2022. Kompozit Malzemeler Polimer Matrisli Kompozitler. Retrieved Date: 11.07.2022. Retrieved from https://cdn.bartin.edu.tr/metalurji/d7ee7cd9-f063-4669-8e1c393503ed6ffb/kompozitmalzemelersunu4polimermatrislikompozitler.pdf

[23] Barut, C., 2015, "Aramid esaslı kompozit malzemelerin balistik performanslarının ve mekanik davranışlarının incelenmesi", Yüksek Lisans Tezi, Afyon Kocatepe Üniversitesi Fen Bilimleri Enstitüsü, Afyon, 5-34.

[24] Karslı, M., 2016, "Hafif silahlar için polimer kompozit malzeme seçimi", Yüksek Lisans Tezi, Karadeniz Teknik Üniversitesi Fen Bilimleri Enstitüsü, Trabzon, 17-25.

[25] Arıcasoy, O. (2006). Kompozit sektör raporu. İstanbul Ticaret Odası, İstanbul.

[26] Rout, D., Nayak, R. K., S., P. 2021. Chapter 13 - Aerospace and Vehicle Industry. In C. M. Hussain, Handbook of Polymer Nanocomposites for Industrial Applications (pp. Pages 399-417). Elsevier.

[27] K. K. Chawla, Composite Materials: Science and Engineerig, Springer, 2012.

[28] Strong, A. B., 2008, "Composites Manufacturing Fundamentals of Materials, Methods, and Applications, Second Edition", Society of Manufacturing Engineers, Michigan, 2, 437-451, 395-399, 453-457

[29] Özek, T. (2005). Polimer Matrisli Kompozitlerin Mekaniksel Özelliklerinin İncelenmesi. Yüksek Lisans Tezi, Afyon Kocatepe Üniversitesi, Fen Bilimleri Enstitüsü, Afyonkarahisar.

[30] Çayıroğlu, İ. ve Dizdar, E. (2004). Kapsülsüz ve Barutsuz Mermi Atan Hafif Silah Tasarımı. Teknoloji. 7 (2), 339-344 s.

[31] Özer, M. T. (2017). Yüksek Kinetik Enerjili Ateşli Silah Yaralanmalarında Yara Balistiği ve Cerrahi Tedaviye Yansımaları. Okmeydanı Tıp Dergisi 33 (Ek sayı), 40-47.

[32] Üner B., Ağır G., Koç S., (1997). Ateşli Silahlar ve Balistik Tarihçesi, Balistik Konulu II. Adli Bilimler Sempozyumu, İzmir Tabip Odası.

[33] Turan, M. (2007). Tabakalı kompozit malzemelerde yüksek hızlı darbe hasarı. Mühendis ve Makina, 48(575), 3-8.

[34] Yavas, M.O. (2008). Hafif silahlara karşı bireysel savunma amaçlı kompozit alzeme tasarımı ve balistik dayanımı. Yüksek Lisans Tezi, Konya Selçuk Üniversitesi, Mühendislik Fakültesi, Konya.

[35] Sürmeli, D., & Neşeli, S. (2020). Mermi Namlu Çıkış Hızı ve Enerjisini Etkileyen Parametrelerin Optimizasyonu. Selçuk-Teknik Dergisi, 19(3), 156-169.

[36] Baran, D. (2018). Namlularda Kendi Kendine Ateşleme Süresinin Belirlenmesi, Yüksek Lisans Tezi, Kırıkkale Üniversitesi Fen Bilimleri Enstitüsü.

[37] Bryan Litz. (2015). Applied Ballistics For Long Range Shooting 3rd Edition, Isbn:978-0-9909206-1-8.

[38] Temiz, S., An investigation about ballistic fabrics and test methods, 3-95, 2005.

[39] Web 1, (2022), https://www.kompozitpazari.com/urun/cam-elyaf-dokumakumas-300-g-m2-twill, (Erişim Tarihi: 11/06/2022).

[40] Web 2, (2022), https://dostkimya.com.tr/tr/urunler/epoksi-sistemler/-epoksihexion-mgs-l160-sistemi, (Erişim Tarihi: 12/06/2022)

[41] A.İ. Kaya, Kompozit Malzemeler ve Özellikleri, Poliüretan ve Kompoz. Sanayi Derg. 8 (2016) 38– 45.

[42] Goushegir, S. M. (2015). Friction Spot Joining of Polymer-Metal Hybrid Structures. Welding in the World, 49(0), 2–4. https://doi.org/http://dx.doi.org/10.1007/s40194-016-0368-y

[43] SHODHGANGA. Indian Electronic Thesis and Dissertations Centre (2016). https://shodhganga.inflibnet.ac.in/bitstream/10603/1479/8/08_chapter1.pdf, 15.09.2020.

[44] Kaw, A. K. (2005). Mechanics of composite materials. CRC press.

[45] Deutsch, S. (1978). Automotive applications for advanced composite materials. In: Proceedings of the 23rd national SAMPE symposium. 34-60.

[46] Daniel, I.M., Ishai, O., 1994. Engineering Mechanics of Composite Materials. Oxford University Press, 416p, New York.

[47] Cheng-Kun, C., Yu-Liang, C., 2010. Ballistic-proof effects of various woven constructions. Fibers & Textiles in Eastern Europe, 18 (6), 63-67.

[48] I. Aatthisugan, A. Razal Rose, and D. Selwyn Jebadurai, "Mechanical and wear behaviour of AZ91D magnesium matrix hybrid composite reinforced with boron carbide and graphite," J. Magnes. Alloy., vol. 5, no. 1, pp. 20–25, 2017.

[49] Y. Huang, J. Li, L. Wan, X. Meng, and Y. Xie, "Strengthening and toughening mechanisms of CNTs/Mg-6Zn composites via friction stir processing," Mater. Sci. Eng. A, vol. 732, no. May, pp. 205–211, 2018.

[50] C. Barry Carter and M. Grant Norton, Ceramic materials: Science and engineering. Springer, 2007.

[51] K. Chawla, Composite materials, vol. 2, no. 4. Springer, 2001.

[52] Moeng, M. S. and Boffard, K. D, 2017, Ballistics in trauma, In: Penetrating Trauma, Berlin, 177-183.
[53] Miner, R., 2013, Computational interior ballistics modeling, Master of Science Thesis, University of New Mexico, Albuquerque, New Mexico.
[54] Carlucci, D. E., 2007, Ballistics: theory and design of guns and ammunition, CRC Press, Boca Raton.
[55] Giglio, M. and Manes, A., 2011, Terminal ballistic effect on the crack growth assessment of a helicopter rotor drive, Engineering Fracture Mechanics, 78 (8), 1542-1554.
[56] Crouch, I. G., 2019, Body armour–new materials, new systems, Defence Technology, 15 (3), 241-253.
[57] Akella, K. and Naik, N. K., 2015, Composite armour—A review, Journal of the Indian Institute of Science, 95 (3), 297-312.
[58] Carr, D. and Lewis, E., 2014, Ballistic-protective clothing and body armour, In: Protective clothing: managing thermal stress, Woohead Publishing, 146-170.
[59] Karahan, M., Jabbar, A. and Karahan, N., 2015, Ballistic impact behavior of the aramid and ultra-high molecular weight polyethylene composites, Journal of Reinforced Plastics and Composites, 34 (1), 37-48.
[60] Sukanya, N. M. and Sundaram, S. K., 2022b, Ballistic performance of synergistically toughened Kevlar/epoxy composite targets reinforced with multiwalled carbon nanotubes/graphene nanofillers, Polymer Composites, 43 (2), 782-797.