DEVELOPMENT OF LIGHT WEIGHT BALLISTIC HELMET WITH ENHANCED COMFORT FOR FRONTLINE SOLDIERS

A PROJECT REPORT

[Phase - II]
Submitted by

PRADEEP S	**(113219081042)**
PRASANNA KUMAR R	**(113219081044)**
SASHTI SUBANKAR D	**(113219081056)**
SATHISH S	**(113219081057)**

In partial fulfillment for the award of the degree

Of

BACHELOR OF ENGINEERING

IN

MECHANICAL ENGINEERING

VELAMMAL
ENGINEERING COLLEGE
The Wheel of Knowledge rolls on!

VELAMMAL ENGINEERING COLLEGE, CHENNAI-66.
(An Autonomous Institution, Affiliated to Anna University, Chennai)

APRIL 2023

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BONAFIDE CERTIFICATE

Certified that this project report **"DEVELOPMENT OF LIGHT WEIGHT BALLISTIC HELMET WITH ENHANCED COMFORT FOR FRONTLINE SOLDIERS"** is the bonafide work of **PRADEEP.S, PRASANNA KUMAR.R, SASHTI SUBANKAR.D, SATHISH.S** who carried out at the project under my supervision.

Signature

Dr. E. GANAPATHY SUNDARAM
PROFESSOR & HEAD
Dept. of Mechanical Engineering
Velammal Engineering College
Chennai – 600 066

Signature

Dr. K. VARATHARAJAN
ASSISTANT PROFESSOR
Supervisor
Dept. of Mechanical Engineering
Velammal Engineering College
Chennai – 600 066

CERTIFICATE OF EVALUATION

COLLEGE NAME : VELAMMAL ENGINEERING

COLLEGE BRANCH : MECHANICAL ENGINEERING

SEMESTER : VIII

Sl. No	Name of the students who has done the project	Title of the Project	Name of supervisor with designation
1	PRADEEP S	**DEVELOPMENT OF LIGHT WEIGHT BALLISTIC HELMET WITH ENHANCED COMFORT FOR FRONTLINE SOLDIERS**	Dr. K. VARATHARAJAN Assistant Professor Supervisor
2	PRASANNA KUMAR R		
3	SASHTI SUBANKAR D		
4	SATHISH S		

This report of project work submitted by the above students in partial fulfillment for the award of Bachelor of Mechanical Engineering Degree in Anna University was evaluated and confirmed to be reports of the work done by the above studentsand then assessed.

Submitted for Internal Evaluation held on 20/04/2023.

Internal Examiner **External Examiner**

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ABSTRACT

Head injuries caused by a bullet penetration or shock waves from the improvised explosive device (IED) are the main causes of military traumatic brain injury or death. Improvements in ballistic and impact protection of helmets may help to increase the survival rate of the soldiers. A ballistic helmet is designed to protect the wearer from impact by absorbing and dissipating energy without transmitting it to the head. Combat or ballistic helmets made from conventional Kevlar material has some drawbacks such as limited strength, thermal discomfort, durability issues and poor moisture resistance. In this proposed work. Ultra-high molecular weight polyethylene (UHMWPE) fiber will be used as a helmet material which is 15 times stronger than the steel and 2 times stronger than the Kevlar. Moreover, in the conventional ballistic helmet three to four holes are provided to fit the accessories. Holes increases the stress concentration which ultimately weakens the strength of the helmet. In this work, the holes will be avoided in the load direction. Finally, a combat helmet will be fabricated based on the simulation results.

ACKNOWLEDGEMENT

We are greatly and profoundly thankful to our honorable Chairman, **Shri. M. V. MUTHURAMALINGAM, B.E**., for facilitating this opportunity. We also record our sincere thanks to our Chief Executive Officer, **Mr. M. V. M. VELMURUGAN, M.A., B.L.,** for extending a generous hand in providing the best resources of the college.

We are thankful to our Principal **Dr. S. SATISH KUMAR, M.E., Ph.D.,** for rendering moral support to us during the course of our project. We are also thankful to our Head of the Department **Dr. E. GANAPATHY SUNDARAM, M.E., Ph.D.,** for the supports and useful suggestions during this project work.

We thank our project guide **Dr. K. VARATHARAJAN, M.E., Ph.D.,** for his constant technical support and encouragement, which enabled us to complete our project successfully.

We would like to express our sincere gratitude to our project coordinator **Dr. S. SURESH, M.E., Ph.D.,** for his moral support throughout this project. We are also greatly indebted to the faculty members of the Mechanical Department for their coordination and support in helping us to finish this project.

We would also like to take this opportunity to thank all our family members, classmates, and friends who offered an unflinching moral support for completion of this project

The success and final outcome of this project required a lot of guidance and assistance from many people and we are extremely privileged to have got this all along the completion of our project.

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CHAPTER - 1

INTRODUCTION

For over three decades, state-of-the-art ballistic helmets depended entirely on aramid fibers. Currently work continues on the production of ballistic composites based on polyethylene fibers of ultra-high molecular weight (UHMWPE), polypropylene (PP) and carbon fibers. The material properties for a ballistic helmet are standard, depending upon the helmet type. The properties of selected materials used for helmets.

Ultra high molecular weight polyethylene fiber was a very promising material for making light-weight high strength and high impact resistant composites, especially for ballistic head protection. Project shows that forming helmets of commercial high strength polyethylene fiber prepreg is possible.

Commercial Dyneema® HB25 materials were used in the study. The Enhanced Combat Helmet (ECH), which has been under development since 2007 for the US Marine Corps and US Army, makes use of Dyneema® HB80 unidirectional composite material, which consists of a matrix of ultra-high molecular weight polyethylene (UHMWPE) reinforced by carbon fibers.

The weathering and gamma radiation effects on the ballistic properties of UHMWPE composite armour were studied by Alves et al. Composite plates were subjected to weathering (2 and 4 months) and gamma irradiation (25 kGy and 250 kGy).

It was found that exposure to weathering for 4 months did not cause significant changes in ballistic impact resistance. However, it significantly increased delamination failures in the plate under a projectile impact, which was attributed to oxygen diffusion between the layers, reducing the interfacial resistance. Also it was observed that exposure to gamma radiation reduced the ballistic resistance.

The higher the gamma radiation dosage, the larger the local damaged area. It was concluded that exposure to weathering and gamma radiation induces modification in the UHMWPE molecular structure, leading to changes in the mechanical and ballistic properties of the composite. It is therefore necessary to test the UHMWPE based helmet periodically to ensure that weathering and gamma radiation do not compromise the ballistic impact resistance of the helmet.

It has become known that UHMWPE/ carbon fiber composites can provide higher ballistic protection at a reduced weight than the composites used in current helmets. Polymer matrix nano-composites, especially those reinforced by carbon nanotubes, can potentially offer the highest ballistic protection. However, their viability in terms of manufacturing feasibility and cost effectiveness needs to be further explored.

The ballistic performance of helmets depends on the composite material properties, the type of fibers and matrix, the fiber orientation, the interaction between the fibers and matrix, as well as on the parameters of processing the composites dedicated for the helmet shell.

In the literature a process was disclosed for producing a hybrid helmet consisting in forming an outer layer of carbon fiber and polyethylene material as well as the application of polyester resin used to glue the outer layers to the inner layers of aramid. Patent specification shows a protective helmet which is made from 17 layers of aramid fabric and 13 layers of polyethylene impregnated with a resin based on vinyl ester.

The composition was pressed at a pressure of 190 tons and temperature of 121 °C for 15 minutes. In turn, U.S. Patent presents a hybrid helmet constructed of composite materials which includes layers of aramid fabric and polyethylene. The fibrous materials used to produce the hybrid ballistic helmet were reinforced with a matrix of resins: phenolic, acrylic and polyester.

A promising area of research aims to provide soldiers with better protection and comfort during combat operations by creating a lightweight ballistic helmet with improved comfort for frontline soldiers using UHMWPE (Ultra-High Molecular Weight Polyethylene).

Due to its exceptional mechanical properties, UHMWPE, a high-strength, lightweight material, has been used in many applications, including body armour. It is the perfect material for creating a lightweight, highly protective ballistic helmet due to its low density and high strength.

UHMWPE has excellent mechanical qualities, but it also has the potential to make the helmet more comfortable by lightening the load and allowing for more ventilation. This can lessen problems like fatigue, heat stress, and discomfort, which can significantly affect how well frontline soldiers perform and are effective in combat operations.

UHMWPE can be used to create a lightweight ballistic helmet that is both highly protective and cosy to wear for extended periods on frontline soldiers. This can increase their capacity for duty performance, lower their risk of injury, and improve their general comfort and well-being throughout combat operations.

CHAPTER 2
LITERATURE REVIEW

Zhaoxiang Liu and Haochen Zhang, 2022 - Ultra-high molecular weight polyethylene is a kind of popular engineering material because of its unique properties stemming from high molecular weights. Nowadays, the preparations and applications of this type of material are widely researched. This review mainly focuses on the preparation of ultra-high molecular weight polyethylene using three types of typical catalysts (heterogeneous Ziegler-Natta catalysts, Fujita's catalysts and α-Diimine Nickel (II) catalysts) and applications in two significant areas (bulletproof membranes and lithium-ion batteries). Ziegler-Natta catalysts and Fujita's catalysts favor the synthesis of linear ultra-high molecular weight polyethylene, but α-Diimine Nickel (II) catalysis favors β-hydride elimination which leads to branched products. Changes in steric, composition, activators, temperature and pressure will affect the tendency towards different mechanisms and influence structures and properties of final products.

Yongqiang Li *et al.*, 2022 - Combat helmets provide protection against ballistic threats and blunt impact forces, and wearing them has greatly reduced head injuries and saved lives of many soldiers. With the new challenges from improvised explosive devices and urban combat operations in modern asymmetric military conflicts, future combat helmets are required to be highly protective, lightweight, comfortable to wear, and compatible with communication and other systems. The aim of this paper is to provide a comprehensive review of existing combat helmets based on aramid and UHMWPE fibers by addressing the critical issues including materials, ballistic impact mechanisms, design, manufacturing, performance, and head injury protection. Various ballistic fabrics and composites used for combat helmets are discussed. The performance of combat helmets as evaluated by ballistic testing and finite element simulations is summarized. Finally, the ballistic and blast impact induced head injuries are elaborated, and the possibility of behind armour blunt trauma predicted by available injury criteria is discussed.

NAYAN PUNDHIR *et al.*, 2021 - Present work deals with the nonlinear finite element analyses of ultra-high molecular weight polyethylene (UHMWPE). UHMWPE has been presented for ballistic design investigation of lightweight body armour using ANSYS-Workbench. The ballistic performance of UHMWPE has been compared with Kevlar/epoxy composite and alumina. The study is presented in terms of the ballistic limit of UHMWPE, Kevlar/epoxy, and alumina plate, the implication of obliquity (at 30°, 45°, and 60°), projectile shape (elliptical, conical, and spherical shape). The sequencing order of material layup for a bi-layer composite and ballistic performance of single-layered UHMWPE has been compared with the multi-layered plate. The parametric studies have been presented in the form of residual velocity, the ratio of energy transferred to impact velocity of the ballistic plate, and perforation rate for the single and multi-layered UHMWPE. The results of the numerical analyses of UHMWPE have been compared with the Kevlar/epoxy composite. It has been found that the armour system made of UHMWPE laminate composite resulted in a 40.6% weight reduction compared to Kevlar/epoxy configuration with a 17.3% higher ballistic limit.

Mingjin Cao *et al.*, 2021 - Ultra-high molecular weight polyethylene (UHMWPE) is widely used as bulletproof material, but it has evident temperature sensitivity, which can lead to the fluctuation of impact resistance. To explore the effect of temperature on the ballistic performance of UHMWPE laminates, ballistic experiments were conducted at different temperatures of −20, 10, 80, and 95 °C, respectively. The ballistic efficiency, back face deformation and opening hole characteristic of the laminates were compared and analyzed. At all considered temperatures, the laminates with a thickness of 10 mm were perforated, while those with thicknesses of 20 and

30 mm were not, and the ballistic response of the 20 mm laminates changed most strongly with the variation of the temperature. The temperatures of 10 and 80 °C had no significant effect on the deformation and failure of UHMWPE laminates, while the laminates hardened evidently at −20 °C and softened evidently at 95 °C, and the temperature treatments at −20 °C and 95 °C generally led to the highest and lowest protection performance, respectively. The bulletproof application of UHMWPE laminates at temperatures above 80 °C need extra attention and further investigated. The results of this study will be useful for the design of more flexible and effective UHMWPE-based protective equipment.

Mayyadah S. Abed *et al.*, 2020 - Composite laminates are considered one of the most popular damage-resistant materials when exposed to impact force in civil and military applications. In this study, a comparison of composites 12 and 20 layers of fabrics Kevlar and ultrahigh-molecular-weight poly ethylene (UHMWPE)-reinforced epoxy under low-velocity impacts represented by drop-weight impact and Izod pendulum impact has been done. During the Izod test, Kevlar-based composite showed damage at the composite center and fiber breakages. Whereas delamination was observed for UHMWPE reinforced epoxy (PE). The maximum impact strength was for Kevlar-reinforced epoxy (KE) and increases with the number of laminates. Drop-weight impact test showed the highest absorbed energy for (KE) composites. The results revealed that different behavior during the impact test for composites belongs to the impact mechanism in each test.

Yazhen Liang *et al.*, 2021 - Despite of the fact that more and more accessory devices are integrated to functionalize a ballistic helmet system, its core ballistic protective function needs to be improved with weight reduction was and still is the main course in engineering design. The two major generic classes of synthetic fibers for ballistic composites are Ultra High Molecular Weight Polyethylene (UHMWPE) fiber (0.97 g/cm^3) and aramid fiber (1.44 g/cm^3). In the area of military helmets, these fibers are constructed into different topologies, draping/forming into double-curvature geometric shape in multiple plies, serving as reinforcement for composite shell. The preforming ways influence the subsequent impregnation/solidification and curing step in manufacture, in terms of the fiber orientation and fiber volume fraction. The inherent structural heterogeneity thus leads to scatter in permeability and composite thickness, and have further impact in generating process-induced defects. During the processing, the fiber continuity without wrinkles, together with voids-free are determinative factors to a quality final part. The aim of this paper is to review the manufacturing technologies characterized by thermo-mechanical forming and Liquid Composite Moulding (LCM), relating their processing parameters respectively to the properties of reinforcements in one dimension (1D), two dimensions (2D) and three dimensions (3D), along with that of the matrix in dry or wet phase, interdependency of them are sought.

Suman Chhetri, Habiba Bougherara, 2020 - Ultrahigh molecular weight polyethylene (UHMWPE) fiber is considered as an ideal reinforcing component due to its high strength-to-weight ratio, good toughness and high chemical and wear resistance. However, poor interfacial adhesion with polymer matrices has hindered the development of UHMWPE-based composites with high performance. This review is intended to understand how physical and chemical changes of fiber surface promote the adhesion strengthening mechanisms at the interface and to guide future developments using the presented modifications' techniques. The review summarized the present state of the art research on surface modification of UHMWPE fiber and

UHMWPE/polymer interfacial properties. Various surface modifications of UHMWPE fiber categorized as ‘wet’ chemical and ‘dry’ techniques have been detailed with appropriate examples. Also, the relationship between fiber/matrix adhesion and mechanical properties of the composites has been reviewed. Lastly, an overview of the potential and challenges of each modification method has been discussed.

Muzamil Hussain *et al.,* 2020 - Ultra-High Molecular Weight Polyethylene (UHMWPE) is used in biomedical applications due to its high wear-resistance, ductility, and biocompatibility. A great deal of research in recent decades has focused on further improving its mechanical and tribological performances in order to provide durable implants in patients. Several methods, including irradiation, surface modifications, and reinforcements have been employed to improve the tribological and mechanical performance of UHMWPE. The effect of these modifications on tribological and mechanical performance was discussed in this review.

Kartikeya *et al.,* 2020 - Quasi-static tensile test of UHMWPE fiber-reinforced composite laminate is challenging to perform due to low inter laminar shear strength and low coefficient of friction. Tensile tests proposed in the literature were conducted and limitations associated with each method led to the evolution of a new method. Tensile test of single-ply was realized as the best representative of tensile strength of a composite than tensile test of UHMWPE laminate. A fixture was developed for single-ply tests which increased friction and provided the mechanical constraint to slipping. The fixture is easy to fabricate and has provided repeatable results for eight grades of UHMWPE fiber-based (0/90) fabrics. Reported tensile strengths are in quite high range of 900–1500 MPa.

Krzysztof Jamroziak *et al.*, 2019 - This paper discusses the general conditions relating to ballistic head protection, analyzing the risks that may occur on contemporary battlefields. A thorough literature review has enabled us to present development trends for helmets used in the largest armies in the world. The authors have focused on impacts to the helmet shell, overloading the entire helmet-protected head–neck system. The main objective of this study is to investigate the protective capability of a helmet shell when subjected to projectile–helmet contact, with contact curvature taken as being an indicator of the impact energy concentration. Blunt head trauma was estimated using backface deformation (BFD). The Wz.93 combat helmet was used for testing. Analytically, dependencies were derived to determine the scope of BFD. A five-parameter model of the helmet piercing process was adopted, thus obtaining the optimal BFD range. Verification of theoretical considerations was carried out on a specially developed research stand. In the ballistic tests, dynamic deflection of the helmet's body was registered using a speed camera. On the impact testing stand, a fragment of the helmet was pierced, producing results in the low impact velocity range. Data have been presented on the appropriate graph in order to compare them with values specified in the relevant standard and existing literature. Our results correlate well with the norm and literature values.

CHAPTER 3
PROBLEM STATEMENT

Head injuries caused by a bullet penetration or shock waves from the improvised explosive device (IED) are the main causes of military traumatic brain injury or death. Improvements in ballistic and impact protection of helmets may help to increase the survival rate of the soldiers. A ballistic helmet is designed to protect the wearer from impact by absorbing and dissipating energy without transmitting it to the head. Combat or ballistic helmets made from conventional Kevlar material has some drawbacks such as limited strength, thermal discomfort, durability issues and poor moisture resistance.

The current ballistic helmets used by frontline soldiers are often heavy, uncomfortable, and restrict movement, leading to fatigue and decreased operational efficiency. This can have a significant impact on the effectiveness and safety of frontline soldiers during combat operations.

To address these issues, there is a need to develop a lightweight ballistic helmet with enhanced comfort that can provide better protection to frontline soldiers. The use of UHMWPE as a material for the helmet offers a promising solution, as it has exceptional mechanical properties, such as high strength and low density, which can provide excellent protection against ballistic threats while reducing weight and improving ventilation.

However, there are several challenges that need to be addressed in the development of a lightweight ballistic helmet using UHMWPE. These include optimizing the design and material selection to balance protection and comfort, ensuring the helmet can withstand various environmental and operational conditions, and meeting relevant industry standards and regulations.

Therefore, the problem statement for the development of a lightweight ballistic helmet with enhanced comfort for frontline soldiers using UHMWPE is to design and develop a helmet that provides superior protection against ballistic threats while also being lightweight, comfortable, and capable of withstanding various operational conditions, meeting industry standards and regulations, and being cost-effective.

CHAPTER 4
METHODOLOGY & OBJECTIVE

4.1 PROCESS INVOLVED

4.1.1 Purchase of source materials UHMWPE

UHMWPE Fabric is available in Indiamart and epoxy resin is available locally.

4.1.2 Simulation studies

Stress analysis and simulation studies to be conducted by using the ANSYS software to find the optimum thickness of the helmet. Heat transfer analysis to find the optimum dimensions for comfort condition also will be conducted.

4.1.3 Preparation of composite samples for mechanical properties evaluation

Composite samples will be prepared by using UHMWPE fabric, epoxy resin and hardener. Hand lay-up process will be used to make the composite. Standard specimens to be prepared and the mechanical properties like impact strength and Fracture toughness will be evaluated.

4.1.4 Mould preparation

A clay pattern will be fabricated based on the design specifications obtained from the simulation. The mould release agent is applied over the pattern and gel coat resin will be coated on it. Now the mould is allowed to solidify for nearly 24hours Finally, the pattern will be removed and the shell will be obtained.

4.1.5 Fabrication of the composite helmet

The composite helmet will be fabricated inside the mould shell. In the first layer of UHMWPE fabric a releasing agent will be applied on it and the layer to be fitted with inner side of the mold. A mixture of resin, hardener then will be brushed on the first layer and the second will be fabricated. The process is repeated until the desired thickness of laminate has been attained.

4.1.6 Fitting of the helmet accessories

Helmet strap and provisions for camera holders will be fitted in the holes provided in the extension of the helmet. Memory foam will be inserted around the head area to improve the comfort.

4.2 OBJECTIVE

Generally, helmets are produced by stacking together multiple numbers of prepregsheets which a compression moulded in a close matched tool. The number of sheets (the thickness of the helmet) depends of the required level of protection and on the area weight (thickness) of the sheets. Thermosetting prepregs are based on bidirectional woven fabrics which are delivered in rolled form. The first step in helmet fabrication is cutting the blanks from the roll. For the replacement of the steel helmet of former JNA with composite one, in the initial development phase, darted blanks were used. Darted blank is a single ply of precut prepreg with material removed within the part area.

During moulding, darts would close up so that their edges nearly join together. To avoid having the darts align with the part, the dart is offset (the blank is rotated) ply to ply within the stack. This prevents wrinkling and folding of the material in the helmet shell. 2D blanks are preformed into a 3D shape before loading on the male part of a close 720 matched die. Retention of the blanks position in relation to each other during preforming is a key process step.

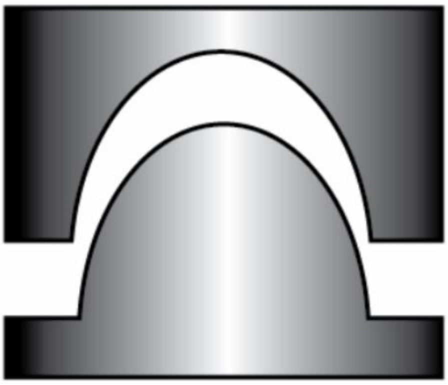

Figure 4.1. Closed Match Die

The curing of the thermosetting resin takes place at 140 ℃ – 160 ℃ under pressure, usually 4 MPa – 8 MPa, within 75 minutes – 90 minutes, into a down-acting press. Fully thermoplastic composites (both, the resin and the fibres are thermoplastic) use the, so called, “deep draw” process. First, the stack of plies is moulded into a flat panel. Prior to moulding the panel is preheated into an infra-red oven to make it softer and more flexible; then, the panel is moulded in a close matched die mounted into a down-acting press and shaped into a helmet shell.

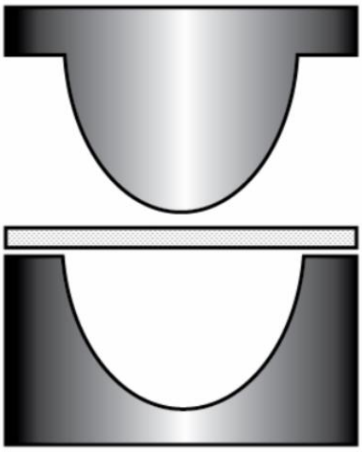

Figure 4.2. Deep-Draw Process

The next step, for the both processes is trimming of the helmet shell. High-performance fibres (aramids, UHMWPE) are very tough to cut using traditional steel or carbide tools. Therefore, in the development of JNA composite helmet water-jet was used to trim the shell.

CHAPTER 5
MATERIALS USED

5.1 UHMWPE FABRIC

Ultra-high molecular weight polyethylene (UHMWPE) fabric is a high-strength textile material made from fibers of UHMWPE polymer. UHMWPE fibers are some of the strongest and most durable fibers in existence, with a tensile strength that is up to 15 times stronger than steel and a weight that is up to 40% lighter than Kevlar.

UHMWPE fabric is commonly used in a variety of applications that require high strength and durability, including body armour, ballistic helmets, cut-resistant gloves, and protective clothing. UHMWPE fabric is also used in sports equipment, such as skis and snowboards, and in various industrial applications, such as conveyor belts and rope.

UHMWPE fabric is known for its excellent strength-to-weight ratio, abrasion resistance, and resistance to chemicals and UV radiation. It is also flexible, making it easy to use in a variety of applications. Additionally, UHMWPE fabric has a high melting point, making it resistant to high temperatures.

One of the main advantages of UHMWPE fabric is its ability to absorb impact and disperse energy, making it an ideal material for use in protective equipment. When used in body armor, for example, UHMWPE fabric can effectively absorb the impact of a bullet or other projectile, reducing the amount of force that is transmitted to the wearer.

Properties

- High strength-to-weight ratio: UHMWPE fabric is incredibly strong and has a very high strength-to-weight ratio, making it ideal for use in lightweight applications that require exceptional strength.
- Low stretch: UHMWPE fabric has very low stretch, which means it maintains its shape and does not elongate under load.
- Abrasion resistance: UHMWPE fabric has excellent abrasion resistance, making it ideal for use in applications where the fabric will come into contact with rough or abrasive surfaces.
- Chemical resistance: UHMWPE fabric is highly resistant to many chemicals, including acids, alkalis, and organic solvents.
- Water resistance: UHMWPE fabric is hydrophobic and repels water, making it ideal for use in wet or damp environments.
- UV resistance: UHMWPE fabric has excellent UV resistance, making it ideal for outdoor applications.
- Cut resistance: UHMWPE fabric is highly cut-resistant, making it ideal for use in applications where there is a risk of sharp objects cutting through the fabric.

Melting Point of UHMWPE Fabric

A thermoplastic polymer with an extremely high melting point is called ultra-high-molecular-weight polyethylene (UHMWPE). Depending on the precise grade and processing of the material, UHMWPE fabric's melting point can change.

UHMWPE typically has a melting point range of 130-138°C (266-280°F). However, the melting point might vary depending on the molecular weight, crystallinity, and processing circumstances.

The fact that UHMWPE does not have a very high melting point like certain other polymers is significant. Instead, it gradually softens and flows at high temperatures, making it appropriate for several processing methods like extrusion, moulding, and 3D printing.

Advantages of UHMWPE Fabric

- Exceptional strength-to-weight ratio
- Low stretch
- Abrasion resistance
- Chemical resistance
- Water resistance
- UV resistance
- Cut resistance
- Lightweight and flexible

Disadvantages of UHMWPE Fabric

- Low melting point: UHMWPE fabric has a relatively low melting point, which means it can be damaged or destroyed by high temperatures.
- High cost: UHMWPE fabric is more expensive than many other synthetic fabrics, which can make it less cost-effective for some applications.
- Difficult to dye: UHMWPE fabric is difficult to dye, which means it is usually only available in a limited range of colors.
- Not suitable for high-friction applications: While UHMWPE fabric has excellent abrasion resistance, it is not ideal for use in applications where there is a lot of friction, as it can generate heat and melt.

Figure 5.1. UHMWPE Fabric

5.1.1 Catalysts for Preparation of UHMWPE

Ziegler-Natta catalysts

Transition metal-based catalysts for the controlled synthesis of polyethylene were firstly discovered by Karl Ziegler and Giulio Natta. This type of catalyst is one of the main catalysts used for olefin polymerizations in industries nowadays and Ziegler-Natta catalysts for preparations of UHMWPE have been researched for a long time. Titanium is typically included as metal centres of the catalysts and magnesium chloride is widely used for supporting this type of catalysts. Typically, other co-catalysts such as tri-ethyl aluminium are required for activating ZN catalysts so that active sites are created for coordination between metal centres and double bonds of ethylene, after which additions of monomers are repeated for increasing molecular weights of products. ZN catalysts feature a synthesis of linear UHMWPE due to the low tendency of bimolecular β-hydrogen transfer at low pressure of ethylene, which is one of the advantages over other types of catalysts.

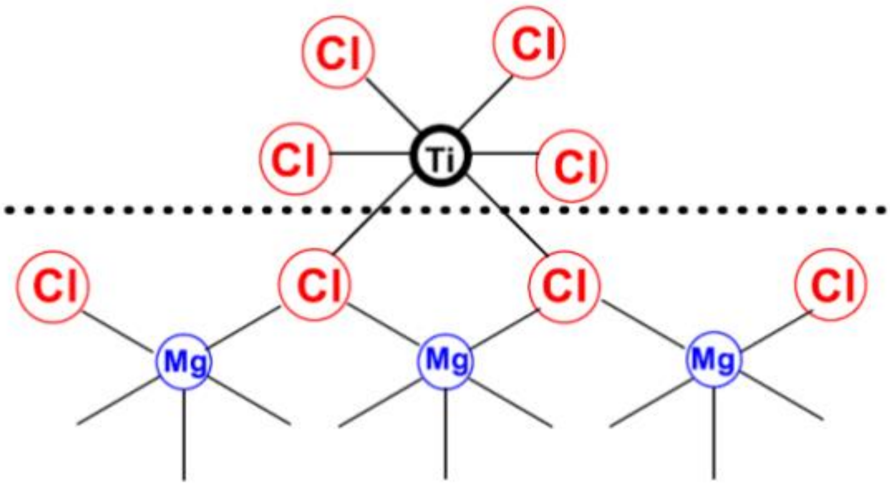

Figure 5.2. Titanium and magnesium chloride-based ZN catalysts.

While different kinds of ZN catalysts are prepared using distinct methods to optimize catalytic activities, the typical process of preparing this type of catalysts can be mainly generalized into two steps: preparations of supporting complexes and preparations of the catalysts based on the supporting complexes. For example, Antoine et al. reported that the addition of ethyl aluminium dichloride (DEAC) could increase particle sizes of catalysts and finally lead to a wider molecular weight distribution. During the synthesis of ZN catalysts, sizes of particles have great influences on both catalytic activities as well as poly-dispersity index of final products, which is mainly controlled during preparations of supporting materials. Additionally, catalytic activities also increase dramatically with the existence of supporting materials since the supporting complexes contribute to slowing rates of decomposition of the active phase and increasing the stabilities of active centres. For instance, Velikova found an unsupported titanium-based ZN catalyst had low activity compared to those supported catalysts.

Preparing ZN catalysts with high catalytic activities is of vital importance since molecular weights of UHMWPE could be influenced by the catalytic activities of catalysts and many properties of UHMWPE depend heavily on molecular weights. Specifically, Velikova stated that while melting points, enthalpy changes of melting, temperatures at which crystallization occurs and resistances to oxidation reactions increase with increasing molecular weights, chain branching decreases with increasing molecular weights. It is also found by Velikova that during the growth of polymer chains catalysed by ZN catalysts, it is possible to form vinylidene groups if polymer chains include oligomers. Since these vinylidene groups can be formed only at the terminal of polymer products, the number of vinylidene groups decreases with increasing molecular weights, which indicates that the measurement of molecular weights of UHMWPE could be based on measuring the number of vinylidene groups. In addition to the formation of vinylidene groups, carbonyl groups can also be formed during preparations of UHMWPE catalysed by ZN catalysts due to possible oxidation reactions, which decreases the thermal stabilities of UHMWPE

Fujita's catalysts

Although extremely high molecular weights of UHMWPE contribute to many outstanding physical properties, high molecular weights also result in high melt viscosities, which prevents UHMWPE from being processed easily. The reason for high melt viscosities is intermolecular interactions between long chains of polymers which are referred to as entanglements. Although synthesis catalysed by ZN catalysts could control the number of entanglements through selections of appropriate solvents, the resulting UHMWPE products may have a broad molecular weight distribution and some of the syntheses are still hard to control entanglements due to heterogeneity reaction systems. Catalysts with transition metals as catalytic centres and bis[phenoxy-imine] as ligands were firstly discovered by Fujita's group and were found to process living polymerization at room temperature. Afterward, Rastogi and Romano discovered FI catalysts with the ability to carry out the synthesis of disentangled UHMWPE with high processibility.

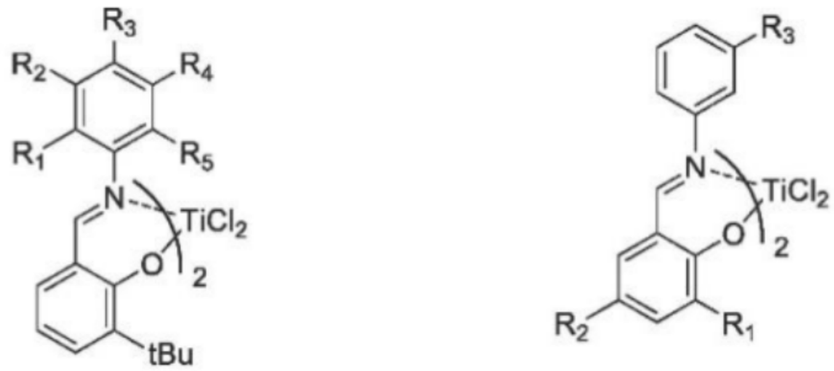

Figure 5.3. Fujita’s catalysts.

Being similar to ZN catalysts, Fujita’s catalysts also feature a low degree of β-hydride eliminations, which makes it possible for the synthesis of linear UHMWPE. Moreover, the dispersion of active sites and further separation between chains during the propagation reactions contribute to decreased number of entanglements during the polymerization, leading to the synthesis of disentangled UHMWPE. For example, Irina et al. reported a catalyst system based on titanium IV dichloride complexes for the synthesis of disentangled UHMWPEs. Irina also found that in addition to the contributions from catalysts, carrying out polymerization below crystallization temperatures also reduces the degree of entanglements by making chains of polymers crystallized immediately. Although Fujita’s catalysts have so many advantages, there are still unsolved problems with this type of catalysts such as degradation of catalysts under high temperatures and low adaptabilities to industries due to limited polymerization conditions. Currently, some researchers focus on transforming Fujita’s catalysts to immobilized catalysts to address the aforementioned issues with Fujita’s catalysts, which is a potential direction of further research on Fujita’s catalysts. For instance, Woo et al. researched single-site catalysts that can be applied to many different polymerization conditions.

Types of co-catalysts for activation of Fujita's catalysts have been found to influence greatly on the properties of UHMWPE products. For example, Fujita's group has found that when methyl aluminoxane (MAO) is used as cocatalysts, trimethylaluminum (TMA) can be dissociated into the solution, exerting a detrimental effect on the catalytic activity of FI catalysts. Although TMA was found to terminate polymerization in many reaction systems, it is found that the negative effects of TMA could be due to secondary catalysts generated in this system. However, this problem can be addressed by using a modifier to trap TMA in the solution. For example, Dario et al. reported 2,6-di-tert-butyl-4-methylphenol BHT could increase the catalytic activity during the synthesis of UHMWPE, which is probably due to an increase in reaction rates or concentration of active sites. With this modifier, increasing polymerization time contributes to disentangled UHMWPE with higher molecular weights.

α-Diimine Nickel (II) Catalysts

Since the work of Brookhart's group in 1995, α-Diimine Nickel (II) catalysts have been widely researched for polyethylene synthesis especially for UHMWPE synthesis. The reason for its popularity is probably this type of catalysts are not only used for the synthesis of UHMWPE with different extents of branching by varying polymerization conditions or catalyst structures but also be used for co-polymerizations for different applications. Some examples of this type of catalysts for UHMWPE synthesis are illustrated. Typically, this type of catalyst features bulky ortho-aryl substituents on ligands so that monomers are blocked sterically from accessing metal axial positions to undergo chain transfer as termination reaction, which ensures the high molecular weights of the final product. Although α-Diimine Nickel (II) catalysts are similar to ZN catalysts and Fujita's catalysts in terms of coordination of double bonds, the propagations catalyzed by α-Diimine Nickel (II) catalysts can undergo either chain growth mechanism for linear UHMWPE synthesis or chain running mechanism for branched UHMWP synthesis. Therefore, the effects of catalyst structures and polymerization conditions on the properties of UHMWPE products are complex and could be different for distinct catalysts even with the same changes in conditions.

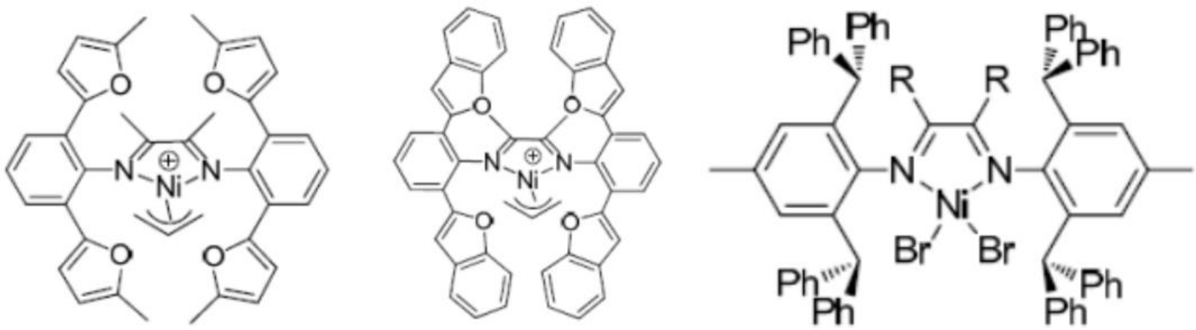

Figure 5.4. α-Diimine nickel (II) catalysts.

Catalyst structures affect the properties of UHMWPE both electronically and sterically. As for electronic effects, Guo et al. reported that while some catalyst systems such as Ni[acac] systems are sensitive to electronic perturbations, others show no dramatic changes upon ligand with various effects. Even with those sensitive systems, no absolute trends are observed. However, since polymerizations involve coordination between positively charged metal centres and double bonds, catalysts with electron-donating ligands may have a higher catalytic activity and lead to UHMWPE with higher molecular weight. Turning to steric effects, in addition to blocking which results in an increase in molecular weights, Guo et al. reported that increasing the bulk of ligands also blocked chain walking reactions, leading to less branched UHMWPE. Finally, Guo et al. also stated that while melting points were only influenced upon electronic perturbations to an extremely small extent, they were found to decrease with increasing bulk for some catalysts systems.

As for the influence of polymerization conditions, although rates of all reaction pathways in the mechanisms increase with increasing temperatures, the chain walking mechanism is generally accelerated more so that UHMWPE with higher branching degrees and lower melting points could be produced by increasing polymerization temperatures [30,32]. Although the increase in temperatures may also increase rates of chain transfers and result in lower molecular weights of UHMWPE, Guo et al. found that the ligands of some catalysts were so bulky that chain transfers are still inhibited, and molecular weights of products are affected minimally even with higher temperatures [30,32]. Derek et al. stated that depending on the nature of the catalyst system, change in ethylene pressure have different effects on the branching degree and molecular weight of UHMWPE.

Although α-Diimine Nickel (II) catalysts have many attractive advantages, some catalyst systems also have problems such as low thermal stabilities, low selectivity of products and high chain transfer rates [32-34]. In the future, more research could be based on addressing these problems either by changing the structures of catalysts or providing alternative reaction mechanisms.

5.2 EPOXY RESIN

Epoxy is a type of thermosetting polymer that is created by mixing two components: a resin and a hardener. The resulting mixture is a highly durable and adhesive material that is commonly used for a variety of applications, including adhesives, coatings, composites, and electronic materials.

Epoxy resins are typically made from epichlorohydrin and bisphenol A (BPA) or other similar compounds. The hardener is usually made from amines or polyamines. When the two components are mixed together, they undergo a chemical reaction that results in the formation of a cross-linked polymer network.

Epoxy is known for its excellent bonding strength, chemical resistance, and durability. It is commonly used in the construction industry for bonding and sealing materials, as well as for coatings on floors and other surfaces. Epoxy is also used in the manufacture of electronics, aerospace components, and sports equipment.

However, it's worth noting that some epoxy resins may contain BPA, which is a chemical that has been linked to health concerns. As a result, there has been a growing interest in developing safer and more environmentally friendly alternatives to traditional epoxy resins.

The mixture ratio of A (resin)/B (hardener) was one-third volume ratio. Two types of composites were prepared: Kevlar–epoxy and UHMWPE–epoxy composites. Laminated composites with different layers 12 and 20 were prepared by hand layup for each type of composite. Mechanical pressure was fixed by jaws and optimized using dial gauge to 2MPa to remove bubbles and excess resin for 24h. The composites were left in room temperature for seven days, and then composite plates were cut for the desired dimensions.

Properties

- High strength and durability: Epoxy resin is known for its high strength and durability, making it suitable for use in a wide range of applications.
- Excellent adhesive properties: Epoxy resin has excellent adhesive properties and can bond well with a variety of substrates, including metals, plastics, and wood.

- Low shrinkage: Epoxy resin has low shrinkage, which means it can be used to create precise molds and parts without significant dimensional changes.
- Chemical resistance: Epoxy resin is highly resistant to chemicals, making it suitable for use in harsh chemical environments.
- Heat resistance: Epoxy resin has excellent heat resistance and can withstand high temperatures without losing its mechanical properties.
- Electrical insulation: Epoxy resin is an excellent electrical insulator, making it suitable for use in electrical and electronic applications.
- Water resistance: Epoxy resin is highly water-resistant, which makes it suitable for use in marine applications.
- UV resistance: Epoxy resin can be formulated to be UV-resistant, which makes it suitable for use in outdoor applications.

Advantages of Epoxy Resin

- High strength and durability
- Excellent adhesive properties
- Low shrinkage
- Chemical resistance
- Heat resistance
- Electrical insulation
- Water resistance
- UV resistance
- Versatility: Epoxy resin can be formulated to have a wide range of properties, making it suitable for use in many different applications.

Disadvantages of Epoxy Resin

- Potentially harmful: Epoxy resin can release harmful fumes during the curing process, and it can cause skin and respiratory irritation if proper safety precautions are not taken.
- Sensitivity to temperature: Epoxy resin can become brittle and lose its mechanical properties at low temperatures, and it can soften and lose its shape at high temperatures.
- Long cure time: Epoxy resin can take several hours or even days to cure fully, depending on the formulation and curing conditions.
- Yellowing: Some types of epoxy resin may yellow over time when exposed to UV light, which can be a problem in applications where color stability is important.
- Cost: Epoxy resin is generally more expensive than other types of resin and may not be cost-effective for some applications.

5.2.1 EPOXY RESIN LY556

It is a clear, low viscosity, unmodified bisphenol A-based liquid resin that is commonly used in a wide range of applications, including coatings, adhesives, and composites. Here are some of the key properties and characteristics of LY556 epoxy resin:

- Low viscosity: LY556 has a low viscosity, which means it can be easily mixed and applied to surfaces.
- Good adhesion: LY556 has excellent adhesion to a wide range of substrates, including metals, plastics, and composites.
- Chemical resistance: LY556 has good chemical resistance, making it suitable for use in harsh chemical environments.

- Low color: LY556 is a clear resin with low color, making it suitable for use in applications where color stability is important.
- Long pot life: LY556 has a relatively long pot life, which means it remains workable for a longer period of time after mixing, allowing for more time for application and manipulation.
- Moderate cure time: LY556 has a moderate cure time, which means it can be used in a wide range of applications that require a balance between workability and curing time.

Figure 5.5. Epoxy Resin LY556

5.3 HELMET MOULD

A helmet mould is a specialized tool used in the manufacturing of helmets. The mould is typically made from metal, such as aluminium or steel, and is designed to create a three-dimensional shape that matches the desired helmet design.

The helmet mould is typically made in two halves, with each half having a cavity that is the negative image of the final helmet shape. The two halves of the mould are brought together, and molten material is injected into the cavity using a specialized injection moulding machine.

The molten material used to make the helmet can vary depending on the application and desired properties of the helmet. For example, some helmets are made from thermoplastics, while others are made from thermosetting resins.

Once the material has been injected into the mould, it is allowed to cool and harden. The two halves of the mould are then separated, and the finished helmet is removed. Any excess material is trimmed off, and the helmet is inspected for quality before being finished and prepared for use.

Helmet moulds are an important part of the manufacturing process, as they ensure that each helmet is made to precise specifications and with consistent quality. The moulds can be expensive to create, but they can be used to produce a large number of helmets with relative ease and efficiency, making them a cost-effective option for helmet manufacturers.

Figure 5.6. Helmet that we used as a mould framework

5.4 LDP (Low Density Polyethylene)

Compared to other varieties of polyethylene, LDP is a polymer with a lower density. It is hence less stiff and more flexible than HDP. LDP is frequently used in products including packaging, plastic bags, and toys where flexibility and durability are crucial. Additionally, it is employed in the manufacture of ballistic helmets, where comfort is of utmost importance.

Properties of LDP

- Low Density: Compared to HDP, LDP has a density of around 0.91 g/cm3. LDP is appropriate for usage in applications that need both flexibility and hardness since it is more flexible than HDP.
- Soft: LDP is more pleasant to wear or handle than HDP since it is softer.
- Good Chemical Resistance: LDP is effective in situations where it may be subjected to a variety of chemicals because of its good chemical resistance. LDP is beneficial in situations where electrical insulation is required since it has good electrical insulation qualities.
- Excellent Processability: LDP is inexpensive to make since it is simple to process and mould.

Melting Point of LDP

LDPE (Low-density polyethylene) is a thermoplastic polymer that has a relatively low melting point compared to other types of polymers. The melting point of LDPE ranges from approximately 105°C to 115°C (221°F to 239°F).

When LDPE is heated above its melting point, it softens and eventually melts into a liquid state, which can be molded or formed into various shapes. This property makes LDPE an ideal material for many applications where flexibility and ease of processing are important, such as packaging films, bags, and bottles.

It's worth noting that LDPE has a wide melting range rather than a specific melting point, meaning that the polymer can transition from a solid to a liquid state over a range of temperatures. The exact melting point of LDPE may vary depending on the specific grade and composition of the polymer.

Advantages of LDPE

- Excellent flexibility and toughness
- Good impact resistance
- Good chemical resistance
- Low cost compared to other types of plastic materials
- Recyclable and reusable
- Easy to process and manufacture
- Good electrical insulation properties
- Good resistance to moisture

Disadvantages of LDP

- Limited temperature resistance
- Poor dimensional stability
- Low stiffness and strength
- Susceptible to environmental stress cracking
- Poor barrier properties to gases and moisture
- Low melting point, making it susceptible to heat damage
- Not suitable for high-temperature applications

Figure 5.7. LDP (Low Density Polyethylene)

5.5 HDP (High Density Polyethylene)

Contrarily, HDP is a polymer with a greater density than other varieties of polyethylene. Because of this, it is less flexible and more stiff than LDP. HDP is frequently used in products like plumbing, furniture, and automobile parts where stiffness, strength, and longevity are crucial. Additionally, it is utilised in the manufacture of ballistic helmets, where toughness and security are crucial considerations.

Properties of HDP

- High Density: HDP is denser than LDP, with a density of around 0.95 g/cm3. HDP is appropriate for usage in applications that call for stiffness, strength, and longevity since it is more rigid than LDP.
- Hard: HDP is less pleasant to wear or handle than LDP since it is harder than LDP.
- Strong Chemical Resistance: HDP is effective in situations where it may be subjected to a variety of chemicals because of its strong chemical resistance.

- Strong Impact Strength: HDP is beneficial in situations where impact resistance is required because of its strong impact strength.
- Excellent Processability: HDP is inexpensive to make since it is simple to process and mould.

Melting Point of HDP

HDP (High-density polyethylene) is a thermoplastic polymer that has a relatively high melting point compared to other types of polyethylene. The melting point of HDP ranges from approximately 120°C to 180°C (248°F to 356°F), depending on the grade and composition of the polymer.

When HDP is heated above its melting point, it softens and eventually melts into a liquid state, which can be molded or formed into various shapes. This property makes HDP an ideal material for many applications where stiffness, strength, and durability are important, such as pipes, containers, and construction materials.

It's worth noting that like LDP, HDP also has a wide melting range rather than a specific melting point, meaning that the polymer can transition from a solid to a liquid state over a range of temperatures. The exact melting point of HDP may vary depending on the specific grade and composition of the polymer.

Advantages of HDPE

- High strength and stiffness
- Good impact resistance
- Good chemical resistance
- Good barrier properties to gases and moisture
- Recyclable and reusable
- Easy to process and manufacture

- Good electrical insulation properties
- Good resistance to moisture and UV radiation

Disadvantages of HDPE

- Limited temperature resistance
- Poor dimensional stability
- Poor resistance to environmental stress cracking
- Low transparency and glossiness
- Low flexibility and toughness compared to some other plastic materials
- Not suitable for high-temperature applications

Figure 5.8. HDP (High Density Polyethylene)

5.6 MALEIC ANHYDRIDE

Maleic anhydride is an organic compound with the chemical formula C4H2O3. It is a white solid with a pungent odor, and it is soluble in water and many organic solvents. Maleic anhydride is commonly used as a precursor for the production of various chemicals, including polymers, resins, and agricultural chemicals.

One of the most important uses of maleic anhydride is as a raw material for the production of unsaturated polyester resins, which are used in a variety of applications, including coatings, adhesives, and reinforced plastics. Maleic anhydride is also used in the production of alkyd resins, which are used as binders in paints and coatings.

Maleic anhydride is also used in the production of fumaric acid, which is used as a food additive and in the pharmaceutical industry. It is also used in the production of agricultural chemicals, such as herbicides and insecticides.

Maleic anhydride is highly reactive and can undergo a variety of chemical reactions, including esterification, amidation, and Diels-Alder reactions. It is also used as a dienophile in the Diels-Alder reaction to form cyclic compounds.

Maleic anhydride has some health hazards associated with it, and it can cause skin irritation, respiratory irritation, and eye damage. It is also flammable and should be handled with care. Proper protective equipment and handling procedures should be followed when working with maleic anhydride.

Properties of Maleic Anhydride

- Melting and boiling points: MA has a melting point of 52-54°C and a boiling point of 202-203°C.
- Solubility: MA is soluble in water, alcohol, and acetone.
- Reactivity: MA is highly reactive and can undergo a variety of chemical reactions, including Diels-Alder reactions, esterification, amidation, and hydrolysis.
- Odor: MA has a pungent and irritating odor.
- Appearance: MA is a white crystalline solid that is typically in the form of flakes or pellets.
- Molecular weight: The molecular weight of MA is 98.06 g/mol.
- Density: The density of MA is 1.48 g/cm^3.

- Acidic properties: MA is an acidic compound and reacts with bases to form salts.
- Polymerization: MA can undergo polymerization reactions to form polymeric materials, such as poly(maleic anhydride).
- Stability: MA is relatively stable at room temperature, but it can undergo spontaneous exothermic reactions if exposed to heat or other reactive chemicals.

Advantages of Maleic Anhydride

- High reactivity: Maleic Anhydride is highly reactive and can be used to produce a wide range of derivatives.
- Versatile: Maleic Anhydride can be used as a feedstock to produce other chemicals, such as unsaturated polyester resins, alkyd resins, and coatings.
- Water-soluble: Maleic Anhydride is water-soluble, which makes it easy to use in various applications, such as water treatment.
- Good thermal stability: Maleic Anhydride has good thermal stability, which makes it suitable for use in high-temperature applications.
- Low cost: Maleic Anhydride is relatively inexpensive compared to other organic compounds.

Disadvantages of Maleic Anhydride

- Health hazards: Maleic Anhydride is highly toxic and can cause respiratory and skin irritation.
- Flammable: Maleic Anhydride is highly flammable and can cause fire and explosion hazards if not handled properly.
- Environmental concerns: Maleic Anhydride is harmful to the environment, and its production and disposal can have negative impacts on air and water quality.
- Limited solubility: Maleic Anhydride has limited solubility in some organic

solvents, which can make it difficult to use in certain applications.

- High reactivity: While high reactivity is an advantage in some applications, it can also be a disadvantage if the reactivity is not controlled, leading to unwanted reactions or byproducts.

Figure 5.9. Maleic Anhydride

CHAPTER 6
RESULTS AND DISCUSSION

6.1 COMPARISON WITH OTHER MATERIALS

6.1.1 UHMWPE Fiber Vs Kevlar

Aramid 1414 Kevlar 49 and UHMWPE woven fabrics were purchased from Yixing Huaheng High-Performance Fiber Textile Co. Ltd, with specifications listed in Table 1. Epoxy resin (Sikafloor-156) is supplied from Sika AG. Sikafloor-156 is a two-part, low-viscosity, solvent-free epoxy resin, with compressive strength ∼95 N/mm^2, flexural strength ∼30 N/mm^2 and shore D hardness 83 (seven days). The mixture ratio of A/B was one-third volume ratio. Two types of laminated composites with different layers 12 and 20 were prepared by hand layup: Kevlar–epoxy and UHMWPE–epoxy composites as shown in Figure 1. Mechanical pressure was applied to remove bubbles and excess resin for 24 h. The composites were left in room temperature for seven days, and then composite plates were cut for the desired dimensions. Low velocity impact testing, drop-weight impact, drop tower impact system INSTRON CEAST 9350 was facilitated to investigate impact resistance of composites according to ASTM D7137M (Test Method for Compressive, 2005). Low-velocity impact tests have been performed at room temperature for composite with dimensions 10 3 15 cm2 utilizing a drop tower height (800 mm), drop mass (5 kg) and speed (3.96 m/s). Special impact equipment consisting of vertically falling impactor was used in the test. The energy is obtained from Drop tower impact systems, (2009) $E=½ mv^2$. The relationship between force–time, deformation–time and energy–time and deformation was obtained. Energy–deformation and force–deformation relationships were also obtained. The depth of penetration and the radius of impactor traces were recorded.

Table 6.1

UHMWPE Fiber Vs Kevlar Properties

Properties	Aramid1414 Kevlar 49	UHMWPE fiber
Density (g/cm^3)	1.45	0.97–0.98
Tensile strength (cN/tex)	200	285.6–408
Tensile modulus (cN/tex)	8,300	9282–14,280
Elongation at break (%)	2.5	3.5–3.7
Temperature range (℃)	204	80
Decomposition temperature (℃)	400	145–160
300℃ 100 h strength retention (%)	60–65	68–70
Moisture absorption (%)	4.5	0.6
Wear resistance	General	Good
Solvent resistance	Good	Good
Acid resistance	Bad	Good
Alkali resistance	Good	Good
UV resistance	Bad	Good

6.1.2 WHY WE CHOOSE UHMWPE?

- Improved protection: The primary objective of any ballistic helmet is to protect the wearer from ballistic threats such as bullets, shrapnel, and other high-speed projectiles. An enhanced ballistic helmet using UHMWPE should provide superior protection against such threats, including multi-hit capability.

- Lightweight design: UHMWPE is a lightweight material, and an enhanced ballistic helmet using this material should be designed to reduce the overall weight of the helmet while maintaining its protective capabilities. A lighter helmet would be more comfortable for the wearer, reducing fatigue during extended wear and improving overall mobility.

- Enhanced comfort: The helmet should be designed to provide maximum comfort for the wearer, including improved ventilation to reduce heat build-up and moisture-wicking materials to keep the wearer dry. The design should also consider the shape and size of the wearer's head to ensure a proper fit.

- Compatibility with other gear: The helmet should be designed to be compatible with other protective gear such as communication systems, night vision goggles, and other equipment to provide seamless integration for military and law enforcement personnel.

- Durability: The helmet should be designed to withstand rugged environments and repeated impacts without compromising its protective capabilities.Overall, the objective for an enhanced ballistic helmet using UHMWPE would be to provide a helmet that is lightweight, comfortable, and highly effective at protecting the wearer against ballistic threats in high-risk environments.

6.2 SPECIMEN TEST

The size for the specimen which we have given for the material testing is 130mm×20mm

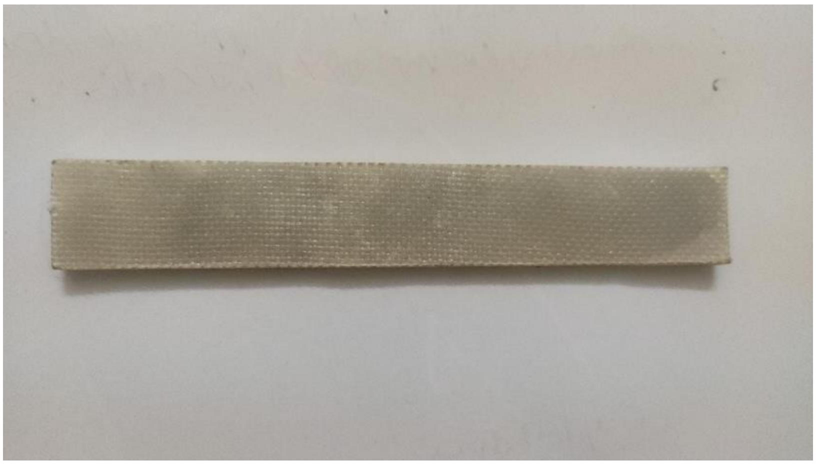

Image 6.1. Specimen Image

6.2.1 IMPACT TEST

An impact test is a type of mechanical test that is used to measure the ability of a material or product to withstand impact or shock. The test involves subjecting the material or product to a high force impact, typically using a specially designed testing machine, and then measuring the response of the material or product to the impact.

Impact tests can be used to assess a wide range of materials and products, including metals, plastics, composites, and finished products such as helmets and safety equipment. The results of an impact test can provide important information about the strength, durability, and safety of a material or product.

There are several different types of impact tests, each of which is designed to measure a specific aspect of the material or product being tested. Some common types of impact tests include:

- Charpy Impact Test: measures the energy required to fracture a notched specimen.
- Izod Impact Test: measures the energy required to fracture a notched specimen that is supported at one end.
- Drop Test: measures the ability of a product to withstand impact when dropped from a certain height.
- Ballistic Impact Test: measures the ability of a material or product to withstand impact from a projectile, typically used for testing body armor.

The results of an impact test can be used to evaluate and improve the design and manufacturing of a product, as well as to ensure compliance with safety standards and regulations.

We have conducted an impact test on UHMWPE fabric to evaluate its resistance to sudden high-stress loading.

Table 6.2. Impact Test Results

S.No	Impact Area	Impact Force (KJ)
1	Side Point	17.2
2	Side Point	18.1
3	Side Point	16.5
4	Side Point	13.3
5	Middle Point	23.9
6	Average	17.8

6.2.2 TENSILE TEST

A tensile test is a type of mechanical test used to measure the strength of a material or product by subjecting it to a controlled amount of tension or stretching. The test involves applying an axial load to a sample of the material, typically in the form of a bar or wire, until it reaches its breaking point or experiences permanent deformation.

During a tensile test, the sample is placed in a testing machine that applies a controlled amount of force to the material. The force is applied in a specific direction and at a specific rate, and the machine measures the amount of force required to stretch the material and the amount of deformation that occurs.

The results of a tensile test can provide important information about the strength and mechanical properties of a material, including its ultimate tensile strength, yield strength, and elastic modulus. These properties can be used to determine the suitability of a material for a particular application, as well as to evaluate the quality and consistency of different batches of material.

Tensile tests can be performed on a wide range of materials, including metals, plastics, composites, and textiles. The testing procedure can be customized to meet the specific needs of the material being tested, and different types of grips and fixtures can be used to accommodate different sample shapes and sizes.

Tensile testing is an important tool for material testing and characterization, and is used in a variety of industries, including aerospace, automotive, construction, and manufacturing.

Table 6.3. TENSILE Test Results

TOCR NO	**2101A T1**	**Test Date**	**19-04-2023**
Sample ID	**1**	**Type**	**Flat**
Size(mm)	24.90*5.10	Area(mm^2)	126.99
IGL(mm)		FGL(mm)	
E(%)	/	FDia(mm)	
RA(%)	/	UTL(kN)	22.527
UTS(MPa)	177	YL/0.2% PL(kN)	/
YS/0.2% PS(MPa)	/	FL	/

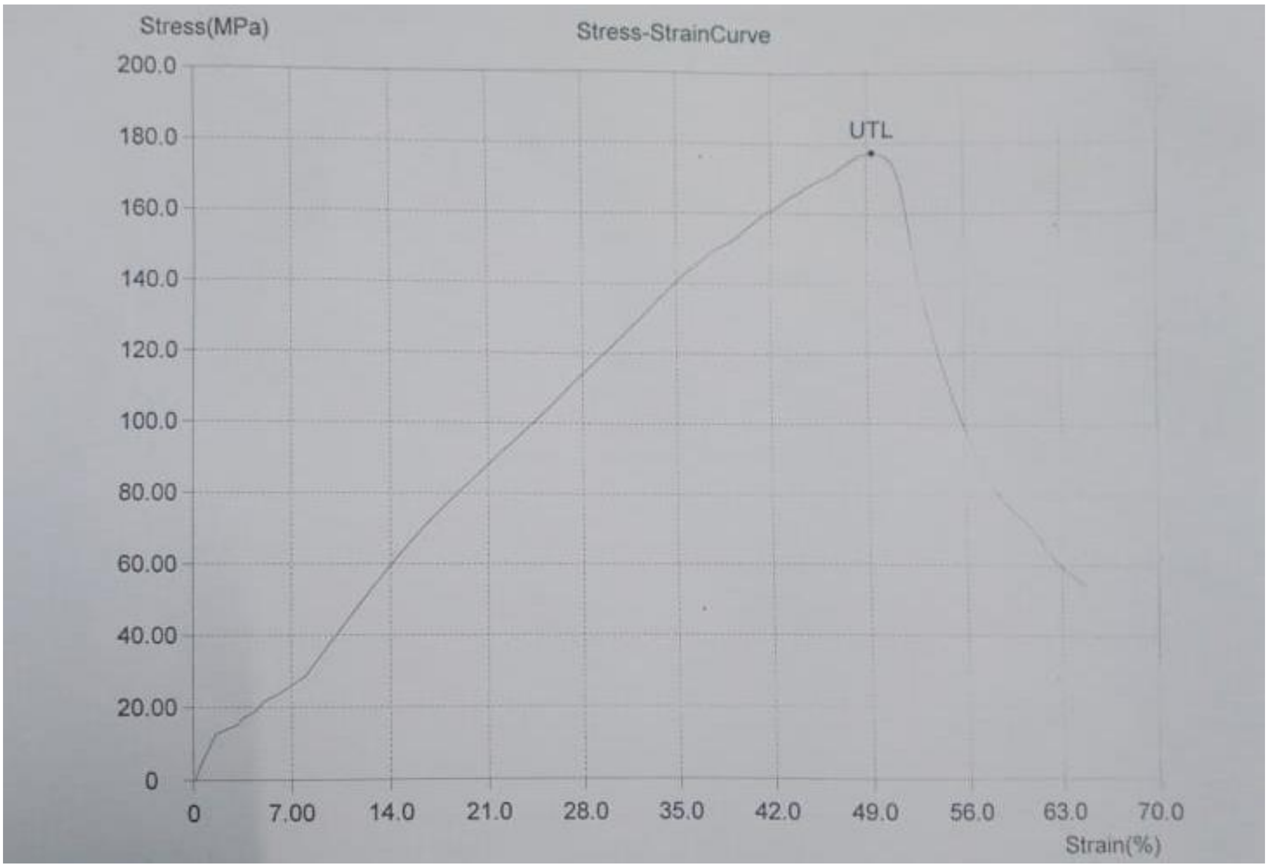

Image 6.2. Graph of TENSILE Test Results

6.2.3 FLEXURAL TEST

A flexural test, also known as a bending test, is a type of mechanical test used to measure the strength and stiffness of a material or product by subjecting it to a three-point or four-point bending load. The test involves applying a force to a beam or flat sample of the material, causing it to bend, and measuring the amount of deflection or deformation that occurs.

During a flexural test, the sample is supported at two points, with a load applied to a third point between the supports. The force is applied in a controlled manner, and the machine measures the amount of force required to bend the sample and the amount of deflection that occurs.

The results of a flexural test can provide important information about the mechanical properties of a material, including its flexural strength, flexural modulus, and toughness. These properties can be used to evaluate the suitability of a material for a particular application, as well as to compare the performance of different materials.

Flexural tests can be performed on a wide range of materials, including metals, plastics, composites, and ceramics. The testing procedure can be customized to meet the specific needs of the material being tested, and different types of supports and loading configurations can be used to accommodate different sample shapes and sizes.

Flexural testing is an important tool for material testing and characterization, and is used in a variety of industries, including aerospace, automotive, construction, and manufacturing.

Table 6.4. FLEXURAL Test Results

TOCR NO	**2101A**	**Test Date**	**19-04-2023**
Sample ID	FRP	W(mm)	25.1
T(mm)	5.1	Span 1(mm)	80
Load (N)	180.70	F.S (MPa)	33.2
EF(MPa)	0.0		

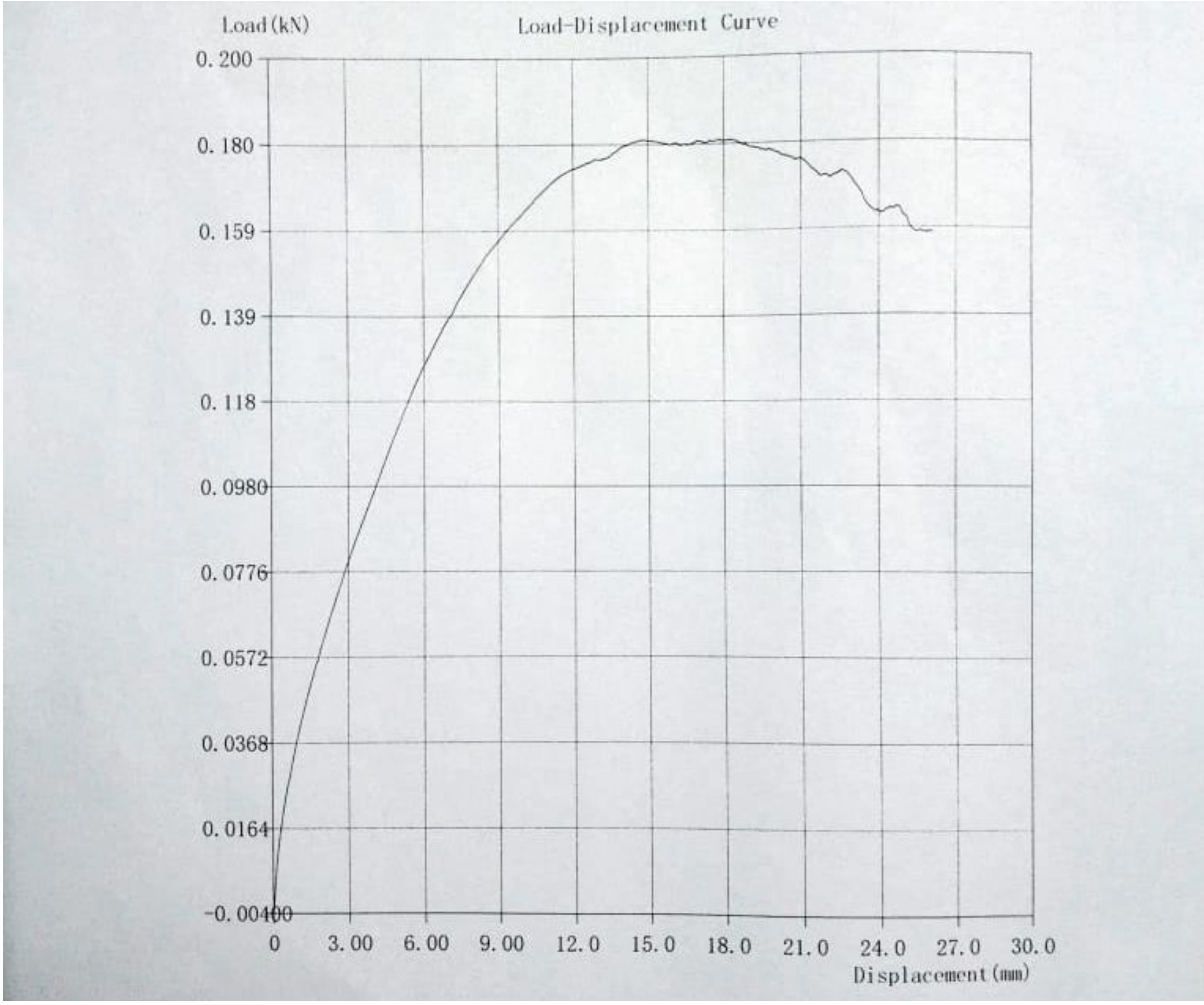

Image 6.3. Graph of FLEXURAL Test Results

CHAPTER 7
CONCLUSION

In conclusion, the development of a lightweight ballistic helmet with enhanced comfort for frontline soldiers using UHWMPE fabric with epoxy resin is a promising solution. UHWMPE fabric is a high-performance material that offers excellent ballistic protection while being lightweight. Epoxy resin is an effective bonding agent that can improve the overall strength of the helmet. The combination of these materials can provide soldiers with a helmet that is both protective and comfortable to wear for extended periods. The use of UHWMPE fabric with epoxy resin in the development of ballistic helmets can be a significant advancement in the protection of frontline soldiers. Further research and development in this area may lead to even more innovative and effective solutions for protecting soldiers in combat situations.

UHWMPE fabric can be effectively bonded with epoxy resin. Epoxy resin is a strong adhesive material that can provide excellent bonding properties when applied to the surface of UHWMPE fabric. The bonding process involves applying the epoxy resin to the UHWMPE fabric, which penetrates the fibers and creates a strong bond when cured. This bond creates a highly durable and robust material that is ideal for ballistic protection applications. The combination of UHWMPE fabric and epoxy resin can provide a lightweight, high-performance material with superior ballistic protection, making it an ideal choice for the development of ballistic helmets for frontline soldiers.

CHAPTER 8

REFERENCE

1. Hamouda, A.M.S., Sohaimi, R.M., Zaidi, A.M.A., Abdullah, S.: Materials and design issues for military helmets. Adv. Mil. Text. Pers (2012). https://doi.org/10. 1533/ 97808 57095 572.1. 103

2. Kulkarni, S.G., Gao, X.L., Horner, S.E., Zheng, J.Q., David, N.V.: Ballistic helmets - Their design, materials, and performance against traumatic brain injury. Compos. Struct. 101, 313–331 (2013). https://doi. org/10. 1016/j. compstruct.2013. 02. 014

3. Carr, D.J., Lewis, E., Mahoney, P.F.: UK military helmet design and test methods. BMJ Mil Heal. 166, (2019). https://doi.org/10. 1136/jramc-2018-001123

4. Jamroziak, K., Bajkowski, M., Bocian, M., Polak, S., Magier, M., Kosobudzki, M., Stepien, R.: Ballistic head protection in the light of injury criteria in the case of the Wz.93 combat helmet. Appl. Sci. 9, 1–16 (2019). https://doi. org/ 10. 3390/ app9132702

5. Breeze, J., Baxter, D., Carr, D., Midwinter, M.J.: Defining combat helmet coverage for protection against explosively propelled fragments. J. R. Army Med. Corps. 161, 9–13 (2015). https://doi.org/10.1136/jramc-2013-000108

6. Zhang, T.G., Vargas-Gonzalez, L.R., Gurganus, J.C., Satapathy, S.S.: Effects of curvature and architecture on ballistic performance of UHMWPE helmets. ASME Int. Mech. Eng. Congr. Expo. Proc. 3,1–9 (2019). https://doi. org/ 10. 1115/IMECE2019-11566

7. Klaue, A., Kruck, M., Friederichs, N., Bertola, F., Wu, H., & Morbidelli, M. (2018). Insight into the synthesis process of an industrial ziegler–natta catalyst. Ind. Eng. Chem. Res, 58: 886–896.

8. Kornet, L., Jansen, J. R., Gussenhoven, E. J., Hardeman, M. R., Hoeks, A. P., & Versprille, A. (1999). Conductance method for the measurement of cross sectional areas of the aorta. Ann. Biomed. Eng., 27: 141–150.

9. Oleynik, I. V., Shundrina, I. K., & Oleyinik, I. I. [2020]. Highly active titanium [IV] dichloride FI catalysts bearing a diallylamino group for the synthesis of disentangled Uhmwpe. Polym. Adv. Technol., 31: 1921–1934.

10. Smith P, Lemstra PJ, Pijpers JPL. (1982) Tensile strength of highly oriented polyethylene. II. Effect of molecular weight distribution. J. Polym. Sci. Polym. Phys. 20:2229-2241.

11. Li, W., Guan, C., Xu, J., Mu, J., Gong, D., Chen, Z.-ren, & Zhou, Q. (2014). Disentangled uhmwpe/POSS nanocomposites prepared by ethylene in situ polymerization. Polymer, 55: 1792–1798

12. L.E. Govaert et al. Tensile strength and work of fracture of oriented polyethylene fiber Polymer (1995)

13. R.L. Woodward et al. Resistance to penetration and compression of fiber-reinforced composite materials Compos Eng (1994)

14. F.X. Kromm et al. Tensile and creep properties of ultra high molecular weight PE fibers Polym Test (2003)

15. M.R. O'Masta et al. Mechanisms of penetration in polyethylene reinforced cross-ply laminates Int J Impact Eng (2015)