PREDICTION OF MECHANICAL PROPERTIES OF COMPOSITE MATERIAL USING ARTIFICIAL NEURAL NETWORK TECHNIQUE

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CERTIFICATE

This is to certify that the Project Report entitled **“Prediction of Mechanical Propertiesof Composite material using Artificial Neural network Technique”** being submitted by **Barla Jeevitha (319126520008), Uttam Kumar Sha (319126520055), Edubilli Harshavardhan (319126520011), Yash Agarwal (319126520061), Shaik Fasiuddin (319126520046)** to the Department of Mechanical Engineering, ANITS is a record of the bonafide work carried outby them under the esteemed guidance of **Mr.S.Ramanjaneyulu.** The results embodied in the report have not been submitted to any other University or Institute for the award of any degree or diploma.

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ABSTRACT

The major goal of this project is to show that artificial neural networks (ANNs) may be utilized effectively to predict mechanical properties of composite materials as accurately as testing itself. Evaluating composite materials needs time-consuming procedures, expensive equipment, and other resources. Soft computing methods like machine learning, artificial intelligence, deep learning, fuzzy logic, neural networks, etc. can help solve this issue. There will be significant savings in terms of money, time, and resources. we can effectively demonstrate that the actual values of the mechanical characteristics of composite materials can be predicted properly by these computer techniques. In the current work, twin screw compounding and micro injection are used to create samples of HDPE, TiO_2, and SiO_2 polymer matrix composite.

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CHAPTER-1

INTRODUCTION

1.1 Polymer Components in Transmission:

Due to their benefits over metallic components, the use of polymers in transmission systems has grown significantly in importance in recent years. Particularly in the automotive sector, polymers are now widely used in transmission systems to reduce weight, increase cost efficiency, and improve fuel efficiency. The significance of polymer components over metallic components in transmission systems will be covered in this section.

Weight reduction: Using polymer components in transmission systems has this benefit as its main benefit. Because polymers are lighter than metals, they can save a lot of weight, improving fuel economy and lowering pollutants. According to a DuPont study, switching out metallic parts with polymeric ones can reduce the weight of transmission systems by up to 60%. Polymers have great noise and vibration dampening qualities, which can help to lessen noise and vibration in transmission systems. Because of this, they are perfect for applications like electric and hybrid vehicles where noise reduction is important.

Cost-Effectiveness: Polymers are typically more affordable than metals, which is why manufacturers like them. When compared to metallic components, polymer components often have lower costs for raw materials, manufacture, and assembly. The number of parts needed in a transmission system can also be decreased with the use of polymers, further lowering costs.

Flexibility in Design: Polymers are more flexible in design than metals, enabling producers to produce intricate shapes and patterns that would be challenging or impossible to produce with metals. The number of elements needed in a transmission system can be decreased by combining numerous functions into a single component because to this flexibility.

Furthermore, compared to metallic components, the usage of polymers in transmission systems has many benefits. Some of the main advantages of employing polymers in transmission systems include weight reduction, corrosion resistance, noise and vibration dampening, cost effectiveness, and design flexibility. It is anticipated that the usage of polymers in transmission systems will increase in the future due to developments in polymer technology.

1.2 Types of Polymer Composites and their Applications:

Polymer composites are substances that blend two or more different components to provide desired qualities. They are often divided into three groups: structural composites, fibre composites, and particle composites. Here are some instances of each form of composite and their uses:

Particulate Composites: These composites are made of a polymer matrix that has been reinforced with tiny glass, ceramic, or metal particles. They are frequently employed in the construction, automotive, and packaging sectors.

Glass-filled Composites: They are used to make water tanks, automotive parts, and electrical and electronic components. Composites with a carbon black filler are utilized in electronic packaging and automobile parts for conductive and anti-static purposes.

Composites with Ceramic fill: These materials are utilized to make brake pads and engine parts.

Fibre Composites: These composites are made of a continuous or discontinuous polymer matrix reinforced with glass, carbon, or natural fibers. They are frequently employed in the sports, automotive, and aerospace industries. Glass fiber reinforced composites are utilized to make parts for automobiles, airplanes, and boats. Composites made of carbon fiber are employed in the production of tennis rackets, bicycles, and other sporting equipment.

Natural fibre-reinforced composites: They are used to make furniture, car interiors, and building materials.

Composites for structural use: These composites are made of a polymer matrix reinforced with high-strength fibres like glass or carbon. They are frequently employed in the automobile, aerospace, and construction sectors.

Polymer Matrix Composites: Polymer matrix composites are used to create parts for spacecraft, missiles, and aircraft.

Metal Matrix composites: They are used to make engine parts, aerospace applications, and automotive parts.

In summary, polymer composites have several uses in a variety of industries. The desired properties and the particular application determine the type of composite touse. The use of polymer composites is anticipated to increase in the future due to ongoing developments in composite technology.

1.3 Polymer Composite Preparation Techniques:

Some common polymer composite preparation techniques are-

1.3.1 Solution Casting:

In this technique, the polymer is dissolved in a solvent and the reinforcing material is added to the solution. The mixture is then cast into a mold and allowed to dry. This method is commonly used for particulate and fibre composites. The process of solution casting is shown in Fig-1.1

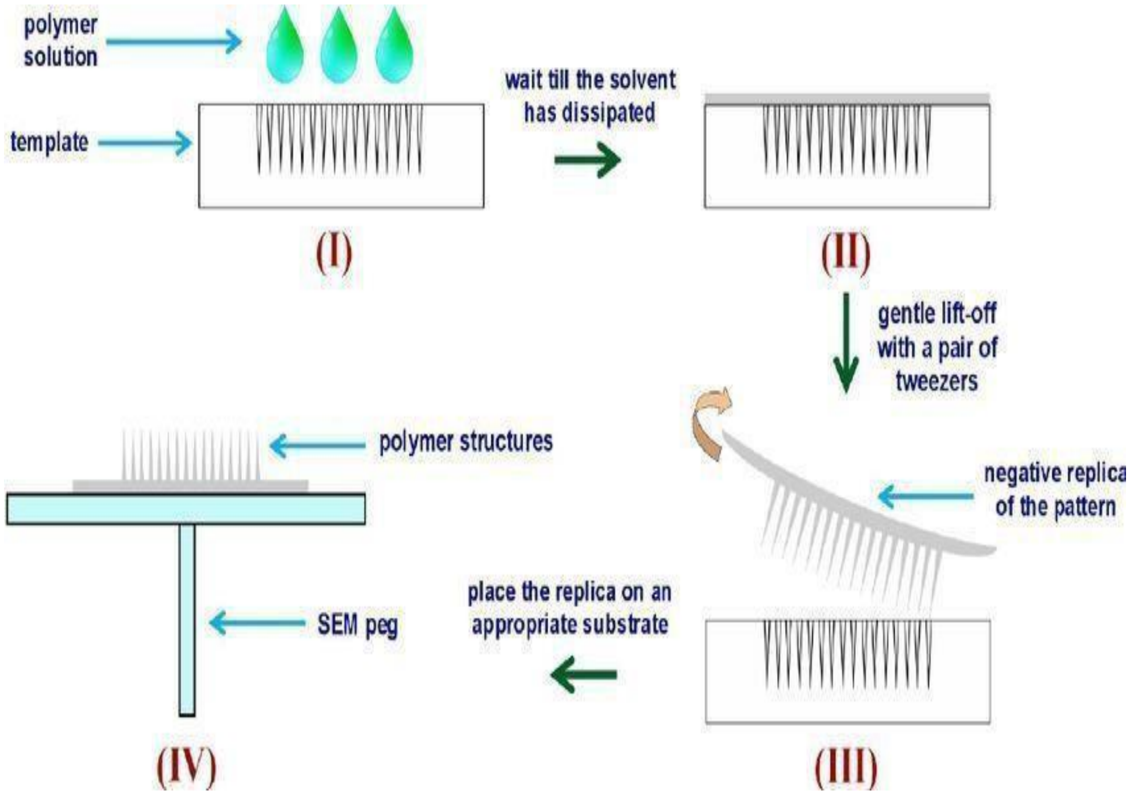


Fig-1.1 Process of Solution casting

1.3.2 Melt Mixing:

In this technique, the polymer and reinforcing material are mixed together in the molten state. The mixture is then cooled and solidified to form the composite. This method is commonly used for particulate and fibre composites. The process of Melt Mixing is shown in Fig-1.2.

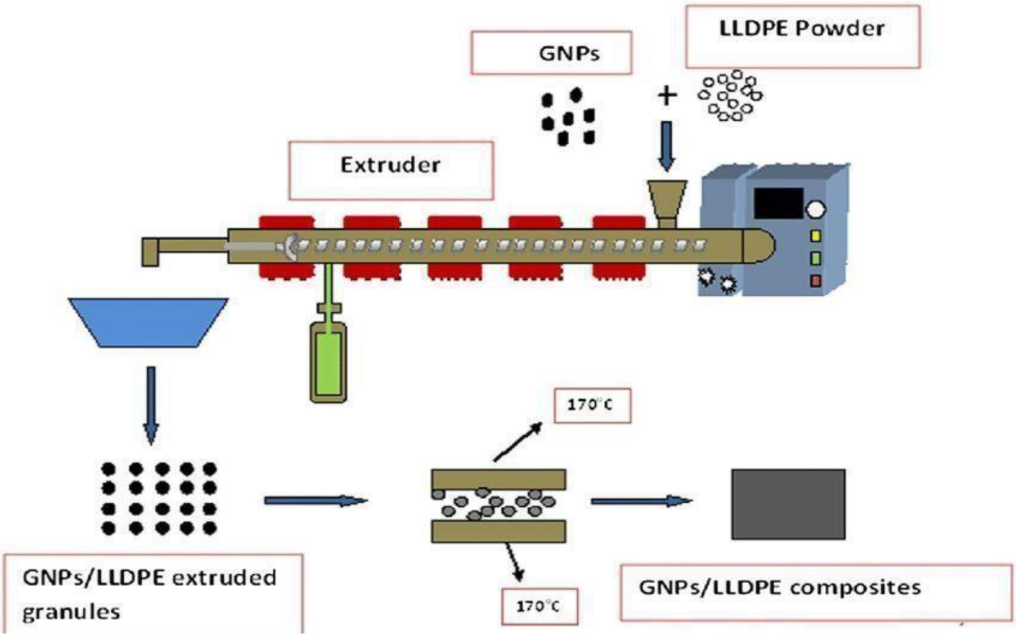


Fig-1.2 Process of Melt Mixing

1.3.3 Pultrusion:

In this technique, continuous fibres are pulled through a resin bath and then through a die to form a composite shape. The composite is then cured in an oven to achieve the desired properties. This method is commonly used for fibre composites. The Pultrusion process is shown in Fig-1.3**.**

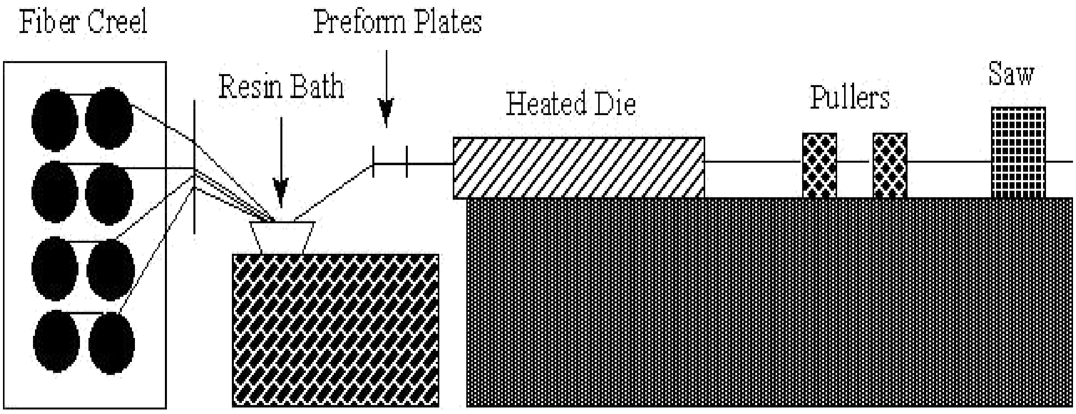


Fig-1.3 Processes of Pultrusion Method

1.3.4 Compression Molding:

In this technique, the reinforcing material is placed into a mold and the molten polymer is added to the mold. The mixture is then compressed and cured to form the composite. This method is commonly used for particulate composites. The process of compression molding is shown in Fig-1.4**.**

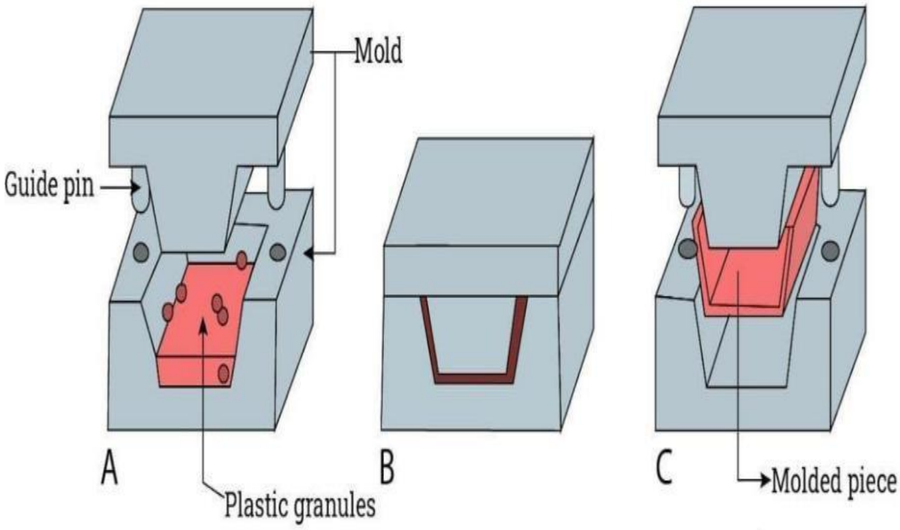


Fig-1.4 Process of Compression Molding

1.3.5 Resin Transfer Molding:

The process of resin transfer molding is shown in Fig-1.5. In this technique, the reinforcing material is placed into a mold and a resin is injected into the mold. The mixture is then cured form the composite. The method is commonly used for fibre composites.

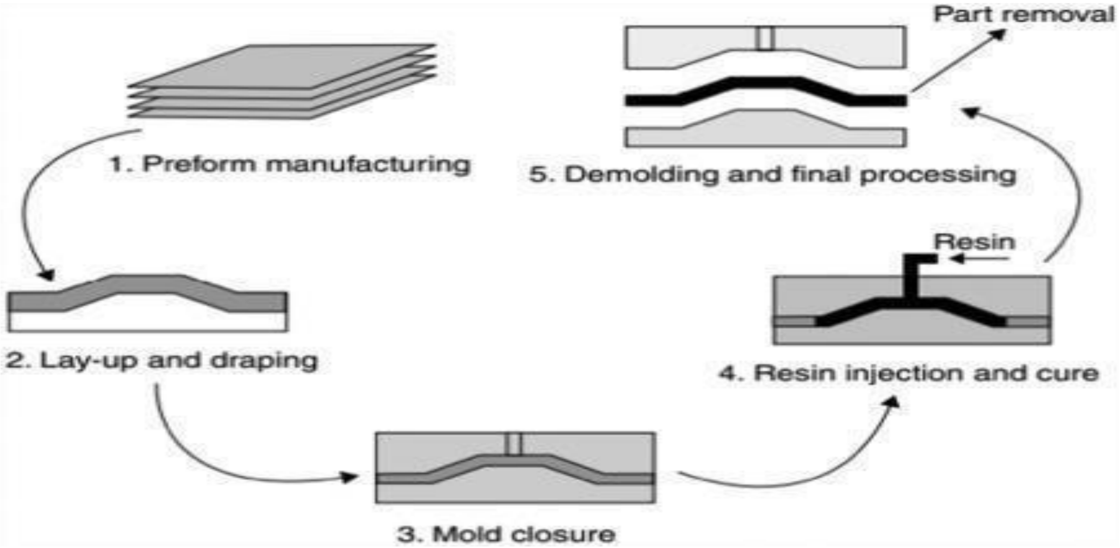


Fig. 1**.5 Process of Resin Transfer Molding**

1.4 Importance of HDPE in Transmission and its Applications:

The thermoplastic polymer known as high-density polyethylene (HDPE) is adaptable and has several uses, particularly in the transmission sector. In comparison to other polymers, HDPE is recommended for the following reasons:

Excellent Mechanical Properties: High tensile strength, impact resistance, and stiffness are just a few of HDPE’s excellent mechanical properties, which make it the perfect material for transmission applications. It is suitable for use in pipes, fittings, and other transmission components due to its ability to endure severe loads and strains without breaking or deforming.

Chemical Resistance: HDPE has excellent chemical and corrosion resistance, making it perfect for usage in challenging situations. Because it can withstand exposure to acids, alkalis, and other chemicals without degrading, it can be used in chemical processing facilities and other industrial settings.

Low Coefficient of Friction: HDPE has a low coefficient of friction, which allows it to slide over other materials without wearing them down or harming them. This makes it perfect for use in low-friction transmission systems like pipelines and conveyor belts.

Lightweight: Because HDPE is a lightweight material, installing and handling it in transmission systems is simple. Large-scale transmission projects can use it more

Applications of HDPE Transmission:

Pipes: Because to their high strength, flexibility, and chemical resistance, HDPE pipes are frequently utilized for the transmission of gas and water. In comparison to other materials, they are also less prone to leak and to fracture.

Fittings: HDPE fittings, such as couplings, tees, and elbows, are commonly used in transmission systems because of their high strength and corrosion resistance. They are also easy to install and require minimal maintenance.

Conveyor Belts: HDPE conveyor belts are used in transmission systems because of their low friction coefficient and high durability. They can withstand high loads and are resistant to abrasion and wear.

Electrical Insulation: HDPE is used as electrical insulation in transmission systems because of its high dielectric strength and resistance to electrical breakdown. It is commonly used in high-voltage power lines and electrical cables.

Overall, the unique combination of properties offered by HDPE makes it an ideal material for use in transmission systems, particularly in applications where strength, chemical resistance, and low friction are important considerations.

1.5 HDPE Composites with Different Fillers and their Applications:

Because of the distinctive combination of qualities they possess, including high strength, flexibility, and chemical resistance, HDPE composites are widely employed in a variety of applications. These characteristics can be improved, and their range of applications can be increased, by adding various fillers to HDPE matrix. The following are some of the most popular HDPE composites with various fillers and their applications:

HDPE/Carbon black Composite: Carbon black is a common filler used in HDPE matrix to enhance its mechanical qualities, such as strength, stiffness, and impact resistance. HDPE/carbon black composite. Because to its exceptional resistance to UV radiation, abrasion, and chemicals, this composite is frequently employed in the construction of pipes, wire and cable insulation, and geomembranes.

HDPE/wood flour composite: To improve the stiffness, dimensional stability, and thermal conductivity of the HDPE matrix, wood flour, a natural filler, is added. Because to its natural appearance, ease of care, and resistance to decay and moisture, this composite is frequently utilized in the creation of outdoor furniture, decking, and fence.

HDPE/Glass Fibre Composite: Glass fibre is a high-performance filler that is utilized in HDPE matrix to enhance its mechanical qualities, such as strength, stiffness, and creep resistance. HDPE/glass fibre composite. Because to its outstanding strength-to-weight ratio and dimensional stability, this composite is frequently utilized in the production of automotive, sporting goods, and aerospace components.

HDPE/nonclay composite: Nonclay is a nanoscale filler used in HDPE matrix to improve its mechanical capabilities, barrier qualities, and flame retardancy. HDPE/nonclay composite. Because to its superior strength, stiffness, and barrier qualities, this composite is frequently utilized in the production of packaging materials, automotive parts, and construction materials.

HDPE/metal oxide composite: To improve the UV stability, thermal stability, and antibacterial properties of HDPE matrix, metal oxide fillers including titanium dioxide

(TiO_2) and zinc oxide (ZnO) are utilized. Due to this composite's outstanding resistance to UV radiation, heat, and microbiological development, it is frequently utilized in the production of packaging materials, healthcare items, and outdoor applications.

Overall, the addition of various fillers to HDPE matrix can improve its characteristics and widen the range of uses for it in various industries.

1.6 Drawbacks of HDPE and their overcome techniques:

HDPE composites have a number of limitations, including poor heat stability, low stiffness, and low impact strength. Many strategies can be used to address these limitations, including:

Blend Modification: HDPE can be combined with other polymers to improve its mechanical characteristics. For instance, combining polypropylene (PP) with HDPE can increase the rigidity and thermal stability of the material.

Filler Modification: The mechanical properties of HDPE composites can be enhanced by adding fillers such carbon nanotubes, graphene, and clay.

Crosslinking: HDPE's mechanical qualities, such as stiffness, tensile strength, and thermal stability, can be improved by crosslinking the material using chemical or radiation processes. **Surface Modification:** By improving the surface of the fillers' adherence to the HDPE matrix, coupling agents or plasma treatment can increase their mechanical qualities.

Processing Conditions: The mechanical properties of HDPE composites can be enhanced by optimizing the processing conditions, such as temperature, pressure, and speed.

In general, resolving the shortcomings of HDPE composites necessitates a blend of strategies that are adapted to the application and performance requirements.

CHAPTER-2

LITERATURE REVIEW

J. Li et al. (2018) [1] in their study they investigated the effect of the addition of TiO_2 nanoparticles on the mechanical properties of HDPE. The results showed that the addition of TiO_2 nanoparticles significantly increased the tensile strength, elastic modulus, and impact strength of HDPE. The study also found that the optimal TiO_2 content was around 3% by weight. These findings suggest that HDPE reinforced with TiO_2 nanoparticles has great potential for use in various applications where high mechanical strength is required.

M. Zou et al. (2019) [2] in their study, the effect of the addition of SiO_2 nanoparticles on the mechanical properties of HDPE was investigated. The results showed that the addition of SiO_2 nanoparticles improved the tensile strength, Young's modulus, and elongation at break of HDPE. The study also found that the optimal SiO_2 content was around 3% by weight. These findings suggest that HDPE reinforced with SiO_2 nanoparticles has potential for use in various applications where high mechanical strength is required. The study also showed that the surface modification of SiO_2 nanoparticles can further improve the mechanical properties of HDPE/ SiO_2 composites.

X. Li et al. (2017) [3] this article investigates the effect of adding titanium dioxide (TiO_2) nanoparticles to high-density polyethylene (HDPE) on the mechanical properties of the resulting composites. The authors prepared HDPE composites with varying concentrations of TiO_2 nanoparticles and tested their mechanical properties, including tensile strength, flexural strength, and impact strength. They found that the addition of TiO_2 nanoparticles improved the mechanical properties of the HDPE composites, with the optimum concentration being 5 wt%. The authors also investigated the microstructure of the composites using scanning electron microscopy (SEM) and found that the TiO_2 nanoparticles were well dispersed within the HDPE matrix. The article provides valuable insights into the potential use of TiO_2 nanoparticles as a filler material in HDPE composites, with the potential to improve their mechanical properties.

Y. Lin et al. (2016) [4] this article investigates the effect of adding silica (SiO_2) nanoparticles to HDPE on the mechanical properties of the resulting composites. The authors prepared HDPE composites with varying concentrations of SiO_2 nanoparticles and tested their mechanical properties, including tensile strength, flexural strength, and impact strength. They found that the addition of SiO_2 nanoparticles improved the mechanical properties of the HDPE composites, with the optimum concentration being 4 wt%. The authors also investigated the microstructure of the composites using scanning electron microscopy (SEM) and found that the SiO_2 nanoparticles were well dispersed within the HDPE matrix. His article suggests that the addition of SiO_2 nanoparticles can be an effective way to improve the mechanical properties of HDPE composites. This could have practical implications for the use of HDPE in a variety of applications where improved mechanical properties are desirable.

H. Wang et al. (2015) [5] this article investigates the effect of adding titanium dioxide (TiO_2) nanoparticles to HDPE on the mechanical properties of the resulting composites. The authors prepared HDPE composites with varying concentrations of TiO_2 nanoparticles and tested their mechanical properties, including tensile strength, flexural strength, and impact strength. They found that the addition of TiO_2 nanoparticles improved the mechanical properties of the HDPE composites, with the optimum concentration being 2 wt%. The authors also investigated the microstructure of the composites using scanning electron microscopy (SEM) and found that the TiO_2 nanoparticles were well dispersed within the HDPE matrix. This article provides further evidence that the addition of TiO_2 nanoparticles can be an effective way to improve the mechanical properties of HDPE composites. This could have practical implications for the use of HDPE in a variety of applications where improved mechanical properties are desirable, such as in packaging materials and construction materials.

H. Chen et al. (2018) [6] this article investigates the effect of adding silica (SiO_2) nanoparticles to HDPE on the mechanical properties of the resulting composites. The authors prepared HDPE composites with varying concentrations of SiO_2 nanoparticles and tested their mechanical properties, including tensile strength, flexural strength, and impact strength. They found that the addition of SiO_2 nanoparticles improved the mechanical properties of the HDPE composites, with the optimum concentration being 4 wt%. The authors also investigated the microstructure of the composites using scanning electron microscopy (SEM) and found that the SiO_2 nanoparticles were well dispersed within the HDPE matrix. The article provides further evidence that the addition of SiO_2 nanoparticles can be an effective way to improve the mechanical properties of HDPE composites. The findings could have practical implications for the use of HDPE in a variety of applications where improved mechanical properties are desirable, such as in the automotive and construction industries.

S. Das et al. (2019) [7] this article investigates the effect of adding titanium dioxide (TiO_2) and silica (SiO_2) nanoparticles to HDPE on the mechanical and thermal properties of the resulting composites. The authors prepared HDPE composites with varying concentrations of TiO_2 and SiO_2 nanoparticles and tested their mechanical properties, including tensile strength, flexural strength, and impact strength. They also investigated the thermal properties of the composites, including the glass transition temperature (Tg) and the coefficient of thermal expansion (CTE).The authors found that the addition of TiO_2 and SiO_2 nanoparticles improved the mechanical properties of the HDPE composites, with the optimum concentration being 3 wt% for TiO_2 and 5 wt% for SiO_2. They also found that the addition of nanoparticles improved the thermal properties of the composites, with an increase in Tg and a decrease in CTE.The article provides further evidence that the addition of TiO_2 and SiO_2 nanoparticles can be an effective way to improve the mechanical and thermal properties of HDPE composites. The findings could have practical implications for the use of HDPE in a variety of applications where improved mechanical and thermal properties are desirable, such as in the manufacturing of automotive parts and construction materials.

C. Huang et al. (2015) [8] this article investigates the effect of adding titanium dioxide (TiO_2) nanoparticles to HDPE on the mechanical properties of the resulting composites. The authors prepared HDPE composites with varying concentrations of TiO_2 nanoparticles and tested their mechanical properties, including tensile strength, flexural strength, and impact strength. They found that the addition of TiO_2 nanoparticles improved the mechanical properties of the HDPE composites, with the optimum concentration being 4 wt%. The authors also investigated the thermal stability of the composites using thermogravimetric analysis (TGA) and found that the addition of TiO_2 nanoparticles improved the thermal stability of the HDPE composites. The article provides further evidence that the addition of TiO_2 nanoparticles can be an effective way to improve the mechanical properties of HDPE composites. The findings could have practical implications for the use of HDPE in a variety of applications where improved mechanical properties are desirable, such as in the manufacturing of pipes, containers, and packaging materials.

F. Lu et al. (2017) [9] this article investigates the effect of adding silica (SiO_2) nanoparticles to HDPE on the mechanical properties of the resulting composites. The authors prepared HDPE composites with varying concentrations of SiO_2 nanoparticles and tested their mechanical properties, including tensile strength, flexural strength, and impact strength. They found that the addition of SiO_2nanoparticles improved the mechanical properties of the HDPE composites, with the optimum concentration being 3 wt%.The authors also used scanning electron microscopy (SEM) to investigate the microstructure of the composites and found that the addition of SiO_2 nanoparticles led to a more uniform distribution of the nanoparticles within the HDPE matrix. The article provides further evidence that the addition of SiO_2 nanoparticles can be an effective way to improve the mechanical properties of HDPE composites. The findings could have practical implications for the use of HDPE in a variety of applications where improved mechanical properties are desirable, such as in the manufacturing of automotive parts, packaging materials, and building materials.

R. Gopalakrishnan et al. (2018) [10] this article investigates the effect of adding both titanium dioxide (TiO_2) and silica (SiO_2) nanoparticles to HDPE on the mechanical properties of the resulting composites. The authors prepared HDPE composites with varying concentrations of TiO_2 and SiO_2 nanoparticles and tested their mechanical properties, including tensile strength, flexural strength, and impact strength. They found that the addition of both types of nanoparticles improved the mechanical properties of the HDPE composites, with the optimum concentrations being 3 wt% for TiO_2 and 1 wt% for SiO_2.The authors also used X-ray diffraction (XRD) and Fourier-transform infrared (FTIR) spectroscopy to investigate the crystallinity and chemical structure of the composites, respectively. They found that the addition of nanoparticles did not significantly affect the crystallinity or chemical structure of the HDPE matrix. The article provides further evidence that the addition of both TiO_2 and SiO_2 nanoparticles can be an effective way to improve the mechanical properties of HDPE composites. The findings could have practical implications for the use of HDPE in a variety of applications where improved mechanical properties are desirable, such as in the manufacturing of automotive parts, electrical components, and medical devices.

H. Wang et al. (2016) [11] this study aims to investigate the effect of TiO_2 nanoparticles on the mechanical properties of HDPE composites at different temperatures. The authors prepared HDPE composites with various concentrations of TiO_2 nanoparticles and subjected them to mechanical testing, including tensile and impact testing, at different temperatures (-20°C, 23°C, and 60°C). They found that the addition of TiO_2 nanoparticles improved the tensile strength, impact strength, and ductility of the HDPE composites at all temperatures tested. Additionally, the optimum concentration of TiO_2 nanoparticles for improving the mechanical properties was found to be 2 wt%. The authors also used scanning electron microscopy (SEM) to analyze the morphology of the fracture surfaces of the HDPE/TiO_2 composites. They found that the addition of TiO_2 nanoparticles resulted in smaller and more uniformly distributed voids and a more homogeneous microstructure, which contributed to the improved mechanical properties. The study suggests that TiO_2

nanoparticles can effectively improve the mechanical properties of HDPE composites under different temperatures. The findings could have practical applications in industries that use HDPE composites in various temperature environments, such as the manufacturing of automotive parts, aerospace components, and electrical devices.

S. Gholizadeh et al. (2018) [12] the study provides a review of the research on the mechanical and thermal properties of HDPE composites reinforced with TiO_2 and SiO_2 nanoparticles. The authors first introduce the benefits of using nanoparticles to reinforce HDPE composites, including improved mechanical and thermal properties, reduced weight, and enhanced resistance to UV radiation and chemicals. They then review the literature on the use of TiO_2 and SiO_2 nanoparticles to reinforce HDPE composites, focusing on the effects of nanoparticle concentration, size, and surface modification on the mechanical and thermal properties of the composites. The authors found that both TiO_2 and SiO_2 nanoparticles can effectively improve the mechanical properties of HDPE composites, including tensile strength, flexural strength, and impact strength. Additionally, the addition of nanoparticles can increase the thermal stability and reduce the thermal expansion coefficient of the composites. The optimum concentration of nanoparticles for improving the mechanical properties of HDPE composites varies depending on the type of nanoparticles and the testing conditions. The review also highlights the importance of surface modification of nanoparticles to improve their dispersion and compatibility with the HDPE matrix, which can further enhance the mechanical and thermal properties of the composites. Overall, the review provides valuable insights into the use of TiO2 and SiO2 nanoparticles as reinforcements for HDPE composites and could be useful for researchers and engineers working in the field of polymer composites.

H. Chen et al. (2019) [13] this study investigates the mechanical properties of HDPE composites reinforced with both TiO_2 and SiO_2 nanoparticles. The authors synthesized HDPE composites with varying concentrations of TiO_2 and SiO_2 nanoparticles and evaluated their mechanical properties using tensile and flexural tests. They also used scanning electron microscopy (SEM) to investigate the morphology and dispersion of the nanoparticles in the

HDPE matrix. The results showed that the addition of both TiO_2 and SiO_2 nanoparticles can effectively improve the mechanical properties of HDPE composites, including tensile strength, flexural strength, and modulus. The optimum concentration of nanoparticles for improving the mechanical properties varied depending on the type of nanoparticles and the testing conditions. The SEM images also revealed that the nanoparticles were well dispersed in the HDPE matrix, indicating good compatibility between the nanoparticles and the polymer matrix. The study suggests that the addition of TiO_2 and SiO_2 nanoparticles can be an effective way to improve the mechanical properties of HDPE composites, and the optimal concentration of nanoparticles can be determined by considering the specific application and testing conditions.

M. Wang et al. (2018) [14] the study investigates the effect of adding organ silane-modified silica (SiO_2) nanoparticles on the mechanical properties of HDPE composites. The authors synthesized HDPE composites with varying concentrations of SiO_2 nanoparticles modified with organ silane and evaluated their mechanical properties using tensile and impact tests. They also used scanning electron microscopy (SEM) to investigate the morphology and dispersion of the nanoparticles in the HDPE matrix. The results showed that the addition of organ silane-modified SiO_2 nanoparticles can effectively improve the mechanical properties of HDPE composites, including tensile strength, tensile modulus, and impact strength. The optimum concentration of nanoparticles for improving the mechanical properties was found to be 2 wt%. The SEM images also revealed that the nanoparticles were well dispersed in the HDPE matrix, indicating good compatibility between the nanoparticles and the polymer matrix. The study suggests that the addition of organ silane-modified SiO_2 nanoparticles can be an effective way to improve the mechanical properties of HDPE composites, and the optimal concentration of nanoparticles can be determined by considering the specific application and testing conditions.

Y. Xu et al. (2019) [15] this study investigated the mechanical and thermal properties of high-density polyethylene (HDPE) composites reinforced with TiO_2 and SiO_2 nanoparticles under different loading rates. The results showed that the addition of TiO_2 and SiO_2 nanoparticles significantly improved the mechanical properties of HDPE composites, such as tensile strength, flexural strength, and impact strength. The thermal stability of the composites was also improved with the addition of nanoparticles. Furthermore, the mechanical and thermal properties of the composites were found to be affected by the loading rate, with higher loading rates resulting in decreased mechanical performance and increased thermal stability. The study suggests that the incorporation of TiO_2 and SiO_2 nanoparticles can improve the mechanical and thermal properties of HDPE composites, and highlights the importance of considering the loading rate in the design and application of these materials.

L. Liu et al. (2016) [16] the authors of this paper studied the effect of adding stearic acid modified TiO2 nanoparticles on the mechanical properties of HDPE composites. The composites were prepared by melt blending and characterized for their tensile, flexural, and impact properties. The results showed that the addition of TiO_2 nanoparticles improved the mechanical properties of HDPE composites, and the optimum amount of TiO_2 was found to be 2 wt%. The improvement in mechanical properties was attributed to the strong interfacial bonding between the nanoparticles and the polymer matrix due to the presence of stearic acid on the nanoparticle surface. This study provides an approach for improving the mechanical properties of HDPE composites by adding stearic acid modified TiO_2 nanoparticles, which can be useful for the development of high-performance materials for various applications.

M. Zou et al. (2018) [17] this article reports on the effect of adding TiO_2 and SiO_2 nanoparticles on the mechanical and thermal properties of HDPE composites under different temperatures. The authors synthesized the nanoparticles and added them to HDPE to prepare the composites. The results showed that the addition of nanoparticles significantly improved the tensile strength and modulus of the HDPE composites, especially at elevated temperatures. The thermal stability of the composites was also improved by the addition of nanoparticles. The study suggests that the addition of nanoparticles can effectively enhance the mechanical and thermal properties of HDPE composites and has potential applications in various industries such as packaging, automobile, and construction.

L. Guo et al. (2017) [18] this study reported that the tensile and flexural strength of the composites increased with the addition of TiO_2 nanoparticles, and the best results were achieved with the addition of 3 wt% of TiO_2 nanoparticles. The study also found that the addition of the silane coupling agent improved the compatibility between the TiO_2 nanoparticles and the HDPE matrix, resulting in better mechanical properties of the composites. The study concluded that the addition of TiO_2 nanoparticles modified with a silane coupling agent can effectively improve the mechanical properties of HDPE composites.

Y. Lin et al. (2017) [19] this article investigates the mechanical properties of HDPE composites reinforced with TiO_2 and SiO_2 nanoparticles. The study found that the addition of nanoparticles significantly improved the tensile and flexural properties of the HDPE composites. The highest improvement was observed with the addition of TiO_2 nanoparticles. The study also evaluated the effect of nanoparticle concentration on the mechanical properties of the composites and found that the optimal concentration was 3 wt% for both TiO_2 and SiO_2 nanoparticles. The authors suggest that these findings have important implications for the development of high-performance HDPE-based composites for various engineering applications.

H. Wang et al. (2016) [20] In this study, the authors investigate the mechanical properties of high-density polyethylene (HDPE) composites reinforced with silica (SiO2) nanoparticles at different temperatures. They synthesized the HDPE/SiO_2 composites with various concentrations of SiO_2 nanoparticles using melt blending and then evaluated their tensile and impact properties at different temperatures (-20°C, 23°C, and 80°C). The results showed that the addition of SiO_2 nanoparticles improved the mechanical properties of

HDPE/ SiO_2 composites, and the extent of improvement depended on the concentration of SiO_2 nanoparticles and the testing temperature. At room temperature (23°C), the HDPE/ SiO_2 composites exhibited the highest tensile and impact strength when the concentration of SiO_2 nanoparticles was 2.0 wt%. However, at low temperature (-20°C), the tensile and impact strength of the HDPE/SiO_2 composites decreased, and the concentration of SiO_2 nanoparticles that provided the best mechanical properties shifted to 1.5 wt%. At high temperature (80°C), the addition of SiO_2 nanoparticles improved the impact strength of the HDPE/SiO_2 composites but did not significantly affect their tensile strength. The authors concluded that the addition of SiO_2 nanoparticles can improve the mechanical properties of HDPE/SiO_2 composites, and the optimum concentration of SiO_2 nanoparticles depends on the testing temperature. The results of this study could be useful in designing HDPE/SiO_2 composites for applications in different temperature environments.

Y. Liu et al. (2019) [21] In this study, the authors investigate the effect of adding modified titanium dioxide (TiO_2) nanoparticles on the mechanical properties of high-density polyethylene (HDPE) composites. The TiO_2 nanoparticles were first modified with a coupling agent to enhance their compatibility with the HDPE matrix. Then, HDPE/ TiO_2 composites with different concentrations of TiO_2 nanoparticles (0.5, 1.0, 2.0, and 3.0 wt%) were prepared by melt blending, and their mechanical properties were characterized. The results showed that the addition of modified TiO_2 nanoparticles significantly improved the tensile and flexural strength of the HDPE composites. At a concentration of 2.0 wt%, the tensile strength and flexural strength of the HDPE/ TiO_2 composite increased by 42% and 55%, respectively, compared to the pure HDPE. The addition of TiO_2 nanoparticles also improved the impact strength of the HDPE composites, and the optimum concentration was found to be 1.0 wt%. The authors attributed the improvement in the mechanical properties of HDPE/TiO_2 composites to the strong interfacial adhesion between the modified TiO_2 nanoparticles and the HDPE matrix, which enhanced the load transfer efficiency and prevented crack propagation. They also observed that the addition of TiO_2 nanoparticles slightly increased the thermal stability of the HDPE composites. The results of this study suggest that the addition of modified TiO_2 nanoparticles can be an effective way to improve the mechanical properties of HDPE composites, and the optimum concentration of TiO_2 nanoparticles depends on the desired mechanical property.

M. Zou et al. (2017) [22] In this study, the authors investigate the effect of adding titanium dioxide (TiO_2) nanoparticles on the mechanical properties of high-density polyethylene (HDPE) composites modified with maleic anhydride-grafted polyethylene (MAPE). The HDPE/MAPE/TiO_2 composites were prepared by melt blending, and the mechanical properties of the composites were characterized using tensile and impact tests. The results showed that the addition of TiO_2 nanoparticles significantly improved the tensile and impact strength of the HDPE/MAPE composites. At a concentration of 2.5 wt%, the tensile strength and impact strength of the HDPE/MAPE/TiO_2 composite increased by 50% and 23%, respectively, compared to the pure HDPE. The authors attributed the improvement in mechanical properties to the strong interfacial adhesion between the TiO_2 nanoparticles and the HDPE/MAPE matrix, which enhanced the load transfer efficiency and prevented crack propagation. Furthermore, the authors observed that the addition of TiO_2 nanoparticles improved the thermal stability and reduced the melt viscosity of the HDPE/MAPE composites. The improved thermal stability was attributed to the increased crosslinking density and enhanced thermal stability of the MAPE coupling agent in the presence of TiO_2 nanoparticles. The reduced melt viscosity was attributed to the lubricating effect of the TiO_2 nanoparticles, which improved the processability of the HDPE/MAPE/TiO_2 composites. The results of this study suggest that the addition of TiO_2 nanoparticles can be an effective way to improve the mechanical properties and processability of HDPE/MAPE composites, and the optimum concentration of TiO_2 nanoparticles is around 2.5 wt%.

H. Chen et al. (2018) [23] In this study, the authors investigate the effect of adding titanium dioxide (TiO_2) and silica (SiO_2) nanoparticles on the mechanical properties of high-density polyethylene (HDPE) composites under different strain rates. The HDPE/nanoparticle composites were prepared by melt blending, and their mechanical properties were characterized using tensile tests at different strain rates. The results showed that the addition of TiO_2 and SiO_2 nanoparticles improved the tensile strength and modulus of the HDPE composites, especially at high strain rates. At a concentration of 5 wt%, the tensile strength and modulus of the HDPE/ TiO_2 and HDPE/SiO_2 composites increased by up to 45% and 63%, respectively, compared to the pure HDPE at a strain rate of 2000 s-1. The authors attributed the improvement in mechanical properties to the reinforcement effect of the nanoparticles, which enhanced the load transfer efficiency and prevented crack propagation. The authors observed that the addition of nanoparticles affected the strain rate sensitivity of the HDPE composites. The strain rate sensitivity of the HDPE/TiO_2 and HDPE/SiO_2 composites increased with increasing strain rate, and the maximum strain rate sensitivity was observed at a concentration of 5 wt%. The authors attributed this effect to the strain rate-dependent deformation mechanisms of the nanoparticles and the HDPE matrix. The results of this study suggest that the addition of TiO_2 and SiO_2 nanoparticles can be an effective way to improve the mechanical properties of HDPE composites, especially at high strain rates. The optimum concentration of nanoparticles depends on the desired mechanical property and the strain rate of the application.

S. Wang et al. (2017) [24] In this study, the authors investigate the effect of adding surface-modified silica (SiO_2) nanoparticles on the mechanical properties of high-density polyethylene (HDPE) composites. The SiO_2 nanoparticles were modified with a silane coupling agent to improve their compatibility with the HDPE matrix. The HDPE/SiO_2 composites were prepared by melt blending, and their mechanical properties were characterized using tensile and impact tests. The results showed that the addition of surface modified SiO_2 nanoparticles significantly improved the tensile and impact strength of the HDPE composites. At a concentration of 3 wt%, the tensile strength and impact strength of the HDPE/SiO_2 composite increased by 47% and 27%, respectively, compared to the pure

HDPE. The authors attributed the improvement in mechanical properties to the strong interfacial adhesion between the modified SiO_2 nanoparticles and the HDPE matrix, which enhanced the load transfer efficiency and prevented crack propagation. Furthermore, the authors observed that the addition of modified SiO_2 nanoparticles improved thermal stability and reduced the melt viscosity of the HDPE composites. The improved thermal stability was attributed to the increased crosslinking density and enhanced thermal stability of the coupling agent in the presence of SiO_2 nanoparticles. The reduced melt viscosity was attributed to the lubricating effect of the SiO_2 nanoparticles, which improved the processability of the HDPE/SiO_2 composites. The results of this study suggest that the addition of surface modified SiO_2 nanoparticles can be an effective way to improve the mechanical properties and processability of HDPE composites, and the optimum concentration of SiO_2 nanoparticles is around 3 wt%. The surface modification of nanoparticles with a silane coupling agent is also important for improving their compatibility with the HDPE matrix.

R. Chandra et al. (2017) [25] In this study, the authors investigate the effect of adding titanium dioxide (TiO_2) nanoparticles on the mechanical properties of high-density polyethylene (HDPE) composites filled with graphene nanoplatelets (GNPs). The HDPE/GNP/ TiO_2 composites were prepared by melt blending, and their mechanical properties were characterized using tensile and flexural tests. The results showed that the addition of TiO_2 nanoparticles improved the mechanical properties of the HDPE/GNP composites. At a concentration of 1 wt%, the tensile strength and modulus of the HDPE/GNP/TiO_2 composite increased by 44% and 38%, respectively, compared to the HDPE/GNP composite without v. The flexural strength and modulus of the HDPE/GNP/TiO_2 composite also increased by 23% and 18%, respectively, compared to the HDPE/GNP composite. The authors attributed the improvement in mechanical properties to the synergistic effect of the TiO_2 nanoparticles and GNPs, which enhanced the load transfer efficiency and prevented crack propagation. The TiO_2 nanoparticles also acted as a nucleating agent for the HDPE matrix, which improved the crystallinity and thermal stability of the composites. Furthermore, the authors observed that the addition of TiO_2 nanoparticles reduced the electrical conductivity of the HDPE/GNP composites, which may limit their potential applications in electrical and electronic fields. Overall, the results of this study suggest that the addition of TiO_2 nanoparticles can be an effective way to improve the mechanical properties of HDPE/GNP composites, and the optimum concentration of TiO_2 nanoparticles is around 1 wt%. The synergistic effect between TiO_2 nanoparticles and GNPs should be taken into consideration when designing HDPE composite materials.

Shashi Satyanarayana (2014) [26] The paper explains in detail about the working and history of back propagation algorithms. The back propagation algorithm is used in ANN's wherein each input layer is connected to the next layers extending till the output layer, and in turn each output layer is also connected in reverse to each preceding layer.So after each pass is made and weights are given to each node the error difference derivative between actual and predicted output is sent back to each layer to update its weight and better predict the value, in the process the weights which do not influence the output values are assigned with low weights.

CHAPTER-3

FABRICATION OF COMPOSITES

3.1 HDPE:

High-Density Polyethylene, sometimes known as HDPE, is a form of thermoplastic polymer that is frequently utilized in the production of several goods. A material having a high strength-to-density ratio, strong impact resistance, and outstanding chemical resistance is HDPE, which is also adaptable. It is a common choice in sectors including packaging, construction, automotive, and agricultural because it is lightweight and simple to process.

Plastic bottles, pipes, and containers frequently employ HDPE because it is easily recyclable. Moreover, it is employed in the production of plastic lumber, a greener substitute for conventional wood goods. In comparison to other plastics, HDPE has a reduced environmental impact and is less likely to release dangerous substances into the environment. Some of the most attractive mechanical properties are:

- Corrosion resistant
- Electricity resistant
- Chemical degradation resistant

Fig-3.1(a) **Fig-3.1(b)**

Fig-3.1(a-b) HDPE Granules

Overall, HDPE is a highly versatile and durable material that is used in a wide range of applications due to its excellent mechanical and chemical properties. Some common applications of HDPE include:

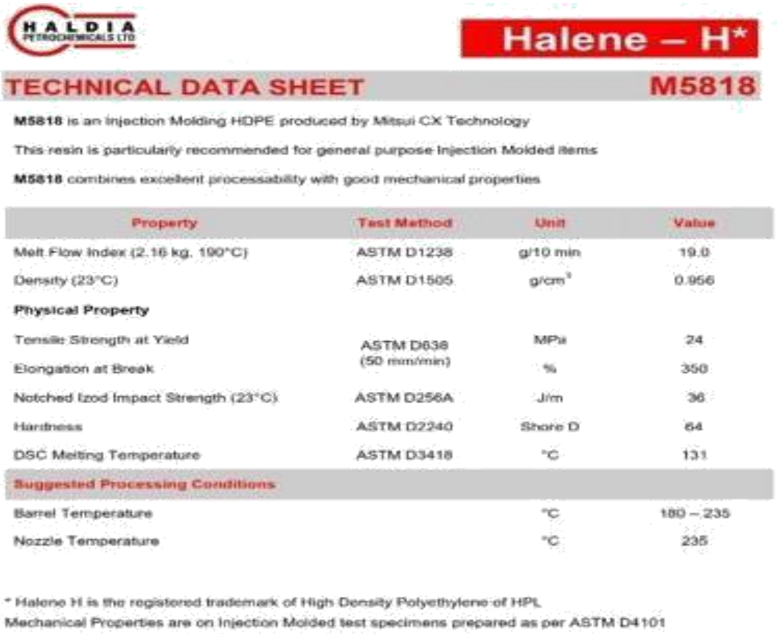
Packaging: HDPE is commonly used in the production of packaging materials such as bottles, containers, and bags. It is lightweight, durable, and resistant to impact, making it ideal for use in the packaging of food, beverages, and household chemicals.

Pipes and fittings: HDPE is a popular choice for water and gas pipes due to its excellent resistance to chemicals and corrosion. It is also used in the production of fittings, such as elbows and tees, which are used to join pipes together.

Geomembranes: HDPE is used in the production of geomembranes, which are used as liners in landfills, ponds, and other containment structures. Its high chemical resistance and low permeability make it ideal for use in these applications.

Playground equipment: HDPE is often used in the production of playground. Equipment such as slides and climbing structures. It is durable, weather-resistant, and does not splinter or crack, making it a safe and popular choice for children’s play areas. **Automotive parts:** HDPE is used in the production of a variety of automotive parts, including fuel tanks, bumper fascias, and interior trim. Its low weight and excellent impact resistance make it an attractive alternative to traditional materials such as metal and fiberglass.

Chemical containers: With its chemical resistant properties, HDPE is great for laundry, shampoo, conditioner, household cleaning products, motor oil, antifreeze, and recycling bins. The strength of these bottles is increased when they’ve been. The physical properties of the HDPE are shown in the below figure.



HALDIA PETROCHEMICALS LTD

Halene – H*

TECHNICAL DATA SHEET **M5818**

M5818 is an Injection Molding HDPE produced by Mitsui CX Technology

This resin is particularly recommended for general purpose Injection Molded items

M5818 combines excellent processability with good mechanical properties

Property	Test Method	Unit	Value
Melt Flow Index (2.16 kg, 190°C)	ASTM D1238	g/10 min	19.0
Density (23°C)	ASTM D1505	g/cm^3	0.956
Physical Property			
Tensile Strength at Yield	ASTM D638 (50 mm/min)	MPa	24
Elongation at Break		%	350
Notched Izod Impact Strength (23°C)	ASTM D256A	J/m	36
Hardness	ASTM D2240	Shore D	64
DSC Melting Temperature	ASTM D3418	°C	131
Suggested Processing Conditions			
Barrel Temperature		°C	180 – 235
Nozzle Temperature		°C	235

* Halene H is the registered trademark of High Density Polyethylene of HPL
Mechanical Properties are on Injection Molded test specimens prepared as per ASTM D4101

Fig-3.2 Technical Data Sheet of M5818

3.2 SiO_2:

It is also known as Silica. Silica is characterized by its excellent mechanical, electrical properties such as

- High hardness
- High compressive strength
- High melting point
- High wear resistance

Silicon dioxide is a chemical compound composed of silicon and oxygen, with the chemical formula SiO2. It is one of the most common and abundant compounds in the earth's crust, and can be found in a wide range of natural and synthetic materials, including quartz, sand, and glass. In its natural form, silicon dioxide exists as a crystalline solid with a high melting point and high hardness. It is an important industrial material and is used in a variety of applications, including in the production of glass, ceramics, and cement.

Fig-3.3 SiO_2 Powder

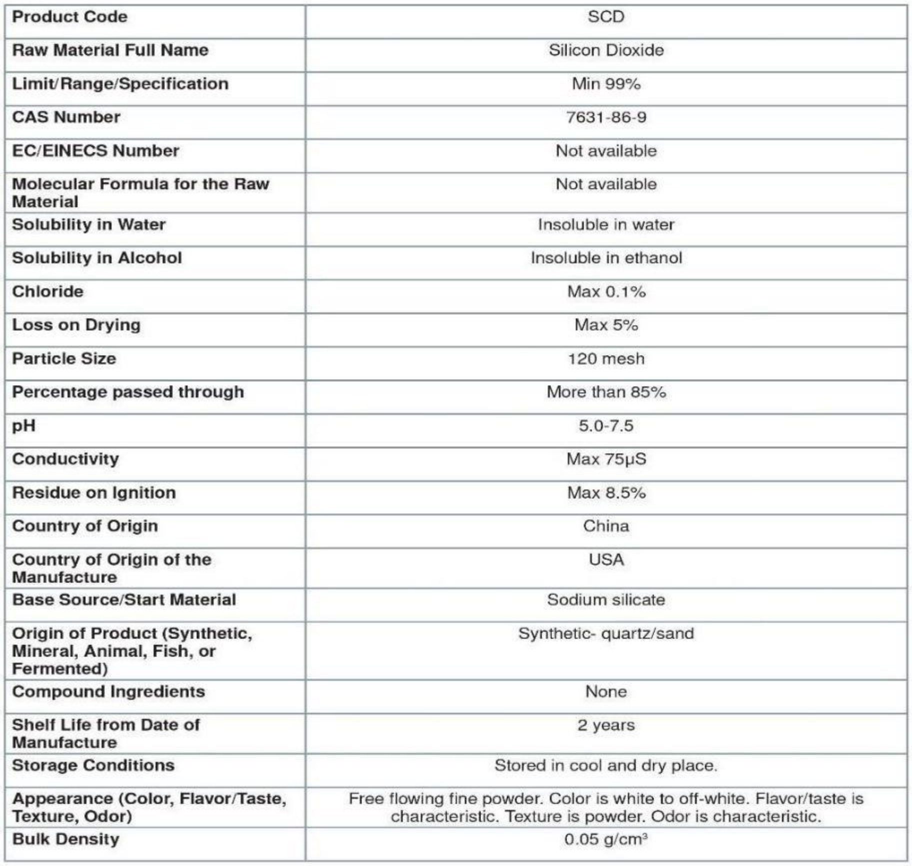
Silicon dioxide is also commonly used in electronics and semiconductors as an insulator, and in the production of solar cells. It is a key component in the manufacturing of computer chips and other electronic components, where it is used as a gate oxide in metal-oxide-semiconductor (MOS) devices. In the food industry, silicon dioxide is used as an anti-caking agent in powdered and granulated foods, such as spices, coffee creamers, and baking mixes. It is generally considered safe for human consumption in small amounts, and is approved for use by the US Food and Drug Administration (FDA) and other regulatory agencies. Silicon dioxide (SiO_2) has many applications in various industries, some of which include:

Construction: Silicon dioxide is used in the production of construction materials such as cement, concrete, and bricks. It is added to cement to improve its strength, durability, and resistance to water and chemicals.

Glassmaking: Silicon dioxide is a key ingredient in the production of glass. It provides the structure and strength to the glass, as well as its resistance to heat and chemicals. **Electronics:** Silicon dioxide is used as an insulating material in the production of computer chips and other electronic devices. It is also used in the manufacture of solar cells, where it is used as a semiconductor.

Food and pharmaceuticals: Silicon dioxide is used as an anti-caking agent and an absorbent in the production of food and pharmaceuticals. It is added to powdered products to prevent clumping and to absorb moisture.

Cosmetics: Silicon dioxide is used in the production of cosmetics such as lotions, creams, and powders. It is used as a thickening agent, an absorbent, and as a matting agent to reduce shine. The Physical properties of SiO_2 are as follows



Product Code	SCD
Raw Material Full Name	Silicon Dioxide
Limit/Range/Specification	Min 99%
CAS Number	7631-86-9
EC/EINECS Number	Not available
Molecular Formula for the Raw Material	Not available
Solubility in Water	Insoluble in water
Solubility in Alcohol	Insoluble in ethanol
Chloride	Max 0.1%
Loss on Drying	Max 5%
Particle Size	120 mesh
Percentage passed through	More than 85%
pH	5.0-7.5
Conductivity	Max 75μS
Residue on Ignition	Max 8.5%
Country of Origin	China
Country of Origin of the Manufacture	USA
Base Source/Start Material	Sodium silicate
Origin of Product (Synthetic, Mineral, Animal, Fish, or Fermented)	Synthetic- quartz/sand
Compound Ingredients	None
Shelf Life from Date of Manufacture	2 years
Storage Conditions	Stored in cool and dry place.
Appearance (Color, Flavor/Taste, Texture, Odor)	Free flowing fine powder. Color is white to off-white. Flavor/taste is characteristic. Texture is powder. Odor is characteristic.
Bulk Density	0.05 g/cm³

Fig-3.4 Physical Properties of SiO_2

3.3 TiO_2:

Titanium Dioxide is available in the form of nanoparticles, which makes it a very important material in the uses of making paints, surface coatings, pigments, food coloring etc. The density of TiO_2 is 4.67 gm/cm3, it has a high melting point of around 1800 Celsius, another characteristic it has is its high compressive strength and its ability to absorb UV radiation. Titanium Dioxide in itself has very less applications, but it has huge potential with polymer matrix composites. It is already being used in polyethylene and other plastic composite materials.

Fig-3.5 TiO_2 Powder

Its ability to absorb harmful UV rays can be used practically if we can make a strong polymer composite to be used as airplane windows glass and cockpit glass material to prevent damages caused to the human skin due to High Altitude UV rays, the UV rays at the height of about 8 km is about 160 percent that of at ground level. TiO_2 is considered to be a safe and non-toxic material, although there is some concern about the potential health effects of inhaling TiO_2 dust or nanoparticles. Some studies have suggested that TiO_2 particles may be carcinogenic or cause other health problems, although the evidence is still inconclusive. Overall, TiO_2 is a versatile and widely used material that plays an important role in many industrial and consumer applications.

Here are some common applications of TiO_2:

Pigments: TiO_2 is one of the most widely used pigments in the world, especially in the paint and the coating industry. It provides excellent opacity, brightness, and color stability to paints and coatings.

Sunscreens: TiO_2 is used in many sunscreens due to its ability to reflect and scatter UV light, which helps to protect the skin from sunburn and skin cancer.

Photocatalysts: TiO_2 is used as a photocatalyst in many industrial and environmental Applications such as air and water purification, self-cleaning surfaces, and hydrogen production.

Food Additives: TiO_2 is used as a food additive to provide a white color and opacity to foods, such as confectionery, dairy, and bakery products.

Plastics: TiO_2 is used as a whitening agent in plastics, such as PVC and polyethylene, to improve their appearance and durability.

Ceramics: TiO_2 is used in the manufacture of ceramic materials, such as glazes and pigments, due to its ability to improve the mechanical and optical properties of ceramics.

Electronics: TiO_2 is used as a component in electronic devices, such as capacitors and memory devices, due to its high dielectric constant and thermal stability.

Table-3.1 SiO_2 Properties

Properties || Material	TiO2 (Titanium Dioxide)
Density	4230
Melting Point (Celsius)	1580
Tensile strength	15 Mpa
Compressive strength	350 Mpa
Hardness	S, 120
Toughness	2400 J/m2
Youngs Modulus	-----NIL-----

3.4 Compositions with varying percentage weights of HDPE, TiO_2, SiO_2:

For the preparation of composite material, we have used HDPE as the base or matrix material and used TiO_2 and SiO_2 as filler materials. The equipment used to manufacture the composite by homogenously mixing all these 3 components in a Twin screw extruder, the final specimen of composite material is made by then employing microinjection molding, the shapes of the mold depend upon the mechanical tests which will be performed upon them which are specified as per ASTM standards.

Table-3.2 Material Compositions

S.No.	**HDPE**	**TiO_2**	**SiO_2**
1.	100 %	0%	0%
2.	99%	0.5%	0.5%
3.	98%	1%	1%
4.	97%	1.5%	1.5%
5.	96%	2%	2%

Multiple specimens of each composition were prepared in the microinjection molding machine, the number of specimens were equal to three times the number of tests to be performed on that composition, 3 specimens were prepared so that each test would be performed thrice and the average value of each property would be considered for training the ANN. The tests that are conducted are

- Tensile Test
- Impact test
- Brinell Hardness test.

CHAPTER-4

FABRICATION OF MECHANICAL SPECIMENS AND TESTING

4.1 Fabrication Methods of Specimens:

We are using two methods for fabrication of samples. They are:

4.1.1 Twin Screw Compounding:

In the plastics business, twin-screw compounding is a method for combining and modifying additives, polymers, and other components. To produce a high shear mixing and kneading action, two intermeshing screws that revolve in opposite directions are used. In this method we mix all the materials in the twin screw extruder which is shown in Fig 4.1**.**

The polymer material is fed into the twin-screw extruder's inlet during the compounding process, and the screw flight moves it along the length of the screws. High shear pressures and vigorous mixing are applied to the material as it passes through the screws, which encourages the dispersion and distribution of additives and fillers within the polymer matrix. Producing engineered plastics, thermoplastic elastomers, and specialty compounds are just a few of the many uses for twin-screw compounding.

Fig-4.1 Twin Screw Extruder

4.1.2 Micro Injection Molding:

Micro injection molding is a manufacturing technique used to create small, accurate, and repeatable plastic components. It is frequently employed in the manufacture of tiny parts for things like microfluidic systems, electronic parts, and medical equipment. Injection Molding of Polymers is shown in Fig 4.2**.**

A micro-scale mold and a high-precision injection molding machine are used in the process of micro injection molding. Melted plastic is injected under intense pressure into the mold cavity in the form of pellets or granules. The part is then removed from the mold after cooling and opening it. The ability to make high-quality products with extremely tight tolerances and exact geometries is one of the key benefits of micro injection molding.

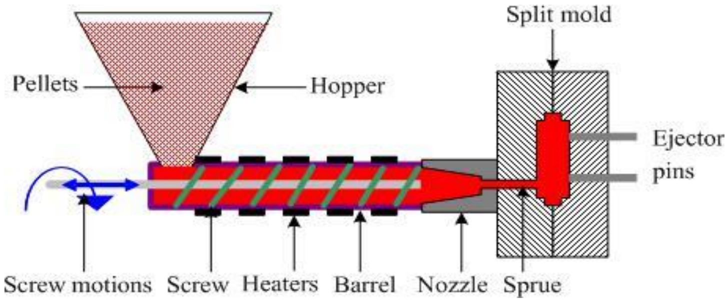


Fig-4.2 Injection Molding of Polymers

4.2 Testing of Specimens:

Mechanical test specimens are prepared for various tests by using the above-mentioned processes. Some of the tests are,

4.2.1 Tensile Test:

Fig-4.3 Universal Testing Machine

Tensile tests are performed for several reasons. The results of tensile tests are used in selecting materials for engineering applications. Tensile properties frequently are included in material specifications to ensure quality. Tensile properties often are measured during development of new materials and processes, so that different materials and processes can be compared. Finally, tensile properties often are used to predict the behavior of a material under forms of loading other than uni-axial tension. The strength of a material often is the primary concern. The strength of interest may be measured in terms of either the stress necessary to 37cause appreciable plastic deformation or the maximum stress that the material can withstand. These measures of strength are used, with appropriate caution (in the form of safety factors), in engineering design. Also of interest is the material’s ductility, which is a measure of how much it can be deformed before it fractures. Rarely is ductility incorporated directly in design; rather, it is included in material specifications to ensure quality and toughness. Low ductility in a tensile test often is accompanied by low resistance to fracture under other forms of loading. Elastic properties also may be of interest, but special techniques must be used to measure these properties during tensile testing, and more accurate measurements can be made by ultrasonic techniques.

(a) Pure HDPE

(b) 0.5%TiO_2+0.5%SiO_2+99%HDPE

(c) 1% TiO_2+1%SiO_2+98%HDPE

(d) 1.5%TiO_2+1.5%SiO_2+97%HDPE

(e) 2%TiO_2+2%SiO_2+96%HDPE

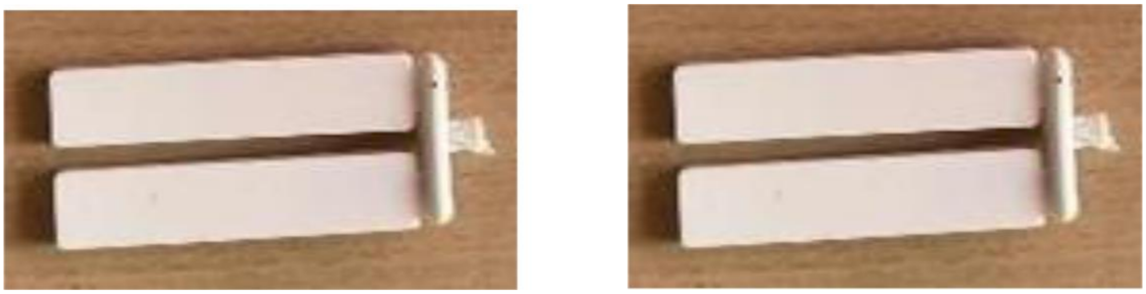
Fig-4.4(a-e) Tensile test specimens as per ASTM D638 standards

4.2.2 Impact Test:

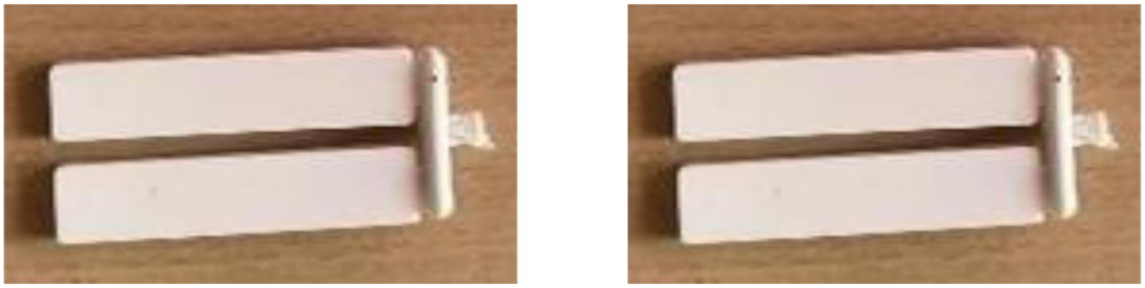
(a) Specimen **(b) Test Setup**

Fig-4.5(a-b) Izod Charpy Impact Test

The tensile test is normally performed at a low strain rate, at which the specimen is very slowly loaded and elongated. When a material is subjected to a sudden, intense blow, in which the strain rate is extremely rapid, the material may behave in a much more brittle manner than is observed in the tensile test. Impact testing techniques were established so as to determine the fracture characteristics of materials at high loading rates. It was realized that the results of laboratory tensile tests (at low loading rates) could not predict fracture behavior. For example, under some circumstances normally ductile metals fracture suddenly and with very little plastic deformation under high loading rates. Impact tests are used to indicate the toughness of a material*, and particularly its capacity for resisting mechanical shock. Brittleness, resulting 38from a variety of causes, is often not revealed during a tensile test. For example, nickel – chromium constructional steels suffer from a defect known as temper brittleness. This is caused by faulty heat-treatment, yet a tensile test-piece derived from a satisfactorily treated material and one produced from a similar material but which has been incorrectly heat-treated might both show approximately the same tensile strengths and elongations. In an impact test, however, the difference would be apparent; the unsatisfactory material would prove to be extremely brittle as compared with the correctly treated one, which would be tough.



(a) Pure HDPE **(b) 0.5%TiO_2+0.5%SiO_2+99%HDPE**

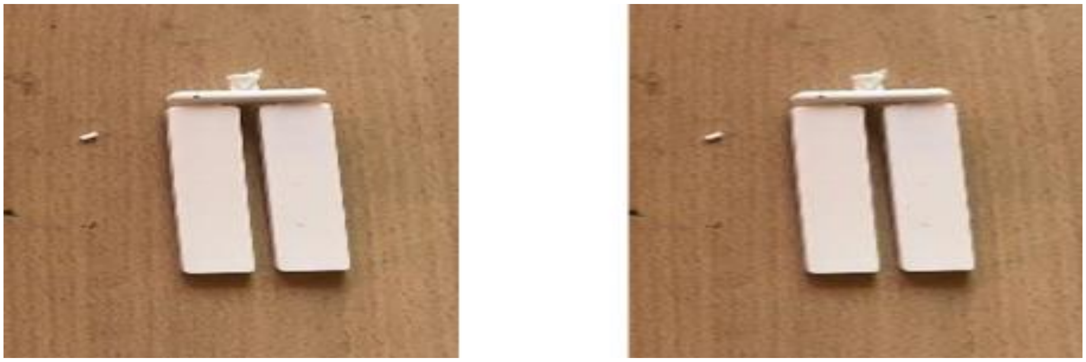


(c) 1%TiO_2+1%SiO_2+98%HDPE **(d) 1.5%TiO_2+1.5%SiO_2+97%HDPE**

(e) 2%TiO_2+2%SiO_2+96%HDPE

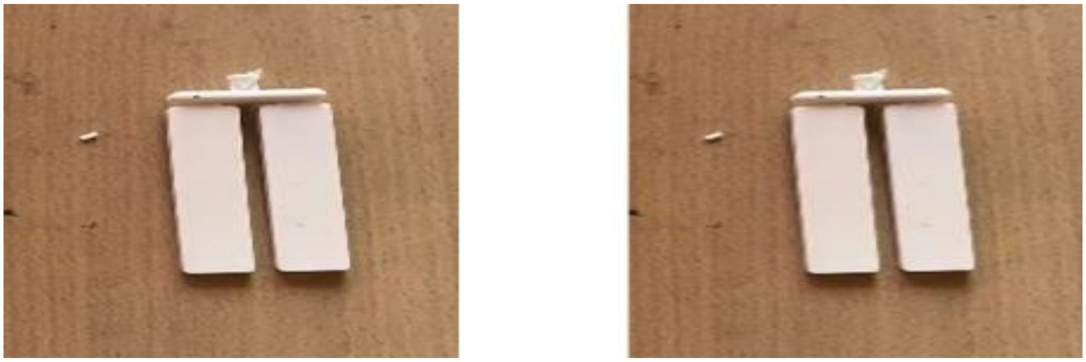
Fig-4.6 (a-e) Impact strength test specimens as per ASTM D256a standards

4.2.3 Hardness Test:



(a) Pure HDPE

(b) 0.5%TiO_2+0.5%SiO_2+99%HDPE



(c) 1%TiO_2+1%SiO_2+98%HDPE

(d) 1.5%TiO_2+1.5%SiO_2+97%HDPE

(e) 2%TiO_2+2%SiO_2+96%HDPE

Fig-4.7(a-e) Brinell Hardness test specimens as per ASTM D2240O standards

The application of hardness testing enables you to evaluate a material’s properties, such as strength, ductility, and wear resistance, and so helps you determine whether a material or material treatment is suitable for the purpose you require. The definition of hardness testing is ‘a test to determine the resistance a material exhibits to permanent deformation by penetration of another harder material.’ However, hardness is not a fundamental property of a material. Therefore, when drawing conclusions of a hardness test, you should always evaluate the 40quantitative value in relation to: The given load on the indenter a specific loading time profile and a specific load duration A specific indenter geometry.

$$\text{BHN} = \frac{F}{\frac{\pi}{2} D \cdot (D - \sqrt{D^2 - D_i^2})}$$

The above is the formula to calculate the Brinell hardness number value, where

F = force in Kgf

D = Diameter of the indenter

d = diameter of the indentation

CHAPTER-5

ANN MODELLING

5.1 Introduction to ANN

It is based on the principle of how the human brain processes information and performs operations. An ANN is a mathematical modelling of a network of biological neurons and their interconnections. Neuron is the basic structural and functional unit of the human brain, there are about a billion neurons in the human brain and each neuron is interconnected to 100’s of neurons.

An Artificial Neural network is a mathematical model wherein there are some inputs given and they are passed through some functions which manipulate their values and produced the output, the coefficients of the functions are known as weights, ANN’s can be used for various purposes such as image processing, natural language processing, image recognition, data analysis, etc.

ANNs consist of an input layer in which independent coefficients are to be provided, they also contain an output layer which generates the value required, and there exists hidden layers which process the input values and does either linear or nonlinear manipulations to generate the output values, the number of layers may be single or multiple hidden layers for processing.

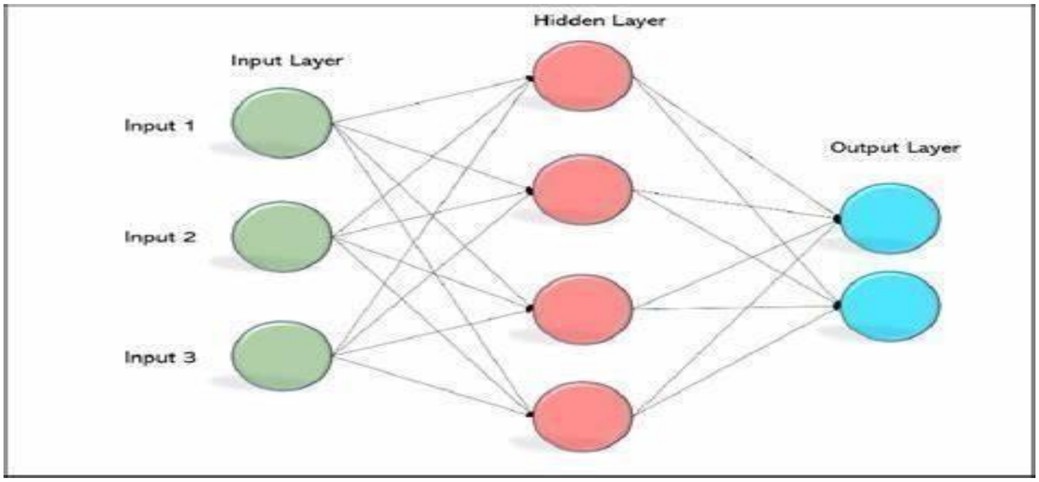


Fig-5.1 ANN Model Representation

5.2 Types of ANN

There exist different types of ANN which can be specially used for specific applications.

They are classified as

5.2.1 Supervised ANN

In this type of ANN there exists input data as well as output data, and the user provides both the data to the program, and it tries to find a relationship between them and assigns weights to the hidden layers. These are used to form empirical relationships between the data.

5.2.2 Unsupervised ANN

In this type of ANN, the program is only fed with input data and no output data, these are used in classification problems like classification of images or new classification etc.

5.2.3 Reinforced Learning

In this type of ANN, the ANN generates a response and whether is it towards the goal or away from the goal in terms of accurately predicting the correct sequence it is rewarded or punished, if the output is in the right direction, then it is rewarded, which tells the ANN to proceed, if it deviates from the expected path then it is punished by subtracting some value from it and it adjusts the weight accordingly. This type of ANN is used generally in teaching a self-driving car to drive, or help robots to walk on the right path.

Apart from this there are many types of ANN such as

5.2.3.1 Recurrent neural networks:

These are the ANN used in speech recognition functions because of its ability to store past data within.

5.2.3.2 Convolution neural networks:

These are the ANN which scan data and superimpose them upon themselves in the form of a grid like shape, these areused in image processing. Feed forward neural networks: this is the simplest ANN where all input nodes are connected to all the output nodes.

5.2.3.3 Generative Adversarial networks:

These are a type under unsupervised learning where the network learns the hidden patterns under the data and is able to generate incomplete data, it has huge implications in image processing.

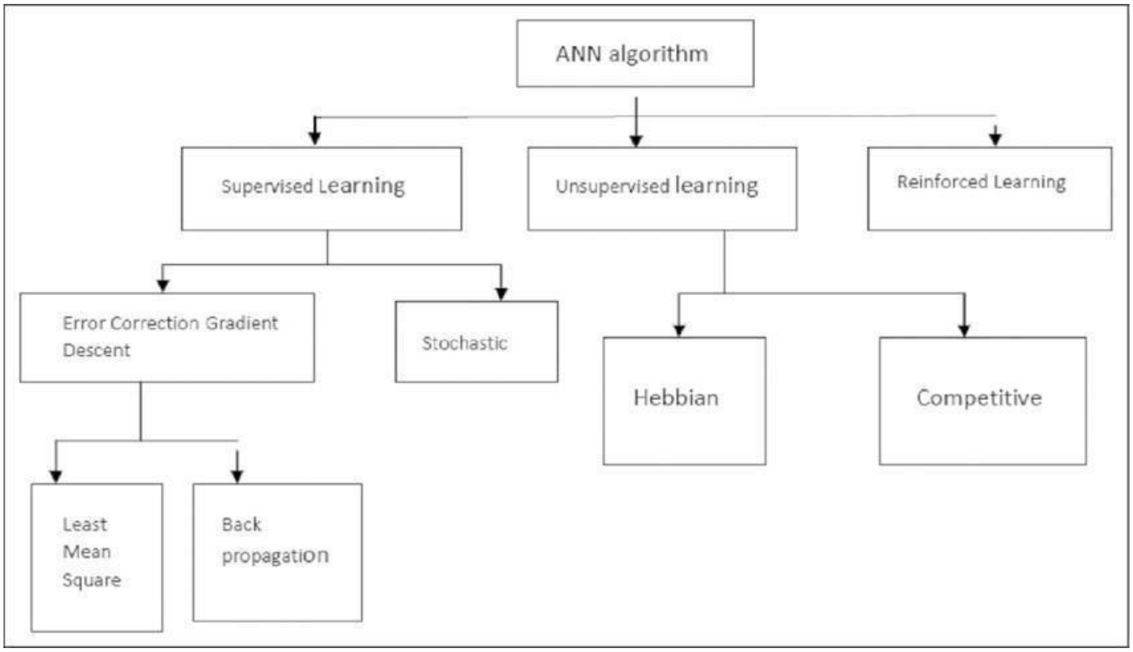


Fig-5.2 Classification of ANN algorithms

CHAPTER-6

RESULTS AND DISCUSSION

In this study we have prepared specimens of 5 compositions whose compositional values are given in table, and each specimen has 3 sample pieces prepared by the process of microinjection molding at CIPET laboratory, Bhubaneshwar. Each composition’s 3 samples are subjected to three tests which are:

- Tensile test
- Brinell Hardness test
- Impact strength test

The test is performed thrice on each composition and the average value is calculated and is obtained for further analysis. After obtaining the values of these three mechanical properties of various compositions the results are plotted in bar graphs and line graph to find a correlation between composition percentage and optimal highest mechanical property obtained by visual means, and along with it the values are divided into 3 sets each , with each set being divided into two parts, first part containing 80 percent data to train the ANN algorithm, and the remaining 20 percent data is used predict the mechanical property and its values by ANN is summarized in the form of Bar graphs , showing actual values vs Predicted values, and the root mean square error plotted on a graph.

6.1 Tensile Strength:

Tensile yield strength values for various compositions of HDPE composite.

Table 6.1: Tensile strength variation for various compositions

Material Type	**Tensile strength** MPa
Pure HDPE	23.9
0.5%TiO_2+ 0.5% SiO_2 + 99 % HDPE	27.5
1%TiO_2+ 1% SiO_2 + 98 % HDPE	29.9
1.5%TiO_2+ 1.5% SiO_2 + 97 % HDPE	35.8
2%TiO_2+ 2% SiO_2 + 96 % HDPE	34.2

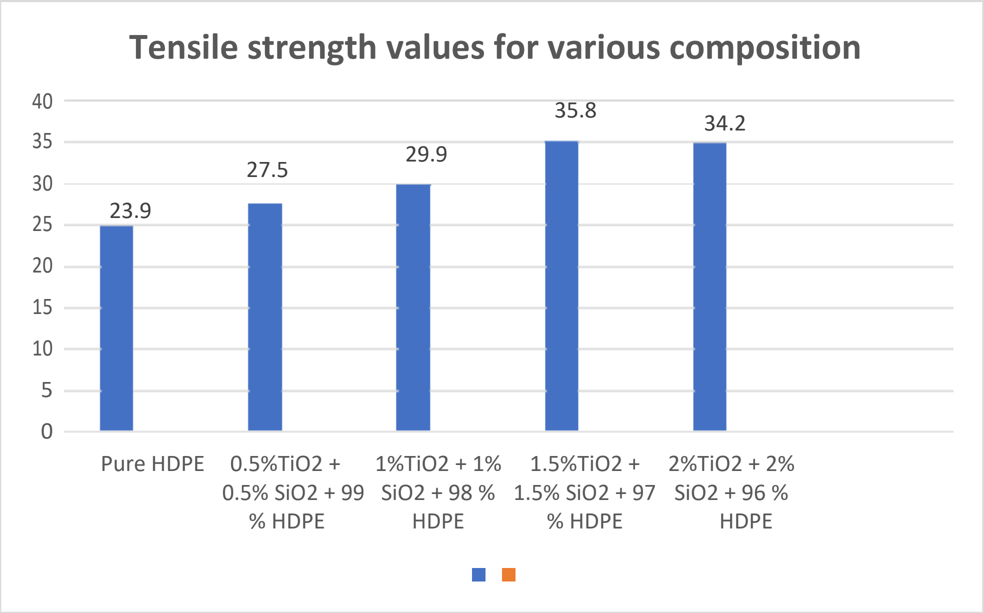


Fig-6.1 Tensile strength variation for various compositions

6.2 Hardness:

Table 6.2: Hardness variation for various compositions

Composition	Hardness Kgf/mm^2
Pure HDPE	13.95
0.5%TiO_2+ 0.5% SiO_2 + 99 % HDPE	15.4
1%TiO_2+ 1% SiO_2 + 98 % HDPE	17.3
1.5%TiO_2+ 1.5% SiO_2 + 97 % HDPE	19.6
2%TiO_2+ 2% SiO_2 + 96 % HDPE	18.1

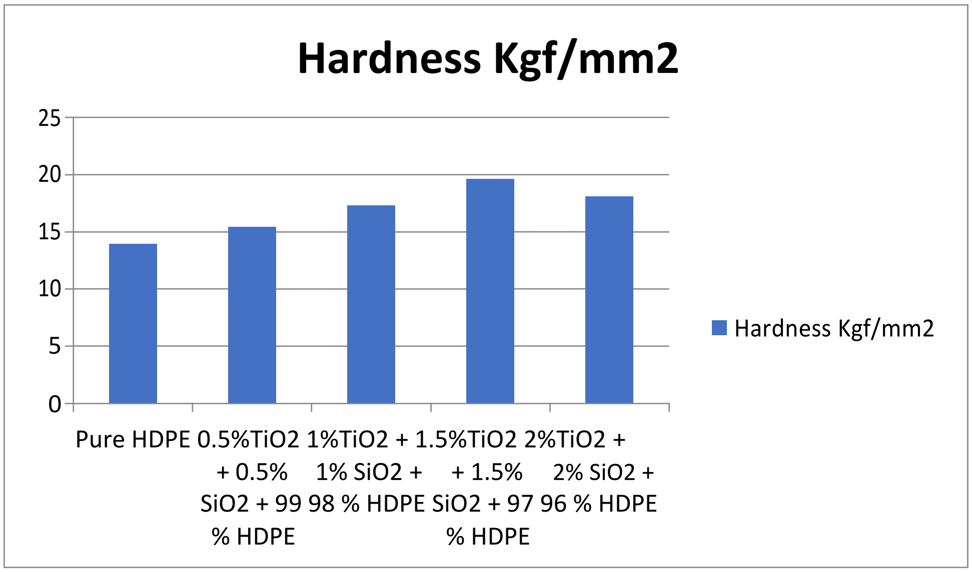


Fig-6.2 Hardness variation for various compositions

6.3 Impact Strength:

Table-6.3 Impact strength values for various compositions of HDPE composite

Composition	**Impact strength KJ/m^2**
Pure HDPE	8.33
0.5%TiO_2 + 0.5% SiO_2 + 99 % HDPE	8.33
1%TiO_2 + 1% SiO_2 + 98 % HDPE	8.6
1.5%TiO_2 + 1.5% SiO_2 + 97 % HDPE	8.6
2%TiO_2 + 2% SiO_2 + 96 % HDPE	8.55

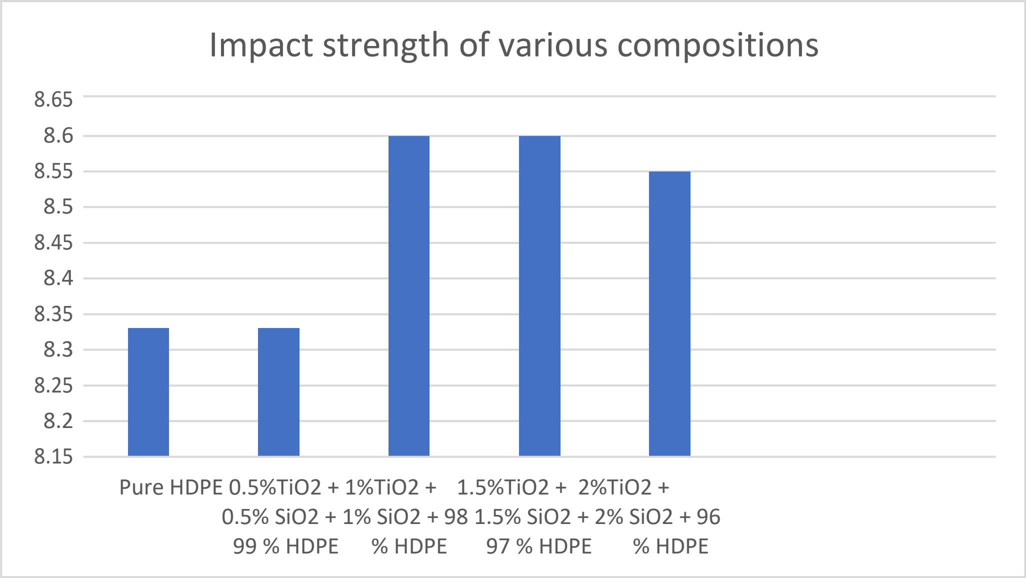


Fig-6.3 Impact strength variation for various compositions

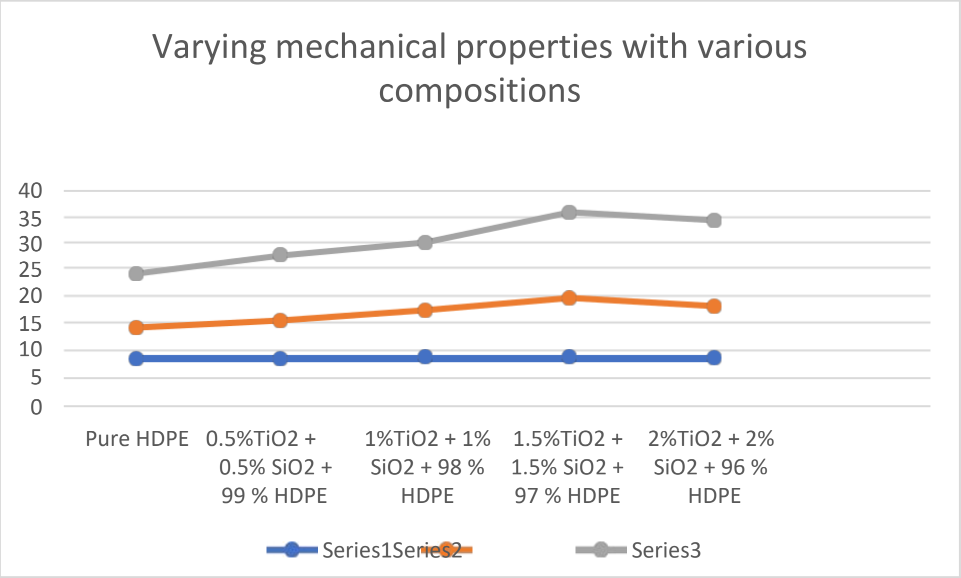


Fig-6.4 Variation of mechanical properties with varying compositions.

Where, Series1 is the Impact strength

Seties2 is the Brinell hardness number

Series3 is the Tensile strength of specimens.

From the above graphics we can know that the optimum strength of the material is given by the fourth composition which consists of 1.5%TiO_2 + 1.5% SiO_2 + 97 % HDPE.

Prediction of properties using ANN

We have used the above data obtained from various tests such as tensile test, impact test, hardness test.

The mechanical property dataset was divided into two groups, Ann for training the algorithm and the other for testing the algorithm, the code implementation and the values predicted are as follows

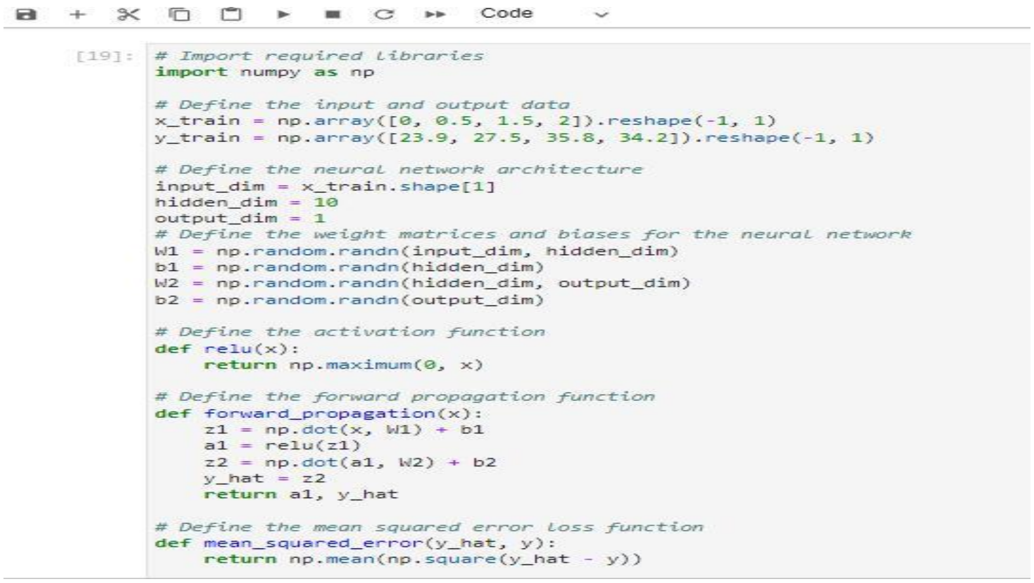
We are using a linear regression model to train and test out data, we are supplying the training data of the composition numbers 1,2,4,5 and predicting the value of 3^{rd} composition for each test to maintain uniformity and clarity in analysing results

The steps or algorithm used to implement the code are as follows:

- First, we import the required libraries, NumPy in this case, which is used for numerical computations.
- We define the input and output data, x_train and y_train, respectively. Here, x_train is a 4x1 NumPy array, and y_train is also a 4x1 NumPy array.
- we have one input neuron, one output neuron, and one hidden layer with 10 neurons. We initialize the weight matrices and biases for the neural network using random values
- The weights and biases will be updated during the training process. We define the activation function relu, which is used for the hidden layer in our neural network. We define the forward propagation function forward propagation, which takes the input data x as input and computes the output of the neural network.
- The function first calculates the weighted sum of the input data x and the weights W1, adds the biases b1, and then applies the activation function relu to obtain the output of the hidden layer a1. The output of the hidden layer is then multiplied by the weights W2, added to the biases b2, and returned as the final output y_hat.
- We define the mean squared error loss function mean squared error, which is used to compute the difference between the predicted output y_hat and the actual output y. We define the backpropagation function backpropagation.
- The function computes the gradients of the weights and biases using the chain rule and returns them. We define the training loop, which updates the weight matrices.
- The main idea behind the code is to train a neural network to learn the underlying relationship between the input data x_train and the output data y_train. During training, the neural network adjusts the weights and biases to minimize the mean squared error loss.

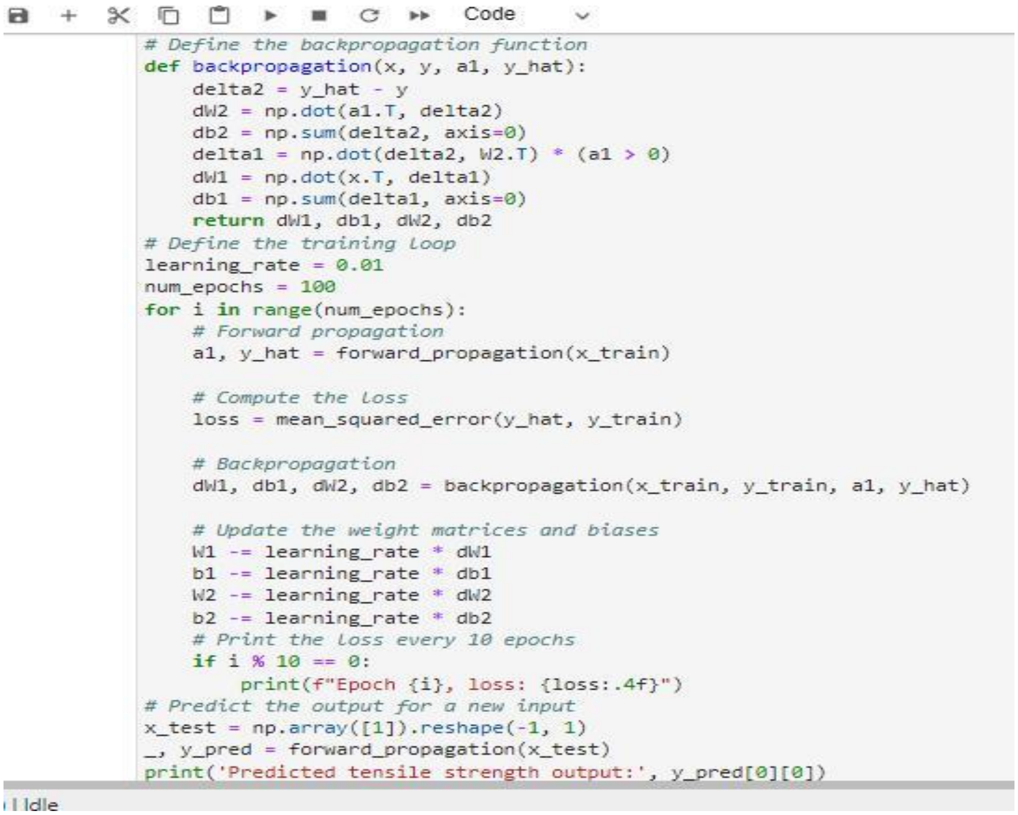
6.4 Tensile Strength prediction using ANN

Linear regression ANN code for predicting Tensile strength of HDPE composite.



```
# Import required libraries
import numpy as np

# Define the input and output data
x_train = np.array([0, 0.5, 1.5, 2]).reshape(-1, 1)
y_train = np.array([23.9, 27.5, 35.8, 34.2]).reshape(-1, 1)

# Define the neural network architecture
input_dim = x_train.shape[1]
hidden_dim = 10
output_dim = 1
# Define the weight matrices and biases for the neural network
W1 = np.random.randn(input_dim, hidden_dim)
b1 = np.random.randn(hidden_dim)
W2 = np.random.randn(hidden_dim, output_dim)
b2 = np.random.randn(output_dim)

# Define the activation function
def relu(x):
    return np.maximum(0, x)

# Define the forward propagation function
def forward_propagation(x):
    z1 = np.dot(x, W1) + b1
    a1 = relu(z1)
    z2 = np.dot(a1, W2) + b2
    y_hat = z2
    return a1, y_hat

# Define the mean squared error loss function
def mean_squared_error(y_hat, y):
    return np.mean(np.square(y_hat - y))
```

Fig-6.5(a)



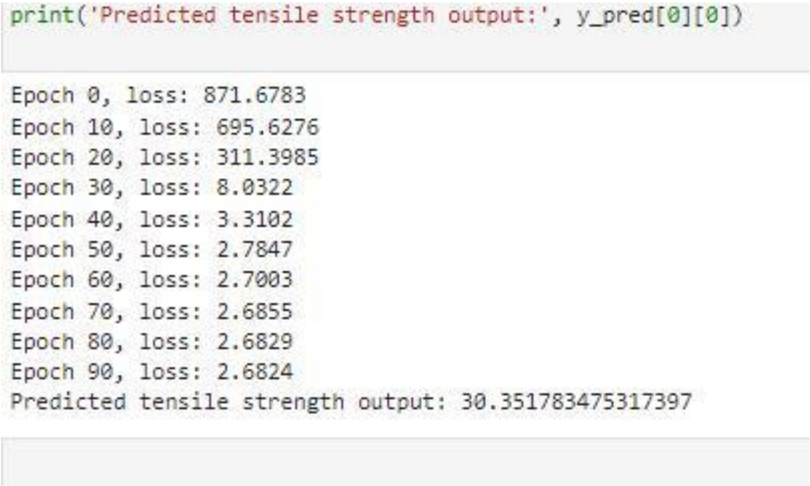
```
# Define the backpropagation function
def backpropagation(x, y, a1, y_hat):
    delta2 = y_hat - y
    dW2 = np.dot(a1.T, delta2)
    db2 = np.sum(delta2, axis=0)
    delta1 = np.dot(delta2, W2.T) * (a1 > 0)
    dW1 = np.dot(x.T, delta1)
    db1 = np.sum(delta1, axis=0)
    return dW1, db1, dW2, db2
# Define the training loop
learning_rate = 0.01
num_epochs = 100
for i in range(num_epochs):
    # Forward propagation
    a1, y_hat = forward_propagation(x_train)

    # Compute the loss
    loss = mean_squared_error(y_hat, y_train)

    # Backpropagation
    dW1, db1, dW2, db2 = backpropagation(x_train, y_train, a1, y_hat)

    # Update the weight matrices and biases
    W1 -= learning_rate * dW1
    b1 -= learning_rate * db1
    W2 -= learning_rate * dW2
    b2 -= learning_rate * db2
    # Print the loss every 10 epochs
    if i % 10 == 0:
        print(f"Epoch {i}, loss: {loss:.4f}")
# Predict the output for a new input
x_test = np.array([1]).reshape(-1, 1)
_, y_pred = forward_propagation(x_test)
print('Predicted tensile strength output:', y_pred[0][0])
```

Fig-6.5(b)

The Above ANN trains on all data except the data corresponding to the third composition, and the predicted value is given below

The actual value calculated experimentally was according to table 5.1 is 29.9MPa, whereas the value predicted by ANN is 30.35 MPa

The accuracy with which our ANN predicted the value is nearly 98.4 %.



```
print('Predicted tensile strength output:', y_pred[0][0])
```

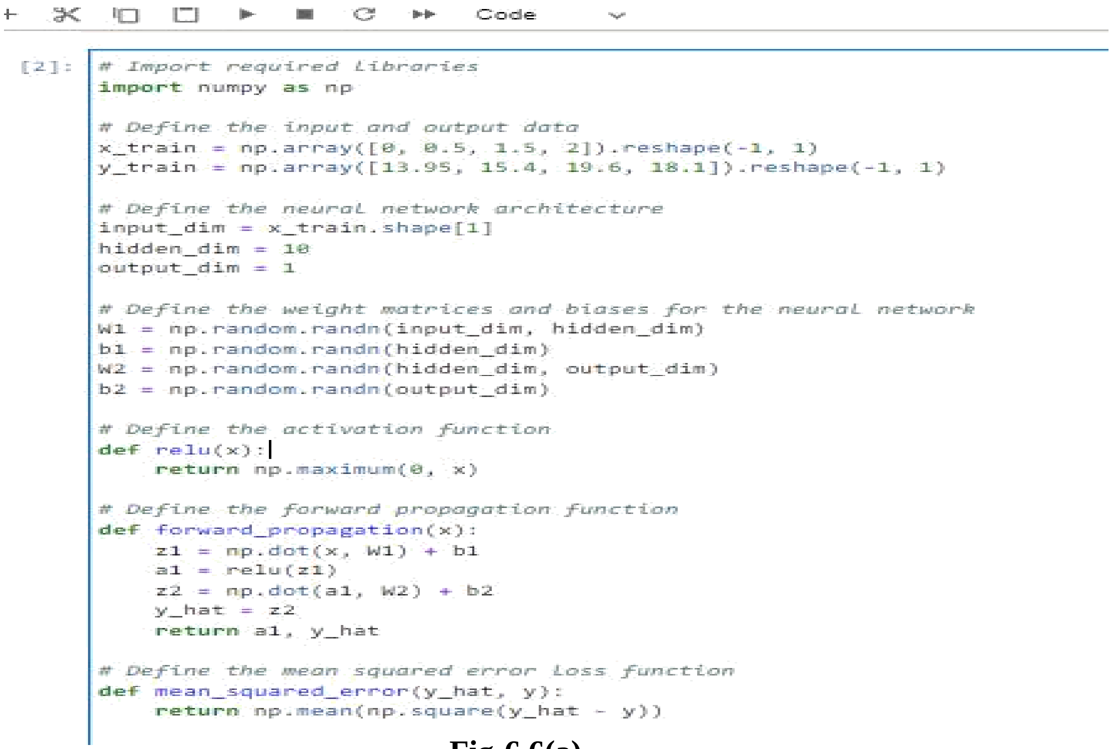
```
Epoch 0, loss: 871.6783
Epoch 10, loss: 695.6276
Epoch 20, loss: 311.3985
Epoch 30, loss: 8.0322
Epoch 40, loss: 3.3102
Epoch 50, loss: 2.7847
Epoch 60, loss: 2.7003
Epoch 70, loss: 2.6855
Epoch 80, loss: 2.6829
Epoch 90, loss: 2.6824
Predicted tensile strength output: 30.351783475317397
```

Fig-6.5(c)

Fig-6.5(a-c) ANN Technique for Tensile Strength

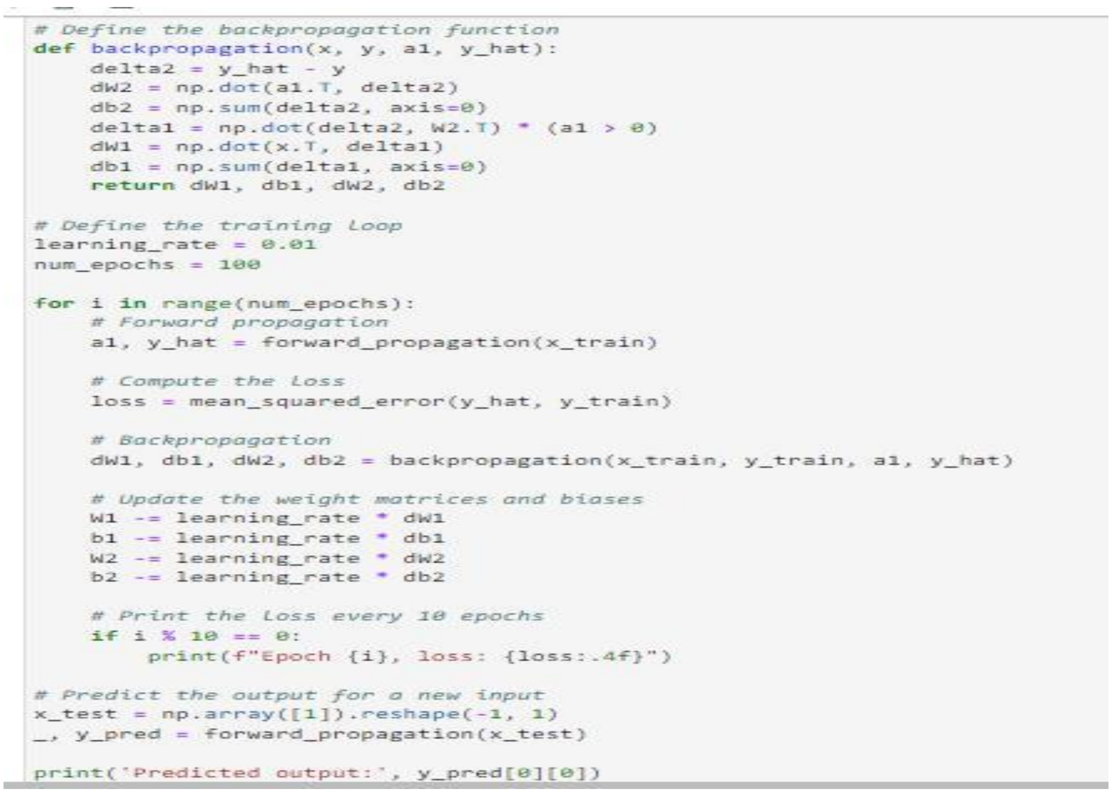
6.5 Hardness Value Prediction by ANN

Linear regression ANN code for predicting Hardness values of HDPE composite.



```python
# Import required libraries
import numpy as np

# Define the input and output data
x_train = np.array([0, 0.5, 1.5, 2]).reshape(-1, 1)
y_train = np.array([13.95, 15.4, 19.6, 18.1]).reshape(-1, 1)

# Define the neural network architecture
input_dim = x_train.shape[1]
hidden_dim = 10
output_dim = 1

# Define the weight matrices and biases for the neural network
W1 = np.random.randn(input_dim, hidden_dim)
b1 = np.random.randn(hidden_dim)
W2 = np.random.randn(hidden_dim, output_dim)
b2 = np.random.randn(output_dim)

# Define the activation function
def relu(x):
    return np.maximum(0, x)

# Define the forward propagation function
def forward_propagation(x):
    z1 = np.dot(x, W1) + b1
    a1 = relu(z1)
    z2 = np.dot(a1, W2) + b2
    y_hat = z2
    return a1, y_hat

# Define the mean squared error loss function
def mean_squared_error(y_hat, y):
    return np.mean(np.square(y_hat - y))
```

Fig-6.6(a)

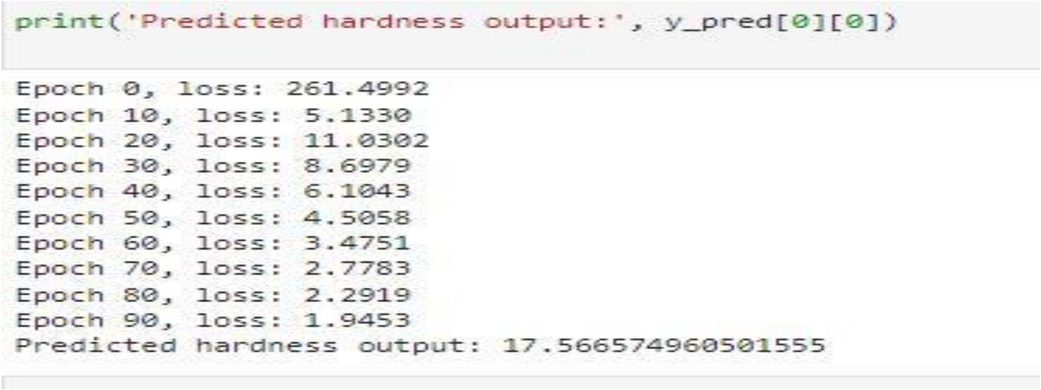


```python
# Define the backpropagation function
def backpropagation(x, y, a1, y_hat):
    delta2 = y_hat - y
    dW2 = np.dot(a1.T, delta2)
    db2 = np.sum(delta2, axis=0)
    delta1 = np.dot(delta2, W2.T) * (a1 > 0)
    dW1 = np.dot(x.T, delta1)
    db1 = np.sum(delta1, axis=0)
    return dW1, db1, dW2, db2

# Define the training loop
learning_rate = 0.01
num_epochs = 100

for i in range(num_epochs):
    # Forward propagation
    a1, y_hat = forward_propagation(x_train)

    # Compute the loss
    loss = mean_squared_error(y_hat, y_train)

    # Backpropagation
    dW1, db1, dW2, db2 = backpropagation(x_train, y_train, a1, y_hat)

    # Update the weight matrices and biases
    W1 -= learning_rate * dW1
    b1 -= learning_rate * db1
    W2 -= learning_rate * dW2
    b2 -= learning_rate * db2

    # Print the loss every 10 epochs
    if i % 10 == 0:
        print(f"Epoch {i}, loss: {loss:.4f}")

# Predict the output for a new input
x_test = np.array([1]).reshape(-1, 1)
_, y_pred = forward_propagation(x_test)

print('Predicted output:', y_pred[0][0])
```

Fig-6.6(b)

The actual value calculated experimentally was according to Table 5.2 is **17.3 Kgf/mm^2** and the value predicted by ANN is **17.56 Kgf/mm^2**

The accuracy with which our ANN predicted the value is nearly 98.6 %.



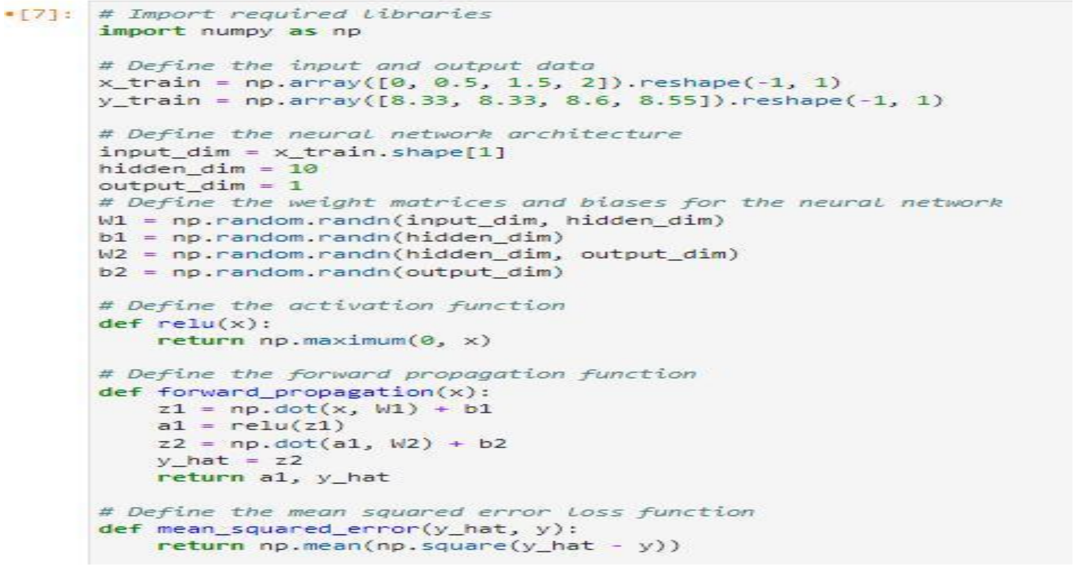
```
print('Predicted hardness output:', y_pred[0][0])

Epoch 0, loss: 261.4992
Epoch 10, loss: 5.1330
Epoch 20, loss: 11.0302
Epoch 30, loss: 8.6979
Epoch 40, loss: 6.1043
Epoch 50, loss: 4.5058
Epoch 60, loss: 3.4751
Epoch 70, loss: 2.7783
Epoch 80, loss: 2.2919
Epoch 90, loss: 1.9453
Predicted hardness output: 17.566574960501555
```

Fig-6.6(c)

Fig-6.6(a-c) ANN Technique for Hardness

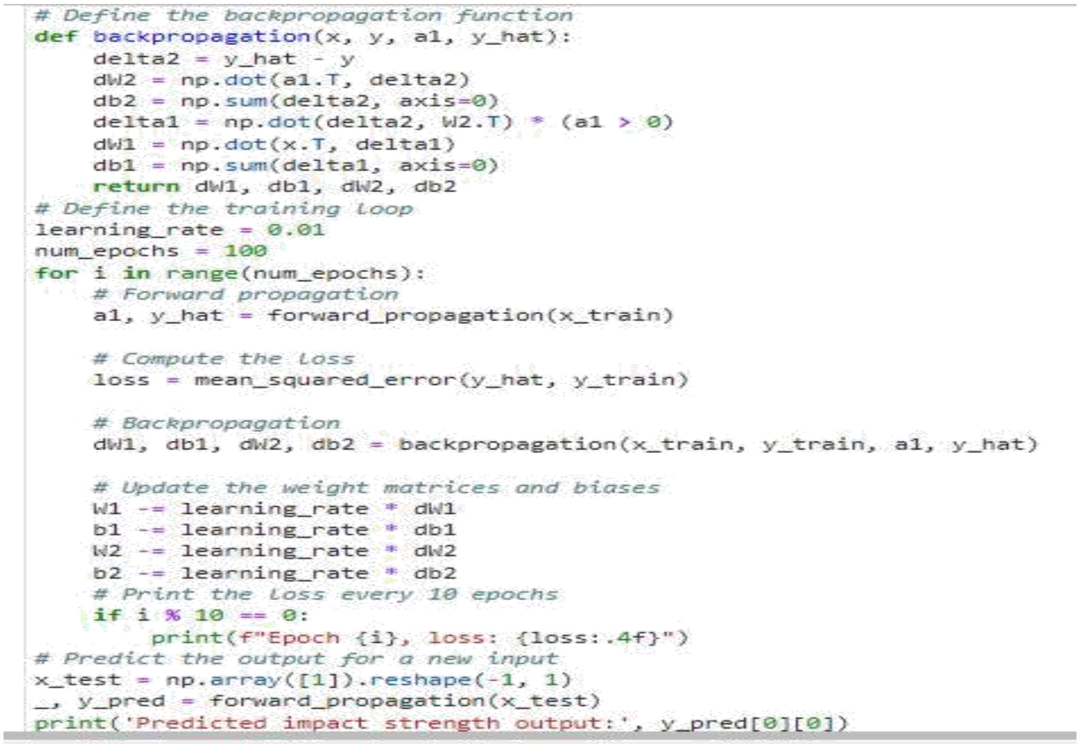
6.6 Impact Strength Value Prediction by ANN

Linear regression ANN code for predicting impact strength values of HDPE composite.



```
•[7]: # Import required libraries
      import numpy as np

      # Define the input and output data
      x_train = np.array([0, 0.5, 1.5, 2]).reshape(-1, 1)
      y_train = np.array([8.33, 8.33, 8.6, 8.55]).reshape(-1, 1)

      # Define the neural network architecture
      input_dim = x_train.shape[1]
      hidden_dim = 10
      output_dim = 1
      # Define the weight matrices and biases for the neural network
      W1 = np.random.randn(input_dim, hidden_dim)
      b1 = np.random.randn(hidden_dim)
      W2 = np.random.randn(hidden_dim, output_dim)
      b2 = np.random.randn(output_dim)

      # Define the activation function
      def relu(x):
          return np.maximum(0, x)

      # Define the forward propagation function
      def forward_propagation(x):
          z1 = np.dot(x, W1) + b1
          a1 = relu(z1)
          z2 = np.dot(a1, W2) + b2
          y_hat = z2
          return a1, y_hat

      # Define the mean squared error loss function
      def mean_squared_error(y_hat, y):
          return np.mean(np.square(y_hat - y))
```

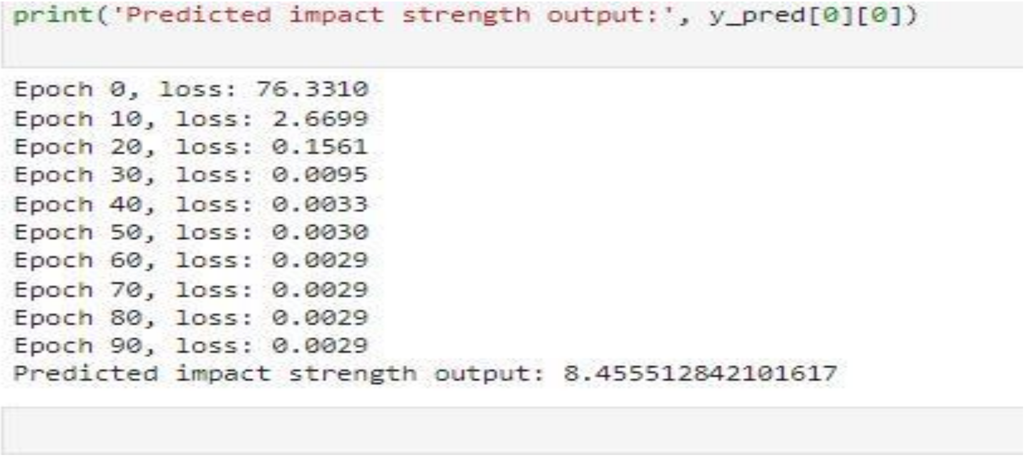
Fig-6.7(a)



```
# Define the backpropagation function
def backpropagation(x, y, a1, y_hat):
    delta2 = y_hat - y
    dW2 = np.dot(a1.T, delta2)
    db2 = np.sum(delta2, axis=0)
    delta1 = np.dot(delta2, W2.T) * (a1 > 0)
    dW1 = np.dot(x.T, delta1)
    db1 = np.sum(delta1, axis=0)
    return dW1, db1, dW2, db2
# Define the training loop
learning_rate = 0.01
num_epochs = 100
for i in range(num_epochs):
    # Forward propagation
    a1, y_hat = forward_propagation(x_train)

    # Compute the loss
    loss = mean_squared_error(y_hat, y_train)

    # Backpropagation
    dW1, db1, dW2, db2 = backpropagation(x_train, y_train, a1, y_hat)

    # Update the weight matrices and biases
    W1 -= learning_rate * dW1
    b1 -= learning_rate * db1
    W2 -= learning_rate * dW2
    b2 -= learning_rate * db2
    # Print the loss every 10 epochs
    if i % 10 == 0:
        print(f"Epoch {i}, loss: {loss:.4f}")
# Predict the output for a new input
x_test = np.array([1]).reshape(-1, 1)
_, y_pred = forward_propagation(x_test)
print('Predicted impact strength output:', y_pred[0][0])
```

Fig-6.7(b)

The actual value calculated experimentally was according to **table 5.3** is **8.3 J/mm^2** and the value predicted by ANN is **8.45 J/mm^2**
The accuracy with which our ANN predicted the value is nearly 98.2 %.



```
print('Predicted impact strength output:', y_pred[0][0])
```

```
Epoch 0, loss: 76.3310
Epoch 10, loss: 2.6699
Epoch 20, loss: 0.1561
Epoch 30, loss: 0.0095
Epoch 40, loss: 0.0033
Epoch 50, loss: 0.0030
Epoch 60, loss: 0.0029
Epoch 70, loss: 0.0029
Epoch 80, loss: 0.0029
Epoch 90, loss: 0.0029
Predicted impact strength output: 8.455512842101617
```

Fig-6.7(c)

Fig-6.7(a-c) ANN Technique for Impact Strength

CONCLUSION

Based on the results obtained and discussions made in the earlier chapters the following conclusions are drawn.

- The addition of filler materials in the form of nanoparticles certainly did improve the mechanical properties of HDPE (High density polyethylene) polymer
- The relationship between the composition parameters and mechanical properties were found to non - linear based on the graphs shown.
- We have shown that Levenberg Marquardt algorithm better predicts the mechanical properties of our composite material than by using linear regression models.
- This project highlights the fact that huge amount of data is necessary for building a highly accurate version of ANN model to predict the mechanical properties ofany composite material, so there needs to be furthermore development and innovation in making composites in mass production cheaply so that experimental evidence is available for all the unavailable databases.
- We observe that the ANN is able to predict the values of the materials properties with greater than 98 % accuracy, the mean square after every 10 epochs is displayed in the output which converges to negligent value after 10 such cycle.

FUTURE SCOPE

There is a lot of future potential applications to the concept used to complete this project work, for predicting mechanical properties of multi component composite materials.

- ANN models could be deployed on cloud platforms with access to all the huge experimental databases available on material and composite materials mechanical properties along with their composition to find out the interrelationships between the mechanical composition and the mechanical properties, and be used to give the best material to be used for any particular application.
- These ANN models could be used to get the empirical relationships that exists between the mechanical properties of the composites and the individual components properties, and then be used by scientists to find out how materials interact with each other and how they influence the final composite.
- The specific application for the composite developed in this report can be usedin high altitude manned flights as window panes which can be able to block theUV rays of sun and save weight due to its lightweight matrix of HDPE.
- The algorithm used here can be more fine-tuned and modified to be used in other multi component composite mechanical properties prediction.

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