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Methodologies with Relative Merits in Polymer Synthesis

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Abstract: **This review study on polymer chemistry, a crucial chemical sub-discipline, is dedicated to the chemical synthesis of polymers, also known as macromolecules. It delves into their structure, physicochemical properties, and applications, particularly in the commercial sector. The study covers thermoplastics, thermosets, elastomers, and the various methodologies used to tailor their physical and chemical properties. Thermoplastic polymers, for instance, can be softened and solidified through cooling processes akin to metal melting and cooling. On the other hand, thermosets are typically three-dimensional networked polymers with a high degree of crystallinity, making them stable for vast temperature ranges. This stability makes them viable for use in diverse fields. Elastomers, another focus of this study, are rubbery polymers that can be easily extended to their elastic length many times without deforming their original dimension. The study also reviews the different techniques applied to these polymers in the polymer industry, along with the challenges and benefits faced in the current technology scenario.**

Keywords: **Thermoplasts, Thermosets, Elastomers, TANG technology, Sustainable technology.**

1. INTRODUCTION

Polymers are macromolecules that are created by the union of several smaller molecules. Until they become polymers, these smaller units are called monomers. Since the early times on Planet Earth, natural polymers have been present. [1]. Two main types of polymerization methods are used to transform small molecules into polymers. Originally, these processes were referred to as polymerization of Addition and Condensation. Additional polymerization is now called chain, chain-growth or chain reaction polymerization, depending on the author. Condensation polymerization is now referred to as polymerization by step-growth or step-reaction. The key differences between these two approaches lie in the kinetics of polymerization. In chain reaction polymerization, two or more distinct monomers are frequently used to yield a polymer containing the appropriate repeat units. This is termed as copolymerization, and the resulting product is called a copolymer. By adjusting the technique of copolymerization and the quantities of each monomer, a sequence of copolymers with considerably different properties can be prepared using as few as two monomers [2].If the amount of monomers used increases, the number of different materials that can be processed increases drastically.

To identify polymeric materials and methodologies applied for preparation for various categories of thermoplastics, thermosets, and elastomers, detailed insight into the physicochemical product properties, preparation, and commercially tailored methodology incorporation has been discussed.

1.1 THERMOPLASTICS

Linear molecular chains make up thermoplastics; this polymer softens when heated and hardens when cooled. Thermoplastic polymers represent a wide number of plastic materials. Three forms of thermoplastic polymers exist:-1. Crystalline thermoplastics are typically translucent with molecular chains that are organized regularly. These polymers have

more mechanical impact resistance compared to other forms. Polypropylene (PP), low-density polyethylene (LDPE), and high-density polyethylene (HDPE) are examples of polymers of this sort. 2. Amorphous thermoplastics, usually translucent with loosely arranged molecules [3], Polyvinyl chloride (PVC), polymethylmethacrylate (PMMA), polycarbonate (PC), polystyrene (PS), and acrylonitrile-butadiene-styrene (ABS), polyethylene terephthalate (PETP), polyvinyl acetate (PVAc) are examples of this form of polymer. Semi-crystalline polymers have the combined properties of amorphous polymers and crystalline polymers. The polyester polybutylene terephthalate (PBT) and polyamide Imide (PAI) are the representative polymers of this category. These polymers have specific characteristics that make them ideal for many applications [4].

The main types of thermoplastic materials, along with their properties and applications (see Table 1), are listed below.

Table 1

Type	Property	Application
Acrylonitrile butadiene renews (ABS)	The most well-known substance among customers is ABS. Plastic products made by ABS plastic molding are strong and durable even at low temperatures. Dimensional stability, abrasion resistance, chemical resistance, heat resistance, and balanced tensile strength are all features of these materials.	LEGO bricks (LEGO is a famous line of construction toys consisting of interlocking plastic building blocks) Safety hats, Whitewater canoes, Musical instruments, Medical disposables
Acetal Copolymer oxymethylene	Because of its lower melting temperature, this thermoplastic is easier and faster to produce than typical homopolymer resins. These thermoplastics are also creep-resistant, have strong moisture resistance, and may be utilized for long periods in temperature applications. Excellent lubricity, high tensile strength, and fatigue resistance are further features.	Lucite Perspex Plexiglass
Acetal Copolymer Poly-oxy-methylene	Because of its lower melting temperature, this thermoplastic is easier and faster to produce than typical homopolymer resins. These thermoplastics are creep-resistant, have strong moisture resistance, and may be utilized for long periods in high-temperature applications. Excellent lubricity, high tensile strength, and fatigue resistance are further features.	Lucite Perspex Plexiglass
Acetal Homopolymer polyoxymethylene	These thermoplastics have excellent weatherability, scratch resistance, and the ability to transmit and regulate light. Polyoxymethylenes are also resistant to discoloration, have minimal haze, and are scratch-resistant, making them suitable for optical applications.	Yarn Rope Conveyor belts Clothing Furniture Blankets Mousepads
Polycarbonates	These polymers have outstanding durability throughout a wide temperature range. Polycarbonates are distinguished by their dimensional stability, heat resistance, hardness, and transparency. This category of thermoplastics contains a wide range of grades, from general-purpose and extrusion molding to particular grades with flame-retardant qualities or contamination resistance for food processing and medical applications.	Injection molding Kitchenware

Polyethylenes	The key properties of this type of plastic are low water absorption, dimensional stability, hardness, and stiffness. Amorphous (transparent) and semi-crystalline (opaque) varieties are available. These polymers are useful for various manufacturing applications due to their gas barrier and chemical resistance.	Packaging film Trash and grocery bags Agricultural mulch Wire and cable insulation Squeeze bottle Toys Housewares
Polypropylenes	These polymers have a reduced density and are suitable for thermal, chemical, and electrical applications. Their weak heat resistance requires heat stabilization to work properly at high temperatures. Polypropylenes are less durable than high-density polyethylene and less brittle than low-density polyethylene, but PP injection molding are extremely fatigue resistant, making them an excellent choice for plastic hinges.	Lab equipment Carpets Textiles Packing Labeling
Polystyrenes	These low-cost amorphous thermoplastics have a lesser heat resistance than other varieties and must be kept at temperatures below 200o F to retain their integrity. They do, however, have acceptable colorability, processing ease, hardness, and clarity, as well as good electrical qualities at ambient temperature and at typical humidity conditions.	Foam cups Smoke alarm housings Models Disposable cutlery CD/DVD cases
Nylons	This categorization of thermoplastics includes a wide range of grades, each with its unique set of valuable features. Nylon has strong fuel, oil, and chemical resistance, as well as great fatigue resistance, hardness, and a low friction coefficient in general.	Carpet Rope Strings for musical instruments Fishing line Fabric

The injection modeling method is the key polymer processing technique that enables various types of components to be produced, such as a computer mouse. Because thermoplastic polymers are cheap, lightweight, and robust, these plastic materials can be designed into various products for various uses. Due to its recyclability, environment-friendly manufacturing, and lack of by-products, this is considered to replace cross-linked polyethylene (XLPE) as power cable isolation in the foreseeable future; thermoplastic power cable insulation attracts many ventures. However, XLPE has been commonly used as powder cable insulation, rather than uncross-linked low-density polyethylene (LDPE), primarily because cross-links can greatly boost the thermo-mechanical property of insulation but retain the excellent electrical properties and flexibility of LDPE [5]. Thermo-mechanical property enhancement helps XLPE insulated cables to work continuously at a high temperature of 90° C. The XLPE insulation can also accommodate metal conductor temperatures above 200 ° C in the case of short-time short-circuits. Therefore, having a sufficient thermo-mechanical property is highly significant for thermoplastic-insulated commodities [6].

In addition, isotactic polypropylene (iPP) having a high melting temperature of about 170° C, also has outstanding electrical features such as good dielectric constant, effective electrical insulation, absorbs less than 0.1% of moisture as it is non-hygroscopic,, making it a potential choice for recyclable insulation system. Nevertheless, iPP suffers from high rigidity and brittleness. Furthermore, due to the large size of spherulite [7], the breakdown strength of iPP is relatively poor. Combining iPPs with other polyolefin products, including polyolefin elastomers (POE) and syndiotactic polypropylene (sPP), will boost flexibility and electrical properties while preserving the excellent thermo-mechanical properties of iPPs. Therefore, considerable interest has been in exploring the possible applications of iPP / polyolefin blends as power cable insulation. IPP, however, is not compatible with most polyolefin, which creates an interface in the blends. The electrical characteristics of the interfacial area vary from the bulk, which can cause property degradation. On the other hand, under normal operating conditions, morphological changes in thermoplastic blend insulation may occur, especially at high temperatures, leading to reduced cable life. In comparison, copolymers based on PP may have enhanced mechanical stability and electrical properties simultaneously [8].In addition, the excellent thermo-mechanical properties of iPP can also be maintained, although an

additional immiscible interface has not been added. Such characteristics make copolymers based on PP more suitable for future thermoplastic power cable insulation. Throughout the last 60 years, due to the ideal properties of thermoplastic polymers, such as corrosion resistance, low density, or user-friendly nature, plastic usage has risen dramatically, becoming more used than aluminium or other metals. Recycling is also one of the most effective steps currently available to minimize these effects, and it is among the most dynamic fields in plastic materials today**.**

1.2 THERMOSETS

In materials science, a thermosetting polymer, often called a thermoset, is a polymer that is obtained by irreversible hardening ("curing"), a soft solid or viscous liquid prepolymer (resin). Once heated, thermosetting polymers cannot be remelted. The starting material for making thermosets is usually malleable or liquid before curing and is often designed to be molded into the final shape. It may also be used as an adhesive. Once hardened, a thermoset cannot be melted for reshaping, in contrast to thermoplastic polymers, commonly produced and distributed in the form of pellets and shaped into the final product form by melting, pressing, or injection molding. Thermosetting polymers are interconnected like a web, resulting in increased rigidity. Thermosetting polymers are more rigid and heat resistant, making them ideal for electrical components and panhandles. They're frequently generated from a liquid mixture that hardens and can't be reformed.

Thermosets are commonly used in many industries, including aerospace, automotive, and electronics. Epoxy resins are among the most used thermosets and have found applications in bulk structural composites, thin specialty protective coatings, encapsulation, and electrical-electronic separation. Their cross-linked design, rigidity, and stability are partly due to the desirable performance of polymeric materials [9]. Camping plates and countertops are made of melamine.

- Araldite glue, casting resin, epoxy resin: a two-part resin and hardener that hardens when combined.
- Panhandles and bottle caps contain phenol-formaldehyde.
- Plug sockets, electrical switches, and door handles all contain urea-formaldehyde.
- Car bodywork and boats are made of polyester resin.

Most polymers are formed by processing crude oil , but they can be made from both natural and synthetic resources. Polymers are sold as sheets, films, bars, rods, granules, and tubes.

Thermosetting polymers are brittle and can only be formed once. They are hard to recycle. They are good insulators and are resistant to heat and chemicals. Few commercial products based on thermosets can be notified (Table 2).

Table 2

Thermosetting polymer	Properties	Uses
Epoxy resin (ER)	Supplied as two parts, one resin and one hardener (see image) - the resin and hardener combine to create an extra-strong adhesive, good chemical and heat resistance, and an excellent thermal insulator can be brittle.	Bonds materials and can be used for waterproof coatings and lamination.
Melamine formaldehyde (MF)	Excellent heat resistance and is resistant to scratching and staining, hard and strong.	Laminates for worktops, food safe so used for picnic tableware
Urea-formaldehyde (UF)	A challenging and stiff polymer with excellent thermal insulation.	Electrical fittings, toilet seats, holding the wood chips together in the making of medium-density fibreboard (MDF)

The majority of epoxy polymers (Thermosetting Plastics) are made from oil. A significant effort in recent decades has been substituting petroleum-derived materials with renewable and environmentally friendly bio-materials. To move towards ecologically safe and environmentally friendly products, substituting biphenyl-A in producing epoxy resins is essential [10]. Compared with starch or vegetable oils, lignocellulosic biomass is a promising resource for processing bio-derived products without affecting the food supply. Lignocellulosic biomass is used to extract various platform chemicals and monomers.

The production of bio-based materials with thermo-mechanical efficiency that can compete with or exceed existing petroleum-based materials has received some attention.

1.3 ELASTOMERS

Elastomers are very high molecular weight materials, typically made up of one or more polymerized monomers or co-polymerized to form a polymer (or copolymer). The polymer consists of a very long chain of chemically bound monomer molecules with a molecular weight of several million to form a single molecule [11]. This massive molecule consists of several tens of thousands of connected tiny units (monomers). It has a wide ratio of length to diameter and does not exist as a structure similar to a straight rod but in a shape known as a random coil. Each random coil will be entangled with many neighbors in a raw, uncompounded polymer, rendering flow difficult. The mass functions as a liquid, but with a viscosity about five million times that of water, but will ultimately flow under the influence of stress and temperature.

As an elastomeric substance, rubber can reversibly deform, which is significantly affected by its chemical structure and molecular weight (MW). Ideally, after removing the applied force, rubber chains can return to their original form. Due to their low glass transition temperature (Tg), the macromolecular chains of rubber are long and oriented without large substituents, making them capable of moving and rotating around chemical bonds at low temperatures. Higher Tg rubber contributes to increased irregularities in the polymer chains or the presence of large substituents (styrene-butadiene rubbers (SBRs)). With the advent of efficient vulcanization methods, producing high-quality rubber on a wide scale at a low cost has risen dramatically [12]. To form a three-dimensional (3D) network between the rubber macromolecules, Vulcanisation is described as the irreversible crosslinking reaction through curing agents (sulfur or peroxide materials). In the rubber vulcanization process, many parameters must be regulated, such as curing time, temperature, and fillers that directly affect cross-linked rubbers' chemical, mechanical, and physical properties. Based on the cross-linked structure created, vulcanizing agents are incorporated into an unsaturated rubber, which increases the rubber's strength. Therefore, vulcanized rubber cannot be recycled directly as an elastic, insoluble, and infusible thermoset material [13]. This is an essential limitation of material recycling, especially after the end of the component's life.

Due to their broad applications in sensors, actuators and energy harvesting devices, highly stretchable dielectric elastomers (DEs) are increasingly becoming common. DE typically deforms in three basic ways, similar to other elastomers: simple extension, equi-biaxial extension, and pure shear. Straightforward extension is the most basic deformation process in which the material's length-to-width ratio is high. The material elongates along its longitudinal direction for a homogeneous uniaxial deformation, leaving the width free to contract. Equi-biaxial is another standard deformation method in which the material is extended from both sides (length and width), which are usually unique [14]. Due to its compatibility and extraordinary performance, this deformation mode includes various application areas. The pure shear deformation mode has recently gained significance in that the width direction is not permitted to contract while the material is stretched in the direction of length. This deformation mode has, therefore, inspired scientists and researchers to develop efficient and compatible actuators and energy harvesting devices due to its flexibility, performance, and more accessible pre-stretching capacity. Some potential Elastomers can be framed as:

Unsaturated rubbers that can be cured by sulfur vulcanization:

- Natural polyisoprene: cis-1,4-polyisoprene natural rubber (NR) and trans-1,4-polyisoprene gutta-percha
- Synthetic polyisoprene (IR for isoprene rubber)
- Polybutadiene (BR for butadiene rubber)
- Chloroprene rubber (CR), polychloroprene, neoprene, Baypren, etc.
- Butyl rubber (copolymer of isobutene and isoprene, IIR)
- Halogenated butyl rubbers (chloro butyl rubber: CIIR; bromo butyl rubber: BIIR)
- Styrene-butadiene rubber (copolymer of styrene and butadiene, SBR)
- Nitrile rubber (copolymer of butadiene and acrylonitrile, NBR), also called Buna N rubbers
- Hydrogenated nitrile rubbers (HNBR) Therban and Zetpol

Saturated rubbers that cannot be cured by sulfur vulcanization:

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- EPM (ethylene propylene rubber, a copolymer of ethene and propene) and EPDM rubber (ethylene propylene diene rubber, a terpolymer of ethylene, propylene and a diene-component)
- Epichlorohydrin rubber (ECO)
- Polyacrylic rubber (ACM, ABR)
- Silicone rubber (SI, Q, VMQ)
- Fluorosilicone rubber (FVMQ)
- Fluoroelastomers (FKM, and FEPM) Viton, Tecnoflon, Fluorel, Aflas, and Dai-El
- Perfluoroelastomers (FFKM) Tecnoflon PFR, Kalrez, Chemraz, Perlast
- Polyether block amides (PEBA)
- Chlorosulfonated polyethylene (CSM), (Hypalon)
- Ethylene-vinyl acetate (EVA)

Various other types of 4S elastomers:

- Thermoplastic elastomers (TPE)
- The proteins resilin and elastin
- Polysulfide rubber
- Elastolefin, an elastic fiber used in fabric production
- Poly(dichloro phosphazene), an "inorganic rubber" from hexachlorophosphazene polymerization

TABLE 3: Properties and applications of commercially important elastomers

Polymer Type	Applications
polyisoprene (natural rubber, isoprene rubber)	tires, springs, shoes, adhesives
styrene-butadiene copolymer (styrene-butadiene rubber)	tire treads, adhesives, belts
polybutadiene (butadiene rubber)	tire treads, shoes, conveyor belts
acrylonitrile-butadiene copolymer (nitrile rubber)	fuel hoses, gaskets, rollers
isobutylene-isoprene copolymer (butyl rubber)	fuel hoses, gaskets, rollers
ethylene-propylene monomer (EPM), ethylene-propylene-diene monomer (EPDM)	tire liners, window strips
polychloroprene (neoprene)	flexible seals, electrical insulation
polysulfide (Thiokol)	hoses, belts, springs, gaskets seals, gaskets, rocket propellants
poly dimethyl siloxane (silicone)	seals, gaskets, surgical implants
Fluoroelastomers	O-rings, seals, gaskets
polyacrylate elastomer	hoses, belts, seals, coated fabrics

2. REVIEW VARIOUS METHODOLOGIES ADOPTED FOR THE PREPARATION OF VARIOUS CATEGORIES OF POLYMERS

A brief overview of the different methodologies/materials implemented for preparing thermoplastic polymers, thermosetting polymers, and Elastomers.

2.1 METHODOLOGIES ADOPTED FOR PREPARATION OF THERMOPLASTIC POLYMERS

Camden et al. [15] analyzed the Additive manufacturing (AM) strengths, especially the tool-less manufacturing model and the rapid production of low-volume products, which are well aligned with the production needs of costly, high-temperature-resistant, thermoplastic engineering polymers. High-temperature polymer parts made with AM for tooling or end-use

applications have been introduced in the aerospace, automotive, and biomedical sectors. However, parts produced from these polymers using conventional manufacturing methods are typically high-value in low-quantity production runs. The authors address common challenges of high-temperature polymers and gaps in the basic understanding of process-structure-property relationships required to define the system design, selection of process parameters, and synthetic modifications to allow process-in-property relationships.

Santiago et al. [16] studied the selection of thermoplastic polymers for use as bipolar plates in direct methanol fuel cell applications. These polymers will decrease their density and cost, increasing their commercialization in direct methanol fuel cells (DMFCs).

Shen et al. [17] analyzed the self-heating and stress-strain behavior of thermoplastic polymers under tensile loading, and a thermo-elastic-viscoplastic-damage model based on thermodynamics has been developed. The constitutive model considers temperature-dependent elasticity, nonlinear viscoplastic flow, and damage evolution. The model involves the substantial self-heating of a polymer caused by viscoelasticity and the dissipation of energy damage during deformation, which is often overlooked. The model parameters are adjusted under various temperatures and loading speeds from the monotonic and repeated loading tests for polyamide 6. In particular, the evolution of the damage is measured by the decrease in stiffness in repeated loading tests. The suggested model is implemented in a finite element kit to predict the polymer's self-heating and mechanical behavior at a high loading rate.

Krairi et al. [18] evaluated thermoplastic polymers in non-isothermal conditions and proposed a new constitutive model for their action. The experimental validation using uniaxial and shear tests at different strain rates and temperatures on Polyamide 66 (PA66) and Polypropylene (PP) showed that the model successfully captures these polymer materials' rate dependency and temperature sensitivity.

Arnaldo et al. [19] investigated Commodity thermoplastics and thermoplastic composites are staples in Additive Expansion. Their use is common and the largest amount of 3D printed materials is accounted for. Kamil et al. [20] & Bui et al. [36] work was to boost the electrical conductivity of carbon fiber-reinforced polymers (CFRP) by developing new carbon nanotube-doped thermoplastic nonwovens. For this, fibers' extrusion and thermal pressing created two kinds of nonwovens containing carbon nanotubes. Nonwovens were placed among the prepreg layers, and CFRPs were manufactured using an out-of-autoclave process. Implementing nonwovens with 7 percent of multi-walled carbon nanotubes improved surface electrical conductivity and volume in all directions. The good quality of the laminates produced and the random distribution of the nonwovens in the composite panels were revealed by microstructure analysis. The evaluation of loss and processing moduli by dynamic mechanical analysis showed the higher flexibility of the laminates and the existence of an extra glass transition peak due to copolyimide in the nonwovens used.

Woigk et al. [21] analyzed Natural fiber (NF) Reinforced composites as an organic alternative to synthetic fiber-reinforced composites and provided exact mechanical properties. While they have great potential, their use today is restricted to non-structural applications, often with matrices of epoxy or polypropylene. The sufficient high-performance thermoplastic matrices improved the mechanical behavior of their bulk properties, fiber-wetting, and composite properties. Matadi et al. [22] investigated the benefits to the mechanical performance against impact loading offered by Acrylic thermoplastic polymers reinforced with glass fiber (GFR), based on the new methyl-methacrylate (MMA) matrix for room temperature cure. For a broad range of engineering applications based on thermoset matrices, glass fiber reinforcement is a standard solution. Its usage, however, poses certain drawbacks, such as adequate production temperature control, problematic recycling, and low tolerance to damage. On the other hand, acrylic polymers have a high potential as an alternative matrix for thermoset composites due to their superior structural properties, low-temperature processing, and recycling possibilities.

Yan et.al [23] analyzed the expansion of wearable technology. The need for sustainable power supply has driven the development of garment-based Turbo Electric Nano Generators (TENGs). New techniques are underway that can boost electrical production efficiency while maintaining the comfort of wearing a product. This investigation used thermoplastic polymeric materials to build a high-performance contact-separation TENG with two turboelectric layers. The research successfully demonstrated the ability of the formed TENG to harvest frictional energy between garments induced by body movements, a remarkable feat that showcases the innovation in wearable technology. Volik et al. [24] studied the new composites based on keratin and EVA (ethylene and vinyl acetate copolymers) that have been developed. These materials were composites based on polyethylene and keratin. Differences are revealed in their mechanical properties. Biodegradation

in composites using EVA is safer because, unlike polyethylene, it has reactive groups. It has been found that introducing keratin into the matrix leads to an increase in the modulus of elasticity regardless of the particle size of the filler. At the same time, the limit values for strength and elongation at break decrease. It was determined that elongation at break depends on the dispersion of keratin.

2.2 METHODOLOGIES ADOPTED FOR PREPARATION OF THERMOSETTING POLYMERS

Majid et al. [25] analyzed a simulation analysis of molecular dynamics conducted to predict the temperature of glass transition (Tg) and the thermal expansion volumetric coefficient (CTE) of carbon nanotube-reinforced thermoset polymer-based nanocomposite (CNT). By using Condensed-phase optimized molecular possibilities for atomistic simulation (COMPASS27) force field, an atomistic model of cross-linked Diglycidyl ether bisphenol A (DGEBA) epoxy and Diethylenetriamine (DETA) was constructed as a matrix. Various molecular models were built with different kinds of CNT embedded in epoxy simulation boxes.

Mary et al. [26] studied the reuse after metal extraction by pyrometallurgy and bioleaching of the by-products of waste. The carbonaceous slag obtained was used as reinforcement to increase the strength of a synthesized nanofibre membrane that could be used for wastewater treatment. There are nano fibers with an average size of 90-110 nm in the synthesized membrane developed using an electro-spinning machine. The 3D image of the membrane captured by the Atomic Force Microscope shows that the sample has nano fiber woven on the surface along with the carbon that improves stability and also that the possibility of fouling by the microbes will be reduced as a mere amount of metal is present on the carbon. Therefore, recycled fiber-reinforced polymer (FRP) is an appropriate membrane to handle household or industrial wastewater.

Syed et al. [27] analyzed thermoset composites as components of advanced devices, and their characteristics depend on their cross-linking state. Unsurprisingly, studies on the impact of micro- and nanoparticles, pigments, additives, and reinforcing agents on thermoset systems' thermal, mechanical, thermo-mechanical, and anti-corrosion properties provide qualitative and quantitative cure studies. There is a consensus that in a highly dense environment where the state of filler-polymer interaction dictates the cross-linking efficiency, full cure results from sufficient particle dispersion. Usually, depending on the form, size, content, and surface chemistry of particles, external filler can promote or impede curing reactions.

Bello et al. [28] investigated curing kinetics for the introduction of barium titanate ($BaTiO_3$) and multi-walled carbon nanotubes (MWCNT) to polyhexahydro-s-triazine (PHT). Isoconversion models were used to estimate PHT's kinetic triplet parameters (activation energy, pre-exponential factor, and reaction model) and its nanocomposites. The conversion of the polyhemiaminal (PHA) into PHT polymer and all nanoparticles studied in this work are dominated by a single phase according to the method of Vyazovkin [29].

Bai et al. [30] analyzed the two benefits of special plastics, which are shape memory polymers (SMP) and self-healing polymers (SHP), which have immense practical potential in various fields. This research prepared a composite by integrating graphene oxide (GO) into a thermoset polyurethane with a light-induced shape memory effect, solid-state plasticity, and self-healing performance. This composite demonstrated outstanding light-induced light based on the great photo-thermal effect of GO. It can be repeatedly reconfigured by NIR (near-infrared radiation) light irradiating to new permanent shapes without losing its shape memory properties and remotely controllable healing with complete structural recovery accompanied by elevated mechanical properties up to 85% of the original value. The practicality of this material is light control actuators, self-healing coatings, and optical welding materials. Compared with thermoplastic SMPs, chemically cross-linked thermoset SMPs usually have superior properties such as higher mechanical strength, thermal and dimensional stability, solvent resistance, and outstanding shape memory properties, demonstrating great application prospects in biomedical and engineering fields and qualified for all of the applications above.

Gabriela et al. [31] examined radiation processing and found that it was an essential pretreatment to alter the surface composition of commercially available fabrics. After a study of the chemical properties of the two kinds of composites, two methods were explored. The first approach for epoxy thermosets is focused on the immobilization of bio-based adhesion promoters, partially epoxidized carbon-carbon-in saturated fatty oils, and epoxy groups that are supposed to serve as binding agents following the simultaneous phase of EB (electron-beam) radiation-grafting. The second approach was based on the peroxidation of flax fabrics selected to strengthen the vinyl siloxane-based impact factor by EB-irradiation in the air. Indeed,

during the curing of the silicone matrix, including vinylsiloxane units, the melting point of peroxyl groups was expected to produce covalent ties between the fibers and the reactive silicone formulas.

Jacob et al. [32] explore the incomparable capabilities of an improved technique of proximity-based molecular dynamics for modeling thermoset polymer cross-linking. The novel methodology makes practical curing simulations by dynamically and probabilistically conducting complex topology transformations while selectively reducing high potential energy classes.

Fei et al. [33] scrutinized Zirconium–silicon carbide (ZrC–SiC) in hypersonic re-entry space vehicles. Ceramics are among the promising candidate materials for thermal safety structures. A thermoset hybrid sol was prepared using a simple sol-gel process to synthesize monolithic ZrC-SiC composites. The raw materials used were furfuryl alcohol, polyzirconoxane, and tetraethyl orthosilicate.

Abdullah et al. [34] analyzed thin films with different graphite particle content prepared using a slip-casting method for large band gap thermoset renewable polymer graphite (TPG) composites. The morphological view revealed that the graphite particles were uniformly distributed and oriented in the matrix by optical microscopy images. About the content of graphite particles, the electrical conductivity of TPG composites was found to increase. The results showed that the TPG composites shortly boosted the main features of the materials appropriate for optoelectronic system applications.

Levchenko et al. [35] investigated new approaches to preparing benzocyclobutene-based monomers, and polymers are being considered. Benzocyclobutene-based polymers are distinct from the classes of polymers containing siloxane, silyl, polyfluorinated fragments, polyimides, polyamides, polyacrylates, polyolefins, and polypropylenes. The essential characteristics of these polymers (temperature of transformation of glass, temperature of onset of decomposition, dielectric properties, moisture resistance) are defined, and the possibility of their use in developing devices for microelectronics is evaluated. The dielectric constant of most known polymeric materials centered on benzocyclobutene is 2.3 to 3.07.

2.3 METHODOLOGIES ADOPTED FOR PREPARATION OF ELASTOMERS

Bui. R, et al. [36] evaluated polymers with animatedly swapping crosslinks that can remain repurposed, in whole or part, after a stimulus. Chain extension or crosslink silicone polymers have enabled imines to undergo complex exchange reactions under mild conditions. Cross-linked polysiloxanes based on Schiff were prepared by reacting with aromatic aldehydes of aminopropyl-functionalized polydimethylsiloxane. The reactions occur effectively, and when the weight fraction of silicone is reasonably large, the water by-product spontaneously separates from the silicone. The dynamic transamination was nevertheless successful, even in the absence of catalysts. Simply placing two elastomer strips in contact resulted in an adhesive bond that was more excellent than the rubber's cohesive strength, depending on the contact surface area.

Ameri et al. [37] analyzed the asphalt combination fatigue life, exaggerated by the addition of waste elastomeric polymers achieved after the polymer manufacture procedure. Meanwhile, the use of polymers is economically expensive, and there are also some by-products in the manufacturing process of polymers; it is important to consider recycled polymers and polymer waste in terms of environmental clean-up. The key objectives of this research are the analysis of the fatigue characteristics of HMA (hot-mix asphalt) mixtures containing waste from elastomeric polymers and their comparison with unmodified mixtures. Furthermore, various fatigue analysis approaches were tested for the most accurate results. Therefore, two alternative fatigue studies were conducted: the system Ratio of Dissipated Energy Shift and the system of Energy Ratio. Both these methods provided a more comparative analysis of the fatigues of these mixtures. As the results indicate, the fatigue life of mixes changed by polymer waste is significantly greater than that of unmodified mixes and is significantly similar to mixes including initial polymers.

Wang et al. [38] scrutinized Thermoplastic elastomers (TPE) in a wide variety of applications, such as adhesives, elastomers, coatings, and fabrics. TPEs have been used in additive manufacturing techniques such as 3D printing. The need for advanced TPEs with adaptive properties constantly increases despite their omnipresence.

Adem et al. [39] examined Using a combination of a non-covalent immobilization approach and surface-initiated future renewable fragment chain transfer (SI-RAFT) polymerization for responsive and selective detection of folic acid (FA), the efficient method of preparing novel molecularly imprinted adhesives (MIP) on poly(dimethyl siloxane) (PDMS) elastomer. The results showed that the proposed approach could extract FA from complex media quickly, effectively, and selectively. Note that this new proposed method would open up a new way to use molecularly imprinted PDMS elastomer materials to detect any selected molecules, such as pesticides, proteins, medicines, etc.

Sharma et al. [40] examined a finite element-based numerical framework for simulating the electromechanical action at finite strains of nonlinear anisotropic dielectric elastomer actuators. Based on the current models for viscous fluid anisotropic neo-Hookean hyper-elastic solids and ideal dielectric elastomers, a theory of anisotropic dielectric elastomers is illustrated.

Jana et al. [41] examined virtually every industry, including health care, aerospace, automotive, and clothing; elastomers are a special and significant class of polymers that enjoy applications. However, additive processing (AM) of elastomers remains challenging due to their inherent physical, thermal, and mechanical properties. This analysis offers an in-depth discussion of the current state of AM polymers of silicone and polyurethane. Also, it addresses polyesters/polycarbonates, liquid crystalline elastomers, and compositions of monomers that include photo-curing with elastomeric properties. Finally, as well as an outlook for this rapidly advancing sector, the current state of standard, commercially available elastomers for AM is given. This analysis will be helpful in any research concerning the additive processing of elastomers.

Kwon et al. [42] observed the analysis of poly (glycidyl methacrylate) (PGMA) coated soft-magnetic carbonyl iron (CI) particles were manufactured and then adopted for a magnetorheological (MR) elastomer using a dispersion polymerization process. The results show that the PGMA-covered CI MR Sample was more significant than that found at PR-CI because of its greater bond strength between particles and the Silicone rubber matrix for PGMA-coated MR elastomer CI, minor Payne effect, and lower tangent loss. The results show that the MR elastomer is smaller than the pure CI-based MR elastomer.

Meram et al. [43] analyzed a discrete model for characterizing a thermoplastic polyurethane elastomer buffer's complex behavior under impact loading. Tanasi et al. [44] investigated Natural rubber (NR) as one of Nature's most outstanding materials and is therefore widely used by industry, particularly the tire industry. There is no appropriate way to do it, considering the interest in recycling vulcanized NR, and most of the tires are discarded in landfills. DA (Diels-Alder) adduct formation was confirmed, and dynamic-mechanical analysis and rheological measurements demonstrated the reversibility of the DA reaction. This study provides a basis for crosslink rubbers, offering a simple strategy for reusing and extending elastomeric products' existence.

Dan et al. [45] investigated to obtain high-performance dielectric elastomer composite materials, natural rubber (NR). By minimizing the entanglement between NR chains and weakening the compliance effect of mTiO2 nanoparticles, the incorporation of polar dioctyl phthalate (DOP) sharply reduced the elastic modulus of mTiO2 / NR composites. At the same time, the dielectric constant of mTiO2 / NR composites was improved by strongly polar DOP and resulted in high electromechanical sensitivity (β). The present study shows that an efficient way to increase the electromechanical efficiency of dielectric elastomer actuators is the plasticizer-enhanced flexibility of inorganic dielectric filler / polymeric materials.

3. PERFORMANCE COMPARISON OF VARIOUS METHODOLOGIES FOR POLYMER PREPARATION

This section provides a detailed comparison and performance analysis of the various methods for evaluating thermoplastics, thermosets, and elastomers. In that review, different techniques/materials are compared based on parameters like the technology used and their advantages and disadvantages.

3.1 Comparison and Analysis of Thermoplastics in Polymer Chemistry

Table 4: Comparison and Analysis Method/materials for thermoplastics in Polymer Chemistry

S.NO	TECHNOLOGY/ MATERIAL USED	ADVANTAGES	DISADVANTAGES	REFERENCE
1	Material extrusion and Powder bed fusion	improved thermal stability, toughness, and deformability	difference in temperature between adjacent layers is above a critical value	Camden et al. [15]
2	Direct methanol fuel cells and multi-criteria decision-making	Allows quantifying the variation over time of hardness, degradation rate, and solution absorption of various thermoplastic materials	high cost, low flexural strength, and poor dimensional stability	Santiago et al. [16]

3	Thermo-elastic-viscoplastic-damage model	to predict the temperature evolution and mechanical response in the self-heating tests	No clear distinction can be observed among the damage data under the three temperatures investigated	Shen et al. [17]
4	Linear viscoelasticity, viscoplasticity, and thermal effects	more appropriate to model the multi-axial aspects of material behavior	This method is only valid under a field of temperature with constant magnitude	Krairi et al. [18]
5	Liquid deposition modeling and direct ink writing	polymer composites are more effective in cost/performance ratio	lack of advanced polymer materials and available nanocomposites	Arnaldo et al. [19]
6	Carbon fiber-reinforced polymers and two types of nonwovens based on two commercial copolyamide	thermoplastic polyamide in the laminates do not affect the glass transition temperature	higher flexibility and additional glass transition peak due to the presence of polyamide	Kamil et al. [20]
7	Poly-L-lactide (PLLA) and Polyoxymethylene (coPOM)	high-performance natural fiber-reinforced thermoplastic composites	still lack the environmental stability to be used in engineering applications	Woigk et al. [21]
8	Glass fiber reinforced and Methyl-methacrylate (MMA) matrix	high potential as an alternative matrix for thermoset composites	adequate control of manufacturing temperature, problematic recycling, and low damage tolerance	Matadi et al. [22]
9	Garment-based triboelectric nanogenerators and composite nanofiber membranes	Facile the fabrication process, low cost, versatility, broad applicability, and result in high electrical output performance	not only provides a novel way for micro-nano-structural triboelectric layers	Shan et al. [23]
10	The copolymer of ethylene and vinyl acetate)	high strength, low density, and high adhesion to various materials	Polyolefins is that these composites feature a low degree of compatibility	Volik et al. [24]

From Table 4. it was known that the various method and technologies based on thermoplastics in Polymer Chemistry, Material extrusion and Powder bed fusion[15] direct methanol fuel cells and multi-criteria decision-making [16] thermo-elastic-viscoplastic-damage model [17] linear viscoelasticity, viscoplasticity and thermal effects [18] liquid deposition modeling and direct ink writing [19] Carbon Fiber Reinforced Polymers and Two types of nonwovens based on two commercial polyamides [20] poly-L-lactide (PLLA) and polyoxymethylene (coPOM) [21] glass fiber reinforced and methyl-methacrylate (MMA) matrix [22] garment-based triboelectric nanogenerators and composite nanofiber membranes [23] copolymer of ethylene and vinyl acetate [24] these are existing Method/materials for thermoplastics in Polymer Chemistry.

3.2 Comparison and Analysis of Thermosets in Polymer Chemistry

Table 5: Comparison and Analysis Method/materials for thermosets in Polymer Chemistry

S.NO	TECHNOLOGY/ MATERIAL USED	ADVANTAGES	DISADVANTAGES	REFERENCES
1	Coefficient of thermal expansion and nanocomposite reinforced by carbon nanotube	The coefficient of thermal expansion has been increased.	There is no improvement in the thermal properties	Majid et al. [25]

2	Pyrometallurgy and bioleaching, recycled Fibre Reinforced Polymer	reinforcement to increase the strength of a synthesized nanofibre membrane	lots of health hazards by damaging the hormonal production	Mary et al. [26]
3	Nonisothermal differential scanning calorimetry and thermal Analysis and Calorimetry	regulate and possibly predict the ultimate properties as well as the performance of advanced materials and systems	The deficient concentration of nanoparticles recommended	Syed et al. [27]
4	Multi-walled carbon nanotubes and polyhexahydro-s-triazine	the absence of variations does not exclude the possibility of multiple reactions	A more homogeneous state statistically will provide more contact between nanoparticles and polymer molecules	Bello et al. [28]
5	Shape memory polymers and self-healing polymers	remote activation is available due to the travel characteristic of light	remote activation is available due to the travel characteristic of light	Bai et.al [30]
6	Epoxy thermosets or silicone materials	enhanced composite performance to weight ratio, as well as in reduced feedstock	storage conditions and duration is a critical point requiring the development of quantification methods	Gabriela et al. [31]
7	Proximity-based molecular dynamics technique for modeling the crosslinking of thermoset polymers	versatile manufacturability and relatively low cost, and their toughness can be substantially improved	do not capture the curing dynamics of crosslinking, reasoning that only the end result matters	Jacob et al. [32]
8	Zirconium carbide–silicon carbide	improve properties of the corresponding materials	compressive strength of the porous ZrC–SiC ceramics are poor	Fei et al. [33]
9	Thermoset renewable polymer graphite and Fourier transform-infrared (FT-IR) spectroscopy	low cost and ease of preparation, as well as energy consumption, too	conduction path could not form as the system is filled by insulating thermoset renewable polymer	Abdullah et al. [34]
10	Thermosetting monomers and polymers based on benzocyclobutene	increase in such operational characteristics as glass transition, decomposition temperature	it does not require the presence of a catalyst or a process initiator to contaminate the final polymer	Levchenko et al. [35]

From Table 5. it was known that the various method and technologies based on thermosets in Polymer Chemistry; coefficient of thermal expansion and nanocomposite reinforced by carbon nanotube [25], pyrometallurgy and bioleaching, recycled Fibre Reinforced Polymer [26], Nonisothermal differential scanning calorimetry and Thermal Analysis and Calorimetry [27] multi-walled carbon nanotubes and polyhexahydro-s-triazine [28], Shape memory polymers and self-healing polymers [30], epoxy thermosets or silicone materials [31], proximity-based molecular dynamics technique for modeling the crosslinking of thermoset polymers [32], Zirconium carbide–silicon carbide [33], thermoset renewable

polymer graphite and Fourier transform-infrared (FT-IR) spectroscopy [34] , thermosetting monomers and polymers based on benzocyclobutene [35], these are existing Method/materials for thermosets in Polymer Chemistry.

3.3 Comparison and Analysis of Elastomers in Polymer Chemistry

Table 6: Comparisons and Analysis Method/materials for Elastomers in Polymer Chemistry

S.NO	TECHNOLOGY/ MATERIAL USED	ADVANTAGES	DISADVANTAGES	REFERENCES
1	Aminopropyl-functionalized polydimethylsiloxane with aromatic aldehydes	dynamic covalent bonds as opposed to non-covalent interactions, such as hydrogen bonding that are often intolerant to solvents	gradual decrease of the average molecular weight in an inverse condensation process	Robert et al. [36].
2	Hot-mix asphalt and Dissipated Energy Change method and the Energy Ratio method	the damage level remains low initial stiffness modulus of the specimen	cumulative dissipated energy does not consider this fact completely	Ameri et al. [37].
3	3D printing and Thermoplastic elastomers	optical transparency, the versatility of printability, abrasion resistance, and low viscosity	comprehensive understanding of both synthetic limitations and block copolymer structure-property relationships	Wang et al. [38].
4	Molecularly imprinted polymers and poly(dimethyl siloxane	an inexpensive and effective method for the detection	the more complicated operation, being time-consuming	Adem et al. [39].
5	Electromechanical behavior of nonlinear anisotropic dielectric elastomer actuators at finite strains	free energy density because of electrical polarization	decouple the displacement and the electric potential fields	Sharma et al. [40].
6	Additive manufacturing and polyesters/polycarbonates, liquid crystalline elastomers	high elongation at break, elastic recovery, recyclability, and high wear resistance	due to the inherent physical, thermal, and mechanical properties of elastomers, the additive manufacturing (AM) of elastomers remains challenging	Jana et al. [41]
7	Poly (glycidyl methacrylate) (PGMA) coated soft-magnetic carbonyl iron (CI)	improve the mechanical properties and heat resistance characteristics	increased energy loss due to the increased interfacial friction	Kwon et al. [42]
8	Thermoplastic polyurethane elastomer buffer and calibrated nonlinear Maxwell viscoelastic impact model	Maximum deflection, dissipated energy, and coefficient of restitution with high accuracy	the amplitude dependency of rubbers was not been considered	Meram et.al [43]
9	Natural rubber and dynamic-mechanical analysis	the vulcanized rubber can be repeatedly self-healed and reused	healing time as to evaluate more than one healing event	Tanasi et al. [44]
10	High-dielectric-constant titanium dioxide and γ-methacryloxypropyl trimethoxy silane (referred to as mTiO2) and polar dioctyl phthalate	high elasticity, large breakage elongation, low dielectric loss, and low cost	highly undesirable for practical applications	Dan et al. [45]

From Table 6, it was known that the various method and technologies based on Elastomers in Polymer Chemistry; aminopropyl-functionalized polydimethylsiloxane with aromatic aldehydes [36] hot-mix asphalt and Dissipated Energy Change method and the Energy Ratio method [37], 3D printing and Thermoplastic elastomers [38] molecularly imprinted polymers and poly(dimethylsiloxane) [39], electromechanical behavior of nonlinear anisotropic dielectric elastomer actuators at finite strains [40], additive manufacturing and polyesters/polycarbonates, liquid crystalline elastomers [41], Poly(glycidyl methacrylate) (PGMA) coated soft-magnetic carbonyl iron (CI) [42], thermoplastic polyurethane elastomer buffer and calibrated nonlinear Maxwell viscoelastic impact model [43] , Natural rubber and dynamic-mechanical analysis [44], high-dielectric-constant titanium dioxide and γ-methacryloxypropyl trimethoxy silane (referred as mTiO2) and polar dioctyl phthalate [45], these are existing Method/materials for Elastomers in Polymer Chemistry.

4. CONCLUSION

This paper has emphasized the role of existing techniques in thermoplastics, thermosets, and elastomers in several areas related to the deployment in applied chemistry and its advantages and disadvantages. Thermoplastics are also among the most widely used plastics currently. In thermoplastics, the most potent continuous power supplies are supposed to be Tribo Electric Nanogenerators (TENG) [23] because they transform not only mechanical energy into electricity but also have many advantages of high output efficiency, outstanding stability and easy production method. With the advance of wearable semiconductor technology, the demand for sustainable power supply has boosted the development of tribo electric Nano-generators. The triboelectric Nano-generator methods are Impact and suitable for large-scale research, showing assurance in many applications, including self-powered systems, wearable electronics, and intelligent technology. The emerging TENG technology has shown great potential in various fields globally and expanding rapidly for more practical applications in the future. At length, the discussion comparing the techniques or materials in terms of their advantages and disadvantages related to thermoplastics, thermosets, and elastomers will support the enhanced and improvised methodologies for the frugal performance of polymers in Applied Chemistry.

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