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Structure Property and Performance of Polymeric Foams: A Review

Noureddine Boumdouha[1,2,*], Jannick Duchet-Rumeau[1] and Jean-François Gerard[1]

[1]UMR CNRS 5223 Ingénierie des Matériaux Polymères, Université de Lyon, INSA Lyon, 20, Avenue Albert Einstein, 69621 Villeurbanne, France

[2]Laboratoire Dynamique des Systèmes Mécaniques, École Militaire Polytechnique, BP17 Bordj El-Bahri, 16046 Algiers, Algeria

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Abstract:

This work covered essential technological progress in all the aspects of polyurethane foam growth, including cell nucleation and stability. The work also included developing an understanding of controlling cell morphology, size, and shape and improving closed and open-cell content. This necessitated a grasp of the character of surfactant catalysts, which also helps control the development of polyurethane foams. Learn the fundamentals of polymer physics and materials science to understand how the viscosity of polymeric matter impacts the most recent performance attributes of various flexible foams, including high elasticity, flex sheet stock, and viscoelasticity.

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*Corresponding Author
Tel: +213-697-005-578;
E-mail: boumdouhanoureddine@gmail.com

1. INTRODUCTION

Polyurethane foams are versatile due to their structure-property relationship. The mechanical, physical, and biochemical properties attract significant attention from R&D [1]. Increasing the use of PU materials can be accomplished by improving manufacturing methods or raw materials or using advanced techniques. It is possible to produce diverse and suitable product units through appropriate methodologies, raw materials, and procedures. This study aims to understand the composition and development of PUR. This research explains PUR's latest advancements and the synthesis of their derivatives for various applications. Additionally, information is given on PUR's responsiveness.

Polyurethane foams (PUR) have several characteristics that distinguish them from other forms of plastic. They can be used in several products, including paints, insulators, elastomers, elastic foams, and entire skins, to name only a few examples [2]. Most of the uses of PUR today are just variations of what German Professor Bayer and his colleagues created long ago [3]. Demonstrates critical forms of PUR, and some examples of the PU industry were created by discovering the polyaddition reaction of isocyanate poll by these researchers in 1937 [4, 5].

PUR was developed as a rubber substitute during WWII. When this product was abundant, it was used to supplement other components in various applications, even to create impregnated paper and insensitive combinations. They have also been used as furniture finishes due to their resistance to mustard gas, exterior sheathing, and gloss colours for aircraft [6]. The first uses of PUR coatings started with separate formulations [7]. Continuous advancements in manufacturing methods, processing techniques, formulation forms, and additives have enabled their wide applications, including PUR, among the most widespread, ubiquitous, and studied materials. This composite replaces metals, plastics, and rubber because it is more durable and more flexible than the alloy [8-10]. The properties of stiffness, elongation, strength, and modulus are included in building designs, biomedical, and several other industries due to their consistency, durability, and resilience [11-13].

The urethane group is the main PU's repeating unit, created based on the reaction of alcohol (–OH) with isocyanate (NCO). However, PUR additionally includes ethers, urea, esters, and some aromatic compounds [15]. Due to the range of sources where the PUR can be modulated and the breadth of their unique applications, they can be divided into several distinct groups according to desired properties: Solid, thermoplastic, flexible, based on water, binders, sealants, sealants, adhesives, and elastomers [16]. Among the main requests, PUR foam is one of the most popular PU-based materials used worldwide in significant numbers. Nearly 50% of the total supply of polyurethane foams is absorbed by the market's need for solid PUR foam [17]. Globally, there are various forms of PUR manufacture, with a preliminary outlook for 2020 in Figure **1** [18].

PUR foams can be conveniently customized to achieve specific materials by simply adjusting the kinds and amounts of surfactants, blowing agents, catalysts, polyol, and isocyanate used in their manufacture, in addition to the amount of intercalation and exfoliation between the ears and matrices that are appropriate for the desired purpose [19, 20]. Specifically, PUR is widely used due to its unique characteristics, such as high mechanical strength. They are used in coatings, corrosion, hardness, high abrasion resistance, chemical tolerance, and stability at low temperatures [21]. PUR elastomers are among the most common varieties of PUR, which have been commonly incorporated into various manufactured products and have been shown to offer flawless characteristics [22]. They are malleable polymeric fabrics manufactured rapidly by extrusion or injection moulding and delivered.

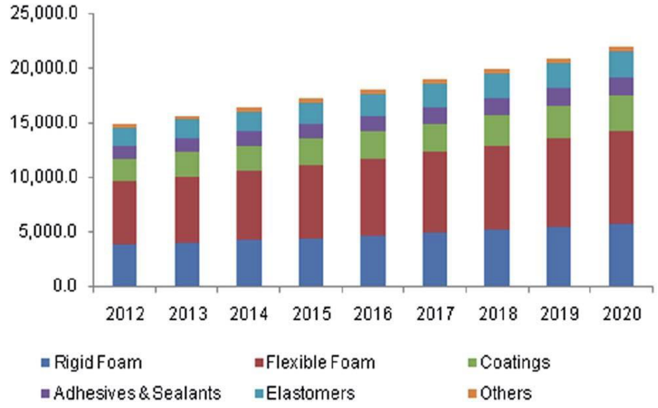


Figure 1: Global demand for PU (Production projection until 2020) [18].

Different PU compounds have been prepared, and their properties tested [11]. Due to the high manufacturing costs, environmentally friendly polyols are now needed. This has just gained a lot of popularity in recent times, as organic vegetable oils, the double molecules of carbon and ester and hydroxyl [23, 24] are the main types of vegetable oils the planning of these oils can be. We carried out using epoxidation, ring-opening polymerization [25], transesterification, and hydroformylation [26, 25]. Vegetable oils considered suitable for processing polyols can be cross-linked with polyisocyanates. As innovation in product growth, nanocomposite has been encouraged by producing nanomaterials in Toyota vehicles [27]. Thus, it has been proposed that the use of nanomaterials offers numerous advantages to favourable results in a wide variety of fields [28-30].

The primary goal of this study is to close the gap between applicable yet disparate innovations from polymer engineering and science and those from foam engineering [31]. And the science that is needed to solve numerous design problems comprising a polymeric foam. The expectation is that by consolidating important information. Furthermore, by combining problem-solving techniques and expertise into a unique source, analysts, polymeric foam manufacturers, engineers, and other specialists will succeed in quickly accessing relevant information and resolving problems methodology. Also, expertise allows them to solve their technological challenges. This problem-solving approach begins with critical research to identify the problem's core components. It continues with producing sound theories based on key evidence, applies fundamental research, and concludes with creating the solution space for the difficulty of linking and micro-structure property relationships to evaluation metrics.

In recent advancements within PU foam technology, the interplay between cell morphology and mechanical properties has emerged as a pivotal study area. This manuscript now delves into the intricate relationship between cellular structure and the resultant physical characteristics of PU foams, drawing upon recent research [32, 33]. Furthermore, the incorporation of nano-fillers has been identified as a significant factor in augmenting the structural integrity and performance of PU foams, with a particular focus on their role in enhancing compressive strength and thermal resistance [34, 35]

2. EXPERIMENTAL METHODS

2.1. Nanocomposites of Polymers

Polymer composites are used extensively in various markets, including automotive, aircraft, manufacturing, and electronics. They outperform pure polymers regarding physical and mechanical properties (e.g., strength, stiffness, and appearance). Historically, inorganic materials such as micron-sized particulate matter and flax fibre have been exploited as the inorganic portion of polymer composites [36]. Nevertheless, using nanoparticles in polymeric materials has garnered considerable attention recently. Nanoparticles have a great potential for major property enhancement at low particle loading levels. Therefore, nanocomposites have emerged as a new form of substances capable of achieving superior properties while retaining the lightweight properties of a make polymer matrix.

The name "nanocomposites" relates to a mixture of material in which, at a minimum, a single phase contains particles of tiny sizes (on the collection of 2 nanometers). Nanoparticles are classified into three groups. The first category of nanoparticles has a shape like a platelet. Layered nano graphite and nanoclay are two kinds of materials. These materials usually have a thickness of a lateral diameter and a few nanometers of several hundred micrometres to nanometers. The second group of nanoparticles has an elongated system with different nanoscale sizes and one microscale dimension, usually between a few and 100 micrometres in length. Nanofibers and nanotubes are two examples of materials. Both of these nanoparticles have high slenderness. However, the third group of nanoparticles exhibits a three-dimensional spherical structure on the nanometer extent. This category includes spherical silica spores, gold, metal nanoparticles, block copolymers, and monocrystals. Nonporous microparticles are a subtype of that third class. If the particle diameter is measured in micrometres, the pore volume sizes are measured in nanometers.

2.2. Polymeric Foams

Foams are commonly used for several purposes, including absorption, insulation, wrapping, and cushioning [37]. Additionally, high-porosity foams with intertwined pores have been exploited as scaffolds for tissue engineering, promoting cell accessory and development [38]. Polyurethane (PU), polyolefins (polyethylene (PE), polystyrene (PS) polypropylene (PP)), polycarbonate, and PVC (polyvinyl chloride), furthermore being used in foam applications (PC). The US used 7.43 billion pounds of silicone foam produced in 2001, equating to a market valuation of around $16.3 billion [39]. Polyurethane has the highest share of the market (53 %) of all resin families regarding volume consumed. Polystyrene stands for the second (26 %).

A foaming system's standard structure involves a polymer, a foaming agent, nucleates, and more additives (flame retardant agent, catalyst, etc.). In general, foaming agents remain classified into actual and agent chemical foaming. The most often used approach for large-scale manufacturing is the direct use of agents' physical foaming. Volatile chemicals, including hydrocarbons (HCs), chlorofluorocarbons (CFCs), and noble gases, are common agents of material foaming (N2, CO2, water, argon). CFCs are soluble in polymer matrices and have low diffusivity and heat conductivity. These qualities create a foam substance with excellent thermal and physical characteristics. However, due to ozone depletion, CFCs and their equivalents and hydrochlorofluorocarbons (HCFCs) will be phased out by 2010. Some substitutes, such as hydrofluorocarbon health effects (HFCs) and hydrochlorofluorocarbons (HCs), require stringent oversight due to their detrimental effects on climate change. Additionally, they can pose a significant fire threat in close-celled foams.

2.3. Polyurethane Foam Chemistry

They are also grouped with other polymeric compounds called reaction polymers, complex resins, epoxies, and endotoxic; PUR [40, 41] are generally synthesized by the isocyanate-polyol reaction when a catalyst is present or when ultraviolet light is activated [42] there must be two or three isocyanates (R−N=C=O) besides polyol (CnH2n+2On) groups correspondingly in the isocyanate and polyol chains [40]. PUR generally exhibits polyol and isocyanate properties. Strong polymers can be made when polyols can be formed from longer segments of polyols. Stretch polymers can be derived from longer polymers, while the reverse is the case for cross-linking. However, a mixture of long-chain molecules with a modest level of cross-linking results in polymers for foaming [12]. The molecules form a three-dimensional form (3D) due to cross-linking in PUR. This is why a certain volume of PUR is called a large molecule, and others remain hard. It is possible to manufacture many distinct forms of isocyanates and polyols while working with different processing additives in combination with polyol/isomerization methods and conditions [43].

Polyols used for PU synthesis contain at least two –OH groups. There are many ways that poles can be made in the laboratory. For example, polyethers are obtained by copolymerizing ethylene-oxide and propylene oxide with compatible polyol precursors. Polyethers derived from the polymerization of tetrahydrofuran are useful in highly elastomeric applications [44]. The characterization of Poly(tetrafluoroethylene) and its preparation has been mentioned by Rajendran *et al*. [45]. Polyols are generally composed of different but identical molecules in molecular weight, and both halves of the molecule have OH groups. Therefore, we can discuss the average functionality of polyols as poles are varied. Industrial-grade polyols have unique properties essential for creating molecules-specific polyurethane foam with coherent structures. Likewise, PUR is made from polyols with reduced molecular weight (a few hundred parts) (about ten thousand units and more) [46]. Different polyols are shown in Figure **2** [47]. The benefits and drawbacks of various polyols are shown in Table **1** [47].

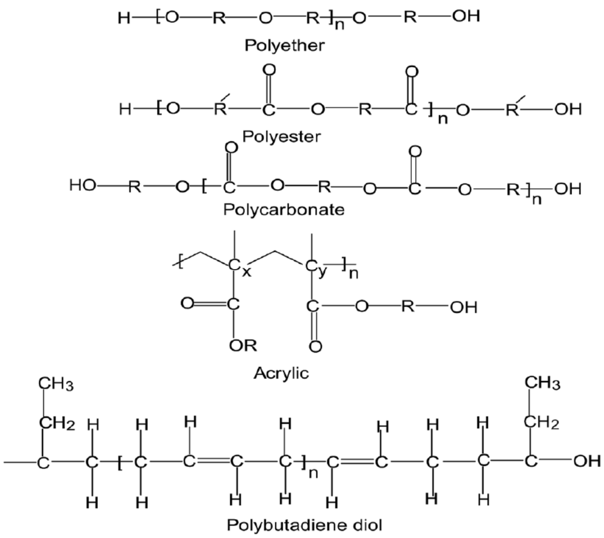


Figure 2: Simplified comparison of polyols [47].

2.4. Types of Polyurethanes

2.4.1. Inflexible Polyurethane Foams

Foams that are not flexible are traditional and energy-efficient insulating materials. These foams will significantly reduce the prices of industrial and residential energy on the one hand and the other. According to reports, heating and air conditioning are the primary sources of electricity in most American homes, costing 48 % of total energy consumption [48]. To optimize domestic and industrial uses, polyurethane foam (and for additional insulation, polyisocyanurate) is also used. These foams are highly insulating and have been used in the insulation process and sealants on windows and roofs.

PU foam can be made using polyols derived from petroleum and with vegetable oils or plant-based

Table 1: Polyols' Benefits and Drawbacks [47]

Polyol	Benefits	Drawbacks
Ethylene oxide and propylene oxide-based polyether polyols	Stability in the hydrolytic phase, viscosity, cost, flexibility	Oxidation stability, resistance, instabilities in the heat, amiability
Polybutadiene polyol solvents	Flexible and resistant at low temperatures	Viscosity, thermally oxidizable, cost (except hydrogenated)
Aliphatic Polyester Polyol	Oxidation stability, modulus/resistance	hydrolytic stability, viscosity
Aliphatic Polyester Polyol	Oxidation stability, modulus/resistance	Viscosity, low accessibility
Acrylic polyols	Stability against hydrolysis/oxidation, hardness	Viscosity, low accessibility, cost
Tetrahydrofuran-based polyether polyols	Modulus/resistance, hydrolytic stability	Oxidation resistance, viscosity, and cost
Polycarbonate polyols	Stability under hydrolysis, stability under oxidation, modulus/strength	Cost, viscosity

polyols. The hydroxyl group of the polyols influences polyurethane's properties in petroleum-based polyols, known as glycerin, which contains the main polyol. On the other hand, polyols (e.g. castor oil) contain secondary hydroxyl groups, and different polyols (PU) are also said to possess a variety of physical and mechanical characteristics [49]. Also, the reaction between such a secondary hydroxylated polyol and the reaction between an isocyanate and a primary isocyanate is slower. Blends of primary and secondary polyols are used together to minimize the volume of petroleum-based polyol required [49]. Two ways to make rigid polyurethane foam are by using glycerol, oil, and a castor mixture [12], plus different polyols can influence the physical properties of PUR. For example, transesterified palm oil contains a secondary hydroxyl group, which acts as a shortening agent [50]; the results reported the treated polyurethane foam has longer (gel time, rise time and no lustre) and is more prolonged.

2.4.2. Polyurethane Foams with a High Degree of Flexibility

PU foams that are adaptable are manufactured using block polymers and phase separation. To impact the ratios of their constituent polyurethane segments, mixtures of these physical properties [51] can yield a compound with high PUR strength flexible polyurethane foe, and their extensive uses in consumer and industrial goods, including underlay for furniture, parts, as well as biomedicine and nano copolymer [52, 53].

Often, PU foams are made in two steps: gelling and blowing. Urea and carbon dioxide are formed during the reaction, while the polyol's isocyanate connections are formed. PU foam has a variety of internal variables, including a level of cross-linking induced by the polyol and the urea group's segmental movement. The extensible foam was given special attention [54]. Several technical factors have the effect of increasing the PU's flexibility; for example, the PU chain lowering density, lowering of the glass cross-to-PU chain transition temperature, and the addition of an extensible PU chain to the PU's main backbone provide a highly flexible PU, owing to the high cross-linking, which makes these varieties chemically tolerant, they are also durable but versatile. To address these shortfalls, we made a hybrid PU foam that's very pliable [55]. A lightweight PU foam was suggested to be reinforced with arid basalt and glass fibres. FPU has high combustibility, meaning many NOx, CO, and HCN are released into the atmosphere where they burn. Consequently, antihemophilic substances must be included in the production process [55].

2.5. Polyurethane Foam Synthesis

PUR can be synthesized in a diversity of ways [41]. The most significant and useful approach involves the reaction of a polyol (Two or several hydroxyl groups with alcohol) with a diisocyanate [3, 12]. Figure **3** depicts the synthesis of conventional polyurethane

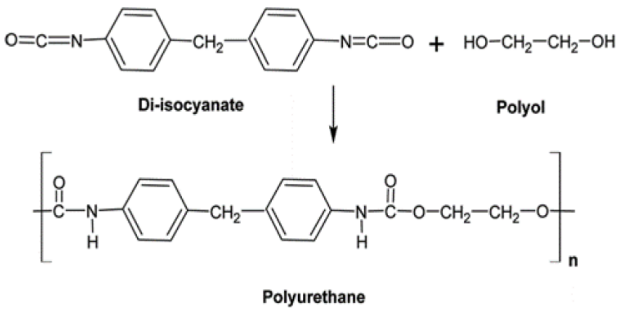


Figure 3: Detailed synthesis process of polyurethane foams.

Table 2: Polyurethanes' Components and the Reasoning for their Inclusion

Additives	Justifications for use	Ref
Polyols	Contribute significantly flexible long segments that result in the formation of soft elastic polymers.	[56]
Isocyanate	Contributes to the curing and reactivity properties of polyurethanes	[57]
Catalysts	To accelerate the isocyanate-polyol reaction and then cause the reaction to take place at a decreased temperature.	[8]
Plasticizers	To decrease the material's hardness	[58]
Pigments	To manufacture coloured polyurethane foam products, primarily for aesthetic purposes	[59]
Agents de gonflement et surfactants	To assist in the manufacture of PU foam, to aid in the control of bubble formation during synthesis, and to aid in the control of the foam cellular structure.	[60]
Flame retardants	To decrease the flammability of the substance	[61]
Cross-linkers / Extending chain	To change the PU molecule's composition and to provide mechanical assistance that improves the material's characteristics.	[62] and [63]
Anti-smoking agents	To decrease the amount of smoke produced when the material is burned	[64]
Fillers	To reduce costs while increasing material characteristics such as tensile strength and stiffness	[19]

additives. Other appropriate catalysts and additives can also be used in the PU synthesis.

Flame inhibitors, dispersants, cross surfactants, and wetting agents are all additives that can be applied to the PU synthesis by varying the volume and type of isocyanate and polyol. The compound's additives may be moulded into shapes, densities, and hardness. Table **2** summarizes the most frequent PU components and the justification for their inclusion.

2.5.1. Polyols

Polyols are divided into polyesters and polyethers. Polyols are formed when an epoxide is activated with hydrogen. Also, they can be synthesized by epoxidation of epoxy monomers. Poly-based polyols can be synthesized via polyoxyethylene and multifunctional carboxylic acids. Moreover, polyols may be used for various purposes. Most commonly use basic polyols (with an average molecular weight of less than 1,000 MW) [12, 37, 65]. Polyols used in versatile PUR often contain inactive initiators such as a solution of sorbitol and water (f =2.76), glycerin (f = 3), and propylene glycol (f = 2).

In comparison, static solid PUR plus needs more practical initiators, such as sorbitol (f = 6), sucrose (f = 8), toluene diamine, and mannish bases (f = 4). The initiators are combined with ethylene oxide/propylene oxide to increase the molecular weight. The property of polyol compounds can be mitigated by adding an oxide [66]. Aqueous, reactive, and even miscible with other chemical agents. Polyols derived solely from propylene oxide tend to be less reactive than polyols that contain a secondary hydroxyl group, which is common [67]. Polyurethane foam nanoparticles, which are often classified as polymer or polyethers, are polyol polyether nanoparticles (referred to as primary –OH groups) that have been constructed. They are used to get the most loading out of high-resiliency, low-density foams. They are also used to extend the elastomers, and polymeric foams have a long life. Low-molecular-weight polyols are synthesized using triethylamine or ethylenediamine.

Polyester polyols are made from virgin commodities and are often synthesized directly from ultrapure diacids, glycols, adipic acid, and 1,4-butanediol. Typically, polyester polyols are more viscous and expensive than polyether polyols [66]. They remain critical, though, since they generate PUR with increased abrasion, cut resistance, and solvent. Another class of polyester polyols is derived from recycled raw materials. The process of transesterification creates them, also called glycolysis, of recycled Polyethylene terephthalate PET or dimethyl terephthalate DMT distillation bottoms with glycols (diethylene glycol, for example). These polymers are aromatic, have a low molecular weight and are often used in manufacturing rigid foams because they are less expensive and have less flammability than polyisocyanurate board stock foam and polyurethane insulation foams. A class of polyols is needed to produce sealants, elastomers, and glue that require improved chemical and environmental resistance. Polysulfide polyols, polycaprolactone polyols, and polybutadiene polyols are just a few.

Polyols can be extracted from several renewable and natural products, including vegetable oils and fatty acids or fatty acids, which may be used as these renewable ingredients [37, 68]. Castor, neem, Pongamia glabra, soybean, and cottonseed oils are all sources of polyol [69]. Flexible sculpted foams, elastomers, and edible are predominantly made from oils obtained from most of these vegetable oils. Due to the inclusion of triacylglycerides in vegetable oils, they are ideal for manufacturing a variety of polymeric fabrics [70, 71]. Polyols derived from renewable headwaters can be combined with isocyanates to create PUR with unique properties ideal for various quests [72]. In one research, castor oil and soya bean oil were modified to make them appropriate for industrial rigid polyurethane foams. The material characteristics of modulated foams were decreased than those of industrial polyol-based polyurethane foams. Conversely, it was discovered to have considerable application potential for rigid PUR foam manufacturing process to its renewable source [73].

Additionally, the polymerization of chlorotrifluoroethylene or tetrafluoroethylene with vinyl ethers, including hydroxyalkyl vinyl ethers, can form fluoroethylene ethers vinyl polyols (FEVE). The synthesis of atmospheric cure paints has been investigated using fluorinated PUR produced with two constituents and requiring the reaction of three to four polyisocyanates to fluorinated polyols. Owing to the high concentration of carbon-fluorine bonds (chemical bond with the greatest strength), fluorinated PUR shows exceptional resilience to ultraviolet light, alkalis, contaminants, acids, solvents, degradation, weathering, microbes, and other microbial assaults. These features make them particularly suitable for superior-quality paints and coatings.

2.5.2. Catalysts

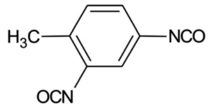
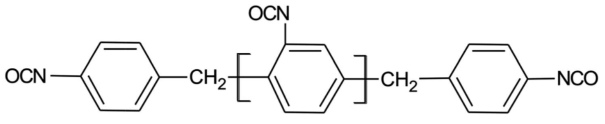
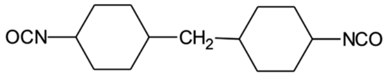
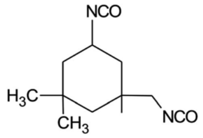
Activated catalysts frequently used in PUR consist of metal complexes and amine compounds. Historically, amino acid catalysts have been composed of amines tertiary, for example, dimethyl cyclohexylamine (DMCHA), 1,4-diazabicyclo [2.2.2] octane (DABCO), triethylenediamine (TEDA), and dimethylethanolamine (DMEA). Catalysts for urethane, urea, or trimerization isocyanate are chosen based on their ability to make these reactions. Metal-building complexes derived from bismuth, zinc, lead, mercury, and tin can also produce usable urethane catalysts. Mercury carboxylates were shown to be particularly useful in the manufacture of PUR sealants, elastomers, and coatings. This is because they show a preference for isocyanate-related and polyol reactions. Even so, they're reportedly poisonous, prompting the new use of bismuth and zinc carboxylates as substitutes. Mercaptides, alkyl tin carboxylates, and oxides are also used in various requests. Tin mercaptides are commonly introduced into water-based formulations because hydrolysis can negatively affect tin carboxylates.

Catalysts are often found to be used in the manufacture of various types of PUR for specific purposes. For instance, novel CuCo2O4 graphitic carbon nitride hybrids were used to mitigate CO formation and reactivity hazards [74]. The responsiveness of such catalysts varies according to their chemical composition. This catalytic activity of two catalysts, tin and zirconium, compared to the processing of isophorone diisocyanate (IPDI), established waterborne polyurethanes [75]. It was discovered that the tin catalyst altered the reactive by the one isocyanate, while the catalyst zirconium did not.

2.5.3. Isocyanates

Isocyanates are essential components in the preparation of PU. They may be classified as heterofunctional or dysfunctional, as well as aliphatic or aromatic, of the various available alternatives, toluene diisocyanate TDI, aliphatic diisocyanates, and methylene diphenyl diisocyanate MDI is the most widely used. Table **3** illustrates the structures of many isocyanates. MDI and TDI are, on average, affordable and more receptive than other isocyanates. Though industrial-sized MDI and TDI are isomers, the majority are made of polymeric materials. These are often used to manufacture flexible foams, including moulded foams for automobile slab stock foam or seats for pallet manufacturing [4]. They could also produce rigid foams, like those used to insulate refrigerators and elastomers (for example, those used in shoe soles). Variation of isocyanates can be accomplished through a partial result by using polyols or adding specific materials that reduce the isocyanates' instability and, inevitably, their toxicity. This can also decrease the freezing temperature, making them easier to treat, as well as an improvement in the characteristics of this material's polymers. The cycloaliphatic isocyanate and aliphatic are also less frequently used isocyanates. These are used in coating and other applications where clarity and colour are desired. That was because aromatic isocyanate-based polyurethanes PUR usually cloud in the presence of light [59]. MDI, H12MDI, IPDI,

Table 3: The Structures of Many Significant Isocyanates [12]

Code	Formation
TDI	 1,6-hexamethylene diisocyanate
MDI	 4,40-diisocyanate dicyclohexylmethane
HMDI	 Hexamethylene diisocyanate
HDI	$OCN-(CH_2)_6-NCO$ 1,6 - hexamethylene diisocyanate
IPDI	 1– isocyanate – 3 – isocyanatomethyl – 3,5,5 – trimethyl – cyclohexane

and HDI are all common aliphatic, including cycloaliphatic isocyanate.

Despite diisocyanates' value, environmental considerations have prompted researchers to look for more effective ways to minimize or potentially eliminate their use, primarily to address environmental concerns and other diisocyanate-associated dangers with toxicity. For instance, a study was conducted to determine the feasibility of producing PUR from carbonated vegetable oils, 3-aminopropyltriethoxysilane, and lignin [76]. The non-isocyanate path included reacting cyclic carbonate through amines [77] and polyol, prepared by oxypropylation of lignin [78]. Another research used polybutadiene oligomeric diisocyanate to make lignin-based PU [74]. 154 A related analysis prepared PUR by reacting a lignin-laminated polyol with diphenyl diisocyanates. Most studies suggested that the lining material primarily determines the characteristics of formulating non-isocyanate-based PUR. The amount of lignin in a substance influences its modulus and cross-linking. The structure in Figure **4** shows traditional synthetic paths.

2.5.4. Chain Extenders

A different group of materials that often contribute significantly to the polymeric structure of PUR is chain extenders (f = 2) and via links (f = 3 at a minimum). There are frequently amine and hydroxyl-terminated molecules with a shallow average mass of a molecule. They are beneficial for optimizing the structure of polyurethane adhesives, fabrics, elastomers, and other essential microcellular materials, including skin foams [40, 79]. These compounds demonstrate elastomeric characteristics owing to the copolymer communication between the soft parts and the hard segments of the polymeric foams. Therefore, the hard segment urethane domain acts as a cross-links during the amorphous segment urethane domains or polyether. This interacting distinction occurs due to the incompatibility and immiscibility of the exact segments (non-polar and low melting) with both the hard segments (both segments are amorphous) (high melting). As a result, phase separation is unaffected by crystallization.

Hard segments made of chain extenders and isocyanate are generally immobile and rigid. In contrast, soft segments made of polyols (molecular masses) can travel freely and frequently perform with foil shapes. The covalent bonding of the hard segments and soft parts prevents plastic movement inside the polymer matrix, resulting in elastomeric resiliency. Deformation of such compounds allows some parts of

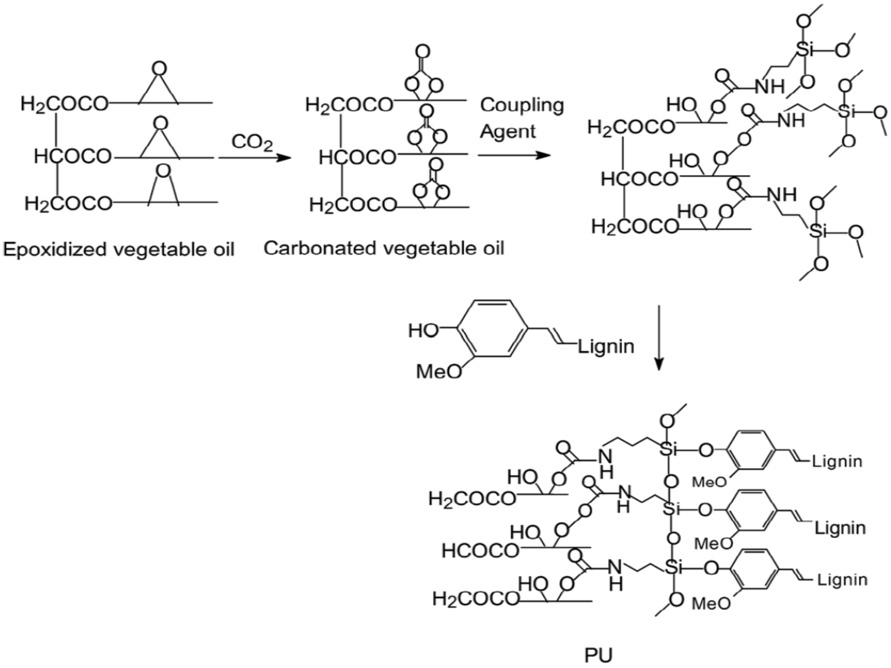


Figure 4: Castor oil and lignin synthesize PU in an isocyanate-free manner.

the strained so section to uncoil, aligning the rough segments in the position of the stress. The reorganization of hard segments, followed by a tight hydrogen bond, results in a material with high tensile energy, tear resistance, and good elongation properties [80, 81]. Proper chain extender selections may also affect the PUR heat resistance, chemical resistance, and flexural properties. Ethylene glycol, cyclohexane dimethanol, 2,2′-(1,4-Phenylenedioxy) diethanol (HQEE), 1,4-butanediol (BDO), and 1,6-hexanediol are several of the more often encountered chain extenders. In Figures **5** and **6**, representatives of biodegradable PUR and their artificial routes are seen using water, including ethylene glycol as long as chain extenders. Such glycols may be used to make thermoplastic polyurethanes (PUR). Additionally, they form excellently hard segment fields that are readily isolated and processable in the melted phase. Only ethylene glycol has been an exception since the related bis-phenyl mixture is vulnerable to unwanted degradation, provided the concentration of hard segments grows excessively [40].

2.5.5. Sufficient Surfactants

Sufficient surfactants are commonly used to strengthen the qualities of foamed and non-foaming polyurethane foam. They are similar to polydimethylsiloxane–polyoxyalkylene block polymers, nonylphenol ethoxylates, synthetic oils, and other organic mixtures. Foams are used in applications to emulsify liquid mechanisms, stabilize cells, and regulate cell size, structures that lead against collapse and vacuum at the subsurface. They are used as anti-foaming and deaeration agents, in addition to wetting agents, in nonfoam applications. Additionally, they may be accustomed to eliminating surface flaws such as peels, sink marks, and pinholes. The surfactants of various types, nonionic [82] and cationic surfactants [83], are ready to form PUR products. Nonionic surfactants demonstrated superior surface activity externally, requiring a fixed critical micelle concentration CMC. On another note, it was discovered that cationic surfactants were obtained preferably for corrosion resistance. There are a few disadvantages to using surfactants in the mixture of PUR. For instance,

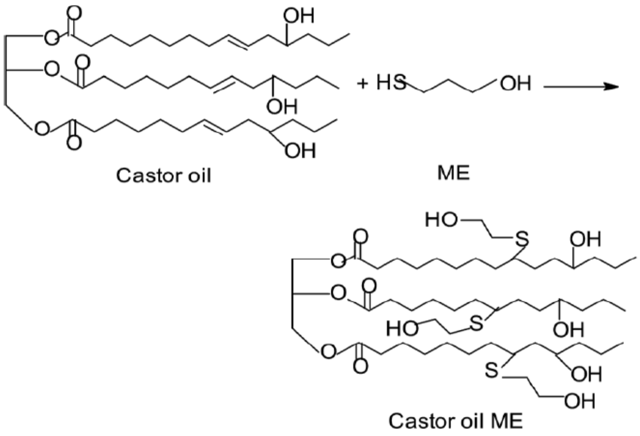


Figure 5: Water is consumed as a chain extender in producing biodegradable PUR.

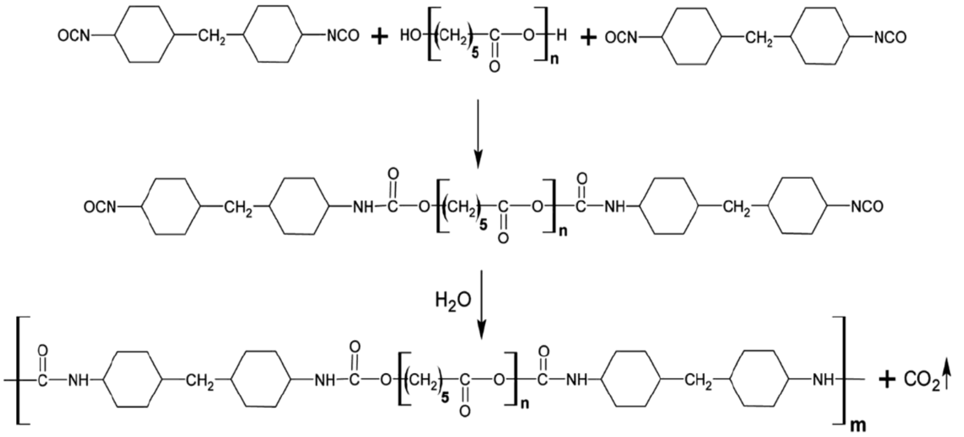


Figure 6: Utilization of ethylene glycol as both a chain extender during the production of biodegradable polyurethane.

traditional surfactants with a low molecular weight behove for delamination and corrosion [84]. Additionally, they readily remain on the surface with PUR materials. As a result, another researcher suggested a surfactant-free PUR [85].

3. TECHNOLOGICAL ADVANCES IN THE SYNTHESIS OF POLYURETHANE FOAM

3.1. Chemistry by Clicking

PUR can be synthesized using a novel reaction method dubbed ‘Chemistry by clicking.’ The technology of Chemistry by clicking is well-known for its ability to synthesize a single substance with high throughput and a high tolerance for functioning groups. There exist several advantages to the click response over other conventional systems. For instance, it has been shown to move fast, be very demanding, operate with heterogeneous or homogeneous systems, be solvent insensitive, and continue at a moderate react temperature.

3.2. Polyurethane Foam Applications: Recent Advancements

Any PUR general physicochemical properties are determined by the character of the reactants, particularly the groups R1 and R2; therefore, it is synthesized. Generally, the characteristics of the polyols, including the quantity of reactive functional groups inside each compound, their molecular weight, and elemental composition, all reflect the final PUR material’s characteristics and intended application. Numerous scientific studies have been undertaken on the development of PU and its future applications. Table **4** summarizes many recently identified PU groups and their synthesis methods.

3.2. Technology in the Field of Building

Modern buildings must adhere to certain criteria for the materials used in their construction, including high-performance, solid materials that are lightweight, simple to install, robust, and flexible. These objectives can be accomplished by incorporating PUR into construction materials. The utilization of PUR has the potential to save natural wealth significantly and benefit the atmosphere by decreasing energy usage. As a result of their unique properties, including excellent thermal insulation capability, a highly attractive ratio of strength to weight, flexibility, and resilience, the use of PUR in construction and architecture applications is increasing. This study aimed to calculate the heat lost using a building enclosure when thermoregulating microcapsules are contained in PUR foam [120]. Research indicated that by adding 41 % microcapsules, it is possible to build a temperature control foam containing two potential benefits: energy collection and transient state insulation.

Additionally, the low cost of such high-performance fabrics and their comfortability have made PUR a permanent feature in many households. PUR can be found in the vast majority of any household area, including floors, for example, in the formation of flexible cushion pads for carpets, and roofing, for example, in the type of heat and materials that have a high degree of reflectivity. In the roofing framework, mostly on PUR surfaces, plastic coatings could help keep a house cool while reducing energy consumption. In general, PUR materials contribute to the flexibility of new homes, especially the entry gate and garage door, which contain foam-cored panels. Additionally, the foam-core boards provide a wide range of colour options and profile options for roofs and barriers.

Table 4: Several Popular Methods for Synthesizing Various Forms of PU

Diverse synthesis techniques	Various forms of PU	References
Cross-linking	Terpene- pus	[86]
Emulsification in two steps	WPUR with a high solids content	[87]
Free rise	PUR foams based on modified tung oil	[88]
Coupling of thiols and enes	PUR derived from aromatic cardanol polyols	[89]
	WPUR derived from vegetable oil	[90]
Following sol-gel synthesis, supercritical CO_2 drying was performed.	PU aerogels	[66]
Polymerization by staged development	PUR formed from secondary amines that are not isocyanate	[91]
One-shot	PUR derived from liquefied lignin	[51]
Prepolymer	PUR derived from vegetable oils and phosphorylated polyols	[49]
	PUR dependent on tannic acid	[92]
	Phosphinated pus	[93]
	PUR that are biodegradable and electroactive	[94]
	UV absorption groups-based WPU.	[95]
	PUR is dependent on isocyanate trimers and polyester polyols	[96]
	PUR conjugated with folate	[97]
	PUR iodo.	[98]
	WPUR with a high solids content	[99]
	WPUR with a hyperbranched form	[100]
	Hybrids of polyurethane and polyhydroxyurethanes	[101]
	Transparent polyurethane films derived from fatty acids	[102]
	WPUR based on polycarbonatediols	[86]
	Polycaprolactone / PUR biodegradable	[103]
	PUR cross-linked with polyrotaxanes	[87]
	Aliphatic polyurethanes that are biodegradable and economical	[104]
	PUR with carbohydrate cross-links	[105]
	A thermoplastic made from rigid spirocetal moieties that are biodegradable	[106]
	WPURs that are environmentally conscious	[107]
	PUR with various branches	[108]
Prepolymerization (one step)	PUR dependent on fluorine	[109]
Isocyanate-free reaction	PU derived from soya beans and lignin	[76]
Prepolymerization (two-step)	PUR dependent on sulfadiazine	[110]
	Polyurethane (PU) focused on cellulose nanofibres	[111]
	PUR derived from cardanol and melamine	[112]
Without the use of a solvent or an emulsifier	Acrylate of fluorinated WPU	[113]
Green solvent	PUR derived from cottonseed and Karanja oil	[114]
Inverse emulsification	PU based on tetraethoxysilane with a side chain and colloidal silica	[115],[116]
Condensation and hydrolysis	WPUR focused on hybrid polyurethane/silica	[117]
Hydroxylation followed by alcoholysis or epoxidation	PUR extracted from jatropha oil	[118]
Following Michael’s inclusion reaction, self-emulsification happens.	PUR derived from medium-chain fluorinated diols	[119]
Microwave-assisted	PUR with cyclodextrin	[63]
Polycondensation	PUR from chitosan	[60]
	PUR dependent on polyester-polyols	[61]
	PU foams with many functions	[60]

3.3. Applications

3.3.1. Applications in Automotive

The automobile industry has various uses for PU. Apart from its widespread application as a foams PUR to improve the comfort of vehicle seats, it can also be used in automobile bodies, doors, bumpers, mirrors, and ceiling parts. Additionally, PUR improves vehicle mileage by reducing weight, fuel economy, effective insulation with adequate sound absorption [121], and enhanced passenger comfort [122], including high corrosion protection. Deng R. asserted that since many automotive seats are composed primarily of foams, users' dynamic comfort can be adjusted by adjusting the foaming property to achieve the coveted quasi-static characteristics [122, 123]. According to reports, PU foams account for the lion's growth of the overall polymeric foam industry [122]. As a result of the low density of polyurethane foams, they're ideal for producing rigid and lightweight parts that can be used as fender liners in ships, structural shapes, for example, ceiling joists, stringers, cores, and turn cores in augmented plastic vessels [122] Numerous other composite materials, fabrics are based on PUR and are used in high-end athletic vehicles, ships, helicopters, and race cars. The PUR content can aid heat shielding, structural stiffness, and energy management during a collision [122]. Polyurethane foam fixatives are also found in car applications such as PU-aluminium laminates [124]. Polycaprolactone polyols, a combination of cycloaliphatic diisocyanate and aromatic, are used to make these adhesives. The PU structure determines the adhesion characteristic. Coatings are an essential part of vehicles and can also be prepared using PU. The advancement of new technologies in the field of nanofillers or nanoparticles has the potential to significantly improve the performance of PU-based innovative protective coatings for automobiles. Verma *et al*. [125] developed a preferential similarity between the hard segments of three polyurethane foam chains and fillers by showing that intercalate and moisturized clay blood platelet has a discriminatory interaction by the hard segments of the PUR chains [125]. Additionally, the distribution and structure of clay may be used to assess the most efficient interfaces for PU chains.

3.3.2. Applications in Marine Environments

PUR materials have made important contributions to recent advances in boat engineering. Epoxy resins based on polyurethane foam help shield boat hulls from the elements, rust, water, and other materials that contribute to drag. Additionally, durable polyurethane foam helps insulate vessels from noise and elevated temperatures. It leads to improved tear and resistance properties and has excellent load-bearing characteristics even at low weight. On this basis, maritime companies often integrate a variety of thermoplastic PUR inside a range of products as a result of their unique properties, which include elasticity, resilience, and simplicity of handling, making them ideal for cable, hydraulic seals, drive belts, wire coatings, engine tubing, hoses, and engine tubular, along with shipbuilding. Certain PURs can also be used to recognize specific active materials [126] and remove specific organic compounds from bodies of water. Cyclodextrin PUR, for instance, effectively removes certain organic compounds from water, paraben [127]. Recently, cyclodextrin PU was synthesized using a microwave-assisted method. The substance was completely characterized utilizing 13C and 1H NMR spectroscopy and determined to be dissolvable in organic compounds but unsolvable in water. As a result, the synthetic PU was determined to be good at extracting phenol and Nile red ink underneath the water. It was also projected for potential use in eliminating hazardous chemicals from the atmosphere [128]. Similar research has shown that iodo PUR is effective at extracting dyes. For instance, blue aniline and crystal violet were extracted and derived from laundry sewage [98].

Speed-up weathering or material ageing studies are important for maritime applications. Swelling, wear properties of the fillers, plasticization, hydrolysis, and lack of mechanical resistance are all potential consequences of these conduct analyses [129]. Several methods exist for quantifying output processes in touch seawater or water over time. ISO norm analysis procedure 11345, accelerated ageing can be conducted at elevated temperatures in conjunction with applying the Arrhenius equation to ascertain the association between the material's activity at low temperatures or over an extended period. Occasionally, lifespan estimation can be accomplished using a linear extrapolating of the fixed period. Over two to five years, analysis was undertaken to observe the competitive advantage through high PUR materials in seawater and unfavourable conditions [76]. The results showed that the structural strength could be preserved underwater in the cells at 100 % for the specified time of immersion. This indicated that the PUR material could contribute to the mechanical stability of merchandise even when exposed to adverse environmentally friendly conditions.

3.3.4. Applications of Coatings

In recent years, ongoing testing has been conducted to determine the most suitable formulations for coating requests. The ability of PUR as the draw and ground materials has been widely documented [130, 131]. Some non-linear hyperpolymers formed in this field have transformed into particular PUR with shine, versatile coating and high solubility properties [132]. However, studies in the literature indicate that the majority of synthesized polymers are unable to survive re-emerging due to their lack of flame-retardant properties. Nitrogen, phosphorus, or halogen can be introduced into these hyperdrive materials to adjust them for some flame-retardant coating applications [131, 133]. Tris (bisphenol A) monophosphate was recently reacting with polyethylene glycol, including castor oil, utilizing a variety of diisocyanates, comprising toluene diisocyanate, isophorone diisocyanate, also hexamethylene diisocyanate. Extremely flame-retardant hyperbranched polyurethane foam was synthesized and considered ideal for nanocoatings and nanocomposites [108]. Another study used a two-step, form one-pot, and pre-polymerization method to create a dependent on hyperbranched castor oil-based PUR that demonstrated a beautiful potential for application as high-tech materials for surface coatings [134]. Another coating-appropriate material for marine antifouling was synthesized using polyester-based polyols. Trimethylolpropane and pentaerythritol were used as initiators, and polycondensation ε-caprolactone 97 % was carried out using the cross-linking agent hexamethylene diisocyanate. Additionally, the synthesized antifouling coating compound was determined to be extremely biodegradable [135]. PU has also been synthesized from fatty acids [68, 102], soybean, polyester polyols, and lignin isocyanate [102] trimmers in recent years for coating utilization [96].

3.3.5. Application in Medicine

PUR is used in various medical uses, including but not limited to particular tubing, catheters, surgical drapes, hospital bedclothes, and surgical gloves. Their use in these applications because they are readily available, have favorable physical and mechanical properties, and are biocompatible [136, 137]. However, short-period implants are the most often used. Incorporating PUR into medicine-related applications increases cost-effectiveness and gives sufficient space for longevity and material toughness [138]. This characteristic enables using polymeric substances instead of more traditional materials like metals, metal alloys, and ceramics. In 2012, the overall demand for bio-based PU was 1,5 tonnes [18]. The resulting polyurethane contains between 30% and 70% biological base material, depending primarily on the form of bio-based raw material used to manufacture the polyols. The worldwide polyols industry hit approximately USD 45.17 billion by 2025, rising at an annual rate of 8.5 % [139]. The demand for bio-polyols is currently valued at USD 5 billion. A recent report by Inc. Grand View Research San US reported that the global biological base polyurethane industry is projected to hit 2021 at 37.5 million USD, representing less than 0.07 % of the overall PU market [140].

One analysis synthesized biodegradable PU using crystalline polymers and water following a chain extending. The structure of the samples PU was related to those obtained utilizing ethylene glycol, such as a chain extending in a polyaddition react. It can be shown that the original material improved in terms of mechanical and corrosion properties and has also been found to be ideal for use as an ingredient in joint endoprostheses. The full synthetic tracks for biodegradable PUR using water and ethylene glycol for chain extending are seen in Figure **7**.

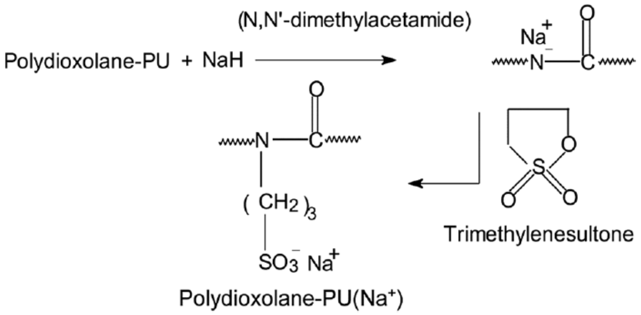


Figure 7: Sulfonic ionomer synthesizing [10].

Biocompatibility is another essential prone polyurethane ionomer. Blood compatibility PUIs have been developed using phosphatidylcholine pairs and sulfonate [141, 142]. Li *et al*. It discovered that segmented PUR and poly (urethane-ureas) had increased haemocompatibility compared to medical-grade PU [142]. These products have been successfully used in several medical uses, including artificial lungs, conduit tubing for hemodialysis tubes, and cardiac pacemakers [143].

Recently, researchers studied the appropriateness of carbohydrates inside biomedicine instruments. Biocompatible and biodegradable PUR based on castor oil is produced through polypropylene glycol, as is that of polyol, in addition to various cross-linked carbohydrates [105]. The characteristics of the synthesized PUR were studied, and it was discovered that the addition of carbohydrates affected the material's thermal, degradation, and mechanical characteristics right to the diversity of carbohydrate structures [144]. The results of the characterizations indicated that carbohydrates were ideal components for biocompatible and biodegradable PUR. As a result, this technique may be applied to creating such biomedical instruments [105]. This study corroborates previous findings that mixing transformed starch in addition to cellulose crystals through PUR will improve their biocompatibility, biodegradability, and mechanical properties [145, 146]. Additional research on the suitableness of PUR for medical equipment can be established in the literature, especially about work detailing the construction of an inexpensive, biodegradable aliphatic PUR with high saline permanence to rise to approximately 37 °C free a substantial loss of mechanical power [104] Additionally, additional studies focusing on medical applications were conducted, including those on a Chitosan-based PUR with antibacterial possessions [147] including biodegradable electroactive PUR for cardiac regenerative medicine [94]. According to this scientific research on the pharmaceutical properties of PUR, it was discovered that most of the substances frequently generated perform only moderately well, significantly concerning resistance to bacterial adherence. This is a result of the majority, for their part, being vulnerable to bacterial invasion, posing an infection risk [147]. As a result, novel methods for developing antibacterial PUR have become important. These may be accomplished by including surfaces capable of resisting or repelling bacterial attachment to the substance surface [147]. These bacteria-resistant surfaces may be developed by applying an antibacterial covering or by modifying the surface characteristics of the substance to improve their anti-biofouling or antibacterial properties.

3.3.6. Applications of Appliances, Flooring, and Packaging

Nowadays, the majority of household appliances are developed with PUR. Rigid PUR foams are the most responsive due to their ability to be used as thermal insulation for refrigeration systems. These matters have become indispensable because of their affordability, making them ideal for use mostly in freezers and refrigerators to achieve the requisite energy ratings. The benefits of rigid PUR foams for this equipment are owing to the mixture of fine foams and cell gases with such a closed-cell arrangement structure that aids in heat transfer prevention.

PUR has a variety of uses in the flooring industry, including top coatings and carpet underpayment foams. They will contribute to the durability, aesthetics, and alleviation of maintenance of floors. Carpets' longevity and semblance can be extended using PUR foam production, which often contributes to improved comfort and decreased environmental noise. PUR-based barrier finishes could also provide solvent, floor coatings, and abrasion protection while being easy to clean and maintain. Apart from those characteristics, the lifespan or service duration is often important to remember.

A PU can also be used in packaging applications as an impression ink or as packing foams. For packaging requests, a PUR plasticizer was made from castor oil and triolein [148]. This PUR plasticizing resin demonstrated excellent freeze and mechanical resistance. On the other hand, PU packing foams (PPFs) have a variety of packaging solutions that can help solve most on-site packaging problems. Additionally, the flexibility of these PUR foams has been investigated for the cost-effective packing of products that need extra safety during transit, such as surgical devices, electronics, significant computer parts, and fragile glassware. Additionally, custom packing materials have been provided for nearly all PU-based shipments.

3.3.7. Applications for Clothing

Initially, after PU was established to stay a strong fibre for clothing, it was turned into thin togs and inserted within nylon to make stretchy, lightweight garments. Recent technical advancements also resulted in the production of improved spandex fabrics and elastomers thermoplastic from PUR. Through the advent of PU manufacturing methods, manufacturers can now create a vast array of PUR-based leather and manufactured hides that can be used for various sports apparel and accessories. Amongst the PUR groups, water-soluble WPU dispersion has been commonly used in textile-related applications [95]. Permeability, the unique composition of her molecules, abrasion tolerance, and softness all contribute to WPUs' suitability as finishing agents.

Additionally, by utilizing WPUs as dye-finishing agents, the crock fastness, wash fastness, and soap stronghold of acid dyes, reactive dyes, and basic colourants on the dyed framework can be significantly increased [149, 150]. Recently, absorption spectra groups were integrated by half WPU to improve the material's usability, UV safety, and rubbing resistance. Additionally, it was designed to ensure the WPU's wrinkle recuperation angle was retained. As an ultraviolet absorber, benzyl-dodecyl-dimethylammonium bromide was utilized [95]. The substance was established to have excellent UV dyeing security of cotton cloth and to be adaptable to various other textile applications [95]. In another analysis, the small particle size of chitosan has now been used to stretch the chain of the PUR prepolymer, resulting in chitosan PU dispersion [151]. This scattering was applied to various types of poly-cotton, dying, and printing cloth to increase stiffness, resistance, and mechanical characteristics. This method was proposed to enhance the consistency of pure thread and woollen framework.

3.3.8. Applications of Wood Composites

PUR is a critical component of various modern products, particularly wood composites. Lately, PU-based dull composites with active carbon have been prepared for EMI shielding [152]. Multiple quantities of active carbon were charged into PUR for thermal conductivity and complicated permittivity measurements. The findings demonstrated the composites' suitability in place of polyethylene and polyester-based fabrics packed with metallic additives. Related research prepared PU wood composites using timber wastes and polyols [153]. The polyols are synthesized chemically from polyethylene terephthalate and commercially available polyols. Glycolysis was used to alter PET chemically. Although efficient load transfer from that matrix for the distributed phase was observed, no change in thermal stability was observed. However, PET-derived materials have been modified to have a range of molecular weighting and physical properties. These modifications were related to several variables, including the glycerol, the reaction conditions, and the molar proportion of the reaction [154]. Using natural fibres or wood in PU-based composite materials is important because they're hydroxyl-rich fabrics that readily chemically bind with diisocyanate [155]. According to the results, monocrystals CNC been combined with high-solid-polyurethanes (PUR) in a tiny volume (0.5 wt. %) to increase the glass transition 76 °C and Young's modulus at 1.50 GPa, and abrasion resistance, among other properties [156] Throughout the polymerization step, covalent bonding between both the PUR chains, also CNC was verified.

4. LITERATURE REVIEW

The exploration of polymeric foams' structure, properties, and performance has been a focal point of research within materials science, given their extensive applications in various industries such as automotive, aerospace, packaging, and construction. The unique characteristics of polymeric foams, including their lightweight, high strength-to-weight ratio, thermal insulation, and energy absorption capabilities, make them invaluable in engineering and technological advancements. This literature review delves into recent findings and methodologies in the study of polymeric foams, drawing upon various scholarly sources and academic databases.

Recent advancements in the fabrication of polymeric foams have led to the development of materials with tailored porosities, cell sizes, and distributions, significantly impacting their mechanical and thermal properties. The work by Srivastava *et al*. highlights the influence of manufacturing techniques such as freeze-drying, gas foaming, and supercritical fluid technology on the microstructure and, consequently, the mechanical behaviour of polymeric foams [157]. These techniques allow for precise control over the foam's architecture, enabling the design of foams with specific properties for targeted applications [158]. The relationship between the microstructural characteristics of polymeric foams and their mechanical properties has been extensively studied. The size, shape, and distribution of cells within the foam significantly affect its modulus, strength, and toughness. De Souza and colleagues' research provides insight into how the cellular structure governs the deformation mechanisms under various loading conditions [159]. Their findings suggest that manipulating the cell morphology can enhance the foam's impact resistance and energy absorption capabilities, which are critical for applications in protective gear and energy-efficient structural components.

Thermal insulation is another critical property of polymeric foams, with applications ranging from building insulation to cryogenic storage. The thermal conductivity of polymeric foams is intricately linked to their cell structure and the presence of gas fillers. Recent studies have shown that introducing nano-fillers such as graphene oxide and carbon nanotubes can significantly reduce the thermal conductivity of foams, making them more efficient insulators [160]. This line of research opens up new avenues for developing high-performance insulation materials.

The durability and environmental performance of polymeric foams are also paramount, especially considering the growing concerns regarding sustainability and environmental impact. Biodegradable and bio-based polymeric foams have emerged as a promising solution, with research focusing on polymers derived from renewable resources and the development of foams that can degrade under specific environmental conditions [161]. These materials reduce the dependency on fossil fuels and mitigate the issue of plastic waste.

In conclusion, polymeric foams are witnessing rapid advancements, driven by the need for lightweight materials with high mechanical performance and thermal efficiency. Future research directions are likely to focus on developing sustainable foam materials, exploring novel fabrication techniques for finer microstructural control, and integrating smart functionalities into foam structures for adaptive and multifunctional applications.

5. CONCLUSION

Polyurethanes (PUR) are among the planet’s most widely used, flexible, and extensively studied materials. They integrate the resilience and hardness of metals through the suppleness of caoutchouc, making them perfect for use in a diversity of manufactured goods in place of metals, rubber, and plastics. They must be integrated into a diversity of different types of manufacturing equipment and used to manufacture a diversity of different products, including paints, elastomers, liquid coatings, elastic fabrics, even integral skins so, rigid insulation, and versatile foams. PUR can be synthesized using a combination of diisocyanates, polyols, additional chain extenders, and cross-linking agents. This makes it possible to manufacture diverse customized products suitable for diverse specialized applications. Initially, most polyols utilized to produce PUR were extracted from petroleum. Still, rising prices, energy needs, and environmental considerations have raised the need for a most appropriate and environmentally sustainable alternative. This has recently resulted in a surge of industrial and academic interest in alternative energy sources, such as vegetable oils. The decade has seen an overwhelming number of research published on using vegetation oils as a substitute for petroleum-based materials in PU processing.

Nevertheless, there are several drawbacks to these types of materials, most notably in terms of durability. It has been proposed that using nanostructures may have additional benefits for favourable results. As a result, the integration of nanoparticles capable of substituting for account hard segments in isocyanate harbinger has been extensively studied. As a result, materials, including carbon nanotubes, carbon nanofibres, and clays, are generating considerable interest as potential additives to PUR products. Thus, PUR is less toxic to the atmosphere and more cost-effective than other traditional polymers.

CONFLICTS OF INTEREST

The author added that the study was conducted without any business or financial arrangement that can be viewed as a possible conflict.

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AUTHOR CONTRIBUTIONS

Boumdouha Noureddine: Formal analysis, Writing - Original Draft Preparation, Funding acquisition, Resources, Writing - Review and Editing, Software, Investigation. Duchet-Rumeau Jannick: Data Curation Conceptualization and methodology. Gerard Jean-François: Review & Editing, Project administration, Supervision, visualization. All writers approved the final manuscript.

DECLARATION OF COMPETING INTEREST

The authors state that they have no known conflicting financial interests or personal ties that might have influenced this study.

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