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Polyurethane as a versatile polymer for coating and anti-corrosion applications: A review

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ABSTRACT

The development of polyurethane materials and process optimization are currently the subjects of extensive study. Polyurethane is characterized by high physicochemical and operational properties. Polyurethanes have high wear resistance, and oil and gasoline resistance. They have excellent thermophysical and elastic properties. This allows the use of polyurethanes in many industries where materials with high-performance properties are required. Polyurethanes are widely used in many industrial applications, protective coating manufacturing, and anti-corrosion agent applications. A significant number of studies have been conducted to improve the physical, mechanical, and operational properties of polyurethane polymers, in particular the anti-corrosion properties of modified polyurethane coatings. The properties of polyurethane polymers for various applications can be improved by changing monomers and their ratios and the process of preparations. Preparation of polyurethane polymers based on polyols and isocyanate monomers using a polyaddition process in the presence of a catalyst as well as solvents including toluene, xylene, and acetone. There are different factors affecting the physical and mechanical properties of polyurethane polymers were investigated by different techniques. The factors were types of isocyanates, polyols, OCN/OH ratios, solvents, catalysts, and temperatures. Generally, the polyols are responsible for the flexibility of the polyurethane polymers and isocyanates are responsible for the rigidity of the polyurethane polymer and crosslinking between the backbone of the polymer. Because of the flexibility of its chemistry, they may modify the coating's characteristics based on the intended use. The effects of different polyols and polyisocyanates' chemistry are assessed. The hydrophobicity, thermal stability, and mechanical and anti-corrosion properties of polyurethane polymers were investigated. As a result, the properties of polyurethane polymers such as hydrophobicity, thermal stability, and mechanical and anti-corrosion properties were all enhanced when all the above factors. An outline of the most modern, financially successful methods for creating protective polyurethane coatings and using them as anti-corrosion agents is given in this review article.

Keywords: Polyurethane, coating, anti-corrosion, polyols, polyisocyanates.

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Introduction

Several years ago, the coating industry used various polymers to manufacture a wide range of coating goods such as acrylic, epoxy, alkyds, polyurea, and polyurethane. Polyurethane was created via polyaddition polymerization of several formulations containing isocyanates and polyols [[1], [2], [3]]. Additives were also applied by the method and product type. They were made without solvent using different isocyanate monomers such as aliphatic and aromatic, and different polyols such as polycarbonate, polyester, and polyether since their toxicity polluted the atmosphere and harmed the ozone layer.

The primary purpose of this review is to screen and adapt prepolymers based on aliphatic and aromatic polyurethane polymers for industrial coatings, particularly anti-corrosion coating. These prepolymers will be environmentally sustainable and have the greatest physical properties. The project will focus on the development of anti-corrosion coatings based on polyurethane prepolymers, both aliphatic and aromatic. An

alternate isocyanate and hydroxyl ratio should be studied to produce the desired product. When combined with additives such as fillers, thickeners, plasticizers, and crosslinking agents, the product produces the appropriate anti-corrosion coatings for pipeline applications. The current study aimed to develop the technology and find the materials and polymers that play important roles to reduce or prevent the corrosion rate of metals.

Polyurethane

Polyurethanes (Pus) are one-of-a-kind polymeric materials with a wide range of physical and chemical characteristics that have been employed in a variety of applications, including foams, coatings, adhesives, and thermoplastic elastomers [[3], [4], [5], [6], [7], [8]]. Material selection, polymer design, production conditions, and application procedures can all be used to create PUs. Polyurethane chemistry is based on isocyanate reactivity toward hydroxyl and amine groups. The isocyanate group's reactivity is

attributed to the positive charge of the carbon atom in the N=C=O group's cumulated double-bond system, as seen in Figure 1.

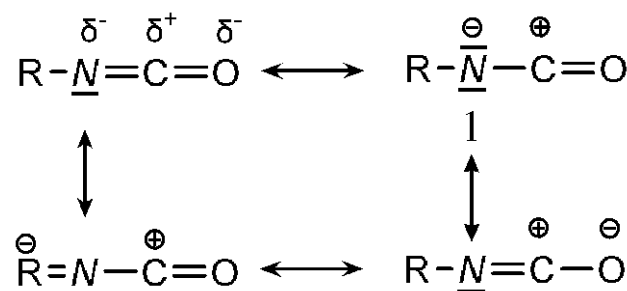


Figure 1 - Resonance structure of the isocyanate group

Isocyanates react with all molecules containing "active" hydrogen atoms, including water, hydroxyl, and amine groups, at temperatures ranging from 60 to 90 °C depending on catalyst type and concentration [9]. The exothermic, reversible process produces urethane. Polyurethane polymers or polyurethane-polyurea polymers containing both urethane and urea groups are used to make PUs, which are created by polyaddition reactions of polyols, polyisocyanates, and polyamines, as illustrated in Figure 2. Polyisocyanate is a molecule that has two or more isocyanate functional groups, while polyol contains two or more hydroxyl groups [10]. Because urea groups are known to interact via bifurcated hydrogen bonds, they are good functionality for usage in hard segments of thermoplastic elastomers. Compared to urethanes and amides, they have a stronger hydrogen bond. Poor melt processibility and insufficient solubility in organic solvents are two disadvantages of these elastomers, though. The temperatures at which urea segments melt or soften are significantly greater than their thermal breakdown temperatures due to the extremely strong bifurcate hydrogen bonding between urea groups.

As illustrated in Figure 3, more "active" hydrogen atoms are present in the urethane and urea groups that are produced, and these groups can react with isocyanate to produce allophanates and biurets.

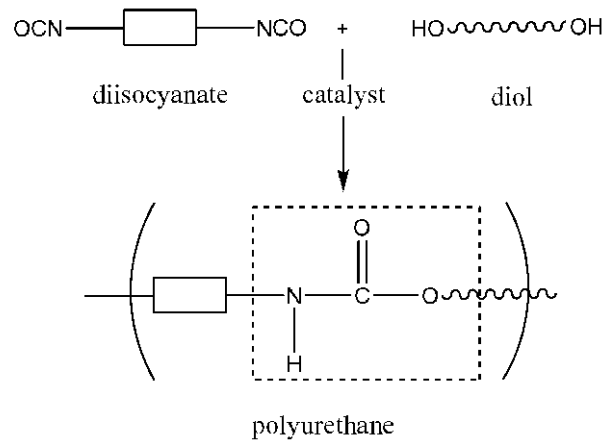


Figure 2 - Polyaddition reaction between diisocyanate and diol

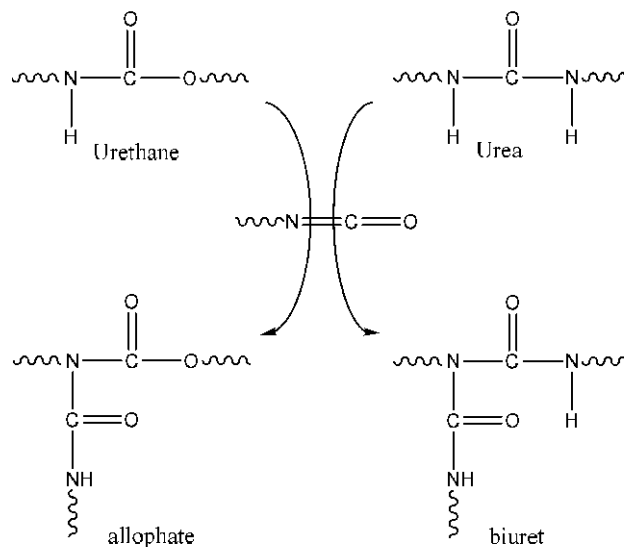


Figure 3 - Urethane and urea groups reacted with isocyanates

Polyols and additives like catalysts, cross-linkers, and polyisocyanates—which produce the polymer's hard segments—make up the raw ingredients for polyurethanes. The polymer's soft segments are inexorably formed by the transistor.

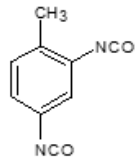
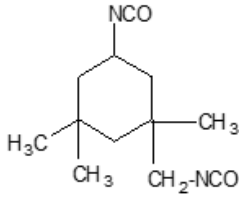


Polyisocyanates

The primary products needed to create polyurethane polymers are isocyanates containing two or more functional groups [11]. PUs' cost and quality are determined by the kind of diisocyanates used, such as aliphatic and aromatic dimethyl cyanide. The bulk of diisocyanates produced worldwide are aromatic isocyanates, despite their low UV resistance. However, because of their strong UV resistance, aliphatic and cycloaliphatic isocyanates are also crucial for the production of

polyurethane materials for outdoor applications. Aliphatic isocyanates are strongly advised. This is because the reactivity of an isocyanate group with an aromatic connection is much higher than that of an aliphatic one. The lower cost of aromatic isocyanates compared to aliphatic isocyanates is another consideration. Isocyanates are distinguished by the percentage of NCO content and their functionality, which reflects the number of NCO groups present in a molecule. Table 1 lists the most regularly utilized isocyanates in the manufacturing of polyurethanes.

The authors studied the properties of segmented PU produced from various diisocyanates [12]. Using 4,4'-diphenylmethane diisocyanate (MDI), 2,4-toluene diisocyanate (TDI) and its isomers, hydrogenated 4,4'-diphenylmethane diisocyanate (HMDI), and 1,6-hexane diisocyanate

Table 1 - The most prevalent diisocyanates used in the manufacturing of polyurethane

No.	Chemical name	Abbreviation	Structure
1	toluene -2,4 -diisocyanate	TDI	
2	Hexamethylene diisocyanate	HMDI	OCN — C ₆ H ₁₂ — NCO
3	Isophorone diisocyanate	IPDI	
4	4,4'-Methylene bis phenylene diisocyanates	MDI	OCN — Ph — CH ₂ — Ph — NCO
5	Cyclohexane-1,4-diisocyanate	CHDI	
6	p-Phenylene -1,4 -diisocyanate	PPDI	

(HDI), they discovered that the diisocyanate structure had a significant influence on the mechanical characteristics of the PUR.

They explained that the hard segment's symmetry and chemical makeup were to blame for the impact. Based on variations in the interatomic bond type, Caraculacu et al. [13] established a new general categorization of many probable isocyanate addition methods. Beginning with the most recent developments in physicochemical techniques, new information was discovered about the structure of isocyanates and the various hydroxyl compound relationships that resulted from additional procedures. It was discovered that the symmetrical diols' intramolecular hydrogen bonding significantly influenced the two OH group reactivities.

Polyols

Alcohols having several hydroxy groups are known as polyols, and they are the main reactants with isocyanates. These substances are characterized by their hydroxyl number (OH number, in mg KOH/g), which is inversely related to molecular weight. Based on their chemical makeup,

polyols can be categorized as acrylic, polyester, polyether, or polycarbonate polyols. Polypropylene glycol (PPG), polyethylene oxide, or polyethylene glycol (PEG), and polytetrahydrofuran, or PTMEG, are the three categories into which polyether polyols fall. Polyols come in mixed aliphatic-aromatic and aromatic forms, as well as in both aromatic and aliphatic forms [14]. When compared to isocyanates, polyols typically have relatively low toxicity. The common polyol types are seen in Figure 4, with each type identified by its backbone structure. Nowadays, polyethers form the basis for over 75% of the polyols used to make polyurethane [15].

The final product's characteristics, polyurethane polymers, are greatly influenced by two essential properties of polyols: functionality and equivalent weight. The average number of functional groups that react to isocyanate in each polyol molecule is known as polyol functionality. The following definition of polyol equivalent weight is applicable:

Equivalent weight = Molecular weight of polyols/functionality of polyols = 56100/hydroxyl number

The hydroxyl number (mg KOH/g) is the number of milligrams of potassium hydroxide present in one

gram of polyols [16]. Acrylic polyols are typically employed in high-performance applications that need UV stability. Acrylic polyols are used in polyurethane coatings for automobile finishes because they are chemical resistant and long-lasting. The chemical composition of the monomers employed in acrylic polyol-based PU coatings has a significant impact. Figure 5 is an example of an acrylic polyol reaction preparation.

Polyols provide flexibility to the network chains' backbone, which is why they are referred to as soft segments or domains in PUs. Polyether polyols are the byproducts of a reaction between alkali initiators and monomers such as ethylene oxide and

propylene oxide. Polyols utilized in polyurethane production are hydroxyl-terminated long-chain macroglycols with varying molecular weights [17]. The structure of polyol is an important aspect in determining polyurethane characteristics.

Polyols can be made from epoxy resins that have secondary hydroxyl groups [18]. Special silicone resins are ideal for heat-resistant PU coatings. Vinyl polymers, alone or in conjunction with other polyols, can be utilized efficiently as polyols. Vegetable or plant oils, such as castor oil, linseed oil, tall oil, and others, can also be utilized as polyols. Because coal tar includes many groups containing active hydrogen, it may also be utilized to make polyols.

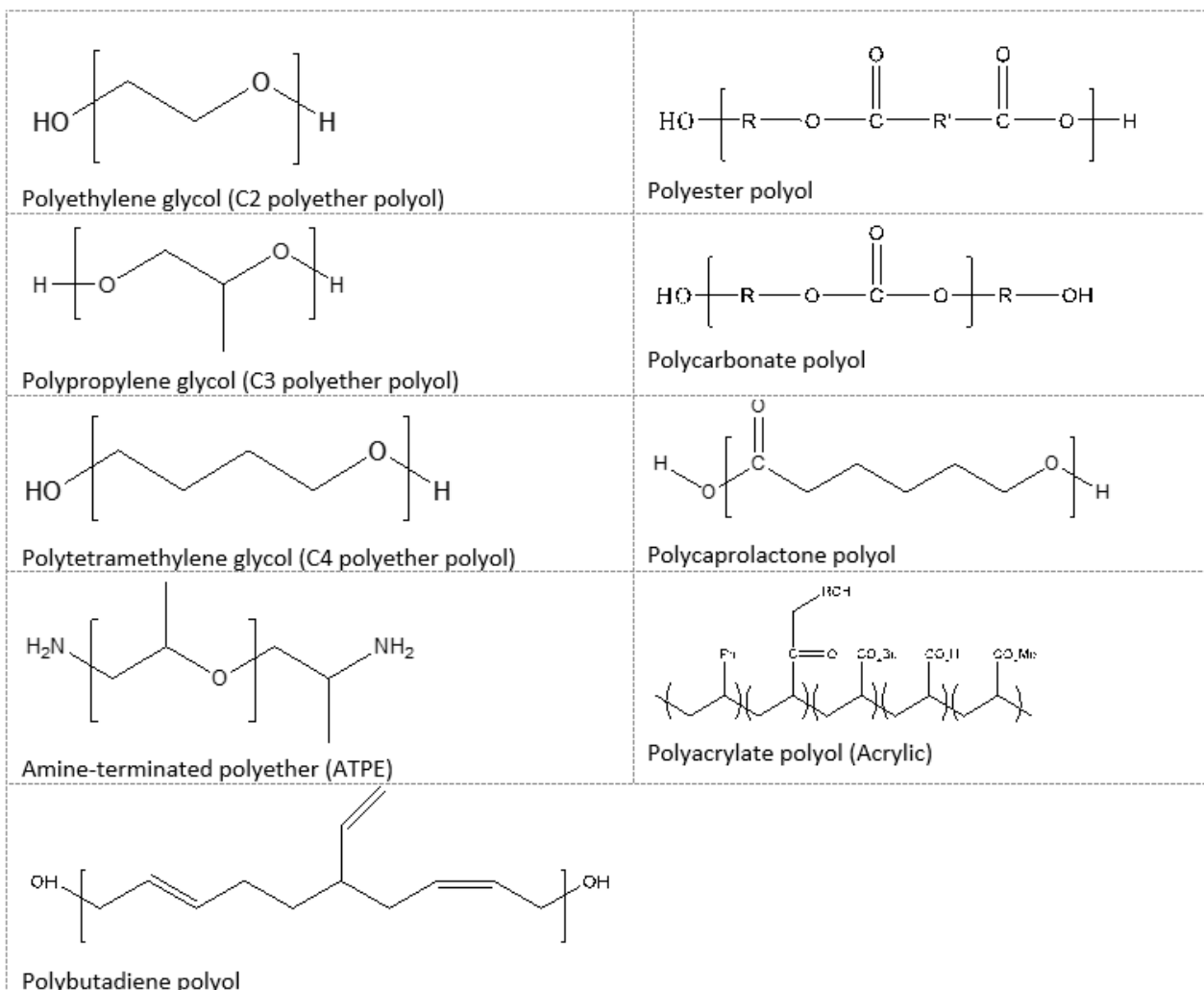


Figure 4 - Common polyol types

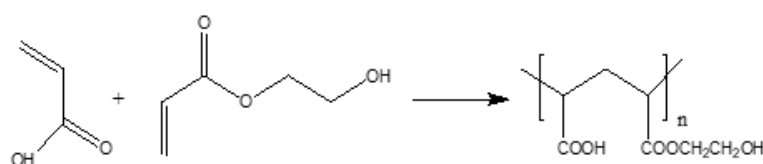


Figure 5 - Preparation of acrylic polyol

Polyester polyols can be made using a variety of methods, including polycondensation of hydroxyl acids or diacids and diol or ring-opening polymerization of lactone. Polyester produced from a combination of two or more diacids reacting with various glycols is a popular commercial product [[19], [20]].

The invention describes polyester polyols with an average equivalent weight between 200 and 4,000. These polyols are made by reacting alpha and omega dicarboxylic acids with butane 1,4-diol, hexane 1,6-diol, propane 1,3-diol, or pentane 1,5-diol. The resulting polyols with three to six hydroxyl groups are then used to create PUR pourable elastomers with enhanced resistance to hydrolysis [21].

The molecular weight and structure of soft segments also affect polyurethane shape. Typically, soft segments with average molecular weights of 1000–5000 are used in the manufacturing of thermoplastic polyurethanes. Phase separation is greater in polyether urethanes than in polyester urethanes due to the reduced compatibility of the polyether soft segments with the polar hard segments.

Both polyester urethane and polyether exhibit changes in characteristics as soft segments' molecular weight is increased. The impact of increasing the molecular weight of the soft segment on the microphase separation and viscoelastic characteristics of polyester polyurethanes was investigated by Velankar and Cooper [22]. DSC, SAXS, and rheology were used to describe a range of polyester urethanes with variable block lengths (soft segment MW = 830, 1250, 2000, and 3000) and constant composition (soft segment \approx 50 wt%). PUs made with SS MW 830 and 1250 were single-phase materials, according to DSC and SAXS data.

These two PUs exhibited rheological behavior that was similar to homopolymer melts and reasonably consistent with Rouse's theoretical predictions. The amount of microphase separation increased gradually with SS MW, according to DSC, SAXS, and rheological study (Time Temperature Superposition) for PUs with SS MW 2000 and 3000. Furthermore, a substantial relationship between soft segment length was observed for both the relaxation time and the Newtonian viscosity.

Korley et al. [23] investigated the effects of crystallinity in the soft segment phase, which is made up of polyether soft blocks with varying inclinations toward crystallization. The authors of this work looked at the morphology and mechanical behavior of a range of polyurethanes with different

hard segment contents that contained PEO (1000 and 4600 g/mol) and PEO-PPO-PEO (1900 g/mol) soft segments. In comparison to polyurethanes including PEO-PPO-PEO soft segments, it was shown that toughness was enhanced and the storage modulus of polyurethane below the T_m of the soft block was raised by soft segment crystallinity in PEO (1000 g/mol). The results of the study demonstrated that organized soft segment areas, which dissipate energy and contribute to the overall deformation process, not only provide extensibility but also reinforce the polyurethane matrix during the process.

Strictly speaking, the urethane process is catalyzed if the catalysts raise the rate of reaction without getting consumed themselves. The most often utilized catalysts are tertiary amines, such as tetramethyl butane diamine (TMBDA) and 1,4-diazo bicyclo (2,2,2)-octane (DABCO), and organo compounds, such as dibutyl tin dilaurate (DBTDL).

A segmented structure with flexible, polyol chains, and rigid segments, as well as segmental length, crystallizability, intra- and inter-segment interactions like hydrogen bonding, overall compositions, and molecular weight, are the characteristics of polyurethane resins [24]. Polyurethane has unique mechanical, thermal, and elastomeric qualities because of its hydrogen-bonding architecture. Because of its flexible chain and lower glass transition temperature than room temperature, the polyester section is referred to as the "soft segment." Instead of a covalent bond being chemically cross-linked, polyurethanes include a large number of hydro gross linkages, which allow them to rearrange upon mechanical deformation [25]. After the tension is released, the hydrogen bond reorganizes and regains its deformation strength. Urethane coatings have a limited capacity for self-healing due to intermolecular hydrogen bonding. This characteristic makes it possible to create polyurethanes that are resistant to solvent swelling and abrasion. Foams, coatings, adhesives, and thermoplastic elastomers are just a few of the applications for polyurethane, a special polymeric substance with a broad variety of physical and chemical characteristics (1–10). Polyurethane holds a prominent place in various applications, particularly in the coating sector, due to its high-quality coating layer that exhibits resistance to solvents, weather stability, and mechanical qualities. The polyurethane coatings industry comprises two main systems. One is referred to as a one-component (1K) system, where the substrate is

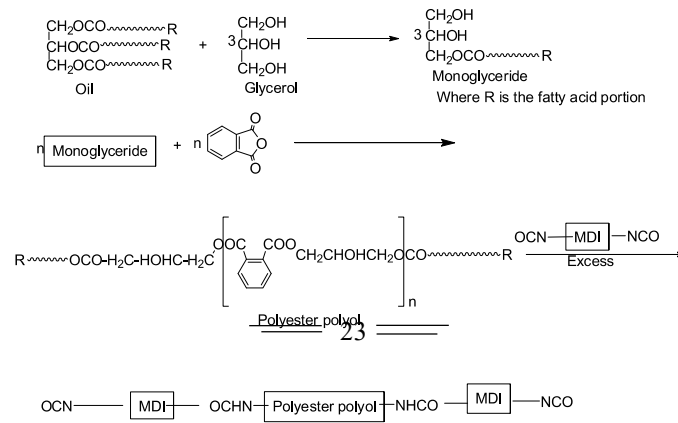


Figure 6 - Reaction sequence of the preparation of polyurethanes

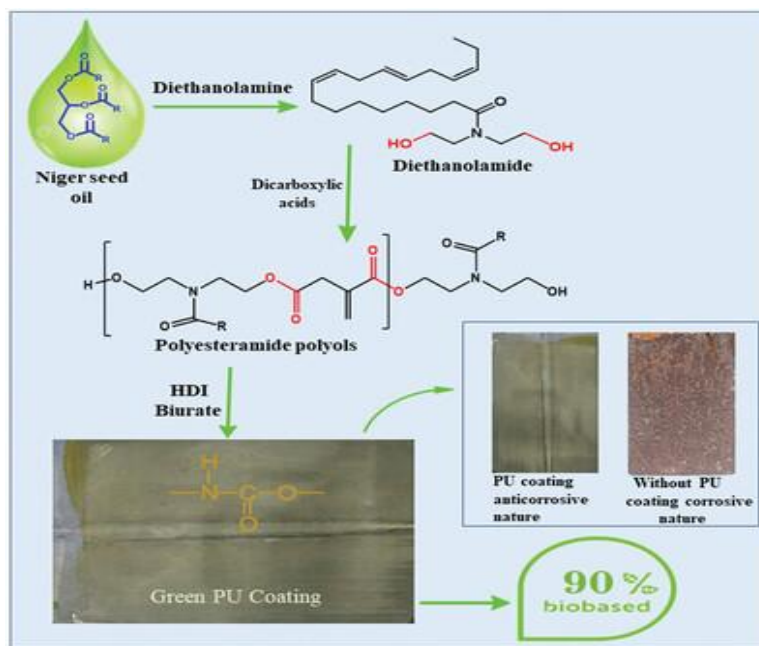


Figure 7 - Green PU coating from Niger-seed oil

physically cured after being covered with high molecular weight polyurethane. The other system consists of two components, hydroxyl functional polymers, and polyisocyanate hardeners with an ng NCO group.

To create monoglycerides, polyester polyol was made using esterified soybean oil and a glycerol:1:3 molar ratio [26]. Polyester polyols were created using a ratio-based reaction between the produced monoglycerides and phthalic anhydride. To create polyester–polyurethane coatings, PU prepolymer (Figure 6) was created by polyaddition reaction of diphenylmethane diisocyanate with polyester polyols at NCO/OH ratios of 1.2, 1.4, and 1.6 using toluene as a solvent. A high NCO/OH ratio is generally considered typical since it results in

tougher, more solvent-resistant coatings. The produced coatings exhibited attributes such as chemical resistance, impact resistance, pencil hardness, and flexibility. As the number of hard segments in the sample increases, so do the produced coatings' favorable attributes.

Velayutham et al. [[27], [28]] used polyester polyols with varied oleic acid concentrations to create PU coatings. To create PU coatings, the polyols reacted with aromatic isocyanate (toluene 2,4-diisocyanate, or TDI). The physical characteristics of PU coatings on mild steel panels were examined about different NCO/OH ratios and polyols' oleic acid concentrations. Physical-chemical characteristics such as solvent resistance, adhesive qualities, drying time, pencil hardness,

corrosion/chemical resistance determination, and solvent resistance were described together with the characterization of PU coatings using IR spectroscopy analysis. The best overall coating qualities are shown by the coatings made from polyol with a 28% content. The mechanical and anticorrosive capabilities of all the coatings increased progressively as the NCO/OH ratio rose.

Niger seed oil (NSO) was used by Ranjeet et al. [29] to create a PU covering (Figure 7). Niger seed oil is amidated with diethanolamine to create polyesteramide polyols, which are then esterified with several biobased dicarboxylic acids (phthalic, itaconic, and dimer) to add the necessary hydroxyl group functionality. Hexamethylene diisocyanate biuret (HDI-B) and synthetic polyesteramide polyols are used to make the polyurethane coatings. The gel content method is used to show the cross-link density of PU coatings, and the saltwater immersion technique is used to conduct the corrosion investigation. By using differential scanning calorimetry and thermogravimetric analysis, the glass transition temperature (T_g) and thermal stability of the PU coatings are also investigated.

Common polymeric coatings like polyurethane offer surfaces in the food processing, marine, and biomedical sectors flexibility, durability, and resistance to abrasion (Figure 8). Because of its adjustable chemistry, polyurethane has enormous potential for materials of the future. Many studies have been conducted on the modification of polyurethane to provide it additional properties like antibacterial, non-fouling, anticorrosive activity, or high heat resistance. Traditional solvent-borne polyurethane

(PU) based on 4,4'-Methylenebis (phenyl isocyanate) (MDI), which is often used in food processing facilities, boat hulls, and floor coverings, was produced by Rudlong and Goddard 2023 [30]. The polyurethane included 1%, 2%, and 3% perfluoropolyether (PFPE).

Wetability and hydrophobicity were assessed using a dynamic water contact angle. The addition of perfluoropolyether blocks (PU-co-1PFPE $131.5^\circ \pm 8.0$, PU-co-2PFPE $130.9^\circ \pm 5.8$, and PU-co-3PFPE $128.8^\circ \pm 5.2$) significantly advanced the water contact angle in comparison to the control polyurethane ($93.6^\circ \pm 3.6$). The surface orientation of fluorine provided support for the lower critical surface tensions of PU-co-3PFPE-modified polyurethane (12.54 mN m^{-1} as opposed to 17.19 mN m^{-1} for unmodified polyurethane).

Because of its superior mechanical and thermal qualities as well as outstanding chemical resistance, epoxy resins find extensive usage in the adhesive, automotive, paint, and aerospace sectors. Nevertheless, the overall impact resistance of these materials is weakened following external impact due to the propagation of cracks in epoxy polymers. As a result, many impact modifiers have been created to lessen epoxy polymers' brittleness. Polyurethanes (PU) can increase the toughness of polymers by acting as impact modifiers. While the fact that polyurethanes (PUs) phase-separate in the polymer matrix during curing is widely known, it has proven difficult to reattach PUs to the matrix to improve the mechanical characteristics of polymers.

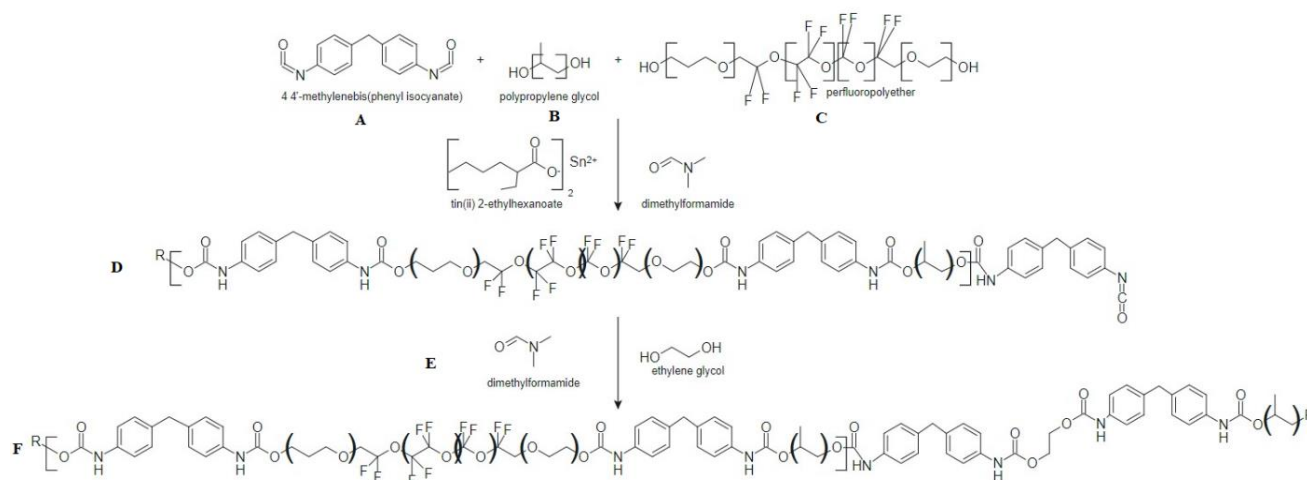


Figure 8 - A two-step prepolymer reaction of MDI (A), PPG (B), and PFPE (C) forms the prepolymer (D). Chain extender (E) added to form final PU-co-PFPE polymer (F).

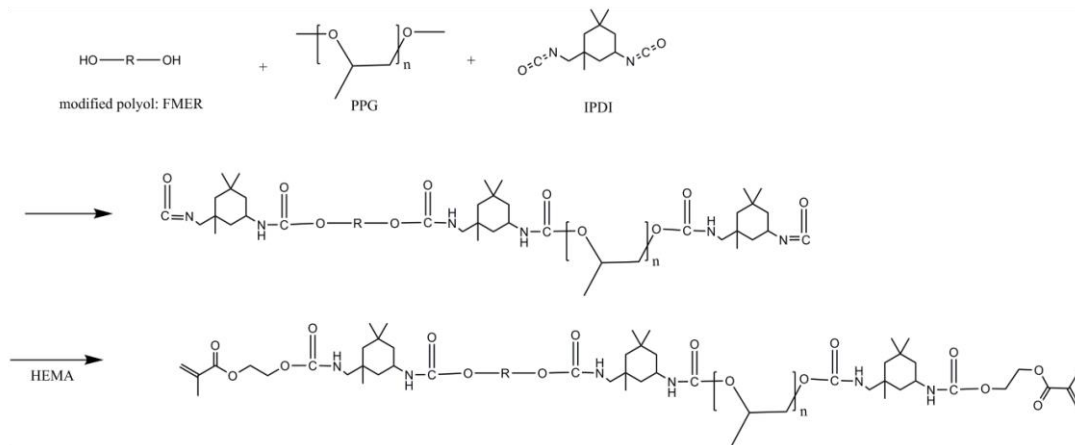


Figure 9 - PU reaction strategy including the reaction of isophorone diisocyanate (FMEP-PU) with hydrogenated epoxy polyol modified by fatty acids

Unlike previous research that concentrated on changing capping agents to establish a network topology between the polymer matrix and PU, Kim et al., 2019 [31] included epoxy functional groups into polyol backbones. By using gel permeation chromatography, we were able to verify the molecular weight of the produced PU. Additionally, the produced material was mixed with the epoxies, and the resultant materials' mechanical and thermal characteristics were assessed. We also measured impact resistance, flexural strength, and tensile strength. The impact strength and mechanical strength of the epoxy compositions were improved and sustained up to 10 phr of PU by the addition of PU (Figure 9).

In 2019, Zaimahwati et al. [32] polyurethane (PU) nanocomposite that has been prepared using castor oil and coated with montmorillonite nanoparticles. After synthesizing polyols from castor oil and organic montmorillonite nanoparticles, polyurethanes (PU) were prepared, evaluated, and used as coating materials for polyurethane nanocomposites. Organic montmorillonite nanoparticles were added to polyols to create a polyurethane nanocomposite, which was then combined with toluene diisocyanate. Using thermogravimetric analysis (TGA) equipment, the thermal properties of polyurethane nanocomposites were used to evaluate their efficacy as heat-resistant coatings. Subsequently, the adhesive strength and morphological characteristics of the material coating were assessed. The results showed that the addition of montmorillonite improved both the adhesive strength of the material coating applied to the material's surface and the heat resistance of the material's film surface layer.

The impact of diisocyanate symmetry and hydrogen bonding on microphase morphology was examined by Yilgor et al. [33]. Their investigation into segmented polyether ureas and non-chain extended polyether urethanes produced some intriguing findings on the microphase separation of these polymers. The researchers observed that polyurethanes prepared with symmetrical diisocyanates, namely 1,4-phenylene diisocyanate (PPDI), 1,6-hexamethylene diisocyanate (HDI), and 1,4-cyclohexyl diisocyanate (CHDI), exhibited a microphase morphology in which the soft segment matrix was permeated by hard segments that resembled ribbons. Conversely, polyurethanes based on diisocyanates that are not symmetrical, such as 1,3-phenylene diisocyanate (MPDI), 2,6- and 2,4-toluene diisocyanate (TDI), bis (4-isocyanate cyclohexyl)methane (HMDI), and MDI, did not exhibit microphase morphology at ambient temperature. All polyether areas, in contrast to their urethane counterparts, showed microphase morphology at room temperature, irrespective of the diisocyanate's structure or symmetry. Their research demonstrates the critical influence that hard segment symmetry has on polyurethane microphase formation. PU coatings are available in several varieties. Solvent-based coatings, or conventional PU coatings, have dominated the industrial coating industry in recent decades. More restrictive laws about volatile organic compound (VOC) emissions, however, nevertheless pose a threat to this position. Because of this, producers of paint and suppliers of raw materials are creating substitute technologies that work just as well but are more environmentally friendly.

track the reactivity of isocyanate groups with the hydroxyl function of PPG, ^1H NMR spectra, and dibutyl amine back-titration were employed. ^{13}C NMR spectroscopy was used to crosscheck the % conversion data for the methanol end-capped prepolymer in the urethane zone. The secondary NCO group is more reactive than the primary group, according to the findings.

In 2003, [43] Semsarzadeh and Navarchian synthesized Poly(urethane-isocyanurate)s created by reacting poly(propylene glycol) and toluene diisocyanate at varied stoichiometric ratios (1-3) with varying amounts of ferric acetylacetonate (FeAA) and dibutyltin dilaurate (DBTDL). Using Fourier transform IR spectroscopy, the impact of the catalyst type and concentration, as well as the NCO/OH ratio, on the degree of urethane and isocyanurate synthesis were investigated. With a rise in the stoichiometric ratio or DBTDL concentration, it was seen that the proportion of the trimer group and the trimer/urethane content rose. Thermogravimetric (TG) analysis was used to examine the thermal breakdown of the polyurethanes in an inert environment.

The TG curves showed three phases of disintegration, with 355 to 385 °C serving as the major degradation temperature. The effects of the NCO/OH ratio, catalyst type and concentration, and heating rate on the thermal stability of the polyurethanes were determined. We estimated the activation energies of thermal decomposition by use of the Kissinger, Flynn-Wall, and Ozawa methods. The swelling behavior of solid polyurethanes in toluene showed that as DBTDL concentration and/or NCO/OH ratio increased, the crosslink density increased and the swelling ratio and average molecular weight between crosslinks decreased. It was demonstrated that the sol fraction of solid polyurethanes decreased with an increase in the stoichiometric ratio or the amount of DBTDL.

Rummi et al. (2013) [44] studied that by reacting a molar excess of diphenylmethane diisocyanate (MDI) with polypropylene glycol (PPG) for two hours at 60°C, polyurethane prepolymers were produced. It investigated how different NCO/OH molar ratios and polyol molecular weights affected the polyurethane plaster cast's tack-free time, setting time, diametral compression strength, percent elongation, and tensile strength. When the NCO/OH molar ratio increases, the cast's tack-free period and setting time reduce but its diametral compression strength increases. Using a universal testing

apparatus, tensile strength was determined to increase as the NCO/OH ratio increased, even though the percentage of elongation had the opposite tendency. As the polyol molecular weight rises, the cast's tack-free and setting times increase while its diametral compression strength decreases. The tensile and diametral compression strengths of blended polyols, such as PPG 1000 and PPG 400 mixed in a 50/50 ratio, are equivalent to those of their unblended equivalents. Compared to fiberglass cast, polyester cast has a higher % elongation and diametral compression strength.

Polyaniline/graphene was used as an anticorrosion filler by Kewen et al., 2016 [45] to create a conductive coating based on aqueous polyurethane. Potentiodynamic polarization curves, electrochemical impedance spectroscopy (EIS), and salt spray were used to evaluate the coating. The maximum conductivity for polyurethane coating was achieved with a polyaniline/graphene ratio of 0.75 wt% and a graphene concentration of 4 wt%. Youtong Wu et al., 2019 [46] used SG-ZP mixtures as an additive to create an aqua polyurethane-based surface. Tafel curves and EIS analysis were used to test the obtained coating. The 0.5 wt% sulfonated graphene/zinc phosphate ratio produced satisfactory results, with a corrosion current density of 0.4252 $\mu\text{A}/\text{cm}^2$ and a charged transfer resistance (R_{ct}) of 10.937 10^3 cm^2 . Cui et al., 2020 [47] investigated if smart anticorrosion coatings outperformed traditional ones. The paper introduced the linked ideas of self-healing and nano-container development. The present issues, their optimization, and potential future consequences have all been explored.

Pei-Ying Tsai et al., 2018 [48] used a complex PU/Gr coating with a ratio of 0,2,4, and 8wt.% for Gr. The anti-corrosion and mechanical capabilities of the mixture were evaluated using EIS, salt spray, and cross-cut tests. At normal conditions, anti-friction properties were evaluated using a tribometer and the ball-on-disc technique. Complexes containing 4 and 8% gr. The friction coefficient data showed that increasing the graphite (Gr) content to 8% reduced the anti-friction qualities of the PU/Gr composite coatings by 61% compared to the standard coating.

Thi Xuan Hang et al., 2015 [49] showed that treatment with 2-aminoethyl-3-aminopropyltrimethoxysilane (APS) resulted in the precipitation of nanosized ZnO. ZnO-APS nanomaterial characterization was performed by UV-Vis, SEM, TEM, and XRD spectroscopy. Under

QUV testing conditions, the degradation of polyurethane coatings containing nano ZnO at a weight percentage of 0.1 and nano ZnO-APS at two weight percentages, 0.1 and 0.5 wt%, was assessed. The findings demonstrate that the nano ZnO-APS particle sizes range from 10 to 15 nm and have a spherical shape. The polyurethane coating's UV resistance was enhanced by nano ZnO, and its effectiveness was further enhanced by surface modification using APS. Notably, the UV resistance of the polyurethane coating was markedly enhanced by the addition of nano ZnO-APS at 0.1 wt%.

Huibin Zhu et al., 2020, [50] used a one-step spray-coating approach to develop superhydrophobic films with flexibility, mechanical robustness, and thermal stability. The coatings, which had a micro-nano structure and a T_g greater than 221°C, kept contact angles over 150 degrees. They were extremely flexible, with a friction value of 1.70. Electrochemical corrosion studies indicated their extraordinary resistance (I_{corr} reaching 8.90×10^{-5} A cm^{-2} under particular conditions), making them promising for harsh environment applications.

Yao Tong et al. 2017, [51] investigated the use of graphite and graphene particles to improve the specific conductance and anti-corrosion characteristics of polyurethane (PU) coatings. In terms of electrical conductance, a hybrid composite including carbon nanotubes outperformed single filler systems, with a significant advantage reported at 5 wt% loading (0.77 S/m, whereas the single filler system remained non-conductive). The conductive mechanism has been discovered. Lower filler loadings in the coatings increased anti-corrosion properties. Resistance readings from Electrochemical Impedance Spectroscopy (EIS) and the four-point probe technique were compared and discussed.

Mahmudzadeh et al. 2019, [52] investigated a cost-effective and ecologically friendly approach for decreasing graphene oxide in an hour using *Urtica dioica* leaves extract at 90°C. The elimination of oxygen functional groups was verified by Raman spectroscopy. Even after accelerated weathering, the decreased graphene oxide increased the corrosion resistance of polyurethane coatings and displayed remarkable protection efficacy, topping 99% in low-frequency impedance studies.

Xiaoyun Yea et al., (2019), [53] demonstrated the fabrication of zinc oxide (ZnO) array/polyurethane (PU) nanocomposite coatings on stainless steel substrates. ZnO arrays were grown

from seeds and then mixed with PU. The coatings' structure, wettability, mechanical characteristics, and corrosion resistance were all evaluated. The ZnO arrays have a hexagonal wurtzite structure and are somewhat more hydrophilic. Mechanical qualities improved as ZnO concentration increased, and the coatings demonstrated good corrosion resistance. Infrared radiation performance improved slightly as well. This innovative organic/inorganic nanocomposite coating is a viable strategy for creating functional coatings with improved corrosion resistance and mechanical properties in a variety of polymer systems.

Hui Wang et al., (2021) [54] investigated a novel anticorrosive coating capable of self-healing in the event of damage. Using Diels-Alder (DA) bonding, a PU prepolymer is combined with a modified CeO₂ furan to form this covering. These DA bonds are efficient in preserving mild steel against corrosion following coating degradation. The photothermal characteristics of dopamine allow this coating to self-heal in settings similar to infrared irradiation for 20 seconds. The mechanical and anticorrosive properties of the coating remained nearly unaltered after such self-healing. The proposed coating (PU DA-d@CeNPs5) exhibited good mechanical properties (38.89 ± 0.52 MPa), adhesion qualities (12 MPa), and an impedance modulus at 0.01 Hz equivalent to 1.29×10^9 -ohm cm^2 . Even after 100 days of continuous immersion, the impedance modulus at 0.01 Hz can still surpass 107 ohms/ cm^2 .

Polyurethane foam waste (PUR) was used and treated with dicarboxylic acids (DA) by Godinho et al., (2021) [55]. Using spectrum analysis, the ratio of PUT and DA was regulated, and the findings indicated that the recycled polyol (RP) has an appropriate hydroxyl number and acidity to form a new polyurethane (PU). This novel substance was utilized to make polyurethane coatings for wood (PUC). When compared to a typical polyol coating, the coating generated from RP has a higher hardness, but less gloss and more hydrophobicity.

Hui Yuan et al. [56] investigated the influence of water-based polyurethane, silicon dioxide, and fillers on the characteristics of modified silicate coatings. Coatings containing 10% polyurethane and 4% silica demonstrated superior mechanical qualities as well as resistance to heat and acids. The changed coatings outperformed the unmodified coatings in terms of strength, heat resistance, and acid resistance by 25.1%, 34.1%, and 32.4%, respectively. A thick microstructure with an

interpenetrating network was revealed by microstructural investigation. The coatings were also found to be less permeable, which increased their properties. Heat resistance at high temperatures (250°C) was fulfilled by the modified coatings.

Fengyuan Zhanga et al., (2020) [57] effectively created water-based polyurethane composites (WPC) containing functionalized graphene oxide (PAFG) generated from polyethyramines. The inclusion of nanoparticles at the optimum concentration improved the characteristics of WPU composites significantly. In comparison to pure WPU, the contact angle with water and water absorption in the WPU composite improved significantly to 98.5°C and 3.01 wt.%, respectively, from 70.5°C and 8.31 wt.%. Furthermore, there were significant improvements in thermal stability and mechanical qualities, particularly with the addition of 0.05 wt.% PAFG. With a 10% mass loss, the decomposition temperature of the WPU composite climbed to 322°C, which was 29.3°C higher than that of pure WPU. When compared to pure WPU, the tensile strength of WPU containing 0.05 wt.% PAFG improved by 130.92%. In terms of electrochemical data, after 31 days of immersion, the $|Z|$ value at 0.01 Hz for WPU dropped, whereas WPU/PAFG0.05 remained steady. This demonstrates that 0.05 wt.% PAFG significantly improves the barrier characteristics of the WPU coating.

Jiahua et al., (2012) [58] used the sol-gel process to construct fluorescent silica shells of varying thicknesses on spherical carbonyl iron (CIP) particles. For metal particle surface compatibility with TEOS, hydrolysis, and condensation of tetraethyl orthosilicate (TEOS) were combined with the usage of gelatin B and 3 aminopropyltriethoxysilane (APTES). This results in a protective silica shell with variable thickness. The silica shell increases the particles' anti-corrosion and heat resistance. SIP and CIP-silica self-healing polyurethane coatings demonstrated increased anti-corrosion and heat resistance.

Tuan et al., (2022) [59] researched a novel anticorrosive coating that may self-repair when damaged. This coating is made of polyurethane acrylate (PUA) with lithium salt added as a polymer electrolyte. UV radiation was used to approve PUA and lithium salt mixtures, resulting in thin coatings with high heat resistance and ionic conductivity. The best conductivity was exhibited by PUA with a 25% mass fraction of lithium salt. The coating's

mechanical and structural properties, as well as its capacity to self-heal under near-infrared illumination, were also investigated.

Cheng et al., (2020) [60] created and tested ecologically friendly non-isocyanate polyurethane (NIPU) anti-corrosion coatings. The synthesis and formulation of these coatings employing several materials, including amine terminated NIPU, TEOS, and BPA epoxy, are the main emphasis of this work. The study evaluates the anti-corrosion performance of NIPU coatings with varying TEOS concentrations and finds that the best anti-corrosion behavior was shown by coatings containing 5% TEOS. Spectroscopic and microscopy methods have demonstrated that variations in anti-corrosion performance are related to the organic/inorganic micro-phase separation.

This research advances our understanding of how TEOS affects the anti-corrosion properties of NIPU coatings. Pavan et al., 2021, [61] investigate the synthesis of bio-renewable materials such as vegetable oils, outlining chemical changes and prospective uses. The analysis also tackles the obstacles and promising technology in the eco-friendly transition of the coatings sector.

Aqdas et al. (2015) [62] emphasize the benefits of ecologically friendly waterborne polyurethane (WPU) coatings, such as reduced VOC emissions and desired characteristics. It goes over current advances in WPU coatings, such as UV-cured and hyper-branched polyurethanes. It also investigates strategies to improve mechanical strength and flame retardancy using additives such as nanoparticles and fire retardants. By incorporating two commercially available inhibitors, Ravindra et al., 2015, [63] increased the anti-corrosive capabilities of polyurethane coatings. The encapsulating technique and its impacts on coating performance are explored, and improved corrosion inhibition efficiency is demonstrated.

Jing Li et al. (2016), [63] discovered that adding the following chemicals to a waterborne polyurethane matrix in the following order improves the anticorrosive characteristics of polyurethane: graphene oxide, moderately reduced graphene oxide, and functionalized graphene. Impedance Electrochemical Spectroscopy and salt spray testing confirmed that the additives are anti-corrosive. The chemical and dispersion states of graphene within polyurethane, according to the findings, impact the material's capacity to resist corrosion. The inclusion of 0.2 wt% of reduced graphene oxide improves the

anticorrosive capabilities of graphene-reinforced polyurethane composite coatings. The findings of the Electrochemical Impedance Spectroscopy demonstrated that, after 235 hours of immersion in a 3.5 wt% NaCl solution, there was no under-painting corrosion and that the impedance modulus at 0.1 Hz was constant at 109 U. This was true over the whole 235-hour period, with very little variation noted.

When 0.2 wt% reduced graphene oxide is added, the anticorrosive properties of graphene-reinforced polyurethane composite coatings are enhanced. After 235 hours of immersion in a 3.5 weight percent NaCl solution, the findings of the Electrochemical Impedance Spectroscopy revealed that under-painting corrosion did not occur and that the impedance modulus at 0.1 Hz was constant at 109 U. This was true throughout the whole 235-hour period, with very little variation detected.

According to Ashraf et al. (2015) [64], a Transmission electron microscopy image indicated that zinc oxide nanoparticles generated by direct precipitation have a pseudospherical shape and diameter of roughly 20.0 nm. Zinc oxide nanoparticles are uniformly disseminated in polyurethane by ultrasonication at loading levels ranging from 0.1 to 2.0 wt.% to improve polymer characteristics. The coatings were shown to be efficient at inhibiting both Gram-positive and Gram-negative bacteria growth. When ZnO NPs are used, the number of organisms growing on the coating's surface decreases. Moreover, better mechanical and corrosion resistance at lower concentrations was obtained by increasing the weight % of ZnO NPs. Scanning electron microscopy data served as the foundation for the conclusions.

Pooneh et al. (2018) [65] showed that the covalent functionalization of graphene oxide nanosheets by 3-glycidyloxypropyl) trimethoxysilane additions contributes to the improvement of mechanical performance and corrosion resistance. The study of nanomaterials was conducted using Fourier transform infrared spectroscopy (FT-IR), thermogravimetric analysis (TGA), field emission scanning electron microscopy (FE-SEM), and X-ray diffraction (XRD). The physical-mechanical characteristics of the coating with nanosheets were assessed by the use of tensile tests and dynamic mechanical thermal analysis (DMTA). In addition, the impact of GO and fGO nanosheets on the surface fracture morphology of polyurethane coating during tensile testing was investigated using

SEM analysis. The results of the study showed that the addition of fGO nanosheets enhanced the mechanical, anti-corrosion, and physical properties of the PU coatings by fortifying the interfacial bonds between the coating and the GO nanosheets. To understand the mechanism of the trimethoxysilane-polyurethane interaction, GO surface quantum mechanics techniques were used.

According to research by Abhijit et al., 2020 [66], polyurethane is a very versatile material that can be created to order when additives and nanoparticles are added. This enables a wide range of properties, including soft-touch coatings and rigid construction materials. The material's mechanical, chemical, and biological characteristics may be adjusted to meet specific needs, which has piqued the interest of several businesses as well as the scientific community. The chemistry of the constituent parts of polyurethane is examined in this study, along with recent advancements and applications in the medical, automotive, coatings, adhesives, sealants, paints, textiles, marine, wood composites, and apparel sectors.

Xiaohua et al., 2013 [67] demonstrated that LipolTM, a bio-based polyol, was made using a variety of vegetable oils. The oligomer dispersion and chemical structures of these polyols were investigated. The polyols were used to create polyurethane coatings with a bio-based content of about 60%. The coatings exhibited satisfactory mechanical and thermo-mechanical properties. The flax PU, which comes from oil that has a high linolenic acid content, had the highest performance because of its low solvent swelling, high glass transition temperature, strong cross-linked networks, resistance to abrasion and water, and hardness.

The goal of this investigation was to determine how various hardeners influenced the protective properties of polyurethane coatings, as investigated by Ewa et al. 2014 [68]. It was necessary to comprehend any modifications to the mechanical qualities, crosslink density, and chemical structure. After being applied to mild steel panels, the wet adhesion, abrasion resistance, and anti-corrosive properties of unpigmented polyurethane coatings with different hardener concentrations were evaluated. The electrical and abrasion resistance of coatings with a greater hardener ratio was demonstrated by the findings. The coating with the stoichiometric hardener ratio exhibited the least degree of adherence. According to the FTIR data, the

coatings' urethane group count dropped when the hardener ratio dropped. The study concluded that electrochemical impedance spectroscopy and DC resistance are helpful methods for determining how well the coatings will hold up over time.

The combination of poly (ethylene glycol) with epoxidized vegetable oil has been researched by Mandar et al., 2015 [69] to create novel polyester polyols. A sustainable method of extracting oil from cottonseed and karanja was used. The molecular weight of the poly (ethylene glycol) was altered. The polyols' spectrum properties and end groups were looked at. These polyols were utilized to replace dipen tene with xylene in ecologically friendly polyurethane coatings. Along with their physical and thermal characteristics, the resultant polyurethanes were evaluated for adhesion, gloss, hardness, impact resistance, and flexibility. These coatings showed promise for industrial use.

Tsao-Cheng Huang and colleagues (2017) [70] investigated the feasibility of ZrP/PU nanocomposite films to ensure consumption security. The electrochemical experiments confirmed the improved consumption resistance of ZrP/PU coatings on steel surfaces as compared with pure PU coatings. The connecting of ZrP nanoplatelets into the PU lattice further strengthened dampness obstructing characteristics. Ying Liang et al. (2020) [71] investigated the use of polydimethylsiloxane and acetylated starch in the manufacturing of bio-based polyurethane coating. The research was done and it was found that an acetylated starch-based polyurethane coating with a 0.5–3% polydimethylsiloxane content has anti-corrosion properties.

The enhancement of the anti-erosion characteristics of aluminum (Al) coatings by the creation of superhydrophobic surfaces was examined by Xiuyong Chen et al. (2014) [72]. The cycle involves using a suspension fire splashing technology to save polyurethane (PU)/nano-Al₂O₃ composites by first curve showering Al coatings onto steel substrates. The result is the successful production of superhydrophobic PU/nano-Al₂O₃-Al coatings with a large spectrum of consumption that are safe. The super hydrophilicity/superhydrophobicity of the coatings may be adjusted by varying the concentration of PU in the initial suspension. A specific layer with 2.0 weight percent PU exhibits excellent hydrophobicity, with water droplets sliding at around 6.5°C and making contact at about 151°C.

For maritime foundations, the PU/nano-Al₂O₃-Al coatings with their solid enemy of consumption capabilities and superhydrophobic qualities can be employed as protective layers.

Four polyurethane saps—polyurethane (PU), epoxy-changed polyurethane (EPU), fluorinated polyurethane (FPU), and epoxy-altered fluorinated polyurethane (EFPU)—were used to create natural cement for the production of coatings with low infrared emissivity, according to a review by Yajun Wang et al. (2011) [73]. It is anticipated that the investigation will examine how these various tar networks affect the guarantee of low infrared emissivity coatings' usage. A neutral salt shower test has been employed to assess the goal, and coatings have been examined using Fourier-change infrared spectroscopy (FTIR) and scanning electron microscopy (SEM). Remarkably, the natural glue covering consolidating EFPU demonstrated exceptional erosion resistance. The simultaneous existence of epoxy aggregates and nuclear fluorine in the EFPU fastener was attributed to this improved presentation.

Fluorine-containing epoxy (FO) compounds that were combined using 2,2,3,3-tetrafluoro-1-propanol (TFP) and epichlorohydrin (ECH) in a single step were investigated by Xia Wang et al. (2015) [74]. A controlled sub-atomic weight fluorinated polyglycol was produced by cationic polymerization. Fluorinated polyurethane (FPO) and FO designs were detailed using techniques such as gel pervasion chromatography (GPC), FTIR, and NMR. Then, using a room temperature relieving procedure, FPO and methyl diphenylenediisocyanate (MDI) were combined to make a two-part fluorinated polyurethane coating. The concentration also evaluated the film surface using SEM (filtering electron microscope) imaging, as well as protection against the salt spray and water resistance.

The combination and representation of silicone-based covering materials that combine siloxane and polyurethane/polyurea copolymer were studied by Anna M. Mikhailova et al. (2012), [75]. Primary study, subatomic representation, warm properties, mechanical qualities, attachment, morphology, and consumption execution are all covered in the analysis, which reveals that aspects other than those covered in the hard part have an influence on the defensive and anticorrosion characteristics. To evaluate these covering materials' defensive and anticorrosion qualities, electrochemical impedance spectroscopy (EIS) was used. Indeed, the assessment

demonstrates that the hard part content does not apply only to these qualities. FT-IR spectroscopy was used to study the formation of the pre-blended copolymer and the ensuing silicone-polyurethane/polyurea copolymer (SPPU) with varying hard fragment (HS) percentages.

In their study on the enhancement of polyurethane-urea coatings, Yixing Zeng et al. (2023), [76] emphasized the importance of the isocyanate file in fitting the properties of polyurethane-urea coatings, providing a methodical approach to safeguarding metal and metal offices while encouraging the practical application of harmful to destructive materials. The coatings were assembled using conductive mica particles as fillers and aromatic isocyanate, amino-ended polyether, polyol derived from castor oil, and polyaspartic pitch as reactants. The review investigated how the isocyanate file affected the polyurethane-urea coatings' synthetic structure, static conductivity, and consumption hindrance. Higher cross-connectivity inside the covering was achieved by expanding the isocyanate file, albeit at the expense of decreased smallness and electrostatic conductivity. The organization of carbon dioxide increases in the overlying layer was blamed for this alteration. Salt shower tests and electrochemical impedance spectroscopy revealed that when the isocyanate record increased, the covering's ability to counter-consume on entire surfaces increased, but its appearance in areas with abandons decreased. Coatings with an isocyanate list of 1.0–1.1 demonstrated excellent electrostatic conductivity and erosion resistance, making them suitable for protecting metal and metallic workplaces.

To improve the enemy of consumption properties due to hydrophobicity and obstruction impacts, Mengting Moa et al. (2016) [77] developed functionalized graphene-supported polyurethane coatings with explicit surface surfaces. This resulted in less water contact and further developed the dispersion opposition of harmful substances. To improve their adversary of consumption qualities, the review focuses on the creation of PU nanocomposite coatings supported by functionalized graphene (FG). Its anti-erosive characteristics were further enhanced by the PU composite covering's surface and all-around dispersed FG. This improvement can be attributed to

the hydrophobic concept of the coatings, which reduces water cooperation and increases the pathway's convolution for the dispersion of harmful media. The majority of these components strengthen the ultimate FG/PU composite covering's defense against erosion. Transmission electron microscopy, examining electron microscopy, nuclear power microscopy, X-beam photoelectron spectrometry, Raman spectroscopy, Fourier change infrared spectroscopy, and other techniques were used to illustrate the main and morphological characteristics of the PU composite coatings. The coatings exhibited a unique round cone shape with distinct characteristics (widths of 8 μm distributed eight, six, and four μm apart, respectively).

Conclusions and Future Perspectives

There has been a steady and robust increase in the need for materials based on polyurethane throughout time. Particle filters (PUs) are widely used as coatings to prevent corrosion on metals. A chance to include new green PU formulations was presented by the growing recognition on a worldwide scale of the significance of environmental and human health. As a result, there has been a lot of interest in the design and development of highly effective polyurethanes (PUs) that are less harmful to the environment than their conventional equivalents made from polyols and polyisocyanates derived from petroleum. The current research on the application of such green polyurethanes—waterborne and bio-based polyurethanes in particular—as protective coatings is gathered in this review.

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Полиуретан қаптауға және коррозиядан қорғауға арналған универсалды полимер ретінде: Шолу

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ТҮЙІНДЕМЕ

Полиуретанды материалдарды әзірлеу және технологиялық процестерді оңтайландыру қазіргі уақытта ауқымды зерттеулердің тақырыбы болып табылады. Полиуретан жоғары физика-химиялық және пайдалану қасиеттерімен сипатталады. Полиуретандар тозуға, майға және бензинге төзімді. Олар керемет жылу физикалық және созылғыш қасиеттерге ие. Бұл полиуретандарды жоғары эксплуатациялық қасиеттері бар материалдарды қажет ететін көптеген салаларда қолдануға мүмкіндік береді. Полиуретандар сонымен қатар көптеген салаларда коррозияға қарсы агент ретінде қорғағыш жабындарын өндіруде кеңінен қолданылады. Полиуретанды полимерлердің физика-механикалық және эксплуатациялық қасиеттерін, атап айтқанда модификацияланған полиуретанды жабындардың коррозияға қарсы қасиеттерін жақсартуға арналған көптеген зерттеулер жүргізілді. Полиуретанды полимерлердің әртүрлі қолдануларға арналған қасиеттерін мономерлер мен олардың арақатынасын, сондай-ақ өндіріс процесінің өзін өзгерту арқылы жақсартуға болады. Полиолдар мен изоцианат мономерлеріне негізделген полиуретанды полимерлерді алу катализатордың қатысуымен полимерлеу процесіне де, толуол, ксилол және ацетон сияқты еріткіштерді қолдануға да негізделген. Әртүрлі әдістермен зерттелген полиуретанды полимерлердің физика-механикалық қасиеттеріне әсер ететін бірнеше факторлар бар. Мұндай факторларға изоцианаттардың, полиолдардың түрлері, ОСN/ОН қатынасы, еріткіштер, катализаторлар және температура жатады. Әдетте, полиолдар полиуретанды полимерлердің иілгіштігіне жауап береді, ал изоцианаттар полиуретанды полимердің қаттылығына және полимердің негізгі бөлігінің бірігуіне (тігілуіне) жауап береді. Реагенттердің химиялық құрамын өзгерту арқылы пайдалану мақсатына байланысты жабынның сипаттамалары өзгертіледі. Қорытынды әсер әртүрлі полиолдар мен полиизоцианаттардың химиялық құрамымен анықталады. Полиуретанды полимерлердің гидрофобтылығы, ыстыққа төзімділігі, механикалық және коррозияға қарсы қасиеттері зерттелді. Нәтижесінде гидрофобтылық, ыстыққа төзімділік, механикалық және коррозияға қарсы қасиеттер сияқты полиуретанды полимерлердің қасиеттері жоғарыда аталған факторлардың әсерінен жақсарды. Бұл шолу мақаласы қорғаныш полиуретанды жабындарды жасаудың және оларды коррозияға қарсы агент ретінде пайдаланудың ең заманауи, қаржылық табысты әдістеріне қысқаша сипаттама береді.

Түйін сөздер: Полиуретан, жабын, коррозияға қарсы, полиолдар, полиизоцианаттар.

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Полиуретан как универсальный полимер для нанесения покрытий и защиты от коррозии: Обзор

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<p>Поступила: 23 ноября 2023 Рецензирование: 8 декабря 2023 Принята в печать: 15 декабря 2023</p>	<p>Аннотация</p> <p>Разработка полиуретановых материалов и оптимизация технологических процессов в настоящее время являются предметом обширных исследований. Полиуретан характеризуется высокими физико-химическими и эксплуатационными свойствами. Полиуретаны обладают высокой износостойкостью, масло- и бензостойкостью. Они имеют прекрасными теплофизические и эластичные свойства. Это позволяет применять полиуретаны во многих отраслях промышленности, где требуются материалы с высокими эксплуатационными свойствами. Полиуретаны также широко используются во многих отраслях промышленности при производстве защитных покрытий в качестве антикоррозионных средств. Было проведено значительное количество исследований, посвященных улучшению физико-механических и эксплуатационных свойств полиуретановых полимеров, в частности антикоррозионных свойств модифицированных полиуретановых покрытий. Свойства полиуретановых полимеров для различных применений могут быть улучшены путем изменения используемых мономеров и их соотношений, а также самого процесса получения. Получение полиуретановых полимеров на основе полиолов и изоцианатных мономеров основано как на процессе полиприсоединения в присутствии катализатора, так и применении растворителей, таких как толуол, ксилол и ацетон. Существуют различные факторы, влияющие на физико-механические свойства полиуретановых полимеров, которые были исследованы различными методами. Такими факторами были типы изоцианатов, полиолов, соотношения ОСN/ОН, растворители, катализаторы и температуры. Как правило, полиолы отвечают за гибкость полиуретановых полимеров, а изоцианаты отвечают за жесткость полиуретанового полимера и сшивку между основной частью полимера. Благодаря гибкому изменению химического состава реагентов они могут изменять характеристики покрытия в зависимости от предполагаемого использования. Конечный эффект определяется химическим составом различных полиолов и полиизоцианатов. Были исследованы гидрофобность, термостойкость, механические и антикоррозионные свойства полиуретановых полимеров. Как результат, свойства полиуретановых полимеров, такие как гидрофобность, термостойкость, механические и антикоррозионные свойства, улучшились под воздействием вышеперечисленных факторов. В этой обзорной статье дается краткое описание наиболее современных, финансово успешных методов создания защитных полиуретановых покрытий и использования их в качестве антикоррозионных средств.</p>
	<p>Ключевые слова: Полиуретан, покрытие, антикоррозионное, полиолы, полиизоцианаты.</p>
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