iJRASET
International Journal For Research in Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 14 Issue: VIII Month of publication: August 2026

DOI: https://doi.org/10.22214/ijraset.2026.84609

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 14 Issue VIII Aug 2026- Available at www.ijraset.com

Polyurethane Dispersion (PUDS) in Textile Application: Systematic Review

Lolla Renuka Tejaswini[1], Ayodya Kavitha2
Department of Textile Technology, Osmania University College of Technology, Hyderabad

Abstract: Polyurethane dispersions (PUDs) have become an important part of today's textile finishing, coating and laminating replacing the conventional solvent based polyurethanes due to rigorous environmental regulations on volatile organic compounds (VOCs). Polyurethane dispersions (PUDs) are colloidal dispersions of polyurethane polymers in water. They have excellent flexibility, high tensile strength, optical clarity, abrasion resistance and tunable breathability. This review offers a detailed look at polyurethane dispersions, covering their basic chemical structure and synthesis, classification based on ionic properties and polyol chemistry, intrinsic physicochemical properties, and methods for their industrial application to textiles. Also, it explores the performance properties of functional garments, technical fabrics and synthetic leather, and the main trends for future bio-based and hybrid compositions.
Keywords: Polyurethane, Textile, Synthetics, Application Methods.

I. INTRODUCTION

Polyurethanes (PUs) are a very versatile class of polymers defined by structural urethane linkages (NH-CO-O-) generated by polyaddition reactions of polyols and polyisocyanates. In the past, textile finishing and coating processes have been heavily dependent on solvent-based polyurethane systems that were dissolved in organic solvents such as dimethylformamide (DMF), toluene or methyl ethyl ketone (MEK). The solvent-borne solutions, while having better film integrity and mechanical properties, have a major emission of volatile organic compounds (VOCs), flammability and related health hazards, which triggered a big change in the industry (Liu et al., 2020).

Waterborne Polyurethane Dispersions (PUDs) have been developed to combine high performance with strict environmental regulations such as REACH and OEKO-TEX (Santamaria-Echart et al., 2021). PUDs are constructed of high molecular weight polyurethane nanoparticles distributed in a continuous aqueous phase. They offer the resilient elastomeric, thermal and mechanical qualities of classic polyurethanes with the assurance of non-toxicity, low or exceptionally low VOC emissions and safe use (De Smet et al., 2021). So far, PUDs have found applications in breathable waterproof clothes, protective clothing, synthetic leather (eco-leather), medical materials, and interiors of vehicles.

II. PREPARATION OF POLYURETHANE DISPERSIONS (PUDS)

However, stable aqueous dispersions of hydrophobic polyurethane polymers are difficult to prepare due to their low solubility in water and their polymer backbone or side chains should contain hydrophilic centers (ionic salt groups or non-ionic hydrophilic segments) (Liu et al., 2020; Santamaria-Echart et al., 2021).

A. Raw Materials

Diisocyanates: Provide the stiff portion of the polymer. Common aliphatic diisocyanates are Isophorone Diisocyanate (IPDI), Hexamethylene Diisocyanate (HDI) and Dicyclohexylmethane Diisocyanate (H12MDI). Aliphatic diisocyanates are preferred for textile applications because they withstand light degradation and do not yellow (Lacruz et al., 2021). Aromatic diisocyanates, such as Toluene Diisocyanate (TDI) and Methylene Diphenyl Diisocyanate (MDI) are used when cost-effectiveness and improved mechanical qualities are more important than UV stability.

Polyols: Make up the flexible parts, and influence the flexibility, low temperature performance and chemical resistance (De Smet et al., 2021). Conventional polyols include:

Polyester polyols: High mechanical robustness and thermal resilience but vulnerable to hydrolysis.

Polyether Polyols: gives a soft, tactile feel, flexibility and hydrolysis resistance but at the expense of some mechanical strength.

Polycarbonate polyols: Offering excellent weather, heat and chemical resistance.

Bio-sourced polyols: obtained from castor oil, soybean oil or dimerized fatty acids for sustainable formulations (De Smet et al., 2021; Lacruz et al., 2021).
Internal Emulsifiers:
Anionic: Dimethylolpropionic acid (DMPA) or Dimethylolbutanoic acid (DMBA) or sulfonate containing diols (Lacruz et al., 2021) with carboxylic group.
Cationic: such as N-methyldiethanolamine (MDEA) Tertiary Amines.
Nonionic polyethylene glycol (PEG) groups.
Neutralizing Agents: Organic bases e.g. Triethylamine (TEA) for neutralization of carboxylic groups or Inorganic bases e.g. sodium hydroxide.
Chain Extenders: Diamines or diols (Ethylenediamine [EDA], Hydrazine, 1,4-Butanediol [BDO]) added to increase the molecular weight during or after dispersion in water (Lacruz et al., 2021).

B. Synthesis Routes Of Chemicals

1) Prepolymer Blend Procedure

This is the most widely used industrial approach (Lacruz et al., 2021): Prepolymerization is carried out by reacting a polyol with an excess of diisocyanate in the presence of an internal emulsifier (DMPA or DMBA) at a temperature of 80 to 90°C to produce an isocyanate-terminated (NCO) prepolymer with pendant carboxyl groups.
Neutralization: The carboxylic groups are neutralized with a tertiary amine (e.g. TEA) to form quaternary ammonium carboxylate ions, which makes the prepolymer self-emulsifying.
Dispersion: Stable water-in-oil/oil-in-water micelles are formed by incorporating the ionic prepolymer into water at high shear rates.
Chain Extension: The addition of a hydrophilic diamine (such as EDA) reacts with the remaining -NCO groups to extend the polymer chain and to form urea linkages (-NH-CO-NH-) which greatly improve the tensile strength and thermal stability (Lacruz et al., 2021; Santamaria-Echart et al., 2021).

2) Acetone Process

A terminated prepolymer with a --NCO group is prepared in low boiling organic solvent (acetone). Chain elongation in the acetone solution leads to the necessary high molecular weight. Neutralization and uptake of water occurs and a fine uniform dispersion is achieved. Acetone is removed by distillation at reduced pressure and recycled (Lacruz et al., 2021; Liu et al., 2020).
Benefit:High molecular weight PUDs with narrow particle size distributions and low viscosity, but needing solvent recovery systems.

3) Method of dispersion by fusion

An isocyanate-terminated prepolymer reacts with urea or biuret to form an oligomer with terminal acylated urea groups. This melt is neutralized, diluted in water and extended in chains with formaldehyde or amine derivatives.

4) Ketimine and Ketazine method

Blocked diamines (ketimines) are incorporated directly into the prepolymer. When water is added during emulsification, the ketimine is hydrolyzed to liberate free diamine, hence starting chain extension and dispersion.

III. POLYURETHANE DISPERSIONS: CLASSIFICATION AND TYPES

A. Classification of Ionic Charges

Anionic PUDs: Carboxylate (-COO-) or sulfonate (-SO3-) groups of anionic PUDs are negatively charged and neutralized by counter cations (TEA+, Na+). Anionic PUDs account for more than 80% of the commercial textile PUD industry owing to their excellent mechanical strength, outstanding water compatibility and stability under alkaline environments (Santamaria-Echart et al., 2021).
Cationic PUDs: They contain positively charged quaternary ammonium compounds (-N+-). They have a high electrostatic affinity to negatively charged textile fibers (such as cellulosics or wool) therefore increasing the absorption of exhaust dye/finish.
Non-ionic PUDs: Stabilized by hydrophilic polyoxyethylene (PEG) side chains or segments. Also excellent chemical stability against electrolytes, shear stresses and a wide pH range make them very appropriate for auxiliary textile chemicals.
Amphoteric PUDs: They have positive and negative sites and perform well over a broad pH range.

B. Classification According to Polyol Soft-Segment

Polyester-based PUDs: high tensile strength, excellent resistance to oils and solvents and outstanding thermal stability. Optimal for structural coatings and long-lasting synthetic leathers (Liu et al. 2020).

Polyether-based PUDs are recognized for their excellent hydrolytic stability, soft touch and low-temperature flexibility. Excellent choice for outdoor wear and sporting wear.

Bio-Based PUDs: Derived from plant oils, bio-derived polyols (dimer fatty acid polyols for example) or natural derivatives (De Smet et al. 2021; Lacruz et al. 2021). They offer similar performance to petroleum-based PUDs while reducing dependence on fossil fuels.

C. Classification based on cross-linking mechanism

1K Systems: Pre-formulated thermoplastic PUDs which cure by evaporation of water, resulting in physical films held together by hydrogen bonds between rigid and flexible segments.

2K Systems: Waterborne polyurethane dispersions with added water-soluble polyisocyanate or aziridine crosslinkers immediately before use. Curing leads to the formation of covalently crosslinked structures, which are more resistant to heat and chemicals (De Smet et al., 2021).

Hybrid PUDs: Polyurethane-Polyacrylate (PUD-A) or nanocomposite enhanced PUDs combining the elastomeric resilience of PUDs with other properties such as electrical conductivity, economic viability, weather resistance and better water repellency (Lacruz et al., 2021).

IV. CHARACTERISTICS AND PHYSICOCHEMICAL PROPERTIES

Property	Behaviour	Structural Origin & Textile Significance
Particle Size Distribution	10 – 300 nm	Sub-micron particle sizes ensure fine dispersion stability, deep inter-fiber penetration, and continuous film formation.
Solid Content	30% – 50% (up to 60% in high-solid grades)	Higher solid content reduces energy consumption during drying and fixation cycles on fabric stenters.
Tensile Strength	15 – 70 MPa	High tensile strength prevents mechanical failure and film rupture under high-stress textile stretching.
Elongation at Break	200% – 1000%	Microphase separation between hard (urethane/urea) and soft (polyol) domains yields high elasticity.
Glass Transition Temp (Tg)	-50°C to 20°C (Soft Segment)	Low Tg ensures that coated fabrics retain soft hand feel and elasticity in freezing environments.

A. Microphase segregation and film formation

The unique physical properties of PUD films are due to the microphase separation between rigid segments (urethane and urea linkages) and flexible segments (polyol chains) (Liu et al., 2020). The hard segments have hydrogen bonds which act as physical crosslinks and result in high tensile strength and elasticity, while the soft segments provide flexibility. When applied to textiles, water evaporates, enabling micellar aggregation and particle fusion into a homogeneous polymer covering (Patti et al., 2021).

B. Balance of Hydrophilicity and Hydrophobicity and Water Resistance

While PUDs rely on hydrophilic moieties for aqueous dispersion, excess residual hydrophilicity may adversely affect water-column resistance of coated materials. Excellent liquid water barrier properties are achieved thru the balance of carboxyl/sulfonate density, inclusion of hydrophobic siloxane or POSS segments, or the use of post-application cross-linking, while dispersion stability is preserved (Lacruz et al., 2021; Patti et al., 2021).

V. APPLICATION METHODS OF TEXTILES PUD

Choice of suitable method for application depends on fabric structure, desired weight, breathability requirements and final end use standards.

A. Direct Application Knife-Over-Roll

Direct knife-over-roll coating is a commonly utilized technique for industrial uses of polyurethane dispersions (PUDs) on densely woven and knitted textiles, especially for durable protective clothing, technical fabrics and outdoor rainwear . In this process a continuous web of textile is conveyed over a rotating backing roll under precisely controlled tension . An aqueous PUD formulation is continuously applied to the moving material . The roll is directly covered on top with a high accuracy, fixed steel blade (knife) that accurately trims and levels the liquid paste and creates a constant, smooth film of the desired thickness over the whole surface of the fabric. The coated fabric is immediately fed into a multi-zone stenter oven where low temperature drying areas (usually 80-120°C) gradually evaporate the moisture to prevent the formation of blisters, then high temperature curing sections (140-160°C) which achieve complete polymer chain elongation, inter-particle fusion and cross-linking. This technique provides a high and continuous surface barrier giving excellent resistance to hydrostatic pressure, chemical attack and wear, therefore making it an important finishing process for technical fabrics (De Smet et al., 2021).

B. Application of foam

Foam coating is a complex and successful way of coating polyurethane dispersions (PUDs) onto delicate knitted goods, porous textiles and substrates requiring a soft, plush feel. In this process, the aqueous PUD formulation is mixed with foaming agents or specialized surfactants and agitated in a high-shear mechanical aerator to form a stable, fine-celled air-liquid foam structure, generally with a density of 0.1 to 0.3 g/cm3. The enhanced foam paste is then applied evenly to the moving textile web by means of a specific knife or roller applicator. The foaming method replaces a large fraction of the liquid water medium by air bubbles. The overall wet pick-up on the cloth is therefore dramatically reduced. At this lower moisture content, the coating does not fully penetrate the fabric matrix, known as strike-through, and thus maintains the inherent drape, flexibility and breathability of the fabric, as well as reducing energy consumption in the subsequent thermal drying and curing operations. Hence, the foam coating is extensively used in the creation of automotive upholstery, clothing linings, light-blocking window treatments, and useful home fabrics.

C. Pad-Dry-Cure

The impregnation or padding using the traditional pad-dry-cure process is an important industrial process. It is intended to bring about a deep structural change in the textile material and not just produce some surface coating. In this process, the textile material is uniformly passed throughout a bath of a low-viscosity, diluted aqueous polyurethane dispersion (PUD) for full saturation and then thru a series of strong pneumatic squeeze rollers. These rollers apply constant pressure to eliminate the excess liquid and achieve a well-controlled wet pick-up, typically at 60% to 80% of the dry cloth weight (Patti et al., 2021). The sub-micron PUD particles are driven by capillary forces and mechanical compression to fill thoroughly in the yarn bundles, inter-fibre gaps and internal capillary systems (Patti et al., 2021). The saturated fabric then passes to a stenter frame where it is dried in a controlled way to remove its water content and then undergoes a thermal curing at high temperature (often between 140ºC and 160ºC). As the water evaporates, the dispersed nanoparticles cluster into a tiny, very flexible polymer barrier around individual fibers, rather than blocking the larger pores of the fabric. This fiber level encapsulation improves the tensile strength, tear resistance, dimensional stability, anti-pilling properties and crease recovery of the fabric, without hampering its natural air and moisture permeability, making it an important treatment for workwear, technical nonwovens, carpet backings and durable press textile finishes.

D. Transfer and Lamination of Coatings

Transfer coating and lamination are advanced industrial technologies for producing high quality, environmentally friendly synthetic leathers, technological membranes and multi-layered performance laminates. Instead of applying the aqueous polyurethane dispersion (PUD) directly on the textile substrate, the transfer coating process includes the consecutive knife-coating of a topcoat and an intermediate tie-coat on a textured, heat-resistant silicone release paper. Each layer is partially thermally dried to remove moisture and generate a tacky, semi-cured coating of polymer. The textile backing material, which may be woven, knitted or nonwoven, is then contacted with the wet tie-coat layer and pressed by hot nip rollers.

Then the full multi-layer structure is sent thru a curing oven to conclude polymer cross-linking and ensure strong interfacial adhesion between the PUD matrix and the textile fibers. After curing , the release paper is manually stripped and rolled up for subsequent use . A perfect textured coating of polyurethane is permanently bonded to the textile basis . This method eliminates toxic solvents like dimethylformamide (DMF) used in wet-coagulation synthetic leather manufacturing, providing a green, zero VOC process for the fabrication of high quality footwear uppers, automotive interiors, eco-friendly apparel leather, waterproof-breathable technical textiles with excellent tactile properties and improved mechanical strength.

VI. USES IN THE TEXTILE INDUSTRY

A. *Waterproof and Permeable Textiles*

Breathable waterproof textiles are a typical use for polyurethane dispersions (PUDs) that are formulated to prevent the intrusion of liquid water from the outside while allowing moisture vapor from the body to escape. This dual capability is provided by two distinct structural mechanisms using particular PUD formulations: microporous film technology and hydrophilic non-porous membrane systems.

In microporous PUD coatings the deposited layer is often tailored via controlled phase inversion or the application of sacrificial pore generating chemicals to build a cohesive network of sub-micron pores with diameters between 0.1 and 5 micrometers. Usually a single droplet of liquid water has a diameter of between 100 and 3000 micrometers. Surface tension prevents liquid water from moving into these tiny pores, even at higher hydrostatic pressures. Hydrophilic non-porous PUD systems do not have pores, but a molecular absorption-diffusion process occurs. These PUDs are prepared by introducing hydrophilic soft segments in the form of polyoxyethylene/polyethylene glycol (PEG) chains into the polyurethane backbone. When the individual sweats, the high moisture content on the inner surface is attached to the hydrophilic parts of the polymer membrane by hydrogen bonding. The absorbed water molecules then migrate across the film thickness along the concentration and vapor pressure gradient and evaporate from the outer surface. The seamless, poreless film is totally impermeable to liquid water, wind, oils and contaminants. It is highly flexible and washable, making it perfect for practical sportswear, medical protective garments and high-end rainwear.

B. *Eco friendly Artificial Leather*

Polyurethane dispersions (PUDs) are leading a huge industrial revolution in sustainable synthetic leather, offering an eco-friendly alternative to natural leather and conventional solvent-based synthetic leathers. Conventionally, the production of synthetic leather (polyurethane or PVC leather) was based on wet-coagulation or solvent-based coating procedures with the use of organic solvents such as dimethylformamide (DMF), toluene, and methyl ethyl ketone (MEK). These outdated procedures have caused severe environmental hazards, increased emissions of volatile organic compounds (VOCs) and toxic chemical residues in the end product, making them more and more incompatible with current international environmental regulations like REACH and OEKO-TEX (De Smet et al., 2021). The conversion to aqueous PUD systems for synthetic leather manufacturing totally eliminates organic solvents with low or very low VOC emissions and a greatly reduced carbon footprint. In industrial manufacturing, a multi-stage transfer coating process is typically used. An aqueous PUD skin-coat is applied to a textured release paper to create the grain texture and surface properties. This is followed by a PUD foam layer or adhesion layer (tie-coat) that attaches the composite to a textile substrate, such as recycled polyester or organic cotton nonwovens. Moreover, recent developments have seen the incorporation of bio-derived polyols, derived from non-food vegetable oils such as castor or soybean oil, into the PUD framework, thus increasing the bio-based composition of synthetic leather without compromising the superior tensile strength, scratch resistance, and flexibility durability that characterize high-quality materials (De Smet et al., 2021). The resulting eco-leather combines the luxurious look, soft feel, and durability of real leather without the animal welfare concerns, environmental damage, or resource-intensive production, making PUD-based synthetic leather the gold standard for sustainable automotive interiors, shoe uppers, upholstery, and fashion products (De Smet et al., 2021).

C. *Durable Water Repellents (DWR) Without Fluorine*

Resilient Fluorine-Free Water Repellents (DWR) is a major breakthrough in functional textile finishing driven by the world's need to remove the use of harmful, bioaccumulative per- and polyfluoroalkyl substances (PFAS). By lowering the surface energy of the fabric to below the surface energy of water 72.8 mN/m and oils, long-chain fluorocarbon coatings (C8 and C6 compounds) previously imparted excellent resistance to water and oil to textiles.

However, the severe environmental persistence and health dangers of PFAS have led to rigorous legislative prohibitions across the globe, prompting the textile industry to turn to eco-friendly replacements. Waterborne polyurethane dispersions (PUDs) are regarded as an ideal medium for fluorine-free durable water repellent (DWR) finishes due to their film-forming ability, robustness and tunable chemical structure (Lacruz et al., 2021).

Functionalized PUDs are developed by attaching elongated hydrophobic alkyl chains, polydimethylsiloxane (PDMS) segments, or polyhedral oligomeric silsesquioxane (POSS) moieties to the polyurethane framework so as to achieve superior water repellency free of fluorinated substances (Lacruz et al., 2021). Using these modified PUDs on textiles using the pad-dry-cure process, an ultrathin uniform hydrophobic coating is formed on the fibers. During the high temperature thermal cure process, the hydrophobic segments orientate outwards to the air-fabric interface resulting in a significant reduction in the surface energy of the textile and initial water contact angles > $1300.

The major benefit of using a PUD-based platform instead of simple wax or paraffin emulsions is its wash fastness. The strong polyurethane-urea film matrix, reinforced by hydrogen bonding and perhaps 2K covalent cross-linking (eg, using water-dispersible polyisocyanates) strongly anchors the hydrophobic groups to the fiber surface. This prevents the functional finish from being lost or worn out during many home laundering operations and harsh outdoor circumstances. Therefore, fluorine-free PUD-based DWR coatings offer long-lasting water repellency, soft hand feel and enhanced breathability in performance outerwear, activewear and technical textiles while meeting strict environmental standards.

VII. FUTURE DIRECTIONS AND CHALLENGES

Despite the obvious ecological and operational advantages, there are many continuing technical problems with waterborne PUD systems:

Energy Demands in Drying: Water has a higher latent heat of vaporization (2260 kJ/kg) than organic solvents (e.g. DMF: 573 kJ/kg), and so the use of special drying ovens or hybrid infrared drying methods is required.

Hydrophilic Sensitivity: Long-term water contact may result in increased film expansion due to prolonged presence of internal emulsifiers. This issue is being handled by research on cross linking technologies and bio generated hydrophobic additives (Lacruz et al., 2021).

Transition to Bio-Based Raw Materials: The focus of the research is on the development of bio-based polyurethane dispersions (PUDs) based on non-food vegetable oils, natural derivatives and renewable diisocyanates for achieving a fully circular textile economy (De Smet et al., 2021; Santamaria-Echart et al., 2021).

VIII. CONCLUSION

The switch to waterborne polyurethane dispersions (PUDs) represents a major leap forward in sustainable textile manufacturing, eliminating the use of harmful organic solvents and VOC emissions, while preserving the mechanical integrity. PUDs offer outstanding tensile strength, flexibility and durability for functional outerwear, zero-VOC synthetic leathers and fluorine-free durable water-repellent (DWR) finishes because to their microphase-separated architecture. PUDs provide tailored solutions for breathable, waterproof and high performance technical textiles with flexible coating, impregnation and laminating processes. Bio-derived polyols, cross-linking strategies and hybrid nanocomposites improvements will improve water resistance and minimize drying energy requirements, making PUDs a key component in sustainable textile manufacturing.

REFERENCES

[1] De Smet, D., Wéry, M., Uyttendaele, W. & Vanneste, M. (2021). Bio-based waterborne PU for high durability textile coatings. Polymers 13, 4229 (2021). 10.3390/polym13234229

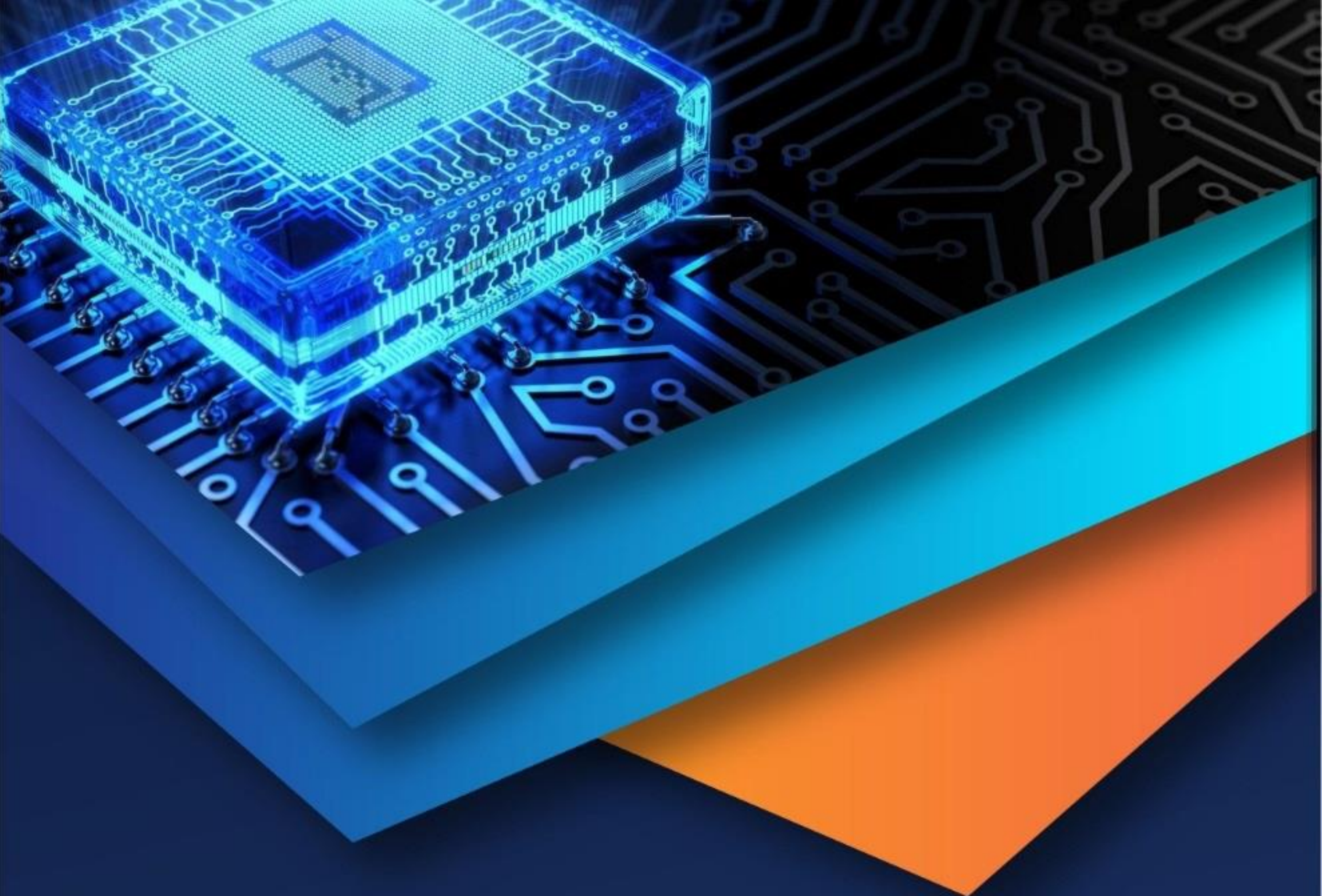
[2] Lacruz, A., Salvador, M., Blanco, M., Vidal, K., Goitandia, A. M., Martinková, L., Kyselka, M., & de Ilarduya, A. M. . (2021). Fluorine-Free Hydrophobic Coatings for Textiles: Biobased Waterborne Polyurethane-Ureas Modified with POSS-OH. Polymers 13 (20), 3526. https://doi.org/10.3390/polym13203526

[3] Lacruz, A., Salvador, M., Blanco, M., Vidal, K., Goitandia, A. M., Martinková, L., Kyselka, M. and de Ilarduya, A. M. (2021). Biobased waterborne polyurethane-urea/SWCNT nanocomposites for hydrophobic and electrically conductive coating of textiles. Polymers 13 (10), 1624. https://doi.org/10.3390/polym13101624

[4] Liu, X., W. Hong, & X. Chen. (2020). Water-borne polyurethanes continuous production: A review. Polymers 12(12), 2875. https://doi.org/10.3390/polym12122875

[5] A., Costa, F., Perrotti, M., Barbarino, D. & Acierno, D. (2021). Polyurethane Impregnation for Enhancing Mechanical and Water Resistance Properties of Polypropylene Based Textiles. Materials, 14(8), 1953. doi:10.3390/ma14081951

[6] Santamaria-Echart, A., Fernandes, I., Barreiro, F., Corcuera, M. A., and Eceiza, A. . (2021). Progress in waterborne polyurethane and polyurethane-urea dispersions and their environmentally friendly derivatives: A review. Polymers, 13(3), 409. https://doi.org/10.3390/polym1303409



10.22214/IJRASET

INDEX COPERNICUS 45.98

IMPACT FACTOR: 7.129

IMPACT FACTOR: 7.429

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY