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A Review on Role of Styrene Butadiene Rubber in Enhancing Mechanical and Durability Performance of Cementitious Composites

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***Abstract:** Concrete is the backbone of modern infrastructure but remains vulnerable to cracking across different scales, from microlevel shrinkage cracks to macrolevel structural fractures. These defects not only compromise mechanical performance but also accelerate durability problems. Styrene Butadiene Rubber (SBR) has emerged as a promising polymer modifier that enhances the toughness and durability of cementitious composites. By refining pore structure, strengthening the interfacial transition zone, and forming flexible polymer films within the matrix, SBR mitigates the initiation and propagation of cracks. The study focuses on mechanisms through which SBR improves the fracture energy, impact resistance and long-term durability. SBR has shown significant potential in enhancing the crack resistance of concrete across multiple scales while supporting goals. Continued research and practical validation will be essential to fully unlock its benefits for next-generation construction materials.*
***Keywords:** Styrene Butadiene Rubber, Durability performance, Crack resistance*

I. INTRODUCTION

Concrete is one of the most widely used construction materials globally because of its versatility, cost- effectiveness and high compressive strength; however, its brittle nature makes it highly prone to cracking at multiple scales, which significantly compromises durability and long-term structural performance. Conventional concrete exhibits limited impact resistance, and cracks formed under dynamic or repetitive loads can lead to sudden structural failures, emphasizing the need for enhanced toughness [1]. Additionally plain cementitious composites have insufficient energy absorption capacity to resist repeated or impact stresses, making them vulnerable to micro and macro cracking under service conditions [2]. To address these challenges, polymer modification has emerges as promising strategy, with Styrene–Butadiene Rubber (SBR) being widely studied due to its unique ability to form flexible polymer films that bridge microcracks and improve the interfacial transition zone (ITZ) between paste and aggregates. Incorporation of SBR not only enhances mechanical properties but also contributes to sustainability by reducing repair frequency and extending the service life of concrete infrastructure.

Experimental investigations using Charpy and three-point bending tests have shown that SBR-modified cement pastes exhibit substantially higher absorbed energy and fracture toughness compared to unmodified mixes, demonstrating its effective role in mitigating crack propagation [4][5]. Mortars modified with SBR in powder and nanoparticle form show improved compressive strength and denser microstructure, which are critical factors in reducing shrinkage-induced microcracking and improving durability [6]. Furthermore, studies on the dispersion mechanism of SBR latex indicate that uniform polymer distribution decreases void content and enhances crack resistance by refining the microstructure and improving bonding at the ITZ [7]. High-performance cementitious materials modified with SBR also display improved resistance to chloride ingress and other aggressive chemical exposures, delaying crack initiation and propagation under environmental stressors [8]. In repair mortars, SBR addition enhances both physical and mechanical properties, resulting in stronger adhesion, reduced shrinkage cracking, and improved performance of overlay systems. Its application in pervious concrete has shown significant improvements in mechanical strength while maintaining adequate permeability, ensuring that sustainability goals are met alongside structural performance [10].

Studies comparing raw and pre-treated SBR indicate that polymer preparation methods influence flexibility and shrinkage behavior, highlighting the importance of optimizing material characteristics for maximum crack control [11]. Fracture behavior analyses reveal that SBR-modified concretes exhibit enhanced post-peak ductility and fracture toughness, enabling them to resist crack propagation under applied loads more effectively than conventional concrete [12].

Moreover, the combination of SBR with fibers demonstrates synergistic effects, improving impact resistance and controlling both micro- and macro-scale cracks [13]. Beyond mechanical improvements, SBR has been found to reduce drying shrinkage and associated early-age cracking, contributing to better dimensional stability and long-term durability of concrete structures [14]. Investigations into fresh and hardened properties also indicate that SBR enhances workability, strength, and shrinkage resistance, thereby improving overall performance under various mechanical and environmental conditions [15].

In addition, SBR-modified concrete has shown potential in mitigating fatigue-induced cracking under cyclic loading, which is particularly beneficial for pavements and bridge decks exposed to heavy traffic. The polymer also improves resistance against freeze–thaw cycles, reducing the likelihood of microcrack formation in cold climates. SBR films within the cement matrix act as flexible bridges, delaying coalescence of microcracks into larger structural cracks. Several studies have reported that combining SBR with supplementary cementitious materials like fly ash and silica fume further enhances durability and toughness. The inclusion of SBR can also lower water permeability, providing additional protection against environmental degradation. By reducing both shrinkage and creep-related cracking, SBR- modified concrete offers improved dimensional stability over the service life. Overall, these combined benefits highlight the importance of SBR as a multifunctional additive for developing sustainable, crack-resistant, and long-lasting concrete structures.

Collectively, these studies demonstrate that SBR serves as a multifunctional modifier, providing mechanical reinforcement, durability enhancement, and multi-scale crack mitigation in cementitious systems. By strengthening the ITZ, forming continuous polymer films, refining pore structure, and synergizing with fibers and supplementary cementitious materials, SBR improves both microstructural and macroscopic properties of concrete. Despite the progress, research gaps remain, including the optimization of SBR dosage, understanding long-term performance under combined mechanical and environmental stresses, and validating behavior in large-scale and field applications. Addressing these gaps will provide valuable insights for designing sustainable, durable, and crack-resistant concrete for modern infrastructure, and guide future experimental and field-based studies in polymer-modified cementitious systems.

II. CHEMICAL COMPOSITION OF SBR

Styrene-Butadiene Rubber (SBR) is a synthetic copolymer composed primarily of styrene and 1,3- butadiene monomers, whose ratio strongly affects the physical and mechanical properties of the resulting material. The polymerization of SBR can be performed through emulsion or solution methods, each influencing the microstructure, molecular weight distribution, and performance characteristics of the rubber. In emulsion polymerization, the reaction takes place in an aqueous medium, producing a random distribution of styrene and butadiene units along the polymer chain, which directly affects the material's glass transition temperature, hardness, and elasticity [16]. Conversely, solution polymerization involves organic solvents and initiators, such as alkyl lithium compounds, allowing for more controlled polymerization and tailored molecular weights, resulting in SBR with improved mechanical uniformity and processing properties [17]. The styrene content in SBR typically ranges from 20% to 25% by weight, providing enhanced hardness, abrasion resistance, and heat resistance, while a higher butadiene content contributes to greater flexibility, resilience, and low-temperature performance [18]. The microstructure of the butadiene units, including cis-1,4, trans-1,4, and vinyl-1,2 configurations, plays a critical role in determining elasticity, strength, and processing behavior, with cis-1,4 units imparting flexibility and trans-1,4 units improving wear resistance. The vinyl content can influence crosslinking behavior during vulcanization, affecting processability, dimensional stability, and final mechanical performance [19]. Molecular weight and molecular weight distribution are also key factors, as narrow distributions promote consistent processing and uniform mechanical properties, whereas broader distributions may enhance toughness and improve processability in certain applications. SBR can be compounded with various additives, including stabilizers, plasticizers, antioxidants, and crosslinking agents, to further modify chemical composition and tailor properties for specific applications such as tires, footwear, and industrial products [17]. For example, plasticizers improve processability and flexibility, while crosslinking agents during vulcanization enhance heat resistance, dimensional stability, and long-term durability. The method of polymerization, along with the choice and concentration of additives, significantly affects the microstructure, glass transition temperature, and mechanical characteristics of the final SBR product [16]. SBR exhibits amorphous regions due to random copolymerization, and the distribution of styrene and butadiene domains influences the balance between hardness and elasticity [20]. The thermal behavior and aging resistance of SBR are dependent on both its chemical composition and the presence of stabilizers or antioxidants, which mitigate oxidative degradation under high temperatures or prolonged environmental exposure. Furthermore, the ratio of cis, trans, and vinyl units influences how SBR responds to mechanical stress, impacting fatigue resistance, crack propagation, and overall durability in structural and industrial applications.

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Recent studies have also shown that the integration of nanofillers or reinforcing agents into SBR matrices can further optimize its properties by improving tensile strength, wear resistance, and crack resistance while maintaining flexibility [16]. The chemical composition, polymerization method, and additive system together define the viscoelastic behavior of SBR, which determines how the rubber will perform under cyclic loading, compression, or dynamic stresses. Additionally, the aging and environmental stability of SBR, particularly when used in asphalt or tire compounds, is directly linked to its styrene-to-butadiene ratio, microstructure of butadiene units, and the protective role of antioxidants or stabilizers [20]. Control over these parameters allows manufacturers to design SBR for high-performance applications requiring specific balances between hardness, elasticity, abrasion resistance, and environmental durability [18]. Understanding the detailed chemical composition of SBR is therefore critical for predicting its performance, optimizing processing conditions, and tailoring it for applications ranging from flexible industrial products to highly wear-resistant components in automotive and civil engineering sectors [19]. The combination of polymer chain configuration, additive incorporation, and controlled polymerization enables SBR to meet stringent requirements for mechanical performance, thermal stability, and chemical resistance. Ultimately, careful design and optimization of SBR's chemical composition make it a highly versatile polymer, suitable for diverse applications where crack resistance, flexibility, and durability are essential.

III. PHYSICAL AND MECHANICAL PROPERTIES OF SBR MODIFIED CONCRETE

Styrene–Butadiene Rubber (SBR) modification of concrete brings a distinct set of physical and mechanical changes to cementitious mixtures that are of direct interest to structural engineers and materials scientists, beginning with fresh-state behavior where the addition of SBR latex or powder typically enhances cohesiveness and reduces segregation and bleeding, enabling more uniform placement and finishing without necessarily increasing water demand when proper admixture compatibility is observed [21]. In many experimental studies, SBR has been shown to act as a microfilm forming agent that coats cement grains and aggregate surfaces in the fresh mix, which modifies rheology by slightly increasing yield stress while improving plastic viscosity and workability retention over short periods, a behavior particularly useful for mixes that require extended handling or pumping. The influence of SBR on setting characteristics is nuanced: low to moderate dosages often retard initial set marginally due to polymer interference with hydration kinetics, whereas optimized formulations with appropriate curing practices can achieve acceptable setting profiles for construction schedules. Bulk density and apparent porosity of hardened SBR-modified concretes frequently reflect the combined effects of polymer inclusion and entrapped air; some reports note a small reduction in bulk density alongside a refinement of capillary pore structure that influences mechanical responses without being discussed here in terms of durability [24]. At the microstructural level, SBR contributes to modification of the interfacial transition zone (ITZ) between paste and aggregate, where polymer films and improved particle packing reduce brittle interfaces and promote load transfer, which has a measurable influence on mechanical properties such as tensile strength and fracture behavior [25].

Compressive strength responses to SBR addition are not universally proportional to dosage; many investigations indicate an initial modest gain or parity with control mixes at early ages followed by variable outcomes at later ages that depend on polymer-to-cement ratios, curing regime, and whether the SBR is used in latex or powder form, with some optimized mixes showing notable compressive strength improvements attributable to improved particle packing and microcrack resistance mechanisms [26]. In contrast to compressive behavior, flexural strength and modulus of rupture tend to respond more favorably to SBR modification, with numerous studies reporting significant increases in flexural capacity and post-cracking load-carrying ability, which is consistent with the polymer's role in bridging microcracks and enhancing ductility under bending loads [27]. Splitting tensile strength and direct tensile tests typically show improvement with SBR content, reflecting enhanced adhesion in the matrix and a more ductile failure mode; this is important because tensile capacity and crack control drive serviceability in many structural elements more than peak compressive strength. The static modulus of elasticity of SBR-modified concretes often exhibits a small reduction relative to unmodified concrete of similar compressive strength, which can be advantageous in applications where increased deformability and energy dissipation are desirable, though designers must account for altered stiffness in structural analysis. Toughness parameters, including area under the load–deflection curve in flexural tests and measured fracture energy in single-edge notched beams or three-point bending, consistently show enhancement with SBR inclusion, indicating that polymer-modified mixes dissipate more energy during crack formation and propagation and therefore exhibit improved post-peak behavior and redistributed stresses after cracking [30]. Impact resistance and resistance to dynamic loads are also enhanced in many SBR-bearing systems, with instrumented drop-weight and Charpy-type tests reporting higher absorbed energy and lower crack growth rates; such improvements are frequently attributed to the flexible polymer phase that blunts crack tips and promotes microcrack coalescence control [21]. When SBR is combined with discrete fibers — whether glass, polypropylene, steel, or polyvinyl alcohol — synergistic effects are commonly observed where the polymer improves matrix–fiber bonding and the fibers contribute to macro-crack bridging, together producing concrete with substantially improved toughness, residual strength after cracking, and resistance to impact and spalling [22]. Creep behavior of SBR-modified concrete may differ from conventional mixes, with some studies indicating slightly higher short-term creep due to increased viscoelastic polymer content but improved long-term deformation control when the polymer promotes a more distributed microcracking pattern rather than localized brittle fracture [23]. Shrinkage phenomena related to physical drying and autogenous mechanisms are influenced by SBR in complex ways: polymer films can reduce early-age tensile stress concentrations and limit microcrack initiation, thereby altering the shrinkage–cracking relationship even where absolute shrinkage magnitudes are not dramatically changed [24]. Bond strength between concrete and embedded reinforcement or between repair overlays and existing concrete is frequently improved by SBR modification because of better adhesion at the microscale and improved mechanical interlock facilitated by a tougher, more compliant matrix, which has clear implications for composite action and retrofit applications. The strain capacity at peak stress and the post-peak softening slope in both compression and tension tests are modified by the presence of SBR, generally trending toward more ductile and gradual failure modes that benefit energy absorption and reduce the brittleness typical of unmodified cementitious materials [26]. In precast and thin-section elements where cracking control and surface quality are critical, SBR-modified mortars produce improved surface finish and reduced incidence of crazing, attributable to the polymer's capacity to accommodate strain differentials at the surface during early curing and finishing operations [27]. In reinforced members where serviceability limits govern cracking behavior, SBR's enhancement of tensile and flexural response can translate into reduced crack widths under service loads, improved load redistribution, and extended intervals before visible cracking occurs, which is a direct mechanical performance advantage independent of any durability considerations [28]. Thermal compatibility and coefficients of thermal expansion are also important in certain applications; while SBR slightly adjusts the composite thermal response due to its elastomeric nature, optimized mixtures show acceptable thermal strain compatibility with typical reinforcement and aggregate choices used in practice. Fatigue performance under cyclic loading has been a focus of several studies, and SBR-modified concretes often demonstrate either improved fatigue life or more favorable fatigue crack growth characteristics, likely because the polymer phase delays crack initiation and reduces the effective stress intensity at existing microdefects [30]. The role of mix proportioning is crucial: excessive SBR dosages can lead to a reduction in strength or other undesired fresh-state effects, whereas low-to-moderate dosages properly balanced with water content, superplasticizers, and cementitious replacement materials can yield optimal mechanical outcomes, underscoring the need for tailored mix-design strategies rather than one- size-fits-all additions. Rheological tuning using SBR also allows for more complex casting techniques and improved consolidation in congested reinforcement regions, improving homogeneity and thus affecting structural performance indirectly through better material distribution. Test methods and specimen conditioning exert a significant influence on measured mechanical properties of SBR-modified concretes; for example, results vary between sealed and unsealed curing, between different loading rates, and between different specimen geometries, so comparisons require careful normalization of experimental procedures. The effect of SBR on shrinkage-induced microcracking interacts with aggregate type and grading, as stiffer aggregate systems may change the stress-transfer mechanisms and thus modify how the polymer phase influences crack initiation and propagation under restrained conditions [24]. For repair mortars and overlay materials, SBR inclusion provides improved handling characteristics and early mechanical capacity that allow quicker return to service for repaired elements, with bond and flexural performance being particularly important metrics for evaluating repair efficacy. In applications such as pavement overlays and overlays on substrates with differing stiffness, SBR can impart sufficient flexibility to reduce reflective cracking and to accommodate slight differential movements between layers, thereby improving mechanical continuity without relying on increased thickness [26]. For high-performance and self-consolidating applications, carefully formulated SBR- modified mixes can achieve impressive combinations of flowability and mechanical strength, enabling complex geometries and thin sections where traditional mixes might fail to meet performance requirements. When SBR is used in conjunction with supplementary cementitious materials in mixes intended for load-bearing members, mechanical synergies can be achieved where pozzolanic reactions produce a refined matrix and the polymer phase mitigates brittleness, resulting in balanced strength and toughness gains [28]. Measurements of fracture toughness and crack-propagation resistance using standardized fracture mechanics approaches routinely show benefits from SBR, with higher critical stress intensity factors and increased energy required to propagate an existing crack compared to control mixes. Finally, practical considerations such as cost, availability, and compatibility with local admixtures influence the feasibility of adopting SBR modifications at scale, but when engineering requirements favor improved toughness, impact resistance, and improved post-cracking performance without substantial increases in weight or thickness, SBR-modified concrete presents a compelling option that merits consideration in design and specification for structural elements where mechanical resilience is prioritized [30].

IV. DURABILITY OF SBR MODIFIED CONCRETE

The durability of Styrene–Butadiene Rubber (SBR) modified concrete has received significant attention in recent years as researchers aim to address long-standing issues of permeability, cracking, and chemical resistance in cementitious systems. One of the primary benefits of incorporating SBR into concrete is its ability to reduce water permeability and sorptivity, which directly contributes to enhanced resistance against moisture-induced damage and delays the ingress of aggressive ions that typically accelerate deterioration. This reduction in permeability occurs due to the formation of a continuous polymer network within the cement matrix that blocks pore connectivity and strengthens the interfacial transition zone, thus acting as a protective shield against harmful agents [33]. In chloride-rich environments such as marine structures and pavements exposed to de-icing salts, SBR significantly restricts chloride ion penetration, thereby reducing the likelihood of reinforcement corrosion and ensuring a prolonged service life for reinforced concrete elements. Studies have shown that the polymer network not only reduces chloride diffusivity but also lowers the concentration of free calcium hydroxide, further mitigating risks associated with steel depassivation and rust formation [35]. SBR modification has also demonstrated considerable improvements in sulfate resistance, which is one of the most common durability challenges in soils and groundwater with high sulfate content. Sulfate ions typically react with hydration products like calcium hydroxide and aluminates to form expansive ettringite and gypsum, leading to cracking and surface scaling; however, in SBR-modified concretes, the reduced porosity and denser microstructure restrict the ingress of sulfates and thus suppress the formation of expansive products [37]. In addition, the hydrophobic nature of SBR further slows down sulfate ion diffusion, providing an additional line of defense against chemical attack [38]. Carbonation resistance is another key durability advantage of SBR-modified concrete, as the polymer-rich matrix reduces CO_2 ingress, thereby maintaining the alkalinity of pore solution that is essential for preserving the passive layer on steel reinforcement. By slowing down carbonation, SBR-modified concretes help in delaying depassivation of embedded reinforcement, making them highly suitable for urban infrastructures where exposure to elevated CO_2 concentrations is common.

Another important dimension of durability is the concrete's ability to withstand freeze–thaw cycles, particularly in regions with fluctuating temperatures. Conventional concrete often suffers from scaling, cracking, and surface deterioration due to ice crystallization within pores; however, the elastomeric properties of SBR help absorb the stresses generated by freezing water, thereby reducing internal damage [31]. Moreover, the polymer phase effectively reduces the volume of freezable water inside the pores, which further enhances resistance to freeze–thaw damage [32]. These benefits make SBR- modified concrete suitable for cold-climate applications such as pavements, bridge decks, and airfield runways where conventional concrete would typically require frequent repair and maintenance. The abrasion resistance of SBR-modified concrete is also markedly superior, as the polymer component provides flexibility and toughness, which resist surface wear under heavy traffic loads. Industrial flooring, which is often subjected to mechanical wear and chemical spillage, benefits significantly from SBR modification due to its dual improvement in both abrasion and chemical resistance [35].

In addition to these chemical and mechanical durability improvements, SBR contributes to reduced shrinkage cracking by distributing stresses more uniformly across the microstructure. Although the total drying shrinkage may not be substantially reduced, the presence of a flexible polymer phase reduces the likelihood of crack formation, which would otherwise serve as channels for ingress of harmful ions and moisture [37]. This improvement in crack resistance is particularly valuable in thin overlays and repair mortars, where shrinkage-induced cracking often leads to premature failure. SBR-modified repair materials are therefore highly durable in practice, maintaining adhesion under thermal cycles, resisting debonding, and providing longer service life for rehabilitated structures. Another often-overlooked aspect of durability is resistance to alkali–silica reaction (ASR), where expansive gels form due to the reaction between reactive silica and alkalis in the pore solution. Research suggests that SBR modification lowers pore connectivity and reduces alkali mobility, thereby limiting ASR-induced cracking and maintaining long-term structural stability.

Overall, SBR-modified concrete presents a multi-faceted improvement in durability by simultaneously addressing permeability, chloride ingress, sulfate attack, carbonation, freeze–thaw cycles, abrasion resistance, shrinkage cracking, and ASR vulnerability. These combined effects ensure that SBR- modified systems provide significantly extended service life, lower maintenance requirements, and enhanced sustainability compared to conventional concretes, making them highly suitable for critical infrastructure.

V. CONCLUSIONS

Styrene–Butadiene Rubber (SBR) is an effective polymer modifier for enhancing the performance of cementitious composites. Its incorporation significantly improves resistance to multi-scale cracking by refining the pore structure, strengthening the interfacial transition zone, and forming flexible films that bridge developing cracks.

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Experimental studies confirm that SBR enhances fracture energy, flexural strength, impact resistance, and tensile performance, leading to improved toughness and ductility in structural applications. The polymer also reduces permeability, thereby limiting chloride ingress, carbonation, sulfate attack, and freeze–thaw damage, which collectively extend the service life of concrete.

Beyond mechanical and durability benefits, SBR promotes better bond strength in repair mortars, reduces shrinkage-induced cracking, and ensures improved adhesion in overlays, making it highly suitable for rehabilitation works. Its synergistic use with fibers and supplementary cementitious materials further amplifies performance, demonstrating versatility across both structural and environmental conditions. However, the effectiveness of SBR depends on appropriate dosage, curing practices, and mix design optimization, which remain areas for ongoing research. In summary, SBR- modified concrete presents a sustainable and practical solution to address cracking and durability limitations in modern infrastructure. Continued investigations, especially long-term field applications and life-cycle assessments, are essential to translate laboratory evidence into widespread industrial adoption and to fully unlock the potential of SBR in next-generation concrete technologies.

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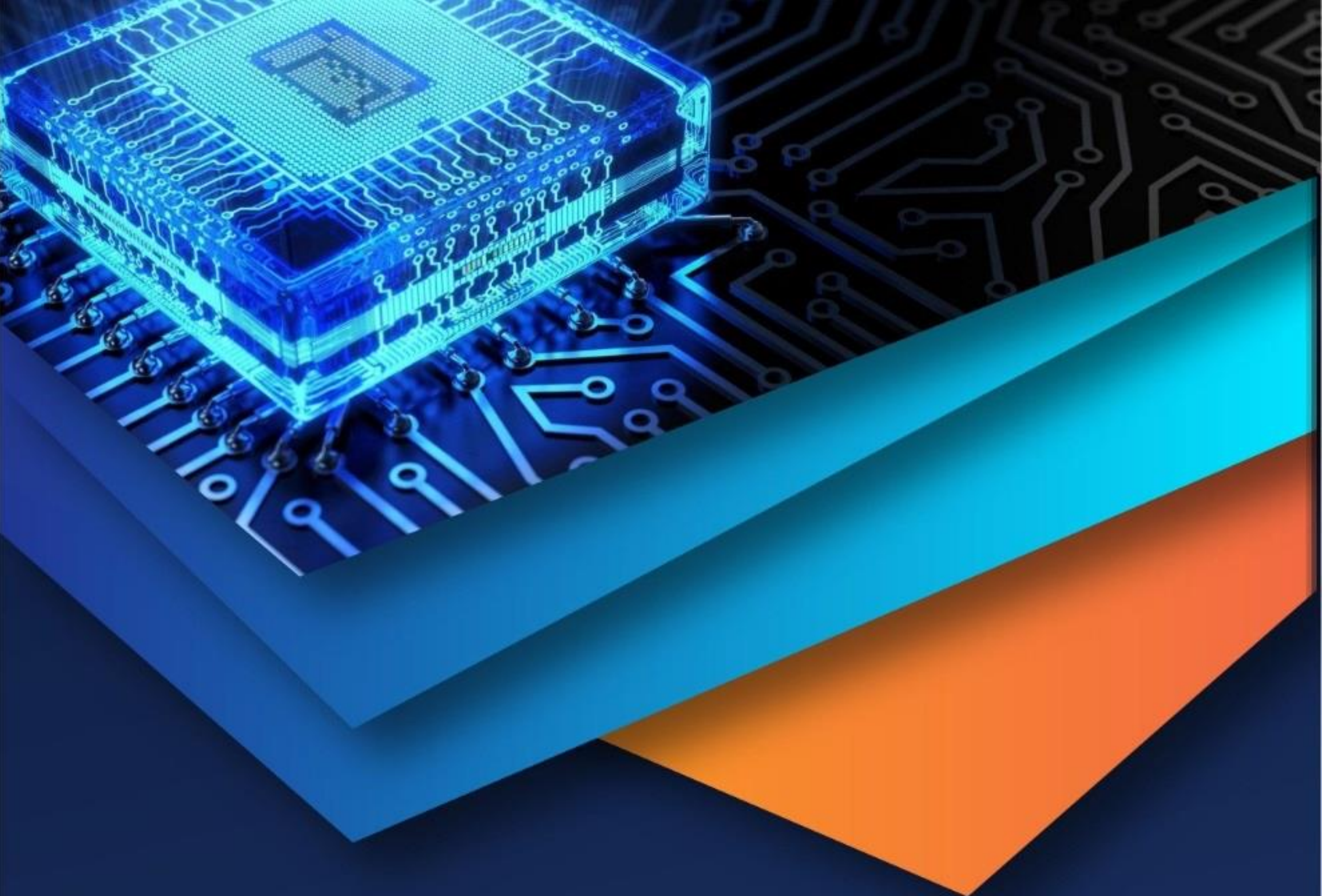

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