

Reframing Waste Tires as Engineered Rubber Geomaterials: A Materials Classification Approach for Circular Infrastructure Systems

Prithvendra Singh ^{1,2,3,*}

¹Institute of Geotechnical Engineering, Southeast university, Nanjing, Jiangsu 211189, China; E-mail: prithvendrasingh@gmail.com

²Jiangsu Key Laboratory of Low Carbon and Sustainable Geotechnical Engineering, Nanjing, Jiangsu 211189, China

³Department of Civil Engineering, Indian Institute of Technology Bombay, Mumbai, 400076, India



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ABSTRACT: Waste rubber tires (*WRTs*), generated in enormous quantities due to the rapid growth of the automobile sector, pose significant geoenvironmental and sustainability challenges when left unattended in landfills and dumpsites. It is worth noting that, despite extensive research demonstrating the suitability of waste tire-derived materials for embankments, backfills, pavement systems, drainage layers, and cementitious composites, their large-scale utilization remains limited. Although several factors, including regulatory uncertainty, supply-chain consistency, economic considerations, and conservative engineering practice, influence their adoption, the absence of a structured materials classification framework represents a critical and largely overlooked barrier to their systematic integration into engineering practice. With this in view, the present study introduces the concept of engineered rubber geomaterials (*ERGs*), and proposes a classification-based framework that links material descriptors with functional performance and application suitability. The framework considers particle characteristics, mechanical response, durability, and aging behavior, and hydro-environmental performance, and further outlines a workflow for material characterization, classification, verification, and specification. In addition, the study discusses the role of *ERGs* in supporting standardization, procurement practices, performance-based design, and circular infrastructure systems. It is envisaged that the proposed framework would facilitate consistent material characterization, improve comparability across studies, and provide a pathway for incorporating waste tire-derived materials into engineering guidelines and specifications. Thus, the study highlights the importance of classification-driven approaches in bridging the gap between materials characterization and large-scale implementation, thereby enabling the transition of waste tires from an environmental burden to a viable engineering resource.

Keywords: Waste tires, Engineered rubber geomaterials, Circular economy, Material classification, Sustainable infrastructure, Resource recovery.

■ INTRODUCTION

The rapid growth of the automobile industry and associated sectors has resulted in the generation of enormous quantities of waste rubber (*WasRub*), primarily originating from waste rubber tires (*WRTs*) at the end of their service life [1-4]. It is estimated that approximately 1 billion *WRTs* are discarded annually worldwide, and this number is expected to increase significantly in the

coming years [4-6]. Due to their cross-linked (vulcanized) structure, *WRTs* are highly resistant to thermal, chemical, biological, and photochemical degradation, and hence remain undegraded under natural geoenvironmental

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conditions [7]. Under these circumstances, unscientific disposal of *WasRub* in landfills and stockpiles leads to several well-known issues, including fire hazards, vector breeding, land occupation, and contamination of the geoenvironment [1,8-10].

To address these challenges, earlier researchers have explored several pathways for the utilization of *WasRub* in infrastructural and geoenvironmental applications, such as embankments, pavement systems, backfills, landfill components, and cementitious composites [3,11–16]. It is worth appreciating that such efforts demonstrate the potential of *WasRub* as a manmade resource, particularly due to its unique characteristics, such as low-density, high-energy dissipation capacity, resilience under cyclic loading, and durability under adverse environmental conditions [17-21]. Needless to state, these attributes make waste tire-derived materials suitable for replacing conventional geomaterials in several applications. However, it is unfortunate that despite such well-established potential, the bulk utilization of *WasRub* has not been realized so far, and its application remains largely limited to case-specific studies [4]. This situation indicates a clear disconnect between laboratory-scale investigations and field-scale implementation. It should be noted that most of the existing studies are focused on evaluating specific engineering properties under controlled conditions, without establishing a generalized framework that can guide their selection and application in practice.

Based on the available literature, it can be inferred that substantial progress has been made in understanding the engineering behavior of waste tire-derived materials, and their suitability for a variety of infrastructural and geoenvironmental applications has been demonstrated under both laboratory and field conditions. However, what remains largely unresolved is the ability to systematically translate this knowledge into routine engineering practice through material specifications, procurement frameworks, certification procedures, and design guidelines. Consequently, although the engineering feasibility of utilizing *WasRub* is reasonably well established, pathways for its consistent classification and integration into existing engineering systems remain inadequately developed. With this in view, the present study seeks to address this gap by proposing a classification-based framework for engineered rubber geomaterials (ERGs), which establishes linkages between material descriptors, functional performance, and application suitability, thereby providing a pathway for their broader implementation within circular infrastructure systems.

Under these circumstances, it can be inferred that the challenge associated with the large-scale implementation of *WasRub* extends beyond the mere demonstration of engineering feasibility. It should be noted that several factors, including economic considerations, regulatory uncertainty, material heterogeneity, supply-chain constraints, and conservative engineering practices, may influence the adoption of waste tire-derived materials in infrastructure projects. However, among these factors, the absence of a structured materials classification framework represents a critical and largely underexplored limitation. Unlike conventional geomaterials, which are systematically categorized using standardized descriptors and embedded within engineering specifications and design procedures, *WasRub* is generally described in terms of processing methods or isolated engineering properties. Consequently, the relationship between material characteristics, engineering performance, and application suitability remains fragmented, thereby limiting the translation of existing knowledge into routine engineering practice.

With this in view, the present study proposes the concept of engineered rubber geomaterials (ERGs), as a classification-based framework for representing waste tire-derived materials within infrastructure systems. The objective of this article is to develop a classification-based approach that links material descriptors with functional performance, thereby facilitating their integration into design frameworks, standardization protocols, and circular infrastructure systems. It is envisaged that such an approach would enable systematic utilization of *WasRub*, reduce dependence on natural resources, and contribute to the Sustainable Development Goals (SDGs) and circular economy objectives.

■ 2. MATERIALS CLASSIFICATION GAP

Over the past few decades, significant efforts have been made by researchers to explore the utilization of *WasRub*, in various infrastructural and geoenvironmental applications [22,23]. These studies have demonstrated that *WasRub*, when processed into different forms such as shreds, chips, and crumbs, can be effectively utilized in embankments, pavement systems, backfills, drainage layers, and polymer- and cementitious-composites [11,24-27]. It is worth appreciating that such investigations have established the suitability of *WasRub* as a potential alternative to conventional geomaterials, particularly due to its unique characteristics such as low

unit weight, high compressibility, resilience, and enhanced energy dissipation capacity.

It is worth appreciating that the engineering behavior of waste tire-derived materials has been extensively investigated over the past three decades. Numerous studies have evaluated their mechanical, hydraulic, durability, and environmental characteristics and have demonstrated their suitability for applications such as lightweight embankments, retaining wall backfills, pavement systems, drainage layers, landfill engineering, and cementitious composites. Consequently, a substantial body of knowledge is now available regarding the performance of *WasRub* under different loading and environmental conditions.

However, it should be noted that the existence of engineering knowledge does not necessarily guarantee widespread implementation. Although favorable performance has been reported in several laboratory investigations and field demonstrations, the utilization of waste tire-derived materials in routine infrastructure projects remains relatively limited when compared to conventional geomaterials. This observation suggests that barriers to implementation may extend beyond material performance alone and include factors related to standardization, design integration, procurement practices, regulatory acceptance, and quality assurance.

However, it is important to note that most of these studies are primarily focused on evaluating the influence of *WasRub* on specific engineering properties under controlled laboratory conditions. Typically, parameters such as shear strength, compressibility, permeability, and durability are investigated for selected material combinations and configurations. While such studies provide valuable insights into material behavior, they remain largely application-specific and do not facilitate generalization of the findings across different projects and field conditions [4,28].

Under these circumstances, it is unfortunate that, despite the availability of substantial experimental evidence, large-scale utilization of *WasRub* has not materialized. This situation indicates that the limitation is not due to a lack of knowledge of material behavior, but rather to the absence of a structured framework that can translate this knowledge into engineering practice [29,30]. Therefore, there exists a gap between material characterization and its practical implementation. It should be noted that conventional geomaterials derive much of their engineering acceptance from established classification

systems, which enable systematic characterization, communication of material properties, development of empirical correlations, and incorporation into design specifications. For instance, soils and aggregates are routinely classified using standardized systems that facilitate material selection and engineering decision-making across diverse applications. These classifications serve as the basis for developing design correlations, specifications, and acceptance criteria, which, in turn, facilitate their widespread use in engineering applications. In contrast, *WasRub* is typically described based on its processing methods or physical form, such as shredded rubber, crumb rubber, or tire-derived aggregates. Such descriptors, though useful for processing, do not directly relate to engineering performance.

Furthermore, a review of the existing literature reveals that engineering properties of waste tire-derived materials are often reported independently for specific applications, without a consistent framework that links material descriptors to performance requirements. Consequently, materials possessing similar engineering characteristics may be categorized differently, while materials falling under the same descriptor may exhibit substantially different behavior due to variations in particle size distribution, composition, aging characteristics, and processing methods. As a result, comparison across studies becomes difficult, transferability of findings remains limited, and pathways for integrating these materials into specifications and design procedures remain unclear. Another important aspect that warrants attention is the disconnect between material characterization and engineering implementation. In conventional practice, material properties are directly linked to design parameters through empirical correlations, acceptance criteria, and code-based guidelines. However, in the case of *WasRub*, such linkages remain largely application-specific and are seldom integrated within a broader classification framework. Consequently, designers often rely on case-specific investigations or conservative assumptions, which can limit confidence in the widespread utilization of these materials. This lack of a formal classification framework also restricts the recognition of *WasRub* as a manmade resource within circular infrastructure systems. Without standardized descriptors and performance-based categorization, it becomes difficult to integrate these materials into procurement practices, regulatory frameworks, and large-scale engineering projects.

Based on the foregoing discussion, it can be inferred that future efforts should move beyond isolated application-specific investigations towards the development of frameworks that systematically relate material descriptors to engineering performance and application requirements. Such an approach would facilitate consistent characterization, improve comparability across studies, support the development of specifications and acceptance criteria, and enhance confidence among engineers and regulatory authorities. In this context, the concept of engineered rubber geomaterials (*ERGs*), presented in the subsequent section, is proposed as a means of addressing the materials classification gap and providing a pathway for the broader integration of *WasRub* into engineering practice.

■ 3. ENGINEERED RUBBER GEOMATERIALS (*ERGs*): A CLASSIFICATION-BASED FRAMEWORK

■ 3.1. Need for a Structured Representation

The discussion in the preceding section indicates that the major limitation of using *WasRub* is not a lack of understanding of its engineering behavior, but rather the absence of a structured framework to facilitate its translation into engineering practice. It should be noted that although several studies have reported the suitability of *WasRub* for different applications, these efforts remain fragmented and do not provide a unified basis for material selection and design.

Under these circumstances, it becomes imperative to consider *WasRub* not merely as a waste material, but as a manmade geomaterial, whose characteristics can be systematically defined and utilized [4]. In this context, the term engineered rubber geomaterials (*ERGs*) is adopted in the present study to represent processed waste tire-derived materials that can be characterized based on their performance attributes. Needless to state, the objective of introducing *ERGs* is not to redefine the material itself, but to enable its systematic representation within the framework of engineering practice.

■ 3.2. Basis of Classification

It is worth noting that for any material to be accepted for engineering applications, its classification must be based on descriptors directly linked to its performance. For greater clarity and systematic representation, the proposed classification framework for engineered rubber geomaterials (*ERGs*) based on performance-linked descriptors is summarized in Table 1. This framework integrates the key characteristics governing the behavior of waste tire-derived materials and establishes their direct relevance to engineering. Needless to state, such a representation facilitates uniform characterization, improves comparability across studies, and provides a basis for their inclusion in design and specification protocols.

In line with this philosophy, the classification of *ERGs* is proposed to be based on four primary characteristics that govern their behavior across different applications.

Table 1: Classification framework for engineered rubber geomaterials (*ERGs*) based on performance-linked descriptors and their engineering relevance.

Category	Descriptor	Key Parameters	Typical Characteristics	Engineering Relevance / Applications
Particle Characteristics	Size, shape, surface texture	Particle size distribution (d_{10} , d_{50}), aspect ratio, roughness	Coarse (shreds/chips) to fine (crumbs); irregular/angular particles	Controls packing, void ratio, drainage, and interaction with the surrounding matrix
Mechanical Response	Deformation and load-bearing behavior	Modulus (E), compressibility, energy dissipation capacity, stress-strain response	Low stiffness, high deformability, high damping capacity	Suitable for lightweight fills, vibration isolation, and impact mitigation
Durability and Aging	Resistance to environmental exposure	Aging characteristics, oxidation, steel/textile content	High resistance to degradation; possible changes under long-term loading	Governs long-term performance in geotechnical and structural systems
Hydro-environmental Behavior	Hydraulic and environmental interaction	Permeability (k), water retention, and leachability	Generally high permeability; potential-controlled leaching	Suitable for drainage layers, landfill systems, and geoenvironmental applications
Functional Classification	Performance-based grouping	Combined behavior of the above descriptors	Materials grouped based on dominant functional response	Enables selection for embankments, pavements, composites, and barrier systems

(i) **Particle attributes, including size, shape, and surface texture:** These parameters control the packing behavior, interaction between particles, and overall load transfer mechanisms within the material. For instance, coarser particles tend to exhibit higher void ratios and enhanced drainage characteristics, while finer particles contribute to improved homogeneity and interaction in composite systems.

(ii) **Mechanical response of the material:** It is well known that *WasRub* exhibits relatively low stiffness and high deformability compared to conventional geomaterials. This behavior becomes advantageous in applications requiring energy absorption, vibration attenuation, and reduction of stress transmission. However, it should be noted that ERG responses are highly stress-dependent and require careful characterization before being employed in design.

(iii) **Durability and aging behavior:** Although *WasRub* is resistant to degradation under natural conditions, its properties may undergo changes due to prolonged exposure to environmental factors such as temperature variations, chemical interactions, and mechanical loading. In addition, the presence of steel and textile components may affect the material's long-term performance.

(iv) **Hydro-environmental behavior, which includes permeability, water retention, and potential leachability:** It is worth noting that *ERGs* generally exhibit higher permeability compared to conventional soils, which makes them suitable for drainage applications. However, the environmental compatibility of these materials must be assessed to ensure that any leachable constituents remain within acceptable limits.

While the descriptors discussed above provide the basis for classification, their practical utility depends on the existence of a systematic procedure through which materials can be characterized and assigned to appropriate engineering applications. In this regard, the proposed ERG framework is intended to function not only as a descriptive classification system but also as a pathway for integrating waste tire-derived materials into engineering decision-making processes. A schematic representation of the proposed workflow is presented in Figure 1.

■ 3.3. ERG Classification Workflow

The proposed ERG framework is based on a sequential classification procedure that links material characterization with engineering implementation. The first step involves characterization of the waste tire-derived material, including determination of particle

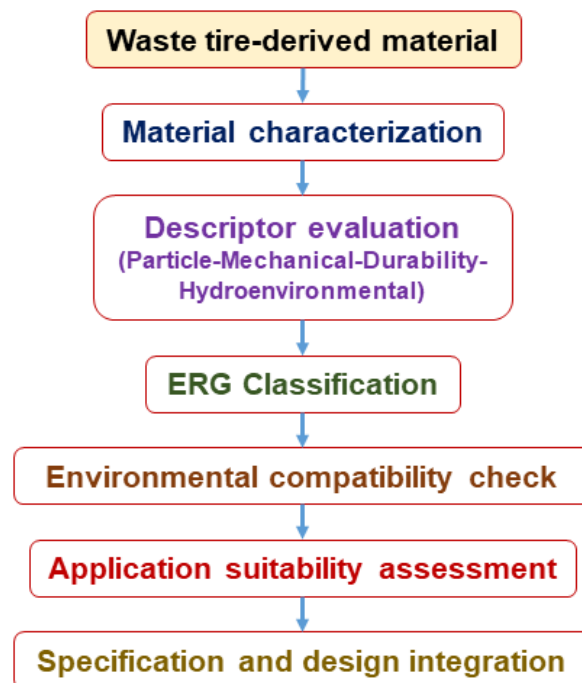


Figure 1: Proposed workflow for classification and application of engineered rubber geomaterials (ERGs).

attributes, composition, and relevant engineering properties. Subsequently, the material is evaluated with respect to the four primary descriptor groups identified in this study, namely particle characteristics, mechanical response, durability and aging behavior, and hydro-environmental performance.

Following descriptor evaluation, the material can be assigned to an appropriate ERG category based on its dominant functional characteristics. It should be noted that the objective of this classification is not to replace detailed engineering testing, but rather to provide a structured basis for comparing materials and identifying potential applications. Thereafter, environmental compatibility considerations, including durability and leachability requirements, may be assessed depending on the intended application.

The final stage involves matching the classified material with suitable engineering functions and application requirements. Such an approach establishes a logical pathway from material characterization to design implementation, thereby facilitating the incorporation of waste tire-derived materials into specifications, procurement frameworks, and engineering practice.

■ 3.4. Illustrative Application of the ERG Framework

To demonstrate the practical utility of the proposed framework, consider a waste tire-derived material consisting predominantly of coarse tire shreds. Such a material would typically exhibit low unit weight, relatively high permeability, and significant deformation capacity. Based on these characteristics, the material may be classified within an ERG category suitable for lightweight fill and drainage applications. Consequently, its use may be considered in embankments, retaining wall backfills, and drainage systems where reduced stresses and enhanced drainage performance are desirable.

Similarly, waste tire-derived materials processed into finer crumb rubber particles may exhibit characteristics that

make them more suitable for incorporation into cementitious composites, asphalt mixtures, and other engineered materials.

■ 3.5. Implications for Design and Standardization

The adoption of a classification-based approach for ERGs provides a pathway for their integration into existing engineering systems. It is worth noting that conventional geomaterials derive their acceptance primarily from the availability of standardized classification systems that enable their incorporation into design codes and specifications. Similarly, ERGs can be systematically incorporated into engineering practice by establishing standardized descriptors, testing methodologies, and performance criteria. This would facilitate the development of design correlations, improve material comparability, and enable the formulation of specifications for their use in different applications. Furthermore, such a framework would also support quality control and certification processes, ensuring consistency in material properties and performance. Under these circumstances, ERGs can be treated on par with conventional materials, thereby enhancing confidence among engineers, practitioners, and regulatory authorities.

■ 3.6. Relevance to Circular Infrastructure Systems

Needless to state, the classification of *WasRub* as ERGs has significant implications from a resource and sustainability perspective [4,5,31–33]. By defining these materials based on their performance characteristics, it becomes possible to utilize them systematically across different applications, thereby maximizing their utility [30]. This enables a transition from the current fragmented utilization to a more structured approach, in which materials are allocated based on their suitability for specific functions. Such a strategy supports efficient material flow within infrastructure systems and reduces dependence on natural resources. Thus, the concept of ERGs serves as a bridge between material

Table 2: Illustrative descriptor–application matrix for engineered rubber geomaterials (ERGs).

Dominant Descriptor	Typical Behaviour	Potential Applications
High permeability	Rapid drainage	Drainage layers, landfill drainage systems
Low unit weight	Reduced overburden stresses	Lightweight fills, embankments
High energy dissipation	Vibration attenuation	Railway foundations, vibration barriers
Enhanced durability	Long-term performance	Retaining wall backfills, geotechnical structures
Fine particle size	Improved matrix interaction	Concrete, asphalt, composites

characterization and engineering applications, enabling the transformation of WasRub from an underutilized waste stream into a viable, scalable resource for infrastructure development.

The proposed framework for integrating waste tires into circular resource systems through *ERGs* is schematically illustrated in Figure 2.

■ 4. IMPLICATIONS FOR CIRCULAR INFRASTRUCTURE SYSTEMS

■ 4.1. Resource Efficiency and Material Substitution

The classification of waste tires as engineered rubber geomaterials (*ERGs*) provides a structured pathway for their utilization as alternative construction materials. One of the primary implications is the potential for direct substitution of natural aggregates in infrastructure applications. Given their low density and high deformability, *ERGs* are particularly suitable for lightweight fills, embankments over soft soils, and backfill systems where reducing overburden stress is critical. This not only decreases the demand for virgin aggregates but also reduces associated environmental impacts arising from quarrying, transportation, and processing.

Furthermore, the use of *ERGs* enables material efficiency in design, where engineering performance can be achieved with reduced material mass due to their functional properties. This contributes to optimized resource utilization, particularly in applications requiring energy dissipation, vibration control, or drainage. Importantly, the proposed *ERG* framework provides a mechanism through which waste tire-derived materials can be evaluated and allocated based on their functional

characteristics rather than solely on their processing history. Such an approach facilitates more informed material selection and supports the replacement of conventional geomaterials in applications where equivalent or complementary performance can be achieved.

■ 4.2. Cascading Utilization and Material Flow Optimization

A classification-driven approach facilitates cascading utilization, where waste tire-derived materials are allocated to applications based on performance requirements [29,34]. Higher-quality or more uniform fractions can be directed toward applications requiring controlled behavior, such as cementitious composites or engineered fills, while heterogeneous or coarser fractions can be utilized in drainage layers or low-load geotechnical applications. It should be noted that the effectiveness of cascading utilization depends upon the ability to consistently identify material characteristics and match them with application requirements. In this regard, the *ERG* framework provides a structured basis for allocating materials according to performance descriptors, thereby reducing uncertainty in material selection and improving resource efficiency across infrastructure systems.

Such hierarchical allocation enables efficient material flow within infrastructure systems, ensuring that the functional potential of waste tires is maximized across multiple applications rather than being confined to limited or low-value uses. This aligns with circular economy principles, where materials are retained within the system at their highest possible utility for as long as possible.

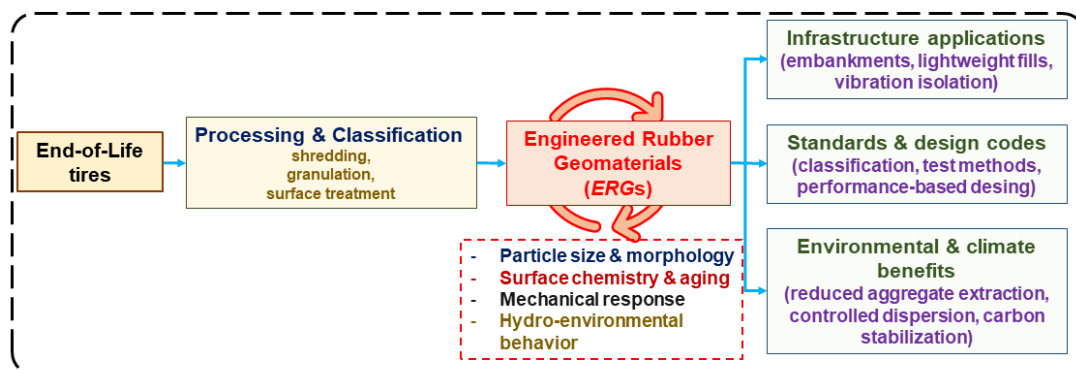


Figure 2: Conceptual framework for the valorization of waste tires as Engineered Rubber Geomaterials (*ERGs*) within circular resource systems.

■ 4.3. Integration into Design and Standardization Frameworks

It is unfortunate that despite the demonstrated potential of *WasRub*, its acceptance in engineering practice remains limited due to the absence of standardized classification systems and design guidelines. It should be noted that for any material to be widely adopted, it must be supported by well-defined standards, testing protocols, and specification criteria. The proposed ERG framework may serve as an intermediate step between laboratory characterization and formal standardization. By providing a common language for describing waste tire-derived materials, it becomes possible to establish performance categories, develop acceptance criteria, and generate empirical correlations that can ultimately support incorporation into engineering guidelines and specifications.

In this context, the *ERG*-based classification provides a foundation for integrating waste tire-derived materials into existing engineering frameworks. This can be achieved by developing standardized procedures for material characterization, establishing correlations between material properties and engineering response, and incorporating these materials into design codes and guidelines.

Furthermore, such integration would facilitate the development of material specifications for procurement and construction practices, thereby improving consistency and reliability. Needless to state, this would enhance confidence among engineers, practitioners, and regulatory agencies, which is essential for large-scale implementation.

■ 4.4. Environmental Considerations and Risk Management

The successful implementation of ERGs in infrastructure systems requires consideration of both performance benefits and potential limitations. It is well known that waste tire-derived materials may exhibit application-specific constraints related to leachability, fire susceptibility, long-term aging, and interaction with surrounding environmental conditions. Consequently, not all ERGs may be equally suitable for all engineering applications.

Under these circumstances, environmental compatibility assessment should be incorporated as an integral component of the classification process. Depending on the intended application, factors such as groundwater

sensitivity, exposure conditions, durability requirements, and regulatory restrictions may influence material selection. It is envisaged that future ERG specifications may incorporate exclusion criteria or performance thresholds to ensure that materials are utilized in applications consistent with their environmental and engineering characteristics. Needless to state, recognition of these constraints does not diminish the potential of ERGs; rather, it contributes to their responsible and informed utilization within infrastructure systems.

■ 4.5. Enabling Circular Infrastructure Systems

The transition from waste management to resource utilization requires coordinated efforts across multiple stakeholders, including material processors, design engineers, regulatory authorities, and project developers. It is worth noting that the lack of a common framework often leads to fragmentation in these efforts, thereby limiting the effective use of *WasRub*. With this in view, the *ERG* classification provides a common platform that can facilitate interaction among different stakeholders. Material processors can tailor their products to meet classification requirements, designers can select materials based on performance criteria, and regulatory bodies can establish acceptance guidelines based on standardized descriptors. Such alignment enables the development of circular infrastructure systems, wherein waste materials are systematically converted into functional resources. Needless to state, this represents a shift from the conventional approach of disposal toward a more sustainable and resource-efficient paradigm. In addition, the proposed framework establishes a common basis for communication among material processors, designers, contractors, and regulatory authorities, thereby facilitating more effective integration of waste tire-derived materials within circular infrastructure systems.

■ 4.6. Overall Implications

Based on the foregoing discussion, it can be inferred that the principal contribution of the proposed ERG framework lies in establishing a systematic linkage between material characterization, functional performance, and engineering implementation. It should be noted that the key to achieving this transition lies in establishing a clear linkage between material characteristics, engineering performance, and system-level requirements. Thus, the proposed framework not only addresses the existing gap between material characterization and application but also provides a pathway to enhance resource efficiency,

reduce environmental impacts, and promote circularity in infrastructure development.

While the present framework is conceptual in nature, it provides a foundation for the future development of quantitative classification criteria, performance thresholds, and application-specific specifications. Such developments would enable progressive refinement of the ERG framework and support its eventual integration into engineering standards and regulatory systems.

5. CONCLUSIONS

Waste rubber tires (*WRTs*), despite being generated in enormous quantities and possessing favorable engineering characteristics, continue to remain underutilized, which indicates that the limitation is not associated solely with their performance but also with challenges related to their systematic integration into engineering practice. It is worth noting that existing approaches for utilizing *WasRub* are largely application-specific and do not provide a generalized basis for material selection, performance comparison, and design implementation. Under these circumstances, the present study demonstrates that treating waste tire-derived materials as engineered rubber geomaterials (*ERGs*), based on a classification-driven approach, can facilitate their systematic representation as design-compatible materials. Needless to state, such a framework enables linkage between material descriptors and functional performance, thereby supporting their inclusion in design specifications, standardization protocols, and procurement practices. The proposed framework also incorporates a structured pathway for material characterization, classification, environmental compatibility assessment, and application selection, thereby bridging the gap between material characterization and engineering implementation. The illustrative descriptor–application matrix further demonstrates how waste tire-derived materials can be systematically allocated to suitable infrastructure applications based on their dominant functional characteristics. Such an approach promotes efficient resource utilization, reduces dependence on natural aggregates, and enables structured material flows within circular infrastructure systems. It is envisaged that future developments involving quantitative classification criteria, performance thresholds, and application-specific acceptance guidelines will further strengthen the practical utility of the ERG framework. Thus, it can be inferred that addressing the materials classification gap is essential to transforming *WasRub* from an environmental burden into a viable, scalable engineering resource, thereby

contributing to sustainable infrastructure development and circular economy objectives.

HIGHLIGHTS

- Waste tires remain underutilized despite demonstrated engineering suitability.
- Proposes Engineered Rubber Geomaterials (*ERGs*) as a classification framework.
- Identifies the materials classification gap as a critical implementation barrier.
- Establishes linkages between *ERGs*, engineering applications, and circular infrastructure systems.
- Advocates transition from waste management to material system design.

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DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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