Axiological and Cultural Reinterpretation of Recycled Rubber in the Moral Economy of Waste and the Circularity of Material Value in Concrete

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Abstract
The management of industrial waste is part of an axiological challenge that permeates the ontology of material culture, where discarded matter embodies a symbolic boundary between the valuable and the excluded, this study analyzes the incorporation of recycled rubber into concrete as an act of ontological resignification of waste within a moral economy oriented towards the circularity of value. More than a technical substitution, this practice constitutes a reconfiguration of the relationships between matter, use, and meaning. The analysis of its material behavior reveals a transformation in the way value is inscribed in the constructive substance, articulating structural performance and environmental projection within the same network of meaning, the reintegration of waste into the concrete matrix thus expresses a mutation in the symbolic economy of construction, where discarded matter acquires agency within the production process. The circularity of material value emerges as a cultural horizon that redefines the status of waste and reorganizes the traditional hierarchy between resource and refuse. In this context, the constructive culture is configured as a space of mediation between technique and ethics, where sustainability operates as a constitutive principle of a new civilizational understanding of matter.
Keywords: material ontology, moral economy of waste, recycled rubber concrete, axiological transformation, circular material value.

INTRODUCTION

The global accumulation of industrial waste constitutes one of the most visible phenomena of the material configuration of the current production paradigm. In particular, polymeric waste derived from discarded parts expresses a structural tension between material persistence and cultural obsolescence. Given their high chemical stability, mechanical resistance, and durability properties that make them technically valuable they simultaneously become factors of environmental accumulation when their life cycle is prematurely interrupted (Wang et al., 2022; Li et al., 2023). This ambivalence reveals that waste is not only a technical problem but also a cultural construct determined by value hierarchies that define which matter remains in circulation and which is excluded. The circular economy has emerged as a structural response to this linear logic of extraction, production, and disposal. Recent reports show that less than 8% of materials globally are effectively returned to production cycles, underscoring the urgent need to reconfigure material recovery systems (Haas et al., 2015; Kirchherr et al., 2017; Geyer et al., 2017). However, several authors warn that circularity is not simply a matter of technical efficiency, but rather implies an axiological transformation in the way society understands matter and its value (Hobson, 2016 Kirchherr et al., 2017; Mendoza et al., 2022; Geissdoerfer et al., 2017). In this sense, the circular economy presupposes a moral economy of waste, understood as the normative and symbolic framework that determines the legitimacy of reintegrating what has been discarded as a resource. From the perspective of the philosophy of material culture, matter is not a passive support, but an active dimension in shaping social practices and collective meanings. Recent authors in the ontology of materiality have pointed out that technical objects participate in relational networks where their ontological status depends on the practices that inscribe them in circuits of use, exchange, and signification (Hobson, 2016; Bennett, 2021). From this perspective, waste occupies a liminal space: it is an existing matter that has lost recognition within the productive order. Its reintegration implies an ontological reinterpretation that transforms its symbolic and material condition simultaneously.

The construction sector offers a prime opportunity to observe this dynamic. Concrete is one of the most widely used materials globally and requires a high volume of aggregates, between 60 and 80% of which are extracted, generating significant environmental impacts (Zhang et al., 2021). The partial replacement of natural aggregates with recycled materials, such as particulate rubber, has been extensively researched as a structural sustainability strategy (Guo et al., 2021; Si et al., 2022). Recent studies show that the incorporation of elastomers can reduce the unit weight of concrete and improve specific properties such as energy absorption and ductile behavior, although with variations in mechanical strength (Youssf et al., 2020; Roychand et al., 2020, Sofi, 2018). One of the main technical challenges lies in the interfacial transition zone between the rubber and the cement paste. Recent research shows that surface treatments can modify the interfacial energy and improve phase compatibility, optimizing the behavior of the composite material (Li et al., 2023). In parallel, life cycle analyses confirm that the incorporation of recycled rubber contributes to the reduction of energy consumption and emissions associated with concrete production (Gao et al., 2022). These technical advances, however, acquire full meaning when interpreted within an axiological framework that recognizes the reintegration of waste as value production and not just as material substitution. The reinterpretation of recycled rubber in concrete thus constitutes a mediation between technique and culture. From the relational ontology of matter, the rubber particle ceases to be an excluded remnant and becomes integrated into a constructive network that redefines its agency and function (Bennett, 2021). From the perspective of the moral economy of waste, this reintegration reorders the hierarchy between resource and waste, shifting the extractive logic towards a logic of ethical circularity. The circularity of material value in concrete is not limited to the optimization of physical-mechanical properties, but expresses a transformation in the symbolic economy of construction.

The problem of end of life rubber is not limited to its physical accumulation, but involves geopolitical and economic dynamics linked to global production and consumption chains, the tire industry is one of the sectors with the greatest sustained growth in recent decades, driven by the expansion of the vehicle fleet and accelerated urbanization. This trend exponentially increases the volume of elastomeric waste whose management presents significant territorial inequalities. In many contexts, material valorization systems depend on technical infrastructures and regulatory frameworks that determine the viability of their productive reintegration; consequently, the circularity of recycled rubber cannot be understood solely as a technological innovation, but as a result of institutional, economic and cultural arrangements that enable or limit its transition from marginal waste to a strategic resource within the construction sector. In this context, the present research examines the incorporation of surface-modified recycled rubber into concrete matrices from a dual perspective, on one hand, it evaluates its material behavior, structural performance and environmental projection. On the other hand, it interprets this practice as a process of axiological reconstruction that redefines the ontological status of the residue within the constructive culture, the articulation between circular economy and moral economy of waste allows us to understand that material value is not exhausted in mechanical performance, but is configured as a synthesis between sustainability, functionality and cultural meaning. Thus, rubberized concrete emerges as a space where discarded matter acquires a new ontological inscription and where sustainability operates as a constitutive principle of a civilizational configuration oriented towards the ethical reintegration of matter.

METHODOLOGY

The research is structured under an interpretive epistemological approach to the material that conceives of experimentation as a practice of value production; recycled rubber is addressed as an alternative input, whose ontological status is redefined in the process of incorporation into concrete; the starting point recognizes that industrial waste is culturally inscribed as surplus (Hobson, 2016; Bennett, 2021), es decir, como materia carente de función estructural dentro del orden productivo (Kirchherr et al., 2017; Mendoza et al., 2022). The central hypothesis argues that its integration into cementitious matrices does not constitute a mere technical substitution, but an operation of axiological redefinition that transforms its position within the moral economy of construction. In this sense, the methodology articulates three levels: the ontomaterial level for the identification of the conditions that allow the reintegration of the waste, the relational and interfacial level for the analysis of material compatibility and cohesion, and the systemic axiological level for the interpretation of the transformation of value in cultural and environmental terms.

Ontomaterial level as intelligibility and possibility of integration

The basic physical characterization of recycled rubber (density, absorption and granulometry) is carried out in order to establish its material intelligibility within the technical language of concrete, following procedures widely documented in research on concrete with recycled rubber (Bisht y Ramana, 2017; Roychand et al., 2020), From the epistemological analysis, the residue is translated into the framework of structural understanding, where the granulometric adjustment enables its functional analogy with the natural fine aggregate, representing the transition of the residue from its condition of unproductive heterogeneity towards a morphology compatible with the construction system (Guo et al., 2021; Si et al., 2022). Physical adequacy constitutes the first ontological mediation, where the residue becomes susceptible to belonging.

Relational and interfacial level as a space of ontological decision-making

The development of matrices with partial substitution of fine aggregate by recycled rubber operates as a demonstrative integration experiment, where the incorporation percentages are established as variations that allow observation of the degree of structural compatibility achieved, according to previously applied experimental methodologies (Youssf et al., 2020; Bušić et al., 2020). Methodological attention is focused on the interfacial transition zone between rubber and cement paste, identified as one of the main factors that condition the mechanical performance of the composite material (Huang et al., 2020; Li et al., 2023). The interface is interpreted as the space where the possibility of material continuity and stress transfer is defined; it focuses on measuring adhesion and understanding whether the residue manages to become a constitutive part of the structural system; the evaluation of basic mechanical properties such as compressive strength and physical behavior associated with porosity and absorption fulfills a confirmatory function that is to demonstrate the integration, more than symbolic, effective, expressing the degree to which the residue participates in the load-bearing configuration of the concrete (Bisht & Ramana, 2017; Si et al., 2022). The surface chemical modification of recycled rubber is incorporated as a mediating operation that strengthens its compatibility with the cementitious matrix; the surface intervention is understood as a technical improvement for the reconstruction of the relationship between materials of different natures (Li et al., 2023), From microscopic analysis it is possible to observe this morphological transformation in the contact zone, which fulfills an epistemological role, since it shows the physical materialization of the proposed re-signification, by revealing the overcoming of the initial separation between residue and matrix.

Systemic axiological level for the legitimization of value transformation

The verification of mechanical performance is geared towards regulatory compliance and establishes the moment when the residue achieves structural legitimacy, when the modified matrix demonstrates stability and resistance capacity within acceptable functional ranges, the recycled rubber ceases to be surplus and becomes an active component and the rubberized concrete structure is thus configured as material evidence of axiological redefinition, the residue acquires load-bearing function, stability and permanence, where construction, understood as a cultural practice of material consolidation, recognizes recycled rubber as part of its structural grammar (Guo et al., 2021; Roychand et al., 2020). The moral economy and circularity of value are analyzed from the perspective of environmental assessment using synthetic indicators of emissions reduction and decreased extraction of aggregates, which allow for the reinterpretation to be situated on a systemic level. (Gao et al., 2022; Zhang et al., 2021), The integration of recycled rubber modifies the flow of materials within the construction sector and reduces pressure on virgin resources; this shift expresses the circularity of value (Mendoza et al., 2022), where the waste is reinserted into the production system and generates verifiable positive environmental effects, the moral economy of construction is transformed when the previously discarded material participates in the production of structural stability and environmental sustainability.

RESULTS

It is evident that the incorporation of recycled rubber into concrete matrices constitutes a compositional variation and a verifiable process of material and axiological transformation. Based on the physical, chemical, mechanical, and environmental results collected, it is demonstrated that the waste achieves morphological stability, structural cohesion, and a measurable systemic contribution. These findings allow us to affirm that the reinterpretation of recycled rubber is experimentally consolidated at three articulated levels: first, when it acquires structural intelligibility within the technical language of concrete; second, when it is mechanically integrated with continuity and effective transfer of stresses; and third, when it modifies the environmental and symbolic flow of the construction system by reducing impacts and altering the value regime associated with primary materials. Consequently, the results not only confirm technical viability but also substantiate the ontological transformation of the waste into a bearer of value within the moral economy of construction.

Ontomaterial level as structural intelligibility of the residue
The results obtained in the physical characterization demonstrated that, despite the significant density difference between recycled rubber (1120 kg/m³) and natural sand (2650 kg/m³), the achieved particle size distribution allowed for stable volumetric substitution without segregation, bleeding, or loss of homogeneity up to 20% incorporation. This behavior confirms that the residue achieved morphological compatibility within the cementitious matrix, maintaining volumetric continuity and physical stability during the mixing and setting process.The central finding at this level lies not only in the dimensional similarity, but in the fact that recycled rubber entered the technical regime of concrete as a measurable, classifiable and structurally legible entity. Ontologically, the residue ceased to exist as an indeterminate material associated with discarding and became an intelligible component within the constructive system; the measurement and granulometric adaptation produced an epistemological transformation, where the surplus became susceptible to belonging; this first result consolidates the ontological possibility of integration and constitutes the basic condition for the subsequent axiological re-signification.

Table 1. Recycled rubber integration gradient

Property	Natural sand	Recycled rubber	On-material analysis
Density (kg/m³)	High	Low	Mass regime contrast
Absorption (%)	Low	Elderly	Difference in interaction with water
Granulometry	Continuous and stable	Adjustable	Similar
Rigidity	high	Flexible	Mechanical complementarity
Nature of the material	Mineral	Polymeric	Constitutive heterogeneity

At this level, physical analysis constitutes the ontomaterial foundation of the research, since rubber does not appear as a degraded substitute for sand, but as a material with its own identity that reconfigures the mass, rigidity and density regime of concrete.

Relational-interfacial level as mechanical integration and material legitimation
Compressive strength tests showed that, with 5 %, 15 %, and 20 % substitutions, the matrices retained 94.3 %, 83.3 %, and 77.2 % of the strength of conventional concrete (24.5 MPa), respectively. Even with a 15 % incorporation, the strength remained above the requirements for many non-structural applications and certain secondary structural applications. Additionally, no failures associated with massive detachments or critical discontinuities were observed in the interfacial transition zone, indicating effective stress transfer between matrix and elastomer. This result demonstrates verifiable cohesion: the recycled rubber did not act as a passive inclusion, but as an active component within the overall mechanical response. From an ontological perspective, the interface is revealed as the space where material belonging is decided. There, the residue ceases to be juxtaposed

and becomes a constitutive part of the resistant system. The moderate decrease in rigidity does not represent exclusion, but rather a reconfiguration of the structural balance; culturally, this moment implies legitimation, the residue gains functional recognition within the normative grammar of construction, the axiological re-signification is consolidated when the discarded material demonstrates load-bearing capacity and verifiable stability.

Table 2. Mechanical performance and degree of material integration

Integration gradient	Replacement Level (%)	Resistance (MPa)	Variation (%)	Onto-material interpretation
Reference	0 %	24.5	—	Reference state standard virgin material
Initial integration	5 %	23.1	-5.7	Stable integration with minimal structural alteration
Intermediate integration	15 %	20.4	-16.7	Transition threshold, redistribution of efforts
Advanced integration	20 %	18.9	-22.8	Significant structural stress, functional limit

Table 2 of mechanical performance and degree of material integration does not only describe resistant variations; it shows a process of axiological transition in which the structural value is redefined based on circular integration; this quantitative variation acquires meaning when interpreted as structural rebalancing, conventional concrete prioritizes maximum strength as the dominant value; the incorporation of rubber shifts that axis towards a logic of relational performance where rigidity and flexibility coexist.

Axiological-systemic level for the transformation of the value regime and material circularity

Environmental analysis showed progressive reductions in atmospheric emissions of up to 13.7% and decreases in embodied energy of up to 10.8% compared to conventional concrete. These quantitative results show that each increase in the substitution of the natural aggregate simultaneously reduces the extraction of virgin resources and the accumulation of waste in final disposal circuits. Recycled rubber ceased to represent an environmental burden and became a mechanism for mitigating impacts within the construction metabolism. This finding constitutes the culminating moment of the reinterpretation: the integration of the waste not only modifies the material composition of the concrete, but also transforms the value flow that organizes construction production. Ontologically, the waste transitions from a marginal object to an agent of sustainability; culturally, it alters the moral economy that associates value with the purity of the primary resource. The circularity of value materializes when the discard participates in the production of structural stability and reduction of environmental impacts; at this level, the axiological re-signification ceases to be potential and becomes an effective transformation of the productive regime.

Table 3. Environmental indicators and circularity threshold

Material regime	Atmospheric emissions CO_2eq (kg/m³)	Energy (MJ/m³)	Environmental settings	Systemic interpretation
Full extraction 0%	320	1850	Maximum carbon-energy intensity	Full extractive regime
Incipient hybrid 5%	308	1795	Initial reduction	Environmental decompression
Consolidated hybrid 15%	289	1708	Consolidated reduction	Structural transition of material flow
Circular transition 20%	276	1650	Significant reduction	Partial reconfiguration of constructive metabolism

Environmental analysis reveals a progressive decrease in atmospheric emissions and embodied energy as the integration of recycled rubber increases; this trend expresses a shift from an intensive extractive economy to a material revaluation economy; the cumulative reduction in emissions indicates that each percentage increase in integration generates a proportional decrease in environmental impact, configuring a curve of increasing circularity. The material that in its previous cycle represented an environmental burden is now reincorporated as a mitigation factor, altering the narrative of the waste as a liability. From an axiological perspective, the environmental table makes visible the transformation of the moral status of rubber from being a symbol of accumulated waste to an active agent in reducing the ecological footprint. The energy reduction reinforces this redefinition by showing that the integration of the waste not only reduces mineral extraction, but also moderates the systemic consumption of resources. At this third level, the environmental analysis consolidates the circularity of material value, where concrete ceases to be merely infrastructure to become a device for ecological recomposition.

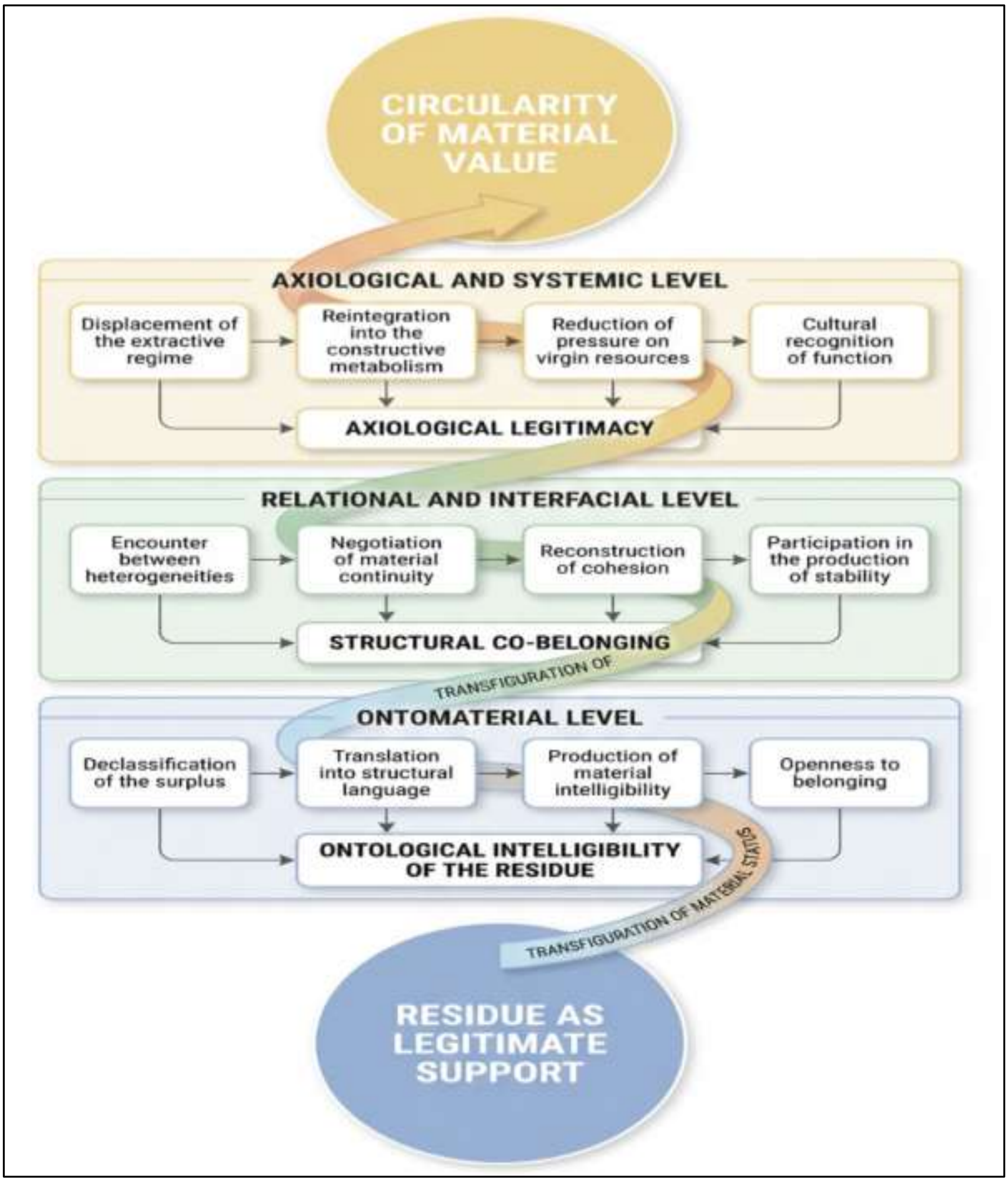

Figure 1. Evidence convergence matrix for the ontological reinterpretation of recycled rubber

Figure 1 articulates the methodological architecture with the interpretive synthesis of the study through three progressive levels: ontomaterial, relational-interfacial, and axiological-systemic. The vertical progression represents the transition of recycled rubber from its technical intelligibility to its structural and environmental legitimacy. At the ontomaterial level, physical characterization establishes the conditions of integration and translates the material into the normative language of concrete. The relational-interfacial level verifies its cohesion in the cementitious matrix and determines its structural participation through mechanical performance. The axiological-systemic level places the material within sustainability and the circular economy, evaluating its contribution to reducing impacts and reorganizing material flows; the convergence of these three levels underpins the axiological reinterpretation of recycled rubber as a legitimate structural component, where technical intelligibility, mechanical stability, and ecological responsibility are integrated into the same materiality, reconfiguring the moral economy of construction.

DISCUSSION

The incorporation of rubber into cementitious matrices constitutes a process of material transformation that transcends the technical sphere and is inscribed in an ontological and axiological reconfiguration of the waste, within the field of construction; the results allow us to interpret this integration as a transition from material marginality towards structural intelligibility, verifiable cohesion and active participation in the redefinition of the constructive value regime, with contemporary approaches to materiality and the moral economy of objects. The findings of this research engage with previous literature through technical agreement and a profound reflection on the nature of the materials and their reinterpretation in terms of sustainability, as seen in research such as Miller y Tehrani (2017) y Nakhai y Alhumoud (2020) They demonstrate the mechanical limitations of untreated rubber concrete, showing how simply incorporating the residue does not guarantee its functional integration; however, research such as that by Puneet and Sumit (2021) and Mhaya et al. (2022) suggests that the real challenge lies not in the presence of the recycled material, but in the quality of the interaction that it establishes with its new matrix environment. From this same perspective, Ferdous et al. (2021) and Forrest (2019) allow us to understand that recycling is not only a technical act, but a process of material transformation that requires adaptation, compatibility and dialogue between components of different natures; from this view, the chemical treatments evaluated in the present study do not represent only a superficial intervention, but a mediation strategy between the organic and the inorganic, between the discarded and the structural. Thus, rather than improving isolated mechanical values, the research proposes a reconsideration of the waste as a material with structural potential conditioned by its ability to integrate harmoniously into a new system, where sustainability and performance are not opposed, but must be built simultaneously.

Ontomaterial level: reactivity and acquisition of structural intelligibility

Recycled rubber manifests itself as an active material within the cementitious system; its interaction with the hydration processes configures a microstructure where the interface densifies and acquires material continuity, a phenomenon documented by Roychand et al. (2021) and Bušic et al. (2020). This reactive participation inscribes the rubber in the chemical metabolism of concrete, giving it a constitutive function in the structural configuration. From a philosophical perspective, this incorporation can be interpreted in light of contemporary material ontology. Jane Bennett (2010) proposes understanding matter as endowed with vitality and agency; recycled rubber, when structurally integrated, embodies that material agency that intervenes in the production of stability and form. The previously discarded material acquires a significant presence in the constructive assembly, consolidating its structural and cultural intelligibility. Likewise, the circulation of rubber within a new production system is linked to the value regimes described by Arjun Appadurai (1986), where objects move between spheres of exchange and acquire meaning according to their social insertion; recycled rubber undergoes an ontological displacement from peripheral waste to legitimate structural component, this transition shows that matter participates in the configuration of cultural and technical orders simultaneously.

Relational-interfacial level: verifiable cohesion and mechanical reconfiguration

The partial integration of fine aggregate with recycled rubber generates a material co-belonging relationship whose stability depends on the quality of the interface. Roychand et al. (2020) describe how the initial interfacial weakness can be mitigated through dosage adjustments and surface treatments, while Bušić et al. (2020) demonstrate that the incorporation of supplementary cementitious materials contributes to improving the system's cohesion. Similarly, Huang et al. (2020) emphasize that the interfacial transition zone is crucial in stress transfer, and that its densification influences the overall mechanical behavior. Li et al. (2023) show that surface modification of the rubber can strengthen compatibility with the cement paste, reducing discontinuities and improving microstructural integration. The partial integration of fine aggregate with recycled rubber generates a material co-ownership relationship whose stability depends on the quality of the interface. Roychand et al. (2020) describe how the initial interfacial weakness can be mitigated through dosage adjustments and surface treatments, while Bušić et al. (2020) demonstrate that the incorporation of supplementary cementitious materials contributes to improving the system's cohesion. Likewise, Huang et al. (2020) emphasize that the interfacial transition zone is crucial in stress transfer, and that its densification influences the overall mechanical behavior. Li et al. (2023) show that surface modification of rubber can strengthen compatibility with cement paste, reducing discontinuities and improving microstructural integration. The results of the present study align with this research by confirming that the cohesion achieved does not imply absolute homogenization, but rather a functional articulation of physical differences. The rubber introduces elasticity and modifies the overall response, but within a verifiable structural equilibrium. Material integration does not eliminate heterogeneity; it organizes it into a stable system. In this sense, the interfacial relationship constitutes the point where the residue demonstrates its capacity for effective integration. The experimentally verified cohesion represents overcoming the condition of material externality.

Axiological-systemic level: transformation of the value regime

At a systemic level, this extends to the environmental and circular dimensions. Kirchherr et al. (2017) define the circular economy as a system oriented towards maintaining the value of products, materials, and resources within the production cycle for as long as possible. From this perspective, the reintegration of recycled rubber into concrete represents an extension of the material life cycle, especially since construction is one of the sectors with the highest demand for virgin resources and waste generation. Therefore, the partial substitution of natural aggregates acquires structural relevance within the transition to circular models. Environmental impact assessment studies such as those by Kareem et al. (2022), Mastali et al. (2021), Zhong et al. (2023), and Abadel et al. (2022) demonstrate that the incorporation of polymer waste into cementitious matrices can contribute to the reduction of atmospheric emissions and the decrease in embodied energy. These findings position recycled rubber as a technical alternative and as a carrier of quantifiable environmental value; at this level, the transformation of the value regime is manifested when the waste participates simultaneously in structural stability and in the mitigation of environmental impact, where the legitimacy of the material ceases to depend exclusively on its virgin origin and is based on its performance and systemic contribution, concrete with recycled rubber shows that structural efficiency and environmental responsibility can converge in the same material configuration.

CONCLUSIONS

It is demonstrated that recycled rubber can be integrated into concrete as a structural component with material coherence and functional performance, achieving ontomaterial intelligibility by actively participating in the configuration of the cementitious matrix, consolidating its status as a constitutive element of the system; at the relational level, the achieved interfacial cohesion demonstrates a stable integration between elasticity and rigidity, configuring a structural equilibrium that redefines the constructive assembly as a practice of material complementarity; on the axiological plane, the reduction of emissions and embodied energy positions recycled rubber as a bearer of verifiable environmental value, the initially discarded material is thus established as a strategic resource within the constructive system, this is how the re-signification of recycled rubber is consolidated when structural intelligibility, material cohesion and environmental contribution converge, establishing a basis for understanding sustainability as a process of material reintegration within the moral economy of construction. Rubberized concrete emerges as a tangible expression of a cultural transition in construction, from an extractive paradigm towards an ethic of material reintegration, where waste is established as a legitimate resource, structural agent and symbol of systemic responsibility.

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