Utilisation of Crumb Rubber in Asphalt Mixtures — A Comprehensive Review

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Abstract: Crumb rubber (CR) produced from waste tyres has been investigated for use in construction, notably asphalt mixtures in the last few decades. Several products are produced from waste tyres (WT) including rubber chips (RC), CR, steel strands (SS), rubber powder (RP) and nylon wire (NW). RP are used as a modifier in asphalt binders, nylon wire for soil reinforcing, CR in concrete and asphalt whilst RC are used both in concrete and hot mix asphalt (HMA) for decades. Despite the wider application of CR, a few investigations were geared towards its application in low-energy/temperature asphalt technologies like the warm mix asphalt (WMA), half warm mix asphalt (HWMA), and to a much lesser extent, cold mix asphalt (CMA). The race to curb greenhouse emission, eschew high-energy consuming production and uphold sustainable construction practices, studies on CMA and its application has gained higher priority. If significant quantity of WT is to be removed from dumpsites or landfills, a higher percentage of its allied waste products must be injected into production, particularly asphalt production. Therefore, CR and RC presents a larger proportion of WT waste as against RP which despite recorded successes in binder modification, yet, accounts to a meager proportion by volume of the WT extracted prodcuts. Thus, interest in CR in CMA stems from environmental benefits (large volume WT reduction), improved pavement performance (rutting resistance, fatigue life), and potential economic advantages. This review summarizes the technology, state of knowledge on crumb rubber types and production, modification technologies (wet and dry processes, rubberized asphalt, reclaimed asphalt with rubber), effects on binder rheology and mixture properties, mix design, specifications ad production considerations, field performance and case studies, environmental and economic aspects, testing and specification issues, common challenges, and future research directions. The review is written to support researchers, pavement engineers, and policy makers considering CR use in roadworks. This review has concluded that significant progress has been made in the use of CR in asphalt mixtures generally, yet, greater opportunity is untapped as regards commercialisation and standardisation for global scale adoption.

Keywords: waste tyre, crumb rubber, cold mix asphalt, binder modification, hot mix asphalt

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INTRODUCTION

Rise in automobile production and use has inreacsed the global tyre consumption with attendant large volumes of waste tyre (WT) generation (Kang et al., 2026). Traditional disposal (landfill, stockpiling, incineration) is increasingly unacceptable environmentally due to obvious emissions of harmful gases, thus, recycling WT or end-of-life tyres (ELTs) into valuable products becomes a priority. ELTs are tyres being replaced at the expity of their service life even when in good looking condition making this category most sourted for retreading thereby extending the lifecycle of the ELTs which in turn curtail dumping of the WT (Cao

et al., 2025a). Conversely, WT may or may not be ELTs, because WTs are tyres used beyond their tagged expiration dates, these category is most common in developing and economically weak countries (Hisbani et al., 2025). The recycling of WT into CR assist in converting significant quantities of WT to better use (Hisbani et al., 2025). WT significantly pose serious threat to life and health of communities. The openly dumped WTs serve as cozy breeding grounds for moisquito causing malaria and rodents (Harrison-Obi, 2019).

In addition to negatively affecting the wellbeing and health condition of the populace, thugs and mobs burns WT on the streeets during electioneering camapigns and communual clashes thereby exacerbating the uprising. In some instances, people got burnt alive by WTs, all this unwholesome acts because of the easy access the populace has to WTs (see fig. 1). In essence, the utilisation of WT for construction ensures that no WT is available for use by hooligans during social unrest or political gatehrings. The literature has established two processing methods for WTs viz cryogenic and ambient grinding. Cryogenic involves the freezing of the WT with liquid nitrogen efore grinding, while the traditional methods crushes the WTs at ambient temperature. Other processes including wet grinding and hydro jet size reduction (Lo Presti, 2013).

CR produced by mechanical grinding (traditional method) of WT or ELTs is a widely available recycled material incorporated in asphalt and concrete mixes alike. In either case, WTs shredded into granulated rubber is as a partial replacement for natural aggregates in concrete production, offering a two-fold environmental advantage. This approach not only removes significant quantitiy of WTs from landfills but also reduces reliance on non-renewable natural resources like river sand and crushed rock aggregates (Feng et al., 2025). This paradigm shift toward alternative aggregates not only encourages waste optimisation but also proves how cheaply sourced construction materials can advance toward greater sustainability whilst solving pertinent ecological challenges. Moreover, increased utilisation of waste material and industrial byproducts for consrcution purposes ameliorates the explotation of non-renewable construction materials, thus, mitigating the environmental burden caused by unwholesome aggregate mining practices. The use of CR in asphalt mixtures either as a binder modifier or partial aggregate replacement offers potential benefits of improved high temperature rutting resistance, enhanced elastic response, extended fatigue life, enhanced flexibility (resistance to fatigue cracking) noise reduction, and environmental of tyres from waste streams. Application of CR in conccete replaces the fine or coarse aggregate thereby producing a durable, light-weight and environmentally sustainable concrete. The extent of grinding determines the extent of CR sizes to obatian at the end of the process. Usually, fine aand coarse fractions are replaced by CR in concrete and asphalt, but asphalt production consumes more aggregate than concerete, hence, focus will be made towards CR in asphalt specifically, CMA mixtures.

This paper reviews relevant technical aspects of crumb rubber in asphalt pavements, summarises typical effects on

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material properties, identifies production and construction best practices, and highlights knowledge gaps and practical barriers to commercial applications.



(a) (b)

Figure 1. (a) Restive youth burring waste tyres at their disposal, (b) Damage to road infrastructure due to burning of waste tyres

1. CRUMB RUBBER: SOURCE, TYPES, AND PROPERTIES

Notably, CR is obtained by processing WT using either traditional means or cryogenic methods, a process termed as dry and wet process respectively.

Genrally the source of CR is originating from WTs of Passenger cars, truck and bus, industrial machinery tyres, and to a lesser extent off-road tires (e.g., agricultural, construction). Depending on the type of endproduct to be produced and the desired property sought, different types of tyres from cars, truck, heavy machinery etc are collected sorted and shredded into chips, crumbs, steel strands and oils (Rodríguez-Fernández et al., 2020).

1.1. Source and production processes

CR is produced by shredding and granulating whole tyres notably from WTs followed by ambient or cryogenic grinding. The typical product sizes range from coarse (several mm) to fine powder (<0.5 mm) and micron or nano-sizes are available. WT shredding physically separates the constituent materilas in a car tyre which comprises of steel strands, nylon wires, rubber crumbs and ….as depicted in fig 2.

Two broad production approaches are:

- Ambient grinding — mechanical shredding at room temperature produces irregular particle shapes and some fiber content. It is energy-efficient and widely used for larger particle sizes.
- Cryogenic grinding — tyres are frozen with liquid nitrogen and then shattered, producing more uniform, angular particles and less fiber contamination, generally yielding smaller particle sizes.

Micro-milling and wet-grinding are other forms of WT processing not commonly used in practice due to the high technicality involved. Moreso, micro-milling was reported as a patented grinding process whereby the crumbs are further grinded into nano-sized particles in aqeous form notably, water. The process is patented thus can be utilised with permission from the owners. Output may be classified by mesh size (e.g., 20 mesh, 40 mesh) or nominal particle diameter referred to as nominal maximum aggregate size (NMAS).

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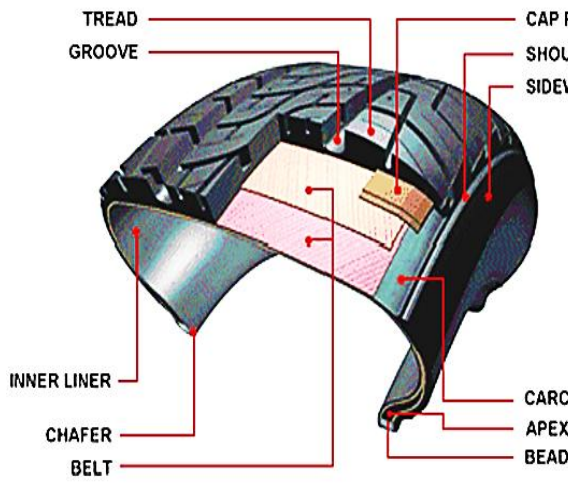

Figure 2: Typical car tyre cros-sectional elements adapted from (Lo Presti, 2013)

1.2. Physical and chemical characteristics

The physical, chemical, and mechanical properties of crumb rubber strongly influence its performance in asphalt mixtures. Specific gravity, texture, surface area, particle size distribution and shore hardness constitute the physical roperties of CR. Typical particle sizes ranges from 0.075 mm to 4.75 mm, though smaller particles promote better blending with bitumen. CR is characteristically angular when ambiend grinding is used, whilst cryogenic processing produces smooth particles. The specific Gravity ranges between 1.10 – 1.20 (lighter than mineral aggregates), for this reason adjustments are made in terms of the quantities for Marshall sample production. The specific surface area for smaller particles lead to higher binder absorption in asphalt mixtures.

Crumb rubber is primarily vulcanised natural and synthetic rubber compounds with additives (carbon black, oils, antioxidants), steel and textile fibers (removed to varying degrees), and inorganic fillers. Key characteristics include:

- Particle size distribution — affects interaction with asphalt binder and blending behavior. Finer rubber disperses more uniformly.
- Specific gravity — typically lower than mineral aggregates and bitumen.
- Absorptivity/porosity — crumb rubber can absorb light fractions of binder or swelling oils.
- Thermo-elastic behavior — imparts increased elasticity and damping to the binder/mixture; response depends on temperature and rubber content.
- Chemical inertness — vulcanised rubber does not chemically react strongly with bitumen under normal mixing conditions; most effects are physical (swelling, absorption) and some chemical interaction (devulcanization or partial depolymerization) under severe conditions.

The chemical properties of CR is inherent in the chemical constituent of its manufacture. These constituents as pictorially depicted earlier composed of natural rubber (NR), synthetic rubber (SBR), carbon black, sulfur, oils, and additives. The oils from CR are extracted via pyrolysis and are utilised as bitumen modifier and as fuel. These products contains cross-linked polymer chains that swell when in contact with asphalt, improving elasticity and are resistant to chemical attack and oxidative degradation (Zerin et al., 2023).

The mechanical properties of CR presents unique features desirable for enhanced asphalt performance. Elastic recovery provides flexibility and reduces cracking in asphalt pavements. While

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thermal resistance reduces susceptibility of asphalt to temperature variations. Several studies had proved that CR inclusion in asphalt enhances durability, fatigue resistance and rutting resistance, though higher binder requirement may result due to absorbance of asphalt oils, modifying viscosity and stiffness (Asgharzadeh et al., 2018).

2.3 Methods of Incorporating Crumb Rubber into Asphalt

Three established principal approaches are commercially employed and in research studies. The two common methods are the wet and dry process.

2.3.1 Wet process (rubber-modified binder / terminal blend)

In the wet process, crumb rubber is blended with hot bitumen (often at higher temperatures and extended mixing times) to produce a rubber-modified binder (RMB) or terminal blend (Hisbani et al., 2025; Zhai et al., 2025). Variations include:

- High-shear blending: this is achieved at temperatures commonly above standard mixing conditions (temperatures reported in practice vary; operators must follow safety and binder stability guidelines). The rubber swells by absorbing light oil fractions, increasing effective binder viscosity and elasticity.
- Terminal blending: this entail the production of rubber-modified binders in commercial quantities and storage for onward distribution.

Wet process binders may be categorized by the extent of interaction: from swollen rubber particles suspended in binder (discrete particle phase) to more integrated, homogenised modified binders after prolonged blending (Ling et al., 2009). The wet process can further be delineated under two distinct or rather similar process termed as the 'McDonald process' and the continuous blending-reaction systems.

McDonald process is a system of producing Recycled Tyre Rubber Modified Bitumens (RTR-MB) used for blending with bitumen. It was first introduced by Charles McDonald in the 1960s. The process yield a Bitumen Rubber blend produced in a blending tank by blending CR and bitumen. The product is then moved to a holding tank equipped with augers rotating at low revolutions per minute to ensure circulation, thereby ensuring the adequate reaction of the blend for a sufficient time period (usually 45–60 min). The blended and modified binder is then used for mix production. The continuous blending-reaction systems is similar to the McDonald process of blending, the distinction with McDonald method is that crumb rubber modifier (CRM) and bitumen are continuously blended during the mix production or prepared by hand and then stored in storage tanks for later use. The reaction largely occurs at the time of blending, this is the reason for the continuous agitation, thus making the process unique (Lo Presti, 2013).

2.3.2 Dry process (rubber as aggregate/partial aggregate replacement or oil-extended mixes)

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The dry process mimics the hot mix asphalt (HMA) production where the aggregate matrix inclusive of the CR are mixed together with the filler and any other additives before introducing the binder. The CR reduces the weight of the mix, add adhesion and enhances flexibility of the mix or modifier in the mix. For the partial aggregate replacement with CR, necessary step must be taken to adjust the weight difference between CR and natural aggregate. Thus, higher volume of CR may be required to balance the equivalent amount of NA for both volume or weight measurements. The CR is often used to replace both fine or coarse aggregate in ana asphalt mix, with the CR targeted to modify mixture properties. On the other hand, the CR is coated by blending with bitumen to further improve adhesion and handling. (Ning et al., 2025).

The dry process can be easier to implement at conventional asphalt plants but may produce less uniform modification of binder properties compared to wet process.

2.3.3 Asphalt rubber and other hybrids

Varying asphalt mixture are produced with the inclusion of CR, these includes asphalt rubber (AR), commonly used in the U.S. AR is characterised by a higher rubber contents 15 - 22% by weight of binder blended together into a monolithic mass with asphalt yielding elastic binders suitable for use in gap-graded mixtures (e.g., open graded friction course, stone matrix asphalt). In HMA, CR is often blended as an admixture and as part of the aggregate matrix, supplementing mechanical performance of anti-rut and fatigue cracking resistance (Pérez & Pasandín, 2017). Polymer modified rubber blends are gaining recognition by researchers recently combining the desirable properties of synthetic polymers (SBS, SBR, EVA) and CR in attempts to leverage both modifiers' advantages (Ghafar et al., 2024; Zakerzadeh et al., 2024).

2.4 Various forms of CR application in construction

2.4.1 Concrete production

The application of CR in concrete is mostly in form of NA replacement for both coarse and fine fractions. As rubber crumb sizes are notably within the range of 0.425 mm to 2.36 mm being defined as fine aggregate by ASTM. CR addition to concrete impart desirable properties on both the fresh and hard concrete properties. CR was reported to decrease the workability of

fresh concrete particularly at higher percentage replacement. More so, theconcrete slump reduces by 10 mm, often attributed to the surface roughness and high specific surface area of CR particles. Concrete slump drastically reduced from 64% to 77% when fine aggregate (FA) is replaced with CR from 10% to 30%. The slump reduction is arributed to increased aggregate-on-aggregate. The reduced slump result in a consequential rise in the friction within the particles aggregate matrix with attendant air-entrainment as CR is added (Hisbani et al., 2025).

In temperate climate, the addition of CR enhanced frost resistance of concrete by yielding higher modulus capable of stretching beyong the normal concrete limit under differential freeze and thaw cycles. CR modification further enhance the frost

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resistance performance via a series of desirable properties including ari-entraining capability, hydrophobic nature of water repulsion resulting in reduced water absorption, pore-structure, flexibility/toughness, and permeability. The entrained air by CR is often released under pressure, assuaging stress from freeze-thaw cycles. Depending on the shore hardness value of the CR which is inherent from the type of WT the CR is generated from, the resulting corresponding toughness aid in absorbing the internal pressures and prevents crack initiation/progression thus improving the overall durability of the concrete in freezing conditions. (Zhai et al., 2025). CR is usually incorporated in lightweight and non-structural concrete and to some certain extent in self-compacting concrete (Zhai et al., 2025).

The inclusion of CR in 4concrtee paving blocks had indicated a progressive decline in strength beyond with increasing CR replacement, though an optimal target strength of 30 MPa was achieved at15% CR replacement with a w/c of 0.5 (Ling et al., 2009, 2010a). Conversely, a study on the long-term strength of rubberized concrete paving blocks corooborated the optimal CR percentage replacement of 15% because 10% showed no difference in strength with the control sample whilst 20% CR replacement resulted in drastic decline in strength. Furthermore, CR modified paving blocks remained intact after crushing and split tensile testing, thus, suggesting toughness and enhanced flexibility (Ling et al., 2010b).

Qaidi et al. (2021) conducted a review on the use of CR to produce sustainable green concrete. The review extensively explored the various WT sources, composition, processing, and applications. The study highlighted the consequence of the unwholesome notable methods of disposing WT viz ; inciberation, pyrolysis and landfill disposal stating the effects of harmful gases from the former two methods (Qaidi et al., 2021). For the processing of landfilled disposed WTs by crushing, the stages of processing is represented in Fig. 3.

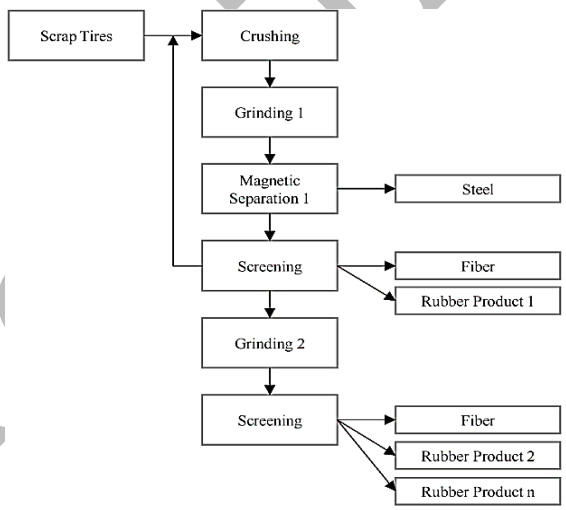

Figure 3. Basic waste tire processing stages in a recycling plant Adapted from (Qaidi et al., 2021)

The reduction in strength with higher CR percentage replacement is also common with fine aggregate replacement in concrete. The reasons been reported as causing strength deterioration include weak interfacial transition zone (ITZ) performance and haphazard distribution of CR particles (Ren et al., 2022).

Several areas of CR application in concrete includes cement mortars, artificaial turf infill, playgrounds and sporting flooring, roofing sheets and shingles, elastomeric pads/bearings, railway tracks, and sealants or

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waterproof compounds (Muniz de Farias et al., 2019).

2.5 Utilisation of crumb rubber in asphalt mixtures

The utilisation of CR in asphalt mixtures takes various forms and in effect utilises almost all the products of CR processing including chips, crumbs, oils, steel wire, and strands (Pérez & Pasandín, 2017). These CR products are used for either bitumen modification, or aggregate replacement, for the former, several key binder properties including multiple Stress and creep recovery (MSCR), linear amplitude sweep (LAS), dynamic shear rheometer (DSR), bending beam rheometer (BBR), and rotational viscosity were reported to be improved. The study reported that blend of 5% polyethylene wax and 18% CR yields better performance energy saving and reduce air pollution (Nasr et al., 2022).

2.5.1 Effects on Binder rheology, mix properties & high-temperature performance

Crumb rubber increases binder viscosity and elastic response, improving resistance to permanent deformation (rutting) at elevated temperatures. Rubberized binders typically exhibit increased complex modulus and reduced phase angle (more elastic behavior) at intermediate/high temperatures in addition to higher softening point and modified temperature susceptibility. The potential kinetic changes creates swelling and gradual release of absorbed oils can change binder composition over time (aging/stabilization) (Nasr et al., 2022).

2.5.2 Low-temperature and fatigue behavior

The low temperature cracking resistance of CR modified mixes notably is enhanced due to increased ductility and stress relaxation. Improvements in fatigue life (strain absorption under repeated loading) have been reported, depending on mix design and rubber content (Aflaki & Memarzadeh, 2011).

2.5.3 Dynamic modulus, resilient modulus, and damping

Rubber increases damping and elasticity in pavement systems; dynamic modulus tests typically show enhanced

modulus at higher temperatures and reduced modulus at low temperature depending on binder content and rubber type — overall often beneficial for resisting thermal and fatigue stresses (Hu et al., 2022).

Table 1 Reported impact resistance of rubberised concrete (Qaidi et al., 2021)

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Refs.	Type of Composite	Type of Substitution	CR Substitution Ratio %	CR Size (mm)	w/c	Value of control	Outcomes
Abdelmonem et al. (2019)	Rubberized concrete	F.A	10, 20 and 30 (vol %)	0-1, and 1-4	0.30	29 J	The IE inc 83%, resp
Dehdezi et al. (2015)	Rubberized concrete	F.A	20, and 50 (wt.%)	2-4	0.54	250 kN mm	The IE inc 660%, res
Aly et al. (2019)	Rubberized geopolymer concrete	F.A & C.A	10, 20, and 30 (vol %)	0.425 (70%), and 1-4 (30%).	N.M	159 J	The IE inc 250%, res
Medina et al. (2017)	Rubberized concrete	F.A & C.A	20, 40, 60, 80, and 100 (vol%)	4-6	0.50	70 J	The IE inc 328%, 90(respectivel
Xue et al. (2019)	Rubberized concrete	F.A	5, 10, 15, and 20 (wt.%)	0.30 and 0.85	0.40	88 J (at +25 °C) & 57 J (at −30 °C)	At +25 °C increased and 275% At −30 °C increased and 346%
Petrella et al. (2019)	Rubberized concrete	F.A	50, and 100 (vol %)	0.0–0.5 & 0.5–2	0.50	3.20 J/cm^2	The IE inc 4840%, re
Murali et al. (2019)	Rubberized concrete	C.A	5, 10, 15, 20, 25, and 30% (vol%)	12–19	0.40, 0.50, &0.55	1383 J (w/c of 0.45), 1180 J (w/c of 0.50), & 956 J (w/c of 0.55)	The failur 41%, 65% respective
(Li, H.-L. et al., 2019)	Rubberized concrete	F.A	20, 40, and 60 (vol %)	0.42–0.85	0.50	34 J	The IE inc 139%, res
Atahan and Yücel (2012)	Rubberized concrete	F.A & C.A	20 40, 60, 80 and 100 (wt.%)	1.5-3 & 13	0.52	42 J	The IE inc 141%, 16 respective
Xue and Shinozuka (2013)	Rubberized concrete	F.A & C.A	15 (wt.%)	6	0.50	$\zeta = 4.70$	The ζ of C
Hassanli et al. (2017)	Rubberized concrete	F.A	6,12, and 18 (vol %)	1.18	0.50	$\zeta = 1.8$	The ζ of Cl and 28%N
Balaha et al. (2007)	Rubberized concrete	F.A	5, 10, 15, and 20 (vol%)	≤4	040, 050, & 0.66	$\zeta = 0.0337$	The ζ incr substitutio
Youssf et al. (2015)	Rubberized concrete	F.A	20 (vol%)	1.18 & 2.36	0.50	$\zeta = 5.75$	The ζ of C

Where:
CR is rubber crumb; CRC is rubber crumb concrete; SCRC is self-compacting rubberized concrete; RAC is recycled asphalt concrete; RSRAC i fiber reinforced recycled aggregate concrete; RCR is roller compacted rubbercrete; LWGC is lightweight geopolymer concrete; N.M: Not Ment C.A is coarse aggregate; vol. is replacing by volume; wt. is replacing by weight; IE is impact energy; ζ is damping ratio; J is joule.

2.5.4 Moisture susceptibility and adhesion

Crumb rubber influence on moisture susceptibility can be mixed. Proper aggregate gradation, effective binder coverage, and use of anti-strip agents are necessary to achieve acceptable moisture resistance. In some studies, rubberized mixtures showed improved cohesion but required attention to bonding (Hu et al., 2022).

2.5.5 Noise and surface characteristics

Porous or gap-graded crumb rubber mixtures (e.g., rubberized open graded friction course) can reduce tire-pavement noise and spray. Texture and skid resistance must be managed during design.

2.6 Mix Design, production and construction considerations

2.6.1 Mix design approaches

Design work must account for optimum binder content adjustments, compaction characteristics and grading and aggregate selection — rubber tends to increase effective binder demand; volumetric design procedures (e.g., Marshall, Superpave) are adapted to consider crumb rubber volume and swollen rubber.

- **Compaction characteristics** — crumb rubber can affect workability and compaction energies; field compaction temperatures and techniques may need adjustment.
- **Grading and aggregate selection** — gap-graded designs are common for AR; fine aggregate replacement strategies in dry mixes need careful control for gradation and void structure.

2.6.2 Plant production and handling

Temperature control is essential to ensure mixing temperatures allow adequate blending while avoiding excessive thermal degradation of rubber or binder. For the mixing protocol, wet blending may require extended mixing times or specific high-shear mixers; dry addition can be handled in conventional plants but may require feed-system modifications. İn terms of the stability of the mixes in storage, rubberized binders can have separation or storage stability issues; stabilizers or polymer additions can help.

Field compaction must accommodate higher binder viscosity and potential cooling rates; finishing operations may need altered

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roller patterns and temperatures to achieve target density.

2. LABORTORY AND FIELD PERFORMANCE

3.1 Laboratory studies

Previous researches and laboratory results on the inclusion of CR in asphalt mixes have shown significant improvement in *rutting resistance* particularlr for rubberized binders and AR mixes compared with unmodified binders; *fatigue life*, depending on the testing protocol and binder type or mix specificstion (Asgharzadeh et al., 2018); *low-temperature cracking resistance* based on ITS/TSR test result – a number of studies have reported improvement in cracking resistance especially with dense-graded and other properly designed mixes (Razmi & Mirsayar, 2018). More so, *moisture damage* of CR modified mixtures is enhanced with the binary blending of CR and anti-stripping additives (Bilema et al., 2021; Chen et al., 2008).

3.2 Field performance and case studies

Field experience from countries with established use (USA — California; some Latin American countries; selected pilot projects worldwide) generally confirms long-term rutting resistance and extended service life. However, performance varies with:

- Construction quality and control.
- Correct match of mixture type to traffic and climate.
- Quality of crumb rubber (particle size, fiber content) and blending method.

3. ENVIRONMENTAL, HEALTH & ECONOMIC CONSIDERATIONS

4.1 Environmental benefits

Using ELT crumb rubber reduces tyres from landfill and stockpiles further contributing to the resource conservation by complementing the use of virgin binder and aggregate in certain designs or mix gradations. Ultimately, CRCMA mixes potentially reduces greenhouse emissions - the life-cycle analyses often find net environmental benefits, but actual result depends on processing energy and transport distances.

4.2 Health and safety

Operational safety is enhanced as high mixing temperatures are managed to prevent emissions of volatile compounds; adequate ventilation at plants and safety protocols are required.

- Worker exposure: dust and particulates during handling of crumb rubber or production must be controlled.

4.2 Economic consideration

Rubber modification can increase production costs (material and process changes). However, extended pavement life, reduced maintenance frequency, and environmental credits can offset initial costs. Economic viability depends on local crumb rubber availability, transport distances, and lifecycle cost analysis (Riekstins et al., 2022).

4. TESTING, SPECIFICATIONS & STANDARDS

5.1 Binder testing

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Standard rheological tests (rotational viscometer, dynamic shear rheometer, bending beam rheometer) are used to characterise rubberized binders; however, interpretation must consider the complex, multi-phase nature of rubberized binders (Zhai et al., 2025).

Standard mixture tests (Marshall, Superpave gyratory compaction, dynamic modulus, flow number, moisture susceptibility tests — e.g., TSR) are used with adapted acceptance criteria.

Many jurisdictions use adapted specification clauses for rubberised asphalt. Clear specification of crumb rubber quality (particle size, rubber content, allowable fiber, ash content), blending procedures, and acceptance testing is critical for consistent performance (Rodríguez-Fernández et al., 2020).

5. CHALLENGES AND LIMITATIONS

The challenges and limitations for the utilisation of CR can be discussed under the following; material variability, mixing and storage stability, construction complexity, perception and procurement and standardisation. The relative shore hardness of different WT garades ranging from cars, trucks, to heavy duty construction equipment tyres will yield differing CR with myriad of physical and chemical characteristcs (Cao et al., 2025b). More so, separation and phase issues can occur in some wet asphalt blends. Additionally, some wet processes require specialized equipment and training. Like the usual cold mixtures, CRCMA lacks universally accepted standardised design and formulation/production procedure which in turn slows widespread implementation in some regions (Xiang et al., 2009).

6. CONCLUSION

İt was established that there is a high rising number of waste tyres in recent yrears due to increased proliferation of automobile production and enhanced constrcution network. The rising landfill disposal of WT is exacerbated by the costly WT recycling methods and non-incentive by respective government. Nonetheless, researchers have explored ways of utilising CR for construction purposes. Crumb rubber utilisation in asphalt mixtures offers a technically promising route to improved pavement performance while providing environmental benefits through WT utılisatıon. The selectıon between eıther wet or dry processıng methods depends on available equipment, desired performance, and economic constraints. İt was descovered that crushing and processing WT yields crumbs, fibre, steel starnds and oils depending on the processing method. These individual components are employed as supplementary material for construction purposes. Early usage was in concrete and soil stabilisation, but in more recent times, CR is employed for microsurfacing, HMA, WMA, CMA and ultimately for binder modification.

This review established that several key engineering features are enhanced by the addition of CR in asphalt mixtures. These features includes low-temperature cracking resistance, fatigue resistance, rutting resistance and resistance to moisture damage. Therefore, it can be concluded that the addition of CR and WT allied products in

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improves the mechanical and engineering performance of asphalt mixtures with attendant mitigation of greenhouse emission, energy and resource conservation and cost-effectiveness. Lastly, a universally-acceptable laboratory design, careful plant production and handling, tailored construction practices, and clear specifications are essential to realize the benefits of CR in construction in practice.

7. FUTURE RESEARCH DIRECTION

Important areas for future work include:

- Mechanistic understanding: microscale studies of rubber-binder interaction and long-term evolution.
- Optimised mix designs: robust procedures for dry and wet processes across climates and traffic.
- Life-cycle assessment (LCA): region-specific LCA to quantify environmental trade-offs.
- Economic models: whole-life cost models including societal benefits (waste diversion).
- Health and emissions studies: characterize emissions during production and laying to ensure safe practices.
- Combined modifiers: studying synergies of crumb rubber with polymers and rejuvenators.
- Standardisation and guidelines: consolidating global best practice into accessible specifications.

AUTHOR CONTRIBUTION

Author 1: conceptualization, methodology, software, validation, formal analysis, investigation, resources, data curation, writing – original draft preparation, writing – review and editing, visualization, supervision, project administration. Author 2: funding acquisition, material acquisition, logistics.

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