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On the New RILEM Technical Committee TC APD: Alternative Paving Materials – Design and Performance

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Abstract

This paper introduces the new RILEM Technical Committee on Alternative Paving Materials – Design and Performance (TC APD), which builds upon the foundational efforts of the former TC 279-WMR focused on the Valorisation of Waste and Secondary Materials for Roads. The TC APD aims to advance the understanding of alternative paving materials, emphasizing their design and performance as essential components of road composites. The committee addresses three areas of investigation, each dedicated to examining the current technological state of the art, the design process and the field performance of composites incorporating alternative paving materials. The manuscript provides a comprehensive overview of the TC's background, outlines the research objectives and activities proposed, and discusses the committee's position within RILEM and the broader research community. Additionally, it details the anticipated outcomes and the potential impact of the committee's work on advancing the field of sustainable road construction.

Keywords: Roads; Alternative Paving Materials; Design; Performance; Field Evaluation.

1 Introduction

Transitioning to a circular economy requires decoupling economic growth from excessive natural resource consumption. This process necessitates formulating strategies for reprocessing, reusing, and recycling end-of-life products. These strategies should enable the adoption of these products as feedstock for identical or alternative uses [1]. With the escalating emphasis on the sustainability of road infrastructure, exploring the feasibility of integrating recycled, marginal, and secondary materials into pavement construction and maintenance has become a pivotal objective. This target is increasingly recognized within the field of road engineering. There is an opportunity to use some of the considerable volume of underutilized, non-recycled, and frequently discarded materials from various activities and sectors. Their significant potential for inclusion as pavement materials within road engineering constituted the foundational premise of the RILEM technical committee TC 279-WMR. This TC was dedicated to the Valorisation of Waste and Secondary Materials for Roads, undertaking a comprehensive examination of the utilization of marginal materials in pavement construction. The committee focused

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on identifying materials suitable for use as additives, modifiers, and aggregate replacements. It also assessed their applicability by analyzing their impacts on the rheological properties and mechanical behavior of road construction materials. Additionally, the analysis included the environmental sustainability of these materials. The TC witnessed substantial engagement, attracting over 100 participants and sparking considerable interest in pertinent research areas. This interest is evidenced by multiple publications emanating from the TC [2-6], numerous conference presentations, and the timely publication of the State-of-the-Art Report (STAR) [1].

2 Background

Enhancing resource efficiency and promoting sustainable consumption within the pavement industry are essential measures for fostering a circular economy. These efforts significantly contribute to minimizing the consumption of virgin raw materials and non-renewable energy use during the production and other pavement lifecycle stages, thereby reducing emissions and allowing the incorporation of secondary resources into the economic cycle [7-9]. Conversely, the accumulation of diverse wastes in landfills and the disposal of materials produced as by-products of technological or manufacturing processes pose significant environmental challenges. The circular economy paradigm is increasingly recognized as a vital strategy for combatting climate change and addressing various environmental issues by separating economic growth from finite resource consumption. Recycling asphalt pavement is crucial in reducing the dependence on non-renewable materials and curtailing solid waste production, thereby moving the road infrastructure sector towards a more sustainable and circular system [10-11]. Over the years, a diverse array of materials, requiring minimal to no refinement, were proposed for use in road and highway construction. Such materials include recycled asphalt, crushed concrete, fly ash and slag from thermal power plants, metallurgical slag, cement and lime dust, silica fume, foundry sand, waste rock, ash from municipal solid waste incineration plants, quarry by-products, roofing tile waste, scrap tire rubber, sewage sludge ash, waste glass, ceramics, recycled plastics, waste paper fly ash (WPFA), and various types of fibers [12-16]. These materials often exhibit a wide range of chemical and physical properties, states of origin, and pre-processing requirements, affecting their widespread market adoption. In that regard, three types of materials have received particular attention from road paving agencies worldwide: recycled tire rubber, recycled plastics, and bio-binders. Each of these materials has the potential to significantly reduce the carbon footprint of road infrastructure by either substituting conventional and non-renewable resources (such as asphalt binder and aggregates) or by enhancing the road's durability and performance. These innovative solutions lead to an extension in the pavement service life, thereby reducing the material requirements for construction/maintenance cycles and allowing resources to be present in the loop for prolonged durations.

In the context of road construction and maintenance, using bio-binders offers notable economic, social, and environmental benefits, presenting the possibility of substituting petroleum-derived asphalt binders. Bio-binders can be produced from various raw materials, including waste cooking oil and oils from castor, sunflower, cottonseed, linseed, and soybean, as well as lignin and bio-oils [17-20]. Many biomaterials are known to enhance the rheological properties at low temperatures, albeit influencing high-temperature properties as well [21]. They could also affect the asphalt mixture performance. For instance, incorporating bio-oil into base asphalt has been found to increase its aging resistance, and regardless of the type of base binder, the modified binder can decrease its viscosity and lower the mixing and compaction temperatures [17-22]. Additionally, some studies have shown substantial improvements in fatigue performance and rutting resistance of those mixtures containing bio-binders. Comparable resistance to moisture damage has also been found for mixtures with bio-binders and unmodified asphalt binders, suggesting their potential use as a partial or complete alternative to conventional asphalt binders [23].

Incorporating recycled tire rubber (RTR) or crumb rubber (CR) from end-of-life tires into paving mixtures is a strategy that enhances the resilient characteristics of these mixtures and contributes positively towards environmental sustainability. RTR or CR can be incorporated into asphalt mixtures as a modified binder through the wet process or as a partial replacement of aggregates in the mixture by means of the dry process. Wet process modification of asphalt binder with RTR can be carried out either on-site (field blends) or at the asphalt plants (terminal blends). Wet process rubber-modified asphalt binder is commonly referred to as Asphalt-Rubber (AR) and defined in ASTM D6114 as a blend of asphalt binder, at least 15% RTR by weight of the base binder, and certain additives [24-25]. Research has demonstrated that rubber granules that are approximately double in volume and particles sized between 0.425 and 1.18 mm when combined with hot asphalt binders can yield superior performing rubber-asphalt concrete mixture properties [26-30]. It has been identified that this combination of binder and tire-derived rubber creates a viscous binder mastic system that significantly enhances asphalt concrete characteristics, including increased binder film thickness, durability, and flexibility [31]. In the dry process, the rubber is added directly to the aggregates and interacts with the asphalt binder during the mixing process, storage, and transportation. Most modern dry CR asphalt concrete manufacturing processes use chemically engineered/processed fine CR particles (0.300 - 0.600 mm) to enhance performance and workability and/or facilitate rubber-binder interaction within a short period of time. Successful laboratory research attempts have been made with larger CR particles (up to 6 mm), displaying promising results for higher rates of mineral aggregate replacement [32]. Further, rubber particles have been found to maintain their physical integrity to a large extent when produced at typical dry process modification temperatures of 160 – 180°C, which influences the crack-inhibiting mechanisms prevalent in AR mixtures [33]. The incorporated CR behaves as hyperelastic inclusions in the mixture and exhibits a crack-pinning mechanism within the mastic phase of AR mixtures [34-35]. The utilization of CR not only improves the physical and mechanical properties of asphalt concrete but also elevates the quality and longevity of road surfaces. This, in turn, contributes to the extended service life of pavements, reducing the maintenance and repair costs associated with road infrastructure and fostering an improved environmental outlook. Despite the extensive body of knowledge, AR has not been widely adopted by the asphalt industry due to various existing knowledge gaps, which include the following, but are not limited to: performance evaluation of various available rubber modifier technologies and quantification of sustainability credentials.

Incorporating polymer additives such as thermoplastic elastomers into paving binders can enhance the original binder properties, thereby increasing the asphalt mixture's durability and resulting in a polymer-modified asphalt binder [36-38]. Such additives bolster the cohesive strength and thermal resistance of asphalt binder while also imparting elasticity and possibly improving the performance in cold temperatures. Nonetheless, the high cost of these modifiers and the desire for enhanced pavement sustainability have prompted research into more economical and environment-friendly alternatives, including plastic waste [38-40]. This waste plastic can be used as a polymer modifier for binders and a partial replacement for aggregates in asphalt concrete. The performance of asphalt mixtures with plastic waste is influenced by various factors, such as the type and proportion of plastic, mixing temperature and duration, and the manufacturing process [39, 41]. Similar to rubber modification, waste plastics can be added directly to the binder (wet process) or the aggregates (dry process). Unlike RTR, several classes of plastics are available to recycle, but currently, the most used plastic for asphalt modification is polyethylene (PE), mainly due to its low melting point. At present, several research gaps exist [42-44], including but not limited to the identification of optimal blending ratios, most compatible plastic types and grades, performance characteristics (long-term durability), and sustainability aspects, as well as universal standards and specifications for the use of waste plastic-modified asphalt mixtures.

The aforementioned research background synthesis highlights several research gaps in the use of waste, secondary materials, and, more comprehensively, alternative paving materials. These research needs (RNs) were also highlighted in the STAR of the TC 279-WMR [1] and during the discussion at the RILEM Cluster F meeting in Palermo in September 2022. The list includes WMR characterization, WMR Blending, WMR mixture design, laboratory and plant manufacturing, tailored characterization of WMR blends/mixtures, recyclability, sustainability assessments, and field performance evaluations. These RNs offer opportunities to deepen the investigation further and define more than one new RILEM technical committee.

3 Rationale and concept of the new TC on Alternative Paving Materials – Design and Performance

Building upon the foundational efforts of TC 279-WMR, the technical committee on Alternative Paving Materials - Design and Performance (APD), in parallel with TC on Alternative Paving Materials – Sustainability (APS), aims to continue and expand the research initiated by TC 279-WMR. TC APD is set to delve deeper into the research areas of design and performance that TC 279-WMR began to explore, moving towards a comprehensive understanding of waste and secondary materials within the wider framework of alternative paving materials (APMs) as integral, native components of road composites. The focus of the new TC will be on identifying specific APMs for detailed investigation, particularly emphasizing bio-binders, recycled tire rubber, and recycled plastics as substitutes for traditional petroleum-based binders, natural aggregates, and polymeric additives. This selection is directly linked to the materials explored by the predecessor TC 279-WMR, with bio-binders representing a novel area of exploration for RILEM technical committees, apart from the isolated work of Task Group 3 of TC 264-RAP - Asphalt Pavement Recycling, which assessed a bio-based asphalt recycling agent [45]. Whereas TC 279-WMR took a broad and exploratory approach to the utilization of various materials on a global scale, it was unable to offer detailed design and performance recommendations at a mature level. Consequently, TC APD will focus its efforts on three primary areas to devise sophisticated solutions to these pressing research challenges (Figure 1):

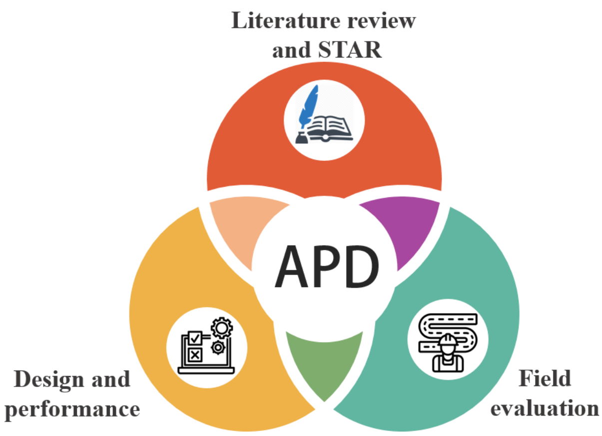

Figure 1. Visual representation of TC APD.

(i) **Conducting a Comprehensive Literature Review**: Existing knowledge on the design and performance of Alternative Paving Materials (APMs) and related paving composites is scattered. A detailed review is crucial to aid related research efforts within the TC. This review forms the groundwork for the final dissemination of the TC's findings, potentially through a State-of-the-Art Report (STAR) or as a specialized collection in the journal Materials and Structures (M&S).

(ii) **Investigating Design and Performance of APM Composites**: This part of the research involves a detailed examination of paving composites with APMs through a layered approach, including the analysis of binders, the intermediate scale (such as mastic, mortar, or fine matrix), and a specific emphasis on the mixture level. The primary objective here is to identify and refine the best methodologies for updating the practices presently employed in the field, covering areas from blend design and performance-driven mix design to manufacturing, testing, and modeling processes.

(iii) **Assessing Field Performance of APM Paving Composites**: The real-world performance of paving composites incorporating APMs remains largely unexplored within the scope of RILEM TCs of cluster F, despite its critical role in understanding material behavior under actual conditions. Leveraging the unique access to national road authority resources, existing test sections, and accelerated pavement testing facilities available to the TC chair and co-chair, this task aims to thoroughly evaluate these materials' field performance, filling a significant gap in the current research.

TC APD is set to catalyze a significant paradigm shift within the road pavement industry, highlighting the critical need to develop and broadly implement innovative solutions that move beyond traditional bituminous materials. This effort emphasizes the importance of fostering widespread acceptance and application. Achieving these goals requires blending a comprehensive global perspective with actionable, interdisciplinary initial steps, aiming to produce robust recommendations. In this context, the collaborative efforts of the newly proposed TCs APD and APS present a prime opportunity to enhance both research and practical outcomes, delivering significant benefits to engineers, practitioners, and regulatory bodies venturing into this novel research domain. Thus, TC APD establishes a premier platform for international collaboration, poised to significantly impact the critical areas related to the performance-engineered design of paving composites that inherently incorporate alternative paving materials. This initiative welcomes contributions from a diverse array of disciplines beyond the conventional scopes of civil engineering and materials science, reflecting the interdisciplinarity of TC APD.

4 Proposed research

The following section describes the three macro-activities planned to address the three research challenges defined in Section 3.

Literature Review and STAR

The aims are twofold: firstly, to compile a comprehensive overview of the international utilization of APMs, and secondly, to oversee the compilation of the TC's concluding research document, which may take the form of either a State-of-the-Art Report (STAR) manuscript or a thematic collection of articles in Materials and Structures (M&S) upon completion of the TC's activities. Two principal tasks will be undertaken to achieve these objectives: a) conducting an extensive literature review to cover design methods, blending, formulation and production, assessment of performance, and testing techniques for paving composites, both with and without APMs, which will support the groundwork for following research effort in TC APD; and b) in parallel, within the same framework, the STAR or collection of articles will be prepared.

Design and performance of paving composites containing APMs

This part of the research aims to establish a performance-engineered design framework for paving composites incorporating APMs. This investigation will draw upon the foundational literature review mentioned above, as well as previous work from TC 279-WMR. This work will focus on APMs such as bio-binders, recycled tire rubber, and recycled plastic, with bio-binders presenting a new area of exploration beyond the scope of TC 279-WMR. Key research areas include examining the thermomechanical properties of blends and composites and devising innovative strategies for their design, production, and evaluation, employing a comprehensive multi-scale approach with a particular emphasis on mixtures. The outcomes of this investigation are also expected to complement and enhance the efforts of TC APS, particularly in terms of design considerations. Consequently, a strong collaborative relationship between the two TCs is anticipated to optimize research outputs.

Field evaluation of paving composites containing APMs

This third macro area of research will compile and assess the in-field performance of paving composites that incorporate APMs, drawing on both previously conducted tests and data from existing test sites, and potentially establish a few selected test sections for new composites designed with APMs following the novel design methodology developed with TC APD. The initial focus will be gathering and analyzing information through a comprehensive literature review and data extraction from various global sources, including prior studies, road authorities, and transportation departments. This process aims to organize and refine the understanding of the in-field performance metrics for materials in this category. Should sufficient data be collected, artificial intelligence tools may be employed to identify overarching trends. Furthermore, utilizing data from Nordic roads designed with APMs that undergo frequent (every 3-4 years) resurfacing, along with data from experimental sections within established accelerated pavement testing facilities in the USA and new field research infrastructures in India, a few targeted field test sections could be planned for newly developed composites containing APMs. These test sections are intended for short-term performance monitoring and evaluation, with the prospect of extending into long-term studies in subsequent RILEM TC initiatives.

5 The position of TC ADP within RILEM and beyond

TC APD represents a pioneering move towards reducing the paving industry's reliance on natural and fossil-derived materials. Stakeholders from previous TC 279-WMR, including industry professionals, road authorities, and academic institutions, have recognized the importance of this research direction, with the goal of leveling the playing field among traditional, secondary, and alternative materials. The new TC APD aims to extend the groundbreaking work of TC 279-WMR, focusing on enhancing research into the design and performance of paving composites that incorporate Alternative Paving Materials (APMs), with notable distinctions and innovations over TC 279-WMR, such as:

TC 279-WMR did not explore specific methodologies for mix design tailored to APMs. Addressing this gap is crucial for optimizing the performance of APM paving composites, developing bespoke testing protocols, establishing appropriate production conditions, and evaluating the applicability of current modeling approaches.

The previous TC did not undertake field evaluations, making it a significant area of interest for TC APD. Organizing and analyzing existing field data, along with the creation of a select number of test cells using APM composites for both immediate and potentially extended future study, presents a valuable research opportunity.

TC APD is poised to leverage the insights and findings from previous RILEM TCs, including TC 237-SIB, 241-MCD, 272-PIM, 252-CMB, and 264-RAP, which have contributed to advancements in fracture mechanics, testing protocols, performance assessment, chemo-mechanics, and material recycling. Additionally, this TC aims to cultivate strong partnerships with TC APS and ensure meaningful interactions with existing TCs, such as (a) TC 295-FBB, which focuses on the physicochemical analysis for the fingerprinting and characterization of bituminous binders; (b) TC 308-PAR, dedicated to Performance-based Asphalt Recycling, particularly concerning manufacturing techniques and mixture performance; (c) TC 307-PPB, which examines the Physicochemical effects of polymers in bitumen, which is pertinent to characterization efforts. Moreover, TC APD, together with TC APS, are set to lay a robust groundwork for future technical committees, which could expand upon their work and findings, especially in the realm of long-term evaluation of field test cells potentially established by TC APD. Therefore, TC APD is in line with RILEM's objectives, aiming to promote advancements in the development of more sustainable materials for road construction. It will explore innovative methodologies through international, cross-disciplinary efforts that encompass comprehensive reviews and collaborative laboratory studies, welcoming participation from new members. The dissemination of its findings through scholarly publications and practical recommendations underscores its commitment to RILEM's mission.

The research domain of this TC is of paramount importance to the road construction sector, providing crucial insights and advice to entities dealing with novel paving materials. Its alignment with the goals and thematic areas of RILEM positions it aptly within Cluster F. In addition, TC APD intends to build on and extend its reach beyond existing partnerships, contributing valuable knowledge and expertise to RILEM's global community. The committee aims to broaden its international presence by inviting participation from beyond European borders and fostering strong ties with both national and international organizations, including FEHRL, PIARC, ISO, ISAP, AAPT, TRB, AAPA, NRRA, AASHTO, ASTM, NAPA, CEN, EAPA, ACI, and Eurobitume, thereby enhancing its impact and relevance across the globe.

6 Expected achievements and impact

TC APD offers direct benefits by conducting a thorough examination of existing performance-engineered design solutions for paving materials and formulating design procedures for paving composites with APMs. It provides a structured overview of the field performance data for existing paving mixtures that incorporate APMs and explores the creation of potential new test sections using these composites. Furthermore, it initiates a supportive framework for state and national transportation authorities in developing APM-based paving composites. The TC's efforts will culminate in a range of outputs, including a thematic issue or collection of papers in the journal Materials and Structures detailing the TC's activities, RILEM recommendations for performance-engineered design procedures of APM paving composites, and a comprehensive dataset on historical and current field experiences with such composites. Additionally, the TC will develop educational resources like short courses and web-based training modules for academia, industry, and highway agencies. Regarding dissemination and collaboration, the TC plans to publish a State-of-the-Art Report or a topical collection of papers in Materials and Structures alongside contributions to RILEM Technical Letters. An international workshop, potentially structured as a summer or winter school in collaboration with TC APS, and a closing symposium towards the TC's conclusion are also anticipated. These events and publications aim to share insights, foster dialogue, and set standards for the use of APMs in paving, reflecting the committee's comprehensive approach to enhancing road construction methodologies and materials.

As previously remarked in this paper, the integration of APMs into paving composites has seen a marked increase in interest from both a research perspective and practical application, as evidenced by the findings of TC 279-WMR. This trend not only supports the principle of resource circularity but also underscores the critical need for scientifically grounded methodologies. With the diminishing availability of natural and fossil-derived resources, there is an urgent desire for alternative solutions that maintain or enhance performance standards in both laboratory settings and real-world applications. This necessitates the development of tailored, performance-engineered strategies for the design and field assessment of APM-infused paving composites to ensure the longevity and durability of road infrastructure. From a scientific standpoint, the TC's impact will be profound, offering significant advancements in the comprehension of design methodologies and performance assessments. This includes understanding the behavior of paving composites made with APMs, such as bio-binders, recycled tire rubber, and recycled plastics, focusing on their rheological properties and performance characteristics.

Traditionally, such materials are relegated to downcycling, incineration, or landfilling. Thus, their application in paving composites represents not only an environmental benefit but also a potential economic advantage. The research findings will underpin the improvement of national and international standards, promoting knowledge sharing among all stakeholders involved. Additionally, the preparation of a State-of-the-Art report, detailed recommendations, and scholarly articles by the TC will enrich educational resources for emerging researchers and engineers, laying a solid foundation for future leadership in sustainable paving solutions.

The outcomes of the Technical Committee (TC) are aimed at a diverse group of beneficiaries, including the academy, road authorities, transportation departments, and standardization bodies. Furthermore, the results will be of interest to testing equipment manufacturers, testing laboratories, and both track and field testing facilities, as well as material producers, construction equipment manufacturers, industry professionals, practitioners, and road agencies at the national, regional, and state level, and the wider research community.

7 Summary and conclusions

The establishment of the RILEM Technical Committee TC 279-WMR marked a significant stride towards embracing the principles of a circular economy in road engineering by investigating the incorporation of recycled, marginal, and secondary materials into pavement construction. This initiative stemmed from recognizing the vast volumes of underutilized materials that could potentially enhance the sustainability of road infrastructure. The backdrop of this research emphasizes the imperative of resource efficiency and conservation within the road industry as critical components of a circular economy aimed at reducing raw material and energy use, lowering emissions, and reintegrating secondary resources.

In this vein, the Technical Committee on Alternative Paving Materials – Design and Performance (APD) seeks to build upon the foundational efforts of TC 279-WMR, delving deeper into the design and performance of paving composites with Alternative Paving Materials (APMs). The committee focuses on bio-binders, recycled tire rubber, and recycled plastics, aiming to refine methodologies for design and performance evaluation and explore their practical applications in paving composites in the field.

TC APD outlines a comprehensive research vision which includes conducting an extensive literature review, investigating design and performance aspects of APM composites, and assessing their field performance. These efforts are expected to result in valuable outputs such as thematic issues or collections of papers, RILEM recommendations, datasets on field experiences, and educational resources.

Therefore, TC APD aligns with RILEM's mission, fostering advancements in the use of sustainable materials for road construction. The committee's anticipated achievements include the development of performance-engineered design procedures for APM paving composites, structured overviews of existing field performance data, and potentially new test sections for short-term performance monitoring and evaluation. These outcomes promise to significantly contribute to the road construction sector, offering guidance to entities exploring novel paving materials and laying the groundwork for future technical committees. In conclusion, TC APD embodies a global approach to enhancing road construction methodologies and materials through the integration of Alternative Paving Materials. By leveraging previous research, fostering international collaborations, and producing valuable scientific and educational outputs, the TC sets the stage for significant advancements in sustainable paving solutions. Its work is poised to influence national and international standards, foster a global exchange of knowledge, and inspire the next generation of leaders in the field of road construction.

Statement

This article has been prepared by the TC chairs and TG leaders of RILEM TC APD - Alternative Paving Materials – Design and Performance

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Authorship statement (CRediT)

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