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# Sustainable Concrete with Beneficial Byproducts

Editor:
Moncef L. Nehdi

SP-334

American Concrete Institute
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# Sustainable Concrete with Beneficial Byproducts

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Concrete with Recycled Materials

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## PREFACE

### Sustainable Concrete with Beneficial Byproducts

To improve the eco-efficiency and sustainability of concrete, the cement and concrete industry can exploit many byproducts in applications that could, in some cases, outperform conventional materials made with traditional ingredients. This Special Publication of the American Concrete Institute Committee 555 (Concrete with Recycled Materials) is a contribution towards improving the sustainability of concrete via using recycled materials, such as scrap tire rubber and tire steel wire fiber, GFRP waste, fluff, reclaimed asphalt pavements, recycled latex paint, and recycled concrete aggregate. Advancing knowledge in this area should introduce the use of recycled materials in concrete for applications never considered before, while achieving desirable performance criteria economically, without compromising the quality and long-term performance of the concrete civil infrastructure.

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# Mechanical Performance of Concrete Incorporating Slender Elements from Recycling GFRP Waste

Yuan Tian and Ardavan Yazdanbakhsh

**Synopsis:** Due to their unique mechanical characteristics, glass fiber reinforced polymer (GFRP) composite materials are difficult to recycle at the end of their service lives. In the present work, a specific approach of recycling GFRP waste for use in concrete is investigated. Scrap from GFRP rebar and waste from a GFRP wind turbine blade shell were processed into slender elements, referred to as "needles," with a length of 100 mm and used in concrete to replace 5% and 10% of natural coarse aggregate. The results of testing various concrete specimens revealed that the incorporation of needles with longitudinally aligned glass fibers increased the splitting tensile strength of concrete significantly. Both types of recycled needles, regardless of the source of waste and orientation of glass fibers, increased the tensile toughness of concrete significantly. In addition, it was observed that incorporating needles did not reduce concrete's slump, due to the relatively high specific surface area of the needles. The findings suggest that recycling GFRP waste into needles as concrete reinforcement may be a viable GFRP waste management strategy and deserves further research.

**Keywords:** Concrete, Discrete reinforcement, GFRP waste, Mechanical performance, Recycled composites

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# Utilization of Reclaimed Asphalt Pavement Aggregates in Portland Cement Concrete for Concrete Pavement

Anol Mukhopadhyay and Xijun Shi

**Synopsis:** Potential issues associated with depletion of good aggregate sources and management of excess RAP stockpiles increasingly motivate use of RAP in PCC as a coarse aggregate replacement. Texas has shown great interest in disposing excess RAP stockpiles and a systematic study on using RAP in PCC for Texas pavement applications was conducted by the authors recently. This paper provides a concise summary of the findings from this study. The major conclusions are (1) PCC mixture with dense aggregate gradation can be achieved by adding coarse RAP with adequate intermediate sized particles, which offers better overall performance in terms of workability and mechanical properties, (2) RAP-PCC with coarse RAP replacement up to 40% showed considerable reduction for modulus of rupture. Asphalt cohesive failure (crack passing through the asphalt layer) was found to be the main mechanism responsible for the strength reductions, (3) the addition of allowable amounts of RAP into PCC provides equivalent durability performance relative to plain PCC, and (4) constructing pavements with RAP-PCC yields economic, environmental and social benefits.

**Keywords:** reclaimed asphalt pavement, portland cement concrete, microstructure, durability, life cycle assessment

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# Investigation of High Strength Concrete Behavior Made with Very High Percentages of Metakaolin and Steel Fibers

Mohammed S. Eisa, Ahmed Ibrahim, and Olaniyi Arowojolu

**Synopsis**: High strength concrete (HSC) is considered a material which have been implemented in many construction applications. The effect of Metakaolin (MK) and steel fiber (SF) combinations on the mechanical properties of HSC was investigated in this paper. Concrete mixtures' compressive strength split tensile strength and bond strength were evaluated. All mixtures were designed as a grade M60 with various levels of cement replacement with high percentages of MK (10%, 15%, 20%, 30%, 40%, and 50% by weight of cement) and steel fibers (0.25% and 0.50% by volume fraction). The results of this study were compared to the recent similar studies conducted, and it showed consistence conclusions. Test results revealed that a 15% of MK as replacement of cement showed the highest compressive and tensile strengths. Even with 50% of cement replacement with MK and SF, the mixtures showed good mechanical properties compared to the 100% cement concrete.

**Keywords**: Steel fiber, Metakaolin, Compressive strength, Tensile strength and bond strength

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# Mechanical Properties of Concrete Made with Fluff

Alessandro P. Fantilli and Bernardino Chiaia

**Synopsis**: A detailed investigation on the use of automotive shredder residues, the so-called fluff, as an alternative aggregate of structural lightweight concrete, is the subject of the present paper. Specifically, a new granulated fluff, obtained through a granulation process already used to treat returned concrete, substitutes the traditional gravel made with expanded clay. Slump values are measured with the slump cone test on fresh concrete, whereas the depth of penetration of water under pressure, and the uniaxial compressive tests as well, are performed on hardened concrete cylinders. As a result, a new parameter, herein called "inconsistency parameter", is introduced and used to define both the mechanical properties (i.e., the strength and ductility) and the workability of the lightweight concretes made with virgin or plastic waste aggregates. According to the required structural performances in service, the optimal value of the inconsistency parameter can be defined as a function of both the water/cement ratio and the content of the granulated fluff.

**Keywords:** Automotive shredder residues, depth of water penetration, inconsistency parameter, lightweight concrete, uniaxial compression test.

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# An Investigation of Tire-derived Lightweight Aggregate Concrete

Fariborz M Tehrani, John Carreon, and Nathan Miller

**Synopsis:** Detailed experimental and analytical studies were carried to investigate the effect of recycled tire-derived aggregates (TDA) on ductility and toughness of lightweight aggregate (LWA) concrete specimens containing coarse expanded shale aggregates and fine mineral aggregates. Investigations covered six different concrete mix with various portions of LWA replaced by TDA. Mechanical properties of each mix, including compressive strength, splitting tensile strength, flexural strength, and modulus of elasticity were measured to obtain the optimum range of TDA to LWA ratio. Further, dynamic destructive tests were carried to highlight the performance of tire-derived lightweight aggregate concrete (TDLWAC) subjected to impact loads. Moreover, the post-peak behavior of these specimens was modeled using a linear elastic fracture mechanics relationship. The model successfully demonstrated the effect of TDA in the enhancement of cracking behavior of TDLWAC.

**Keywords:** tire-derived aggregate; lightweight aggregate; ductility; toughness; fracture; compression test; static modulus of elasticity; splitting tensile strength; flexural strength

# Comparison Among Different Mix-Design Procedures for RCA Concrete

Diego Jesus De Souza, Leandro Sanchez, Faraz Ahimoghadam and Gholamreza Fathifazl

**Synopsis:** Various studies on the use of recycled concrete aggregate (RCA) were developed in the past decades. Yet, very often direct replacement techniques are adopted to proportion RCA concrete, which leads to inferior performance of the recycled material when compared to conventional concrete. RCA is a multi-phase material comprised of original virgin aggregate and residual mortar (RM) and thus these distinct phases should be considered during the RCA mix-design process. The Equivalent Mortar Volume (EMV) mix-design method accounts for the RM to proportion RCA concrete. Although great results are normally achieved in the hardened state, EMV-designed mixtures may present important challenges in the fresh state. Modifications of the original EMV such as the modified-EMV and the Equivalent Volume method were recently proposed to tackle issues related to the fresh state and binder efficiency of recycled mixtures. This paper discusses the differences among the recent mix-design procedures developed to proportion RCA concrete.

**Keywords:** recycled concrete aggregate, equivalent mortar volume method, modified equivalent mortar volume method, equivalent volume method.

# Properties of Fly Ash-Based Geopolymer Mortars

A.M. Said, O. Saleh and A. Ayad

**Synopsis:** There is a growing need for alternative binders with smaller carbon footprint. The cement manufacture is an energy intensive process that is one of the major global contributors to carbon dioxide emission. Fly ash-based geopolymer binders represent one of these potential alternatives. Beside consuming a largely produced byproduct, fly ash-based geopolymers generally have better mechanical performance when exposed to elevated temperatures. This study evaluates the effect of the initial curing temperature and the alkaline activation solution proportions on the strength, pores structure and crystal structure of fly ash-based geopolymer mortars. The geopolymer was synthesized using Class F fly ash, potassium hydroxide solution and sodium silicate solution. The specimens were made using various ratios of sodium silicate to potassium hydroxide and were initially cured at different temperatures and their properties were studied in terms of mechanical and microstructural properties.

**Keywords:** Geopolymer; High temperature; Compressive strength; Alkali activated binder; Fly ash.

# Self-Consolidating Concrete using FRAP and High Volume of Supplementary Cementitious Materials

Yasser Khodair, Arif Iqbal, and Mohammed Hussaini

**Synopsis:** This study discusses the results of an experimental program conducted to study the fresh, hardened and unrestrained shrinkage characteristics of self-consolidating concrete (SCC) using fine recycled asphalt pavement (FRAP) and high volume of supplementary cementitious materials (SCMs) including class C fly-ash (FA) and slag (S). Sixteen mixtures were prepared with different percentages of FA, S, and FRAP. SCC mixtures were divided into four groups where each group had a different percentage of FRAP replacing fine aggregate (10%, 20%, 30%, 40%) and Portland cement being replaced by different percentages of SCMs. The water to cementitious material (w/cm) ratio of 0.4 was used for SCC mixtures with a target slump flow higher than 500 mm. The flowability, deformability, filling capacity and resistance to segregation were measured to determine the fresh properties of the mixtures. Moreover, the compressive strength at 14, 28, and 90 days and split tensile strength at 28 days were determined and durability characteristics including unrestrained shrinkage up to 90 days were tested. Analysis of experimental data showed that most of the mixtures satisfied the SCC fresh properties requirements. The addition of FRAP had an adverse effect on the compressive, tensile strength and unrestrained free shrinkage of SCC mixtures.

Keywords: self-consolidating concrete; cementitiuous materials; shrinkage; recycled asphalt pavement; fly ash, slag, fresh properties, hardened properties.

# Properties and durability of polyvinyl alcohol (PVA) fiber-reinforced rubber mortar

Ruizhe Si, Qingli Dai, and Jiaqing Wang

**Synopsis:** The fresh and mechanical properties as well as the durability of the polyvinyl alcohol (PVA) fiber-reinforced rubber mortar were evaluated in this study. The mini-slump test showed that the workability of the cement mortar was decreased with the both added rubber aggregates and PVA fibers. The mechanical strength was reduced in rubberized mortar compared with the plain cement mortar. The added PVA fiber with optimized content improved the compressive strength of the rubberized mortar. The ultrasonic wave velocity test showed that the dynamic modulus of the rubberized mortar was lower than that of plain mortar. In addition, the fiber reinforcement can enhance dynamic modulus (shown as the increased ultrasonic wave velocity) in the rubberized mortar mixtures. The drying shrinkage of the cement mortar was reduced by using the low content of the rubber aggregate as well as applying the PVA fiber reinforcement.

**Keywords:** Rubberized mortar; Fiber reinforcement; Ultrasonic wave velocity; Drying shrinkage; Compressive strength.

# Recycled Additive to Improve Freeze-Thaw Durability of High Fly Ash Content Mortar

Ahmed A. Gheni and Mohamed A. ElGawady

**Synopsis:** Statistics show an increase in the use of fly ash in concrete to improve both sustainability and performance. However, concrete incorporating high volume fly ash has encountered an issue with incompatibility between fly ash and air entraining admixture (AEA). This study investigates using ground recycled rubber (GRR) as an eco-friendly alternative to AEA to improve the freeze-thaw performance of mortar mixtures incorporating two different types and ratios of fly ash. Two different sizes and ratios of GRR were used in this study. The results were compared with mixtures having two different types and dosages of AEA as well as a reference mortar mixture having neither GRR nor AEA. Foam indices were determined for both types of fly ash and compared with cement. The compressive strength retention values of mortar cubes after exposing them to 36 freeze-thaw cycles were determined and linked to the air content of each mixture. This study revealed that the GRR outperformed the AEA in terms of the freeze-thaw durability where all mixtures retained their compressive strengths. However, the performance of mixtures including AEA was inconsistent depending on the chemical composition of the fly ash, fly ash replacement ratio, and AEA dosage.

**Keywords:** recycled rubber, freeze-thaw, fly ash concrete, durability, eco-friendly, sustainable construction admixture.

# Durability of Class C Fly Ash-Based Alkali Activated Concrete

Eslam Y. Gomaa, Ahmed A. Gheni, and Mohamed A. ElGawady

**Synopsis:** The durability of alkali activated concrete (AAC) synthesized using high calcium fly ashes (FAs) was studied. Surface resistivity, bulk electrical resistivity, rapid chloride ions penetration, and freeze-thaw resistance tests were carried out on AAC made with five different FAs. The specimens were either oven-or moist-cured. The effect of adding air entraining admixture (AEA) and recycled crumb rubber to the AAC specimens on the freeze-thaw resistance was investigated as well. It was found that the durability of AAC was higher than that of comparable ordinary Portland cement (OPC) concrete. Adding the AEA improved the freeze-thaw resistance but not enough to complete the 300 cycles, per ASTM C666-15. Adding the rubber to the AAC mixtures improved the freeze-thaw resistance significantly.

**Keywords:** Class C fly ash; slag; crumb rubber; alkali activated concrete; fresh properties; compressive strength; durability; ambient curing; oven curing

# Pervious Concrete Production using Recycled Waste Latex Paint

A. Said and O. Quiroz

**Synopsis:** In the U.S. and around the world, large amounts of waste latex paint are generated annually, which creates a significant challenge in terms of disposal in an economic manner. Paint contains some chemicals that may be harmful to the environment if recycled as it contains volatile organic compounds. However, waste latex paint can be used to produce an economic latex-modified pervious concrete that is similar or superior to regular pervious concrete. Previous studies investigated recycling waste latex paint in concrete applications such as sidewalks. This study investigates the use of waste latex paint in producing pervious concrete and the effect of using different ratios of paint addition on the properties of the studied mixtures. The properties evaluated included physical, mechanical and hydraulic properties. Results show that while waste latex paint recycling in pervious concrete can slightly reduce its mechanical properties at 5% polymer to cement content, it can still be a viable option to prevent paint disposal in landfills.

**Keywords:** Waste latex paint; Latex-modified concrete; Pervious concrete; Durability; Hydraulic properties.

# CDW Integrated Management, from Linear to Circular Economy in Bogota

Luz Angélica Rodríguez-Bello, Pedro Nel Quiroga, Juan Pablo Agudelo, and María Paulina Villegas-De-Brigard.

**Abstract***:* Construction and demolition waste (CDW) has become an environmental, social and economic problem in some regions. Many initiatives to increase CDW recycling and concrete with recycled aggregates have failed or have not accomplished the goals, due to the lack of good management. In Bogotá, even though regulations establish that 25% must be harnessed, only 17% is achieved. To obtain rates as high as the global ones, a CDW diagnosis in works is run and policy instruments that would allow the application of a circular economy concept as opposed to a linear economy are determined. It is found that economic and informative instruments are the most popular worldwide and the most requested at the national level, in comparison to regulatory instruments which currently prevail in Bogotá. Likewise, the literature highlights prevention actions and the national context prefers recycling and disposition actions.

**Keywords***:* Construction and demolition waste - CDW, circular economy, recycling, policy instruments, integral management.