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Recycled materials applications in various construction fields

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Abstract: A comparative analysis of the properties of fresh and hardened concrete with different replacement ratios of natural with recycled coarse aggregate is presented in the paper. Recycled aggregate was made by crushing the waste concrete of laboratory test cubes and precast concrete columns. Three types of concrete mixtures were tested: concrete made entirely with natural aggregate (NAC) as a control concrete and two types of concrete made with natural fine and recycled coarse. Ninety-nine specimens were made for the testing of the basic properties of hardened concrete. Load testing of reinforced concrete beams made of the investigated concrete types is also presented in the paper. Regardless of the replacement ratio, recycled aggregate concrete (RAC) had a satisfactory performance, which did not differ significantly from the performance of control concrete in this experimental research. However, for this to be fulfilled, it is necessary to use quality recycled concrete coarse aggregate and to follow the specific rules for design and production of this new concrete type.

Keywords: mechanical properties; structural concrete; recycled aggregate concrete; RAP.

INTRODUCTION

The main material included in CDW is the cement concrete from which, by application of appropriate recycling technologies, recycled aggregates result; they can successfully substitute crushed/quarry natural aggregates to the construction of rigid pavements (Muscalu & Ţăranu, 2010). Thus, by limiting the consumption of natural aggregates and use of recycled cement concrete from CDW, an important impact reduction of the construction on the environment is achieved. It has been speculated that in some municipalities recycled materials costs less to use than conventional crushed-stone base material by as much as 30%. The most widely used recycled materials are recycled asphalt pavement (RAP) and recycled concrete aggregate (RCA). RAP is produced by removing and reprocessing existing asphalt pavement and RCA is the product of the demolition of concrete structures such as buildings, roads and runways. The production of RAP and RCA results in an aggregate that can be well graded and of high quality. The aggregates in RAP are coated with asphalt cement that reduces the water absorption qualities of the material. In contrast, the aggregates in RCA are coated with a cementitious paste that increases the water absorption qualities of the material.

The following classification is recommended to remove ambiguity in nomenclature: RAP refers to the removal and reuse of the hot mix asphalt (HMA) layer of an existing roadway; full depth reclamation (FDR) refers to the removal and reuse of the HMA and the entire base course layer; and recycled pavement material (RPM) refers to the removal and reuse of either the HMA and part of the base course layer or the HMA, the entire base course layer and part of the underlying subgrade implying a mixture of pavement layer materials. Unless specified, these three distinct recycled asphalt materials can be collectively referred to as RAP.

can be stockpiled, but ismost frequently reused immediately after processing at the site. Typical aggregate gradations of RAP are achieved through pulverization of the material, which is typically performed with a rubber tired grinder.The production of RCA involves crushing the concrete material to a gradation comparable to that of typical roadway base aggregate. Fresh RCA typically contains a 4 high amount of debris and reinforcing steel, and the RCA must be processed to remove this debris prior to placement. The remaining concrete material after debris removal is further crushed and screened to a predetermined gradation. RCA can be derived from concrete pavements or buildings (building derived concrete).

Material Properties & Applications

The gradation of RAP can be compared to that of a crushed natural aggregate, although with a higher content of fines. The high fine content is the result of degradation of the material during milling and crushing operations. In RPM the inclusion of subgrade materials in the recycled material also contributes to a higher instance of fines. Finer gradations of RAP are produced through milling operations compared to crushing operations. Table 1 provides a breakdown of typical physical and mechanical properties of RAP.

RCA is processed exclusively through crushing operations, and is very angular in shape. Depending on the crushing methods, the particle size distribution of an RCA can have a wide variability, with a lower particle density and greater angularity than would normally be found in more traditional virgin base course aggregates. Residual mortar and cement paste are typically found on the surface of the RCA, as well as contaminants associated with construction and demolition debris. The presence of this mortar contributes to a rougher surface texture, lower specific gravity, and higher water absorption than typical aggregates. The self-cementing capabilities of RCA are an interesting secondary property. The crushed material exposes un-hydrated concrete that can react with water, potentially increasing the materials strength and durability when used as unbound base course for new roadway construction. It follows that service life could also be extended as a result of these properties. Although widely acknowledged, not much actual documentation has been published regarding this secondary hydration.(5)Although the cause of self-cementing properties has been studied, the actual effect of such parameters as age, grade, and mix-proportions of the RCA on the overall cementitious effect has yet to be determined. This effect is outside the scope of this literature review. Table 2 provides a breakdown of typical physical and mechanical properties of RCA.

The organization of a recycled aggregate production site does not differ much from those engaged in the production of natural crushed aggregates; same equipment can also be used for crushing, sorting and storage of recycled aggregates. Recycled aggregates are obtained by compression/impact crushing of broken cement concrete using equipment. For better control of recycled aggregates grading curve it is recommended that the recycling of cement concrete to be carried out in two stages of crushing. First, using a jaw crusher and sieving equipment, the broken concrete is reduced to a granular mix with maximum particle size of 31…40 mm and sorted through the 16/20 mm sieve. In the second stage, the material remaining on the sieve is sent to an impact crusher where the desired maximum size of the recycled aggregate results.

Currently, because of both lack of studies in understanding the recycled aggregates and lack of standards and norms for testing and design of cement concrete manufactured with recycled aggregates, most of CDW, especially the mixture from broken cement concrete and bricks, is used in low value applications such as fillings, earthworks and access roads.

Paving Lane Access

Demolition teams were scheduled to remove sections of HMA placed over unfinished concrete and nine inches of existing PCC pavement. Additionally, approximately seven inches of the existing base was removed. After demolition and grading, the truck access lane would have a surface elevation sixteen inches higher than the adjacent lane prepared for paving. In order for paving equipment to access the paving lane and the prepared subgrade, paving equipment had to be transferred over a 16 inch ledge. Paving materials would also have to be transferred across the sixteen inch lip from dump trucks to paving machines. To circumvent this material transfer obstacle, the contractor placed two dump trucks into the construction pit with the paving equipment. A material transfer vehicle was stationed at the end of the construction pit to mix and transfer material from delivery dump trucks in the access lanes to dump trucks down in the pit. The pit dump trucks would then back down the construction zone and deposit their load into the paving machine. Figure 19 and Figure 20 show the material transfer process. The contractor used a similar type operation for both HMA and PCC paving.

Fresh & Recycled Concrete Properties and its Applications

This section discusses results from previous research in regards to the effect of coarse RCA on the workability, air content, and density of fresh and recycled concrete.

Workability

RCA replacement for coarse NA has been shown to decrease workability of fresh and recycled concrete mixes. One reason for this is that RCA, depending on the crushing process, has more friction potential due to angular shape and rougher surface conditions than NA. The greater absorption capacity of RCA can also result in a reduction in workability by effectively reducing the water-cement ratio. Several solutions have been suggested to counteract this effect including the use of water reducing admixture, fly ash, or a combination of the two. In addition to reduced workability, fresh concrete mixtures incorporating RCA commonly experience more rapid slump loss due to the increased absorption capacity of RCA.

Air Content

The air contents of concrete mixtures with coarse RCA are slightly higher and more variable than those with only NA. This is attributable to the entrained air and greater porosity of the RCAs due to the adhered mortar. As a result, target air contents should be raised in order for concrete mixtures incorporating RCA to achieve the same durability performance as those with only NA. However, in order to circumvent the variability of this characteristic, it may be better practice to remove as much as possible of the adhered mortar portion from RCA prior to usage.

Density

It can be expected from the discussion in preceding sections that the inclusion of coarse RCA in mix design results in a reduction in mix density. As noted before, RCA has a smaller specific gravity, and is therefore less dense due to the greater amount of entrained air and porosity of the adhered mortar. Consequently, concretes mixtures incorporating coarse RCA will have a reduced density.

Hardened Concrete Properties

This section discusses the effects of RCA replacement of coarse NA on the performance of hardened concrete as determined by compressive strength, modulus of rupture, drying shrinkage, and durability.

Compressive Strength

The compressive strengths of concretes incorporating coarse RCA, in general, are the same if not slightly lower than those with only NA. The degree to which RCA reduces compressive strength has been a point of disagreement in a number of studies. A 2012 investigation concluded that compressive strength is relatively unaffected by the replacement of NA with coarse RCA, theorizing that strength is maintained because the RCA has better interfacial transition zone with new cement paste as well the possible presence of unhydrated cement on the RCA.

Compaction Characteristics

Maximum dry unit weight (MDU) varied within a narrow range of about 1 kN/m^3 and optimum moisture contents within 3 % for both RAP/RPM and RCA samples. The average MDU was about 19-20 kN/m^3 for both RAP/RPM and RCA samples. However, the average OMC was higher for RCA (about 10%) than RAP/RPM (about 7%) samples due to higher absorptive capacity of RCA samples. OMC can be estimated empirically as a function of uniformity coefficient and percent absorption and MDU as a function of optimum moisture content for both RCA and RAP/RPM samples as given in RMRC Project No. 46 report.

Resilient Modulus and Plastic Strains

Resilient modulus is the primary design property of pavement materials. Various studies as well as the tests conducted on these samples indicate that the resilient modulus of both RCA and RAP/RPM are equal or higher than that of natural aggregate. Typically, a representative modulus is computed for base course termed Summary Resilient Modulus (SRM) as suggested in NCHRP 1-28a, corresponding to a bulk stress of 208 kPa. For the RAP/RPM samples, SRM ranged from 627 to 989 MPa. RCA samples had slightly lower SRM (ranging from 549 to 715 MPa) in comparison to RAP/RPM, while Class 5 natural aggregate has the lowest SRM (525 MPa). The resilient modulus of both RCA and RAP/RPM can be estimated empirically in terms of compositional characteristics such as grain size, asphalt content, absorption, percent fines as given in Project No. 46 report.Various studies indicate that the plastic strains of RAP is greater (nearly 10 times) than that experienced by natural aggregate and RCA. This may be of concern for potential conribution to rutting. This concern will be addressed in the design section.

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Table 1: Typical Physical Properties of RAP

Physical Properties	
Unit Weight	1940 - 2300 kg/m^3 (120 - 140 pcf)
Moisture Content	Normal: Up to 5% Maximum: 7 - 8%
Asphalt Content	Normal: 4.5 – 6%
Asphalt Penetration	Normal: 10 – 80% at 25°C (77°F)
Absolute Viscosity or Recovered Asphalt Cement	Normal: 4000 – 25000 poises at 60°C (140°F)
Mechanical Properties	
Compacted Unit Weight	1600 – 2000 kg/m^3 (100 – 125 pcf)
California Bearing Ratio (CBR)	100% RAP: 20 – 25% 40% RAP and 60% Natural Aggregate: 150% or Higher

Design Application of Recycled Concrete

A methodology to incorporate granular recycled aggregates as base course (alone and stabilized with binders such as fly ash, cement, cement kiln dust) in pavement design is developed. Mechanical behavior of these materials was characterized through a large-scale model experiment (LSME) as well as laboratory bench-scale resilient modulus (BSRM) tests in accordance with NCHRP 1-28a at the University of Wisconsin-Madison (RMRC Projects 46, 48, 53, and 61). In some cases, field modulus data were obtained via falling weight deflectometer (FWD) tests. Data from the BSRM test were compared to those from the LSME and FWD to account for the effects of the test conditions and scale on resilient modulus. Resilient moduli and plastic deformations obtained from the LSME were then used to develop a methodology for designing pavements with these materials. Two design methods using the AASHTO 1993 and AASHTO 2008 (Mechanistic Empirical Pavement Design Guide (MEPDG) were considered.

As mentioned earlier, modulus of a granular pavement layer depends not only the stress level but also the strain level thus layer thickness. An example of the SMR as a function of layer thickness is shown in Fig. 1. When considered for the typical range of base course thicknesses (i.e., 0.1 to 0.4 m), for the unstabilized base materials, the SRM is consistently higher for thicker base course layers due to the lower shear strain amplitude in thicker layers for the same surface load whereas it is essentially constant for the cementitiously stabilized materials. Two design approaches are provided for flexible pavements using unstabilized and stabilized recycled aggregates in the base: design using AASHTO-1993 design guide and lifetime expectancy-based design using the Mechanistic Empirical 9 Pavement Design Guide (MEPDG). To simulate field conditions, SRM from the LSME were used to develop the method.

Scaling

The current model of resilient modulus takes the dependency on the state of stress in the base course but does not consider the effect of strain amplitude on resilient modulus. In other words, a thicker base course of the same granular material under the same wheel load would deform less even if the difference in stress level is taken into account because the thicker layer would have lower strains and consequently higher modulus. How this is taken into account is described in the next section on design.

Recycled aggregates and natural crushed aggregates can be used concomitant for the construction of cement concrete pavements in different proportions. In literature, laboratory tests show that if maximum 30% of natural aggregates used in cement concrete manufacturing is replaced with recycled aggregates, the performance characteristics of hardened concrete are not significantly affected. This could be the most simple, economical and less problematic method for using recycled aggregates in concrete manufacturing.

Conclusion

Several important findings were noted in the course of this literature review. The cement concrete recycling from CDW leads to improvement of environmental pollution parameters by preserving natural resources and generating free space in landfills. Also adequate economical value recovery of the cement concrete will be achieved by producing recycled aggregates which can be used in higher value construction works. The experimental study shows that with minimum effort, appropriate aggregates can be obtained by cement concrete recycling which may compensate the consumption of needed natural crushed aggregates in pavement engineering. The performed laboratory tests have proved that recycled aggregates had similar performance characteristics with crushed gravel as chippings used in rigid pavement construction.

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