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Strength and stiffness of concrete with recycled concrete aggregates

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HIGHLIGHTS

- Regional variability in RCA and RAC properties was investigated across a wide range.
- Strength of RAC decreased 16.6% at 50% replacement and 26.4% at 100% replacement.
- Stiffness of RAC decreased 26.4% at 50% replacement and 34.4% at 100% replacement.
- RCA absorption and deleterious material were primary strength/stiffness predictors.
- Coarse aggregate gradation impacted RAC similarly to impacts noted for NA concrete.

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ABSTRACT

By crushing old concrete to make recycled concrete aggregates (RCA) for use in new concrete, the overall environmental impacts of concrete are reduced. However, a better understanding of the use of RCA in new concrete is necessary before adoption in structural concrete applications can be widely realized. In particular, the strength, stiffness (Modulus of Elasticity), workability, and durability of concrete using RCA can be different than concrete that uses natural aggregate (NA). Variability in RCA properties from source to source also must be addressed if guidelines for RCA use are to be adopted. This paper describes properties of RCA and recycled aggregate concrete (RAC) with materials from four distinct areas of the United States (Northeast, South, Midwest and Southwest regions), making this study the most geographically varied study of RCA known. Variability in aggregate properties and the relationships between them are addressed within the paper. Equations allowing concrete mix designers to predict strength and stiffness of mixes are shown to be applicable across a much broader range of RCA properties than previously known. Similarly to concrete with natural aggregates, the strength and stiffness of RAC is shown to be impacted by the gradation of the coarse aggregates – smaller aggregates make stronger, stiffer concrete.

1. Introduction

Natural aggregate (NA) is a vital constitutive material used for designing and constructing civil infrastructure systems. Concrete is one of the most versatile building materials on Earth and makes up a significant proportion of the past, present, and future infrastructure. The production of NA also has a major impact on the environment. The idea of the conservation of NA has been largely ignored (especially in the United States) despite the fact that coarse aggregates make up 40–50% of a concrete mix by volume [22] while cement makes up about 10%. Using recycled concrete from the demolition of existing infrastructure to either partially or fully replace the natural coarse aggregate in future construction, has the potential to improve sustainability of reinforced concrete structures. McGinnis et al. [21] probed the sustainability aspects of recycled concrete aggregate (RCA) and shows that RCA has approximately half the environmental impact of NA. However, the use of RCA in the U.S. has been limited to non-structural applications such as sidewalks and road base even though the quality of the material is significantly higher than is required in these applications. Recycling old concrete into material suitable for structural applications is also likely to be cost-effective [14]. Despite the above mentioned benefits, only a small amount of RCA has been used in structural engineering projects in the U.S. The primary obstacles against their increased utilization are:

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1. Few previous works exist on the service and ultimate load performance of concrete structures utilizing RCA from U.S. sources.
2. Even though RCA can readily pass the prescriptive requirements for coarse aggregates in structural concrete [4], the variability in material properties and quality needs to be quantified and incorporated into design.
3. As a result of (1) and (2), few engineering guidelines/standards currently exist for the design and construction of reinforced concrete utilizing RCA manufactured using currently common processes.

The University of Notre Dame, The University of Texas at Tyler and New Mexico State University are participating in a research project designed to probe these issues. The project team assembled the largest database of RCA samples known to the authors and evaluated these samples in terms of their physical properties. Then, these aggregates were used to make concrete whose strength and stiffness (Modulus of Elasticity) were evaluated.

2. Background

RCA tends to have decreased specific gravity, increased absorption, and increased L.A. abrasion loss compared to NA, since they contain the mortar paste from the original concrete. Because of the increased absorption, RAC also has greater water demand [2], which can be resolved by increasing the amount of mix water, presoaking the aggregates, and/or by using water reducing admixtures and fly-ash. Generally, RAC has lower compressive strength, less stiffness, increased creep, and increased shrinkage [13,15,32] as compared to NA concrete. At full aggregate replacement, the much of the previous research found concrete compressive strength losses ranging from 10% to 20%. In comparison, the effect of RCA on the stiffness of concrete is greater with losses up to 33% at full replacement [2]. Some have explored various methods to manufacture RCA with better properties, such as removal of adhered mortar paste via microwave treatment [12], or acetic acid treatment [35], or treating with polymer emulsions [20] with Shi et al. [24] providing a review of some of these methods. The current paper focuses primarily on RCA produced via the common approach of simple crushing of old concrete (noting here that even crushing can be accomplished through many methods – no attempt was made to determine the crushing method for the particular RCA samples collected in the current study). Previous work in this area has shown that RCA can be used to make good quality structural concrete – two recent programs by Silva et al. and Knaack and Kurama are good examples. Silva et al. have proposed a classification system for RCA based on density, absorption and abrasion loss [25], and they have investigated RCA compressive strength [26], tensile strength [27], creep [28], stiffness [29] and design [30]. An important limitation of previous research – lack of quantitative evaluation of the variability in the RCA properties from different sources and the effect of this variability – was addressed recently by Knaack and Kurama [17,19]. In that study, the strength, stiffness, creep and shrinkage of RAC from 16 sources in the U.S. Midwest were investigated. It was shown that, although the different types of replacement methods (direct volume replacement (DVR), direct weight replacement, and equivalent mortar replacement methods) had only small impacts on strength and stiffness, the workability of mixes was strongly negatively impacted by all methods except DVR. Therefore, the DVR method was recom-

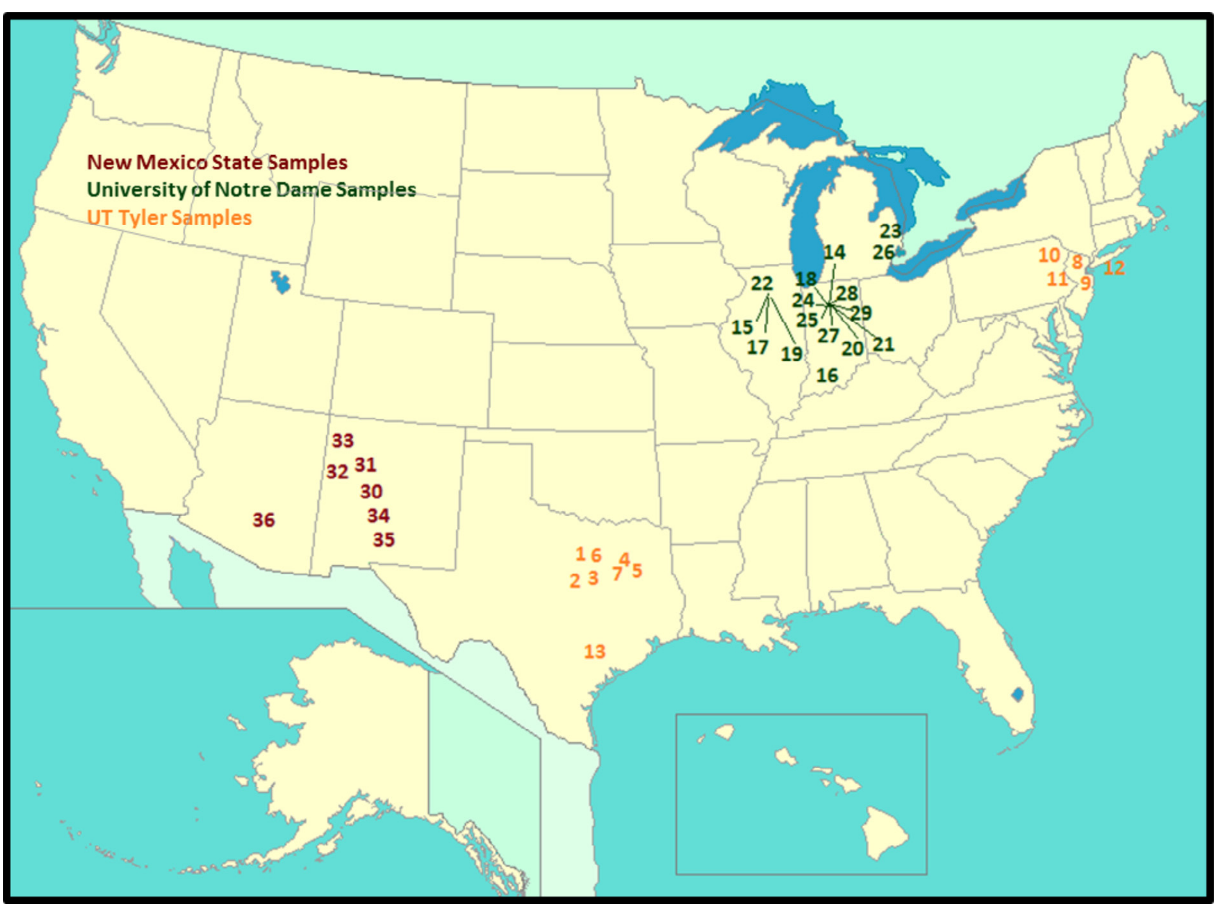

Fig. 1. Locations of sample collection (Number 14–29 from Knaack and Kurama [17]).