PROPERTIES OF CONCRETE CONTAINING RCA

Through proper mixture design, concrete containing recycled concrete aggregate can have fresh and hardened properties very similar to concrete containing only virgin aggregate.

Aggregates typically occupy about 70% of the volume of fresh concrete. Despite the differences in properties between recycled concrete aggregate (RCA) and virgin aggregate, concrete containing RCA can be designed and proportioned so there is minimal, if any, impact on either the fresh or the hardened properties of the new concrete. These nominal differences are not enough to preclude the use of RCA, which offers economic, environmental and potential performance benefits. This publication details many of these fresh (plastic) properties and physical/mechanical properties of hardened RCA concrete. More about these topics is available in ACPA's EB043P, "*Recycling Concrete Pavements*."

When RCA is used to produce new concrete mixtures, its effects on the mixture's properties can range from minimal to significant, depending upon the nature, composition and gradation of the RCA. For example, when little reclaimed mortar is present in coarse RCA, and when virgin fine aggregate is used, the handling characteristics and engineering properties of the resulting concrete will be practically the same as if all virgin aggregate had been used. Changes in mixture design and admixture usage can reduce (and sometimes eliminate) many differences in the properties of RCA concrete mixtures.

Properties of Fresh (Plastic) RCA Concrete

The use of RCA in concrete mixtures can alter the properties and behavior of the fresh concrete (also known as "plastic concrete"), mainly because of the more porous, rough-textured nature of the reclaimed mortar that comprises a portion of the RCA. The magnitude of the effects varies with the nature and quantity of reclaimed mortar that is present. A summary of the possible ranges of these effects on fresh concrete is presented in Table 1.

Table1. Effects of RCA on Fresh Concrete Properties and Behavior (after FHWA 2007, ACI 2001)

	Range of Expected Changes from Similar Mixtures Using Virgin Aggregates	
Property	**Coarse RCA Only**	**Coarse and Fine RCA**
Workability	Similar to slightly lower	Slightly to significantly lower
Finishability	Similar to more difficult	More difficult
Water Bleeding	Slightly less	Less
Water Demand	Greater	Much greater
Air Content	Slightly higher	Slightly higher

RCA particles tend to be angular and rough-textured, which can increase the harshness of fresh concrete mixtures. The irregular shape and texture of coarse RCA particles have generally not caused significant workability problems. The use of fine RCA however, can greatly increase the harshness of the mixture, as the angular RCA particles replace the more spherical conventional sands that often act as tiny ball bearings, decreasing the workability of the mixture and making it more difficult to finish properly (Yrjanson 1989). Water bleeding from RCA concrete is generally slightly less than that from mixtures prepared using virgin aggregates (Mukai et al 1979, Hansen and Narud 1983).

The higher absorption capacities of RCA (especially fine RCA) can lead to a rapid loss of workability, which can severely limit the time available for placing and finishing the concrete. Problems associated with the rapid loss of workability should be addressed by altering and controlling the moisture content of the RCA before mixing and not by adding water in excess of the approved mixture design at the jobsite.

Air contents of fresh concrete containing RCA often are up to 0.6% higher and are slightly more variable than the air contents of fresh concretes using conventional aggregates (Snyder and Vandenbossche 1993). This is generally assumed to be caused by the air that is entrained and entrapped in the reclaimed concrete mortar (Wade et al 1997). Because of this, it may be necessary to either increase total target air contents for RCA concrete mixtures or to use air measurement systems that measure only the air in the fresh paste or the air void analyzer (AVA, described in Fick 2008 and Taylor et al 2006).

Physical and Mechanical Properties of Hardened RCA Concrete

The magnitude of the effects of RCA on the physical and mechanical properties of hardened concrete can range from non-existent to significant, depending upon the nature, composition and gradation of the RCA. A summary of the possible ranges of these effects on hardened concrete is presented in Table 2.

Table 2. Effect of RCA on Physical, Mechanical and Durability Properties of Hardened Concrete (after FHWA 2007, ACI 2001, Hansen 1986)

	Range of Expected Changes from Mixtures Using Virgin Aggregates	
Property	**Coarse RCA Only**	**Coarse and Fine RCA**
Comp. Strength	0% - 24% less	15% - 40% less
Tensile Strength	0% - 10% less	10% - 20% less
Strength Variation	Slightly more	Slightly more
Mod. of Elasticity	10% - 33% less	25% - 40% less
CTE	0% - 30% more	0% - 30% more
Drying Shrinkage	20% - 50% more	70% - 100% more
Creep	30% - 60% more	30% - 60% more
Specific Gravity	0% - 10% less	5% - 15% less
Permeability	0% - 500% more	0% - 500% more
Freeze-Thaw Durability	Depends on air void system	Depends on air void system
Sulfate Resistance	Depends on mix	Depends on mix
ASR	Less susceptible	Less susceptible
Carbonization	Up to 65% more	Up to 65% more
Corrosion Rate	May be faster	May be faster

Concrete containing coarse and/or fine RCA can be produced with adequate levels of compressive and flexural strength for paving and other applications, sometimes even with 100% replacement of virgin aggregate with RCA (Yrjanson 1989, ACI 2001).

The elastic modulus of concrete containing only coarse RCA is typically 10 to 33% lower than that of conventional concrete. When both coarse and fine RCA are used, the difference increases to 25 to 40% (ACI 2001). These reductions are attributed to the increased overall mortar content (new and reclaimed), which has a lower elastic modulus than most virgin aggregate.

The coefficient of thermal expansion (CTE) of RCA concrete is typically about 10% higher than for conventional concrete, but may be up to about 30% higher (Wade et al 1997). The CTE is primarily a function of virgin aggregate type and content.

Drying shrinkage is primarily a function of paste content and water-to-cementitious materials ratio (w/cm) ratio and is restrained by virgin aggregate particles. Because concrete manufactured using RCA generally presents a higher paste content, it is no surprise that studies have found 20 to 50% higher shrinkage in concrete containing coarse RCA and natural sand, and 70 to 100% higher shrinkage in concrete containing both coarse and fine RCA (ACI 2001 after BCSJ 1978).

The creep of RCA concrete typically is 30 to 60% higher than that of comparable concrete produced using virgin aggregate. This is because creep is proportional to paste content, which can be up to 50% higher in RCA concrete (ACI 2001).

The density of RCA concrete is typically 5 to 15% lower than that of concrete manufactured using virgin aggregate (Hansen 1986). This is because reclaimed mortar has a much lower specific gravity than most virgin aggregates and can easily comprise 50% of the RCA volume.

The overall permeability and absorption characteristics of the concrete depend upon both the absorption capacity of the included aggregate and the permeability of the concrete matrix. If properly accounted for in design, the RCA concrete mixture can be engineered so that its permeability is no different than that of the concrete used to create the RCA.

RCA concrete can be highly durable (i.e., resistant to freeze-thaw, sulfate, and ASR; have a low rate of carbonation; and feature slow corrosion rates of embedded steel) even when the RCA is produced from concrete with durability problems, provided that the mixture proportioning is done properly and the construction is of good quality.

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