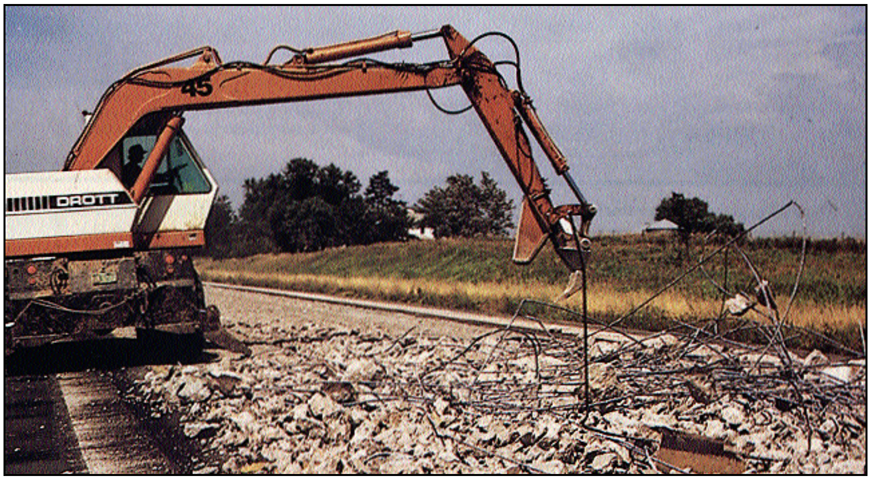

Figure 1. A rhino horn snags reinforcing steel and pulls it free from concrete fragments. Workers can then use torches or pneumatic or hydraulic shears to cut the steel to lengths that are easy to transport.

Recycling concrete pavements

By James W. Mack, Clinton E. Solberg, and Gerald F. Voigt

Using crushed concrete as aggregate conserves resources and eliminates disposal costs

Breaking up an old concrete pavement and reusing it as aggregate is a cost-effective option for reconstructing deteriorated pavements. Recycling eliminates disposal problems and tipping fees. In urban areas where landfill space is scarce, dumping concrete is difficult and costly. The cost of recycling concrete pavements only includes the cost of crushing. Costs for aggregate hauling and concrete disposal are eliminated.

In some areas, the supply of acceptable natural aggregates is dwindling. Reusing existing material is helpful where quality supplies are scarce. A new concrete mix can contain up to 100% recycled coarse aggregate, and recycled fines can replace 10% to 15% of virgin sand. Recycled aggregate also can be used in concrete shoulders, median barriers, and granular and lean concrete base layers. Fine aggregate also makes good fill for subgrade corrections.

Recycling operations

The existence of reinforcement in concrete pavement is no longer a limitation to recycling. Advancements in crushing equipment and techniques allow doweled, mesh-reinforced, and continuously reinforced pavements to be recycled.

The goal of recycling concrete pavement is to maximize production of coarse aggregate. The coarse aggregates are more valuable and more usable than fines. A contractor has many choices of recycling equipment and processes, each affecting the yield of coarse aggregate. The key steps in recycling portland cement concrete pavements are preparation, breaking, concrete removal, steel separation, and crushing.

Pavement preparation. The first step is to remove joint sealant, shoulders, asphalt patches or overlays, and anything else that may contaminate the recycled aggregate. Typically, front-end loaders are used to remove joint sealants (with a metal tooth that rakes out the sealant), scrape off asphalt overlays, or pick up loose material after milling. The loader can dislodge any material still adhering to the old concrete surface. Brooming removes most loose particles. Asphalt shoulder removal should precede breaking operations on reconstruction projects. Removing the shoulders takes away lateral support on the slab, which eases portland cement concrete (PCC) pavement breaking and removal.

Pavement breaking. Breaking shatters concrete for ease of handling, and debonds concrete and reinforcing steel. Heavier breakers can rupture steel wire mesh. Typically, breaking machines are classified as impact and resonant. Diesel hammer and drop weight devices operate at 90 blows per minute, and break rubble into pieces 18 to 24 inches across. Resonant devices deliver more than 2,600 vibrations per minute and tend to form pieces about 6 inches across.

Several factors affect the production rate of breaking equipment. More impact energy is needed with greater slab thickness, concrete strength, and quantity of reinforcing steel. As base support increases, less impact energy is needed to effectively break the concrete pavement.

Breaking energy can be varied by the number of passes, forward speed, or drop height of the breaker. The desirable size of broken pieces is typically less than 24 inches. Front-end loaders and dump trucks can easily remove and transport broken pavement. However, break energy should not push concrete pieces into underlying granular layers, subgrade, and culverts. This will force loaders to pick up base material along with broken concrete, which contaminates the old concrete and introduces fines. The use of buckets and blades with digging teeth helps minimize the removal of base materials. Additional aggregate will be required to replace material picked up during concrete removal.

Pavement and reinforcing steel removal. Typically, reinforcing steel removal occurs during several phases of the recycling process. Most often, contractors remove continuous reinforcement on-site; dowels and tie bars are removed at the recycling plant.

Continuous reinforcement is separated and removed with a rhino horn—a 30-inch curved pick that hooks the steel and pulls it free from the concrete (Figure 1). Large breakers can completely sever steel mesh in concrete. A rhino horn mounted on a backhoe breaks any large fragments, then

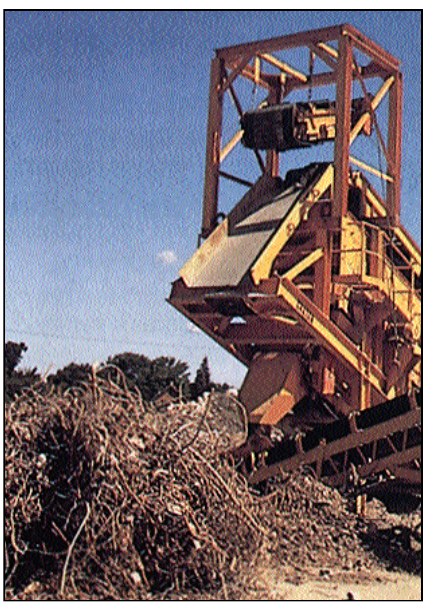

Figure 2. Final removal of steel (typically dowels and tie bars) takes place at the recycling plant during crushing. An electromagnet catches steel moving along a conveyor belt between primary and secondary crushers. In the foreground is a pile of steel removed during crushing operations.

Aggregate Characteristics

Most of the same tests performed on virgin aggregate are necessary for recycled PCC pavement aggregate. Extensive research on recycled material helped set test limits and target value ranges for recycled aggregate. Many of these tests have shown recycled aggregate to be of better quality than most virgin material. Here are some basic characteristics of recycled coarse aggregates:

Gradations—Recycled aggregates can be specified to the same gradation ranges as virgin materials.

Specific gravity—The specific gravity of recycled coarse aggregate will be lower than that of virgin aggregate. Typical values are 2.2 to 2.5.

Absorption—Recycled aggregate water absorption is much higher because of old cement mortar attached to the particles.

Abrasion loss—Typical recycled aggregate values range from 20% to 45%, which is less than the upper limit of 50%.

Sulfate soundness—It is not necessary to run the sulfate soundness test on recycled aggregate. Typical values are 3 or less, which is far below the maximum loss allowable by ASTM.

Residual chlorides—Residual chloride from road salt applications usually varies from 0.07% to 0.09%, which is below the critical threshold values.

Contaminants—Contamination limits for recycled aggregate used in concrete mixes should be the same as virgin coarse aggregate. Contamination usually is not a problem in rural highway or airport pavement recycling if the pavement is prepared and removed carefully. No problems will result from some contamination in a base course aggregate.

The type of crushing equipment used influences fine aggregate gradation. Usually the fine material will be very angular, with an extremely high absorption rate and a low specific gravity, because the majority of the fine material is mortar from the old concrete. in recycled fine aggregate the chloride content is about 0.03%o.

lifts, separates, and piles the broken concrete. A front-end loader places the material into trucks for transport. This permits pavement removal without any steel cutting at the roadway.

Final removal of steel from concrete fragments takes place during the crushing operations at the recycling plant. An electromagnet placed between primary and secondary crushers catches steel moving along a conveyor belt (Figure 2). The salvaged steel becomes the property of the contractor, who can sell the material as scrap metal.

Crushing. The same basic equipment that processes virgin aggregates crushes, sizes, and stockpiles recycled PCC pavement. Most recycling plants have a primary and a secondary crusher. The primary crusher normally reduces the material down to about a 3- to 4-inch size.

A vibrating screen separates fines (less than ⅜ inch) which are stockpiled. Material larger than ⅜ inch is fed to a secondary crusher, which breaks it into the maximum desired coarse aggregate size. Crushing fragments with embedded steel requires lowering the belt below the primary crusher, which provides room for long pieces of steel to fall without jamming and ripping the belt.

The basic types of crushing machines are cone and jaw compression crushers and vertical and horizontal impact crushers. The difference between them is how they pulverize the concrete. Newer pavement crushers can process broken concrete at rates of 200 to 500 tons per hour.

Yield. Recycling concrete pavement yields 45% to 80% usable coarse aggregate. Yield will vary based on pavement type and crushing plant design. Average yield is about 65%. The contractor should adjust the crushing operation to maximize the yield of coarse aggregate while maintaining a typical coarse aggregate gradation. Crushing for large top-size aggregate produces greater total yield than smaller topsize since less crushing is necessary. Proper screen selection enables a crushing plant to meet American Association of State Highway and Transportation Offficials (AASHTO) gradations 57 and 67. A plant can meet any desired gradation with appropriate adjustments.

Using recycled aggregate

Recycled aggregate meeting the requirements for virgin aggregate can be included in the concrete mix or used in base courses. Typically, the contractor decides how to best use the material. The most common application is for base course. The cost of using recycled aggregates for base material includes only the cost of crushing operations. Breaking, removal, steel separation, and transportation costs are incidental.

When using recycled aggregate in concrete, no special handling, batching, or mixing procedures are necessary. However, the high absorption of recycled aggregate may make it necessary to add more water and start with a higher slump. Dry recycled aggregate continues to absorb mix water after mixing in the batch plant. This results in less workability and a lower slump at the paving site. Some contractors use sprinklers to keep recycled aggregate stockpiles moist.

In most cases, recycling provides more than enough coarse aggregate if material to replace an existing pavement, and no new virgin coarse aggregate is required. When using recycled aggregate, normal mix design methods are followed. Trial batches help verify that a mix will meet specifications. The table shows concrete mix designs for three highway recycling projects.

Special care is necessary when using recycled fine aggregate in a new concrete mix. Too many recycled fines can produce a harsh, unworkable mix. Typically, only about 10% to 20% recycled fines are used; the rest is virgin sand. Testing recycled fines at several substitution rates will determine the optimal mix.

New pavement Construction

No special techniques are necessary for constructing a new concrete pavement made with recycled aggregate. These projects can meet the same quality standards as those using virgin materials.

The workability of a concrete mix depends on the amount and characteristics of the recycled fines. Mixes with a large quantity of recycled fines can be harsh and difficult to finish due to their angularity and high absorption rate. Using natural sand in the concrete mix will minimize these problems. Recycled coarse aggregate produces little variation in concrete workability. In some cases, pavements are built in two courses. The slab design has a bottom layer of concrete using recycled aggregates and an upper slab portion using high-quality virgin material. The design requires an upper layer thickness of about 1½ inch. A modified slipform paver or spreader places the lower layer of recycled-aggregate concrete, then a slipform paver places the high-quality concrete upper layer. The base course is still wet during placement of the top course. After consolidation and curing, the two courses become a monolithic slab.

Finished Concrete properties

Compressive strengths of recycled-aggregate concrete are similar to those for virgin-aggregate concrete. For mixes containing recycled fines, expect some minor strength reductions. This is because natural sand particles are stronger than recycled fine aggregates. The majority of the strength loss is from material smaller than 0.08 inch.

Flexural strength of concrete with recycled coarse aggregate might be slightly lower than a similar mix with virgin aggregate usually no more than 10% when natural sand is used. Using recycled fine aggregate in the mix might reduce flexural strength 10% to 20%.

Many recycled aggregates produce concrete with better freeze-thaw durability than concrete made with all virgin materials. When recycling D-cracked concrete, improved freeze-thaw durability is possible by reducing aggregate size to a maximum of ¾ inch. It is important to perform freeze-thaw durability tests on specimens containing aggregates from an old D-cracked PCC pavement. The addition of about 20% fly ash also can enhance durability.

Other Considerations

The top size of coarse aggregate is especially important when using recycled aggregate in jointed reinforced concrete pavements. Because reinforced panel lengths are much longer than panels without reinforcement, joints and cracks undergo much wider movement than joints in plain pavements. A completely open midpanel crack may lose aggregate interlock, especially if the coarse aggregates are small (less than 1 inch). Shear and bending stresses on mesh reinforcement are high without the additional load transfer that aggregate interlock provides. This results in steel ruptures and cracking.

Drainage systems may need alteration when using recycled concrete for an unstabilized drainable base. Crushing operations may produce dust and fine material that can cling to the larger coarse aggregate particles. In an unstabilized permeable base, draining water may wash the dust off the larger aggregates, which can clog pipes and filter fabric. If a Portland cement-stabilized permeable base is used, this will not happen and adjustments to drain system design are unnecessary.

If a pavement exhibits alkali-silica reactivity, evaluate and test a mix before deciding to recycle the pavement. Avoid including recycled alkali-silica material as an aggregate if virgin material is readily available. In aggregate-scarce locations, it may be important to investigate using the material. A new mix using recycled alkali-silica material should contain a low alkali Type II cement and a low water-cement ratio to reduce further reactivity. Adding a Type F fly ash meeting ASTM C 618 also can reduce the potential for further reactivity.

Reference

Recycling Concrete Pavement, Publication No. TB-014P, American Concrete Pavement Association (ACPA), Skokie, IL, 1993.

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