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The Influence of the Addition of Recycled Asphalt Shingles on the Compressive Strength of Concrete

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An Honors Thesis submitted in partial fulfillment of the requirements for Honors in the Department of Civil Engineering and Construction.

By
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ABSTRACT

The purpose of this study is to explore the effect of recycled asphalt shingles (RAS) as an additive on the compressive strength of concrete. This was accomplished by designing a concrete mix and creating 4” by 8” cylindrical test specimens containing 0, 5, 10, and 15 percent RAS by weight. The compressive strength was measured through axial loading until failure utilizing a compression testing apparatus. With these results, a relationship between the content of RAS and compressive strength was able to be developed, giving insight as to how RAS could be used in concrete mixes in the future. This study will help further sustainability knowledge in the field of construction and could lead to the creation of a sustainable technique for recycling an otherwise wasted construction material.

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Introduction

With our population continuing to grow exponentially, the production and disposal of waste is proving to be a difficult challenge. This is especially true for the construction industry. New roads, bridges, and housing are always in demand, and the production of these structures is very environmentally taxing. In most cases, the materials from these structures are wasted at the end of their lifetime. In fact, 600 million tons of construction and demolition debris were generated in the United States in 2018, which is more than twice the amount of municipal solid waste generated [1]. It is paramount that the construction industry considers the life cycle of industrial materials and works to repurpose the waste created.

Luckily, research is moving in this direction. Many projects have considered adding recycled aggregate or electronic waste into the concrete mix. In a 2009 study, Valeria Corinaldesi found through her testing that concrete made with 100% recycled aggregate had a compressive strength class value of 25 MPa. This is impressive considering that the control concrete made with all virgin aggregate had a compressive strength class value of 30 MPa [2]. These results prove the promising future of recycled aggregate. Another common topic of sustainable construction research is the use of recycled asphalt shingles (RAS) in the production of asphalt. Most state departments of transportation, including Georgia's, already allow up to 5% by weight of RAS in asphalt mixes [3]. These states recognize the economic savings potential of this recycling, as replacing high-cost mixture components such as virgin binder and virgin aggregate allows contractors to be more competitive in the market [4]. It is suspected that as research continues on mix design and long-term durability, the use of this material will continue to grow nationally. While these topics are being explored individually, there has been minimal research on the strength impact of adding RAS to a traditional structural concrete mixture. Ideally, a relationship could be developed to determine the viability of this technique as a way of further repurposing RAS material.

This study intends to find that relationship by assessing the compressive strength of concrete samples with varying amounts of RAS added. This will contribute to the understanding of how this material might be utilized for construction purposes and what the exact role of this amended concrete could be.

Methodology

For the tests themselves, a standard concrete mix design was created with a target strength of 3,500 psi. This is representative of typical concrete that is used for construction, as it falls within the range of average strength. To test the behavior of the concrete under the influence of RAS, this standard mix was used along with an addition of 0, 5, 10, and 15 percent by weight of RAS to create four different testing groups. Mixes were completed on a standard concrete mixer, shown in Figure 1.

The shingles were processed before mixing using shears and a ruler. Each shingle was cut into pieces with a maximum size of one square inch to ensure that the RAS was able to be mixed with the concrete and create the proper share within the testing molds. This process was intended to be inexpensive and effective, as a process too involved would discourage the recycling of this material in the industry.

The different mixes were then used to fill standard 4 by 8-inch test cylinders, which are traditionally used for compression testing. Each testing group consisted of nine total cylinders, to ensure reliable data is gathered in the testing phase. All cylinders were made and tested following American Society of Testing and Materials (ASTM) standard C192 [5]. This standard specifies specific instructions for pouring and tampering the concrete in the molds, procedures to strike off and cap the molds, and a strict curing process to ensure the proper strength profile development. Samples were cured in a shared water bath in the lab, shown in Figure 2.

Figure 1. Concrete Mixer

Figure 2. Water Bath

Compressive strength testing occurred after three, eight, and 27 days of the curing process, where three cylinders were tested in each instance. Testing involved applying compressive axial load to the cylinders until failure occurred, in accordance with ASTM standard C39 [5]. This was done with a standard concrete compression testing machine, shown in Figure 3. The compressive strength of the specimen was then calculated by dividing the maximum load reached during the test by the cross-sectional area of the cylinder.

Figure 3. Concrete Compression Test Machine

Procedure

Firstly, the materials were massed and portioned as called for by the mix design. If the mix required RAS, this was also set aside. Next, all of the coarse aggregate and about half of the mixing water were added to the mixture, and allowed to rotate for a few full rotations. Then, the mixer was stopped, and the rest of the materials were added, along with the rest of the water. The mixer was run for three minutes, followed by a three-minute rest, and run again for a final two minutes. Then, the mixer was tilted while running to allow the mixture to flow out into a wheelbarrow.

Next, within five minutes of the concrete mixture being removed from the mixer, the slump test was conducted. First, the mold and cone were dampened, and then they were set up on a flat surface. The mold was then filled with the mixture in three layers, with 25 strokes from the tamping rod in between each layer. The rod was then used to stroke off the top of the cone. The cone was lifted off the plate, with careful attention paid to lifting it completely vertically. The mold was then placed upside down adjacent to the sample, and the vertical distance between the top of the mold and the displaced top of the original sample was measured. This measurement was recorded, and if considered satisfactory, the mixture was used for cylinder testing.

Next, a scoop or shovel was used to place concrete in the 4’ by 8’ cylindrical test molds. Remixing of the concrete was allowed in the wheelbarrow, if necessary, around this time. When filling the molds, three even layers of concrete were added, and each layer was tamped 25 times using a ⅝ inch tamping rod. Each cylinder was finished by striking the top off and capping it with a plastic cap. Nine total cylinders were prepared with each percentage mix. Once the samples were prepared and capped, they were allowed to cure at room temperature for 24 hours.

After the initial curing period, the cylinders were removed from the mold with a concrete cylinder stripping tool and a hammer. These samples were moved into the water bath to cure submerged for their designated amount of time. Three of the nine total samples were allowed to cure for each testing period - those being 3, 7, and 28 days.

After curing was complete for each section, the cylinders were to be tested on the compression testing machine. The three samples were removed from the water bath. It is important to maintain the moist condition of the samples for testing, so this test should be completed as soon as practicable after removal from the moisture cure. Cylinders were capped with capping rings and pads and placed inside the tester. The sample was carefully aligned to the center of the upper and lower blocks on the tester. The tester was turned on, and the motor was engaged at a moderate pace to apply load to the sample. The load was continually applied until the sample failed, and a reading of its total compressive strength was taken. This step was repeated for the three samples in each curing period, a total of nine times at each curing interval for the individual mixes.

The entire process was repeated for each mix design, until all required data was collected.

Results

With the data collected through the experimental trails, a relationship between RAS addition and compressive strength could be identified. The numerical results are provided in Tables 1 through 3 and depicted in Figures 4 through 6. When comparing the strength values of each group to the control, it is obvious that the addition of RAS has a negative effect on the strength capacity of concrete.

This can be observed across all the tables and is easier seen in the graphic figures. In Figure 4, we see an expected increase in compressive strength with additional curing time across all groups. What is notable about this study is the decrease in this strength within each RAS group. One can see that there is a consistent decrease in the strength capacity while the percentage of RAS increases by group. This can also be observed in Figure 5, with the results separated into individual groups. The standard deviation of the test results is denoted by the error bars on each point. While the deviation is much higher for the 5% group than any of the others, it is still within an acceptable amount for the data set. The most significant data from the experimental findings is shown in Figure 6, which is the strength reduction factor of each group as compared to the control. As stated before, this graph shows an obvious inverse relationship between RAS addition and the strength of concrete. It appears that the reduction, relative to the amount of RAS, stays generally consistent regardless of the curing time. This reduction factor data stands as the main basis of comparison for this study, and illustrates that concrete is still usable in structural applications with the addition of RAS.

Table 1. Strength Results for 3 Curing Days

Results After 3 Curing Days				
RAS Addition by weight (%)	Compressive Strength (psi)			
	Trial 1	Trial 2	Trial 3	Average
0	1975	1981	1978	1978
5	1625	1345	1688	1553
10	874	990	1019	961
15	579	587	-	583

Table 2. Strength Results for 7 Curing Days

Results After 7 Curing Days				
RAS Addition by weight (%)	Compressive Strength (psi)			
	Trial 1	Trial 2	Trial 3	Average
0	2329	2331	2472	2377
5	2265	1895	1747	1969
10	1043	1119	1072	1078
15	581	688	-	635

Table 3. Strength Results for 28 Curing Days

Results After 28 Curing Days				
Asphalt Addition by weight (%)	Compressive Strength (psi)			
	Trial 1	Trial 2	Trial 3	Average
0	3001	3042	3284	3109
5	2068	2320	2183	2190
10	1438	1386	1193	1339
15	1108	1038	1051	1066

Figure 4. Compressive Strength vs Curing Duration

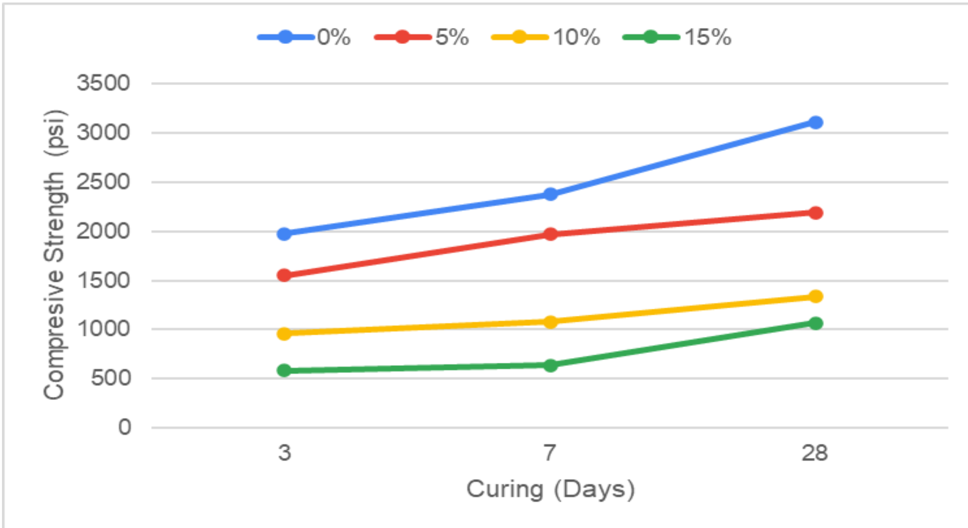


Figure 5. Strength Increase by Group

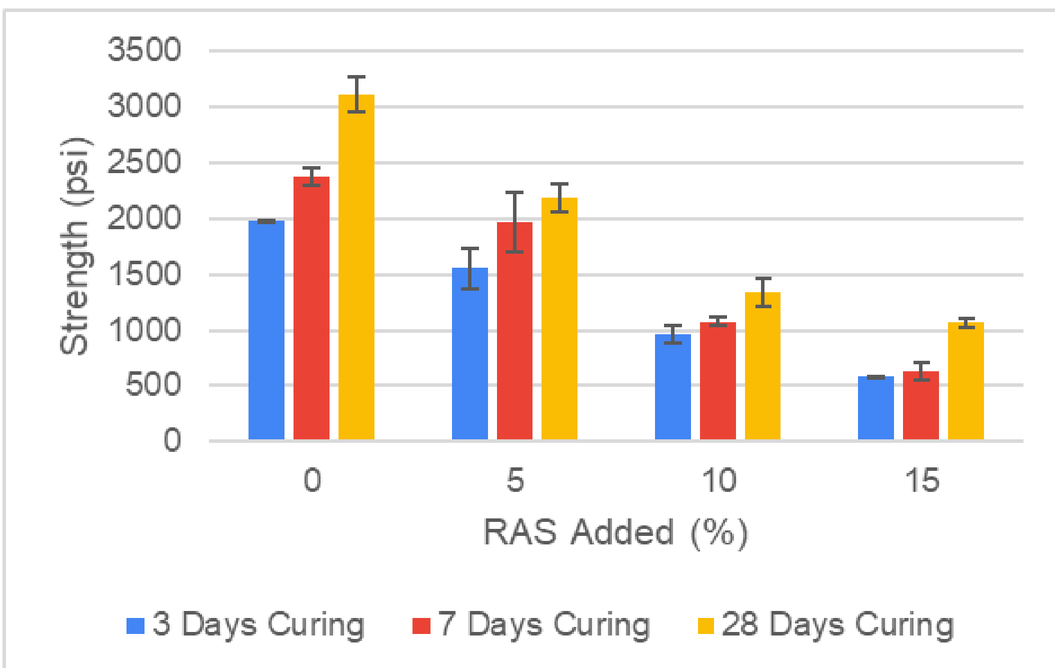
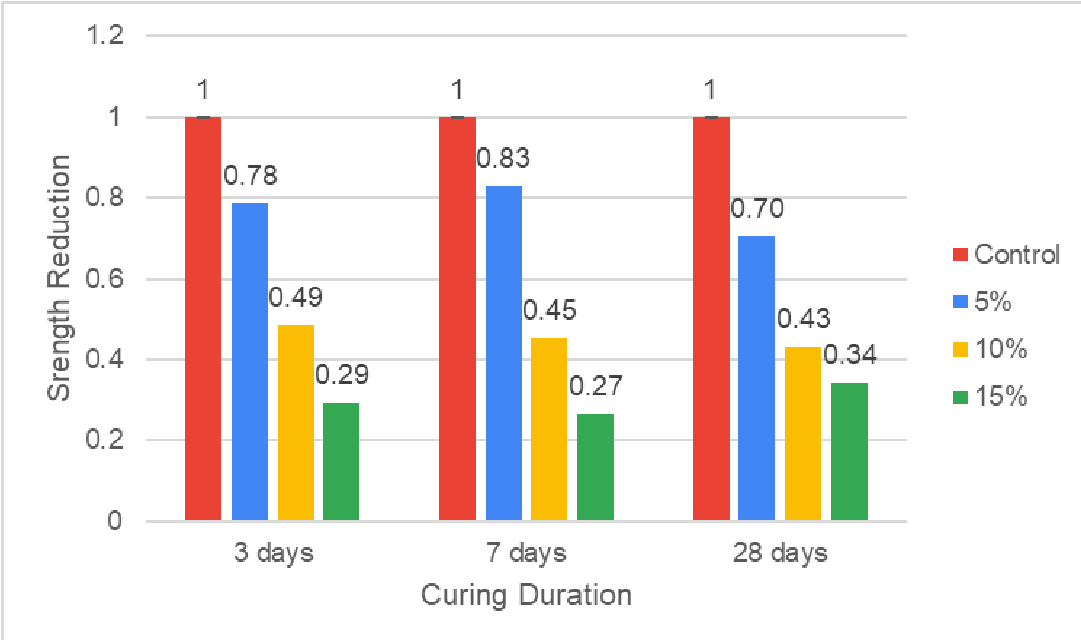


Figure 6. Reduction in Compressive Strength



Discussion

This data is significant and shows the promise of this technique for recycling asphalt shingles. Considering that 5% RAS by weight can be added to a concrete mix with around a 23% reduction in strength, this is certainly a viable solution. However, I do think most individuals would shy away from any contributions to major structural concrete that decreased overall strength. That is why I feel these results point to a less structural oriented focus for the RAS amended concrete, and a possible future for its use as low strength concrete. Low strength concrete, typically defined as concrete with a compressive strength below 20 megapascals (or around 2,900 psi), can be utilized in various construction applications where high strength is not required. Backfill material is a very common use of this concrete, often used as material for trenches and underground structures, such as pipes and cables. RAS amended concrete would certainly be a viable option for this application. There are previous studies supporting the use of waste material in backfill, noting that use of high-volume by-products or/and waste materials is an effective way to control the low strength requirement of controlled low strength material and minimize the environmental concerns related to the disposal of waste materials [6]. I believe that RAS amended concrete could also be successfully used in other applications, such as non-structural walls or precast concrete products. Low strength concrete is often used to build non-structural walls, such as partitions and infill walls, which do not carry significant loads. It can be used to make precast concrete products, such as pavers, blocks, and curbs. These products are typically used for landscaping, pedestrian walkways, and low-traffic areas. RAS amended concrete could fulfill these roles, seeing as the concrete created for this study satisfies the strength requirements for these low strength concrete uses. This would be an effective way to recycle this material, putting it to effective use and reducing landfill bound waste.

While the data gathered allowed for a reasonable conclusion to be drawn, there are some issues and limitations with this study. For one, not all the samples in the 15% RAS group were capable of being assets for their compressive integrity. As an effect of the remarkably high content of shingles, some of the samples had issues forming properly within the molds. It should be noted that in Tables 1 and 2, there are missing data values for the 15% RAS group. Two of the samples had to be discarded, as they could not be safely tested. It was also observed that most of the samples failed at a corner on a piece of RAS. If the RAS samples were processed or laid out differently, there is a chance that the cylinders could have resisted more compression. If this type of recycling were to be widely implemented, a processing machine could be designed to streamline shingle use. The shape of the shingles could also be assessed, as this too could change how force is distributed within the concrete. Future research could consider these different techniques for processing singles, and how that might affect the strength envelope. Also, within the bounds of this project, it was only possible to consider one type of testing for the concrete. It could be useful to see how similar mixes fared in a flexural strength test.

Conclusion

This research aimed to identify a relationship between the addition of recycled asphalt shingles by weight and the compressive strength of concrete. Based on a quantitative analysis of strength trials for groups consisting of 0, 5, 10, and 15 percent by weight addition of RAS, it can be concluded that compressive strength and addition of RAS have an inverse relationship. However, with the strength reduction factors found in the study, it is entirely viable to use this RAS amended concrete for low strength concrete applications. This conclusion could lead to future research into the exact applications in which this concrete could be practical, or a further investigation of how this process could be economically implemented on a larger scale. Overall, this study has proven that there could be a future for RAS amended concrete as an effective way to recycle an otherwise wasted material and help to curb the problem of excessive waste within the construction industry.

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