EVALUATION OF CARBON CONDITIONING ON MIXED RECYCLED AGGREGATE AND RECYCLED CONCRETE AGGREGATE

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The process of carbon-conditioning on both mixed recycled aggregate and recycled concrete aggregate is known to strengthen mechanical properties of recycled aggregate concrete. The accelerated injection of carbon dioxide (CO_2) is able to provide a chemical reaction in which calcium hydroxide is converted into calcium carbonate. Consequently, the smaller calcium carbonate crystal densifies both recycled concrete aggregate as well as mixed recycled aggregate. This paper reveals the lasting effects of carbon-conditioning on mixed recycled aggregate and recycled concrete aggregate exposed to CO_2 for durations of 30, 60 and 120 minutes in addition to CO_2 pressures of 25, 75 and 200 kPa. Mixed recycled aggregate gains density from a range of 0.81% to 2%. Unfortunately, as mixed recycled aggregate contains construction and demolition waste outside crushed concrete, it loses half of the weight gained within hours of carbon conditioning. Whilst it takes 266 hours for recycled concrete aggregate to become a stable weight, half of the CO_2 gas escapes quickly. Subsequently, mixed recycled aggregates should be mixed within concrete shortly after carbon conditioning. Recycled concrete aggregate contrasts the weight loss of mixed recycled aggregate as it is not subject to a weight loss after carbon conditioning. Recycled concrete aggregate is characterised by pure crushed concrete and therefore experiences a permanent densification as a consequence of the presence of calcium carbonate in all aggregates. Recycled concrete aggregates experience a weight gain of 0.84% to 1.41%.

INTRODUCTION

The objective of carbon-conditioning is to form calcium carbonate crystals. The application of pressurised CO_2 accelerates the natural reaction of the gas, creating calcium carbonates at the expense of calcium hydroxide [1]. Calcium carbonate crystals are smaller than that of calcium hydroxide, consequently, generating denser cement. A great amount of calcium carbonates are formed during the carbon conditioning process, assisting in the strengthening of both recycled aggregate and recycled aggregate concrete [1].

Strength increases formed from supplementary calcium carbonates can permit recycled aggregate and recycled concrete to rival virgin aggregate concrete in terms of physical and mechanical properties [2]. There are procedures in which calcium carbonates can be produced. Ultimately the procedure in which calcium carbonates are created should be practical, finically viable and environmentally friendly.

The surface treatment of recycled aggregate through microbial carbonate precipitation is another method for producing calcium carbonates in cement [3]. A bacterium was added to the recycled aggregate in order to introduce calcium carbonate. The microbial treatment generated a denser aggregate with a reduced water absorption [3]. However, this method does not allow for the sequestration of CO_2 and therefore does not eliminate additional greenhouse gases.

Gabriec et al. [4] implemented a similar investigation, through the utilisation of calcium carbonate bio deposition. Similarly to the previous study, bacteria were used in a different methodology, allowing calcium carbonate to occupy recycled concrete aggregate. The supplementary calcium carbonate also fashioned aggregate with a decreased water absorption [4].

Carbon conditioning has been explored in recent years and offers great potential to recycled concrete products [1, 5]. Zhan et al. [6] found that recycled aggregate benefited from carbon-conditioning in multiple avenues, including densifies adhered mortar, a densified recycled aggregate and a reduced water absorbency. Carbon-conditioning is a very practical method of inducing the conversion of calcium hydroxide to calcium carbonate [6]. Carbon conditioning allows for sequestration of CO_2 and is an easy method to implement.

However, there are many characteristics of recycled aggregate that warrant investigation in order to attain a comprehensive understanding of the carbon conditioning method. An important factor in the practical utilisation of recycled aggregate is the duration of the effectiveness of carbon-conditioning of recycled aggregate.

AIM

This paper investigates the time length effectiveness of carbon-conditioning on mixed recycled aggregates and recycled concrete aggregate. It is recognized from previous literature that carbon conditioning assists in the mechanical strengthening of both recycled aggregates and recycled concrete [1, 5]. However, it must be recognized if there is an amount of time in which aggregate must be mixed into concrete before potentially losing the effects of carbon conditioning. Mixed recycled aggregate contains a mixture of construction and demolition waste such as brick, tile and concrete. Particular materials within mixed recycled aggregate, for instance brick, do not directly contain calcium carbonate. As a result, these materials may have the potential to lose pressurised CO_2 gases. The phenomenon must be considered.

MATERIALS

MIXED RECYCLED AGGREGATE

The mixed recycled aggregates utilised in experimentation comprised of a mixture of construction and demolition waste. These aggregates were procured from a south-eastern Australia centralised recycling plant.

The 10mm recycled aggregate contains a greater amount of cement, a crucial category of aggregate which has the permanent reaction of converting calcium hydroxide to the smaller calcium carbonate.

The size distribution of the aggregate is important to carbon-conditioning as a greater amount of surface area allows for a greater amount of CO_2 to enter the aggregate. Consequently, 10mm mixed recycled aggregate has a superior likelihood for increased densification. The material size distribution was completed in reference to the Australian standards [7]. Figure 1 illustrates the particle size distribution of mixed recycled aggregates.

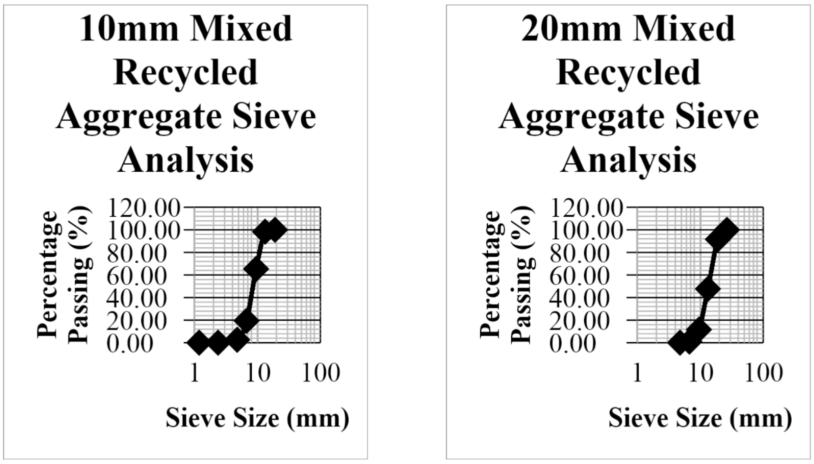

FIG 1. Particle size distribution of mixed recycled aggregate: 10mm and 20mm.

The immediate properties of the mixed recycled aggregate were taken to ensure the material was enhanced in a similar fashion to past researchers [1, 6]. The aggregate properties tests parallel the properties of virgin aggregate against recycled aggregate as well as carbon-conditioned recycled aggregate. The aggregate properties include water absorption [8], particle density [8], flakiness index [9], misshapen particle [10], weak particle [11], aggregate crushing value [12] and wet/dry strength [13] all conforming to the appropriate Australian standards (Table 1).

Australian Standard	Experiment Description	Reference
AS 1141.11	Particle size distribution	[7]
AS 1141.6.1	Water absorption	[8]
AS 1141.6.1	Particle density	[8]
AS 1141.15	Flakiness index	[9]
AS 1141.14	Misshapen particle	[10]
AS 1141.32	Weak particle	[11]
AS 1141.21	Crushing value	[12]
AS 1141.22	Wet/dry strength	[13]

TABLE 1. Australian Standard Experiments

The mixed recycled aggregate experiences an improvement in density, water absorption as well as crushing value. Unfortunately, the improvements created do not bridge the gap between virgin aggregate and recycled aggregate. These similar discoveries are backed by previous research [1, 6]. Table 2 indicates the improvement of mixed recycled aggregate after carbon-conditioning.

RECYCLED CONCRETE AGGREGATE

The recycled concrete aggregate required for investigation was characterised by 99% pure old crushed concrete materials. Crushed concrete materials encompasses both hydrated, adhered cement in addition to virgin aggregate. The recycled concrete aggregate was obtained from a southern Australian centralised recycling plant. The size distribution [7] of the recycled concrete aggregate can be observed in Figure 2.

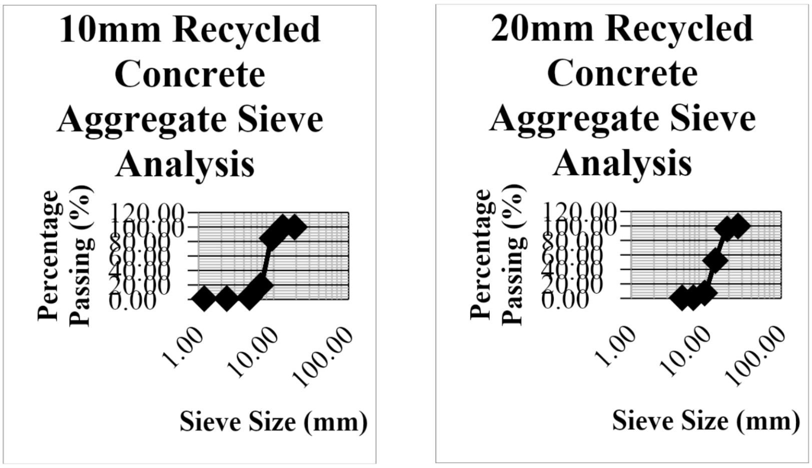

FIG 2. Particle size distribution of recycled concrete aggregate: 10mm and 20mm.

The recycled aggregate concrete, alike mixed recycled aggregate, experienced an enhancement in density, water absorption as well as crushing value. The recycled concrete aggregate did not contain any weak particles as the process of securing purer aggregate is subject to scrutinizing controls.

Properties	Virgin aggregate		Recycled aggregate		Carbon-conditioned recycled aggregate	
	10mm	20mm	10mm	20mm	10mm	20mm
Water absorption	1.41	1.41	8.50	7.04	3.02	4.20
Particle density on oven-dried basis	2.63	2.78	2.07	2.12	2.33	2.23
Particle density on saturated and surface-dried basis	2.70	2.84	2.27	2.30	2.44	2.38
Apparent particle density	2.81	2.98	2.59	2.59	2.62	2.61
Aggregate crushing value	16.65		23.15		22.75	
Flakiness index	11.78	12.88	5.61	7.87	5.61	7.87
Misshapen particle	-	11.09	24.65	13.41	24.65	13.41
Wet/dry strength variation 13.2-9.5	85		40		40	
Weak particle	-	-	0.004455	0.002069	0.004455	0.002069

TABLE 2. Mixed recycled aggregate properties against virgin aggregate

METHODOLOGIES

CARBON-CONDITIONING CHAMBER

A carbon-conditioning chamber was designed and fabricated for producing carbon-conditioning recycled. The chamber is made from heavy steel, welded in a rectangular formation. The top of the chamber comprised of a substantial lid, placed upon a seal and fastened down with several bolts. The chamber is coupled with a CO_2 tank via a pressure regulator used for maintaining specific pressures. CO_2 is than introduced to the aggregate for the purposes of experimentation. The aggregate placed in the chamber is of natural moisture content. Silica gel is also placed in the chamber so that any water produced in the reaction is absorbed by the gel.

EXPERIMENTAL PROCEDURE

In order to ascertain a density increase within aggregate a scale with a tolerance of 0.00g was required. An amount of aggregate was weighted at natural weigh then place in the carbonation chamber, exposed to CO_2. These samples where then weighed a second time after carbon-conditioning to observe a weight gain and then weighted every ten minutes until weight stabilisation. The experimental procedure permits the observation of weight gain as well weight loss. It must be emphasised that excess water produced via this chemical reaction is absorbed via the addition of silica gel within the carbonation chamber and not taken into account when weighing.

RESULTS AND DISCUSSION

MIXED RECYCLED AGGREGATE

Mixed recycled aggregates experience a weight gain followed by a weight loss back to a constant weight. Construction and demolition materials such as brick do not contain calcium hydroxide for CO_2 to convert to calcium carbonate. This results in a gas weight gain followed by a descent. However, overall, the aggregate densifies as 68% (10mm) and 53% (20mm) of the mixed recycled aggregate is made from old cement or concrete which does have calcium hydroxide which is permanently converted to calcium carbonate. Table 3 indicates this trend.

The results show a quick amount of weight loss over the first couple of hours. It does also indicate that not all gas weight is loss until roughly 16,000 minutes or 266 hours depending on carbonation variations. However, as a result of substantial gas loss over a quick period of time it would be advantageous to mix the mixed recycled aggregate into concrete closely after carbon conditioning to ensure the imprisonment of the CO_2 gas within fresh concrete.

Specimen Code	Original Weight (g)	Weight after Conditioning (g)	Weight gain after Conditioning (g)	Final Resting Weight Gain (g)	Weight Lost after Conditioning (g)	Final Resting Weight Gain (g)	Percentage gain after Conditioning (%)	Percentage Loss after Conditioning (%)	Percentage Remaining after Loss (%)
10-30-25	517.36	521.61	4.25	519.68	1.93	2.31	0.81	-0.37	0.45
10-60-25	548.88	555.74	6.86	553.10	2.64	4.23	1.23	-0.48	0.76
10-120-25	502.08	512.56	10.47	508.99	3.57	6.90	2.04	-0.70	1.36
10-30-75	514.46	519.75	5.29	517.19	2.55	2.73	1.02	-0.49	0.53
10-60-75	507.12	512.65	5.53	510.84	1.81	3.72	1.08	-0.35	0.73
10-120-75	503.49	513.51	10.02	511.45	2.06	7.96	1.95	-0.40	1.56
10-30-200	506.77	511.95	5.19	509.41	2.54	2.65	1.01	-0.50	0.52
10-60-200	508.74	515.82	7.08	512.06	3.76	3.31	1.37	-0.73	0.65
10-120-200	505.23	513.06	7.84	508.84	4.22	3.61	1.53	-0.83	0.71
Specimen Code	Original Weight (g)	Weight after Conditioning (g)	Weight gain after Conditioning (g)	Final Resting Weight Gain (g)	Weight Lost after Conditioning (g)	Final Resting Weight Gain (g)	Percentage gain after Conditioning (%)	Percentage Loss after Conditioning (%)	Percentage Remaining after Loss (%)
20-30-25	547.24	552.87	5.63	548.98	3.89	1.74	1.02	-0.71	0.32
20-60-25	490.06	499.23	9.17	490.55	8.68	0.50	1.84	-1.77	0.10
20-120-25	546.87	557.06	10.19	552.57	4.49	5.70	1.83	-0.81	1.03
20-30-75	548.69	554.09	5.40	550.65	3.44	1.96	0.97	-0.62	0.36
20-60-75	538.87	544.93	6.06	541.30	3.63	2.43	1.11	-0.67	0.45
20-120-75	546.05	555.29	9.24	550.96	4.33	4.91	1.67	-0.79	0.89
20-30-200	548.37	554.87	6.50	549.90	4.97	1.52	1.17	-0.90	0.28
20-60-200	544.43	554.96	10.54	547.87	7.09	3.45	1.90	-1.29	0.63
20-120-200	545.41	558.11	12.69	548.30	9.80	2.89	2.27	-1.79	0.53

***TABLE 3.** Mixed recycled aggregate weight trends (each result is an average of two results)*

The result shows that while the mixed recycled aggregate can gain a weight from 0.81% to 2% it will also drop to a range of 0.4% to 0.7% (depending on carbonation variables). Consequently, if mixed recycled aggregates are not mixed into concrete promptly a smaller amount of CO_2 is trapped. The 10mm sized aggregate consistently exemplified a larger permanent or resting gain. The class distribution of the mixed recycled aggregate is the reason behind the 10mm aggregates superior performance. The 10mm mixed recycled aggregate contained a larger amount of cement meaning the CO_2 was permanently converted into calcium carbonates and could no longer escape. Overall, the mixed recycled aggregates can typically loss half the weight gained by carbon-conditioning if not mixed into concrete promptly.

Theoretically, the escaping CO_2 can have a beneficial effect on the ITZ or the bond between aggregate and new cement if mixed within concrete punctually. The escaping CO2 if mixed into concrete can react with the new cement paste densifying the ITZ in the same way recycled concrete aggregate is densified.

RECYCLED CONCRETE AGGREGATE

Recycled concrete aggregate does not face the same problems of poor classification like mixed recycled aggregate. Recycled concrete aggregate is not subject to weight loss. Weight gained via carbon conditioning is kept as a consequence of the aggregates ability to sacrifice calcium hydroxide to become calcium carbonate. Table 4 displays the everlasting carbonation characteristic of recycled concrete aggregate.

Specimen Code	Original Weight (g)	Carbon-Conditioned Weight (g)	Weight Change (g)	Percentage Change (%)
10-30-25	1441.63	1453.68	12.05	0.84
10-60-25	1433.50	1451.12	17.62	1.23
10-120-25	1415.54	1435.29	19.75	1.40
10-30-75	1464.40	1476.14	11.74	0.80
10-60-75	1427.41	1443.08	15.67	1.10
10-120-75	1448.20	1464.51	16.31	1.13
10-30-200	1415.40	1429.79	14.38	1.02
10-60-200	1430.84	1446.19	15.35	1.07
10-120-200	1428.40	1446.56	18.16	1.27
Specimen Code	Original Weight (g)	Carbon-Conditioned Weight (g)	Weight Change (g)	Percentage Change (%)
20-30-25	1418.36	1430.88	12.53	0.88
20-60-25	1415.41	1429.93	14.52	1.03
20-120-25	1401.39	1422.78	21.39	1.53
20-30-75	1457.83	1472.14	14.31	0.98
20-60-75	1426.03	1440.71	14.68	1.03
20-120-75	1400.84	1418.27	17.43	1.24
20-30-200	1428.52	1442.38	13.87	0.97
20-60-200	1459.60	1475.05	15.46	1.06
20-120-200	1421.48	1441.56	20.08	1.41

***TABLE 4.** Recycled concrete aggregate weight gain*

The longer 120-minute duration combined with the 200 kPa pressure produced the greatest weight change or densification. 10mm recycled concrete aggregate also seemed to gain slightly more weigh based upon the greater amount of surface area present as an outcome of smaller practicals.

The permanent effect of carbon conditioning permits practical utilisation of carbonated recycled concrete aggregate. Aggregate can be carbonated well in advanced of mixing into concrete with the full effect of the supplementary strengthening process. Consequently, recycled concrete aggregate can be considered a more practical aggregate for the carbon conditioning process. Conversely, although mixed recycled aggregates should be mixed into concrete punctually, the aggregate type recycles a greater amount of material that requires less initial processing.

CONCLUSION

Carbon conditioning is an effective process for improving the mechanical quality of both mixed and recycled concrete aggregate. The carbon conditioning of aggregate greatly contributes to the enhancement of water absorption, density and crushing value. However, mixed recycled aggregate and recycled aggregate concrete react differently to carbon conditioning. The findings of this paper uncover that carbon conditioning can enhance mixed recycled aggregates and recycled aggregate concrete. Mixed recycled aggregate should be mixed into concrete as soon as possible after conditioning as CO_2 weight is lost quickly. Whilst this can be difficult in large scales it demonstrates the mixed recycled aggregate can be used effectively in conjunction with carbon conditioning. Recycled concrete aggregate is more practical as the carbon conditioning effect is permanent and can be mixed into concrete without speed or punctuality. Mixed recycled aggregate as well as recycled concrete aggregate have a large potential for improvement when utilised in combination with the carbon conditioning process.

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