The Use of Recycled Building Materials as Aggregate in Concrete

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ABSTRACT: In South Africa high quality natural aggregates have always been available at a very low cost in most parts of the country. This has resulted in limited use of recycled aggregates. With the refurbishment of inner cities and the increased awareness of the environmental damage caused by wastage - the use of recycled building materials as aggregate in concrete is becoming an option for an increasing number of developers and clients.

This paper highlights the effect that the quality of building materials used to manufacture the recycled aggregate has on the properties of the concrete made using the recycled aggregate. Results compare the mechanical and physical properties of concrete made using old, discarded railway sleepers as an aggregate source to that of concrete, which is produced using dolomite.

BACKGROUND

The environmental impact of producing concrete can be significantly reduced by not only using waste materials as extenders in cement but also by replacing a fraction of the large volume of natural aggregates used in concrete with waste material.

The scarceness of high quality natural aggregate in some developed countries has resulted in significant research, over a long period of time, followed by the successful use of various types of recycled aggregate in concrete.

In South Africa the low cost of high quality natural aggregates has resulted in very limited use of recycled aggregates. But with the environmental awareness a large number of inner city refurbishments are opting for recycled building materials to use as aggregates.

Little has been published locally on recycled aggregates and results published by international researchers indicate that the quality of concrete can be negatively affected by the use of waste [1][2]. Many researchers suggest that the waste content should be limited [3] [4], or that the fine material should be screened out and only coarse aggregate should be used [5].

The aim of this paper is to establish whether the quality of the building materials used to manufacture the recycled aggregate has a significant effect on the properties of the concrete made using the recycled aggregate.

To optimise the waste usage the coarse aggregate in the concrete were completely replaced with recycled aggregate, while the fines generated during the crushing process was used to partially replace the fine aggregate. Results compare the mechanical and physical properties of concrete which have been made using old, discarded railway sleepers as an aggregate source to that of concrete made using dolomite [6].

In the design of concrete mixes containing recycled aggregates literature indicates that minor modifications to standard mix design procedures will be required [7] such as:

- The water/cement ratio required for a certain compressive strength can be assumed to be the same for recycled concrete as for conventional concrete.
- Target strengths should be calculated using higher standard deviations if the quality of the recycled aggregates varies.
- To maintain constant workability, recycled aggregate concrete requires a free water content 10 ℓ/m^3 higher than for conventional concrete.
- The cement content of recycled aggregate concrete mixes should be adjusted according to the increase in water content, probably resulting in a slight increase in cement content.
- The actual density of recycled aggregate should be measured and used in mix design calculations.

EXPERIMENTAL SETUP

To establish the effect of the quality of recycled aggregate on the concrete properties, five different sets of mixtures were cast. A reference mixture was cast using crushed dolomite as aggregate, while four different streams of construction waste were crushed with a laboratory jaw crusher before being use as recycled aggregate in concrete.

The first three streams of waste were obtained from concrete that was tested after 28 days of water curing. The concrete was divided into three classes, strong (in the region of 100 MPa concrete), medium (in the region of 50 MPa concrete) and weak (less than 20 MPa concrete). The fourth waste stream was building rubble obtained from a clay brick masonry wall that was demolished.

Table 1: Aggregate properties

Mix	A	B	C	D	E
Coarse Aggregate	Dolomite	Strong	Medium	Weak	Rubble
Moisture absorption (%)	0,3	0,8	1,1	1,5	11,2
Relative Density	2,86	2,7	2,6	2,54	2,29
Sieve Size (% passing)					
19	100,0	100,0	100,0	100,0	91,1
13,2	83,7	77,3	85,6	72,0	73,9
9,5	22,5	63,0	65,4	55,5	60,4
6,7	1,1	48,8	45,7	43,4	52,6
4,75	0,2	36,9	33,9	35,4	46,4

Fine Aggregate	Dolomite	Strong	Medium	Weak	Rubble
Sieve Size (% passing)					
4,75	100,0	100,0	100,0	100,0	100,0
2,36	71,5	65,6	54,7	71,5	79,5
1,18	47,6	48,6	30,5	51,5	64,0
0,6	32,4	34,5	18,8	36,0	51,3
0,3	23,2	25,1	13,1	23,5	34,8
0,15	17,6	19,1	10,2	15,1	20,0
0,075	14,0	15,7	8,8	11,2	11,4

The properties of the aggregate used can be seen in Table 1. As expected the moisture absorption of the recycled aggregates are significantly higher than that of naturally crushed aggregates, with the building rubble absorbing considerably more moisture than the recycled concretes. This increase in moisture absorption would result in a reduction in workability as the free water content would be reduced. To maintain a constant free-water content, the aggregates were left in water overnight and surfaced dried before mixing. As the strength of the concrete that was crushed to manufacture the aggregates decreases, so the relative density of the aggregates produced reduce.

During the crushing process more than a third of the waste was crushed to particle sizes of less than 4,75 mm and any requirement for only using coarse recycled aggregates would not be viable as it would not only result in a new waste stream, but the separation process would add cost, making recycling financially less viable. It was therefore decided to use all the crushed recycled material to completely replace the coarse aggregate while partially replacing the fine aggregate. The intention was to keep the volume of coarse aggregate constant and after adding sufficient recycled material to replace all the coarse aggregate with recycled material - a significant percentage of fines had already been replaced. The fine aggregate in all mixes was supplemented with dolomite sand to keep the total volume constant. The ratio of coarse to fine aggregate for the reference mixes containing only dolomite aggregate was kept at 50:50.

The particle size distribution and densities as indicated in Table 1 were used to calculate the mix composition for each stream of aggregate. Three different water/cement ratios (0,35; 0,5 and 0,65) were used for each aggregate stream. The free water content was kept constant at 195 ℓ. A commercially available super-plasticiser was used in all the mixes as recommended by the manufacturer to 0,5% of the cement content with a Cem I 42.5N cement.

The concrete properties were determined using the average of a set of three results. All test specimens were cast and then kept in a constant temperature room until de-moulding took place after 24 hours. Samples were cured in water in a constant temperature bath at 25 °C and tested after surface drying. Sets of 100 mm cubes were used for compressive strength testing while 150 mm diameter cylinders were used to determine the Modulus of Elasticity.

RESULTS

Despite the fact that the aggregates were pre-wetted to make provision for the water absorption of the aggregates, the use of recycled aggregates still resulted in a significant loss in workability. The irregular shape of the recycled particles as well as the rough surface would contribute toward the loss in workability. It would have been possible to improve the workability by increasing the water and the cement contents, but to keep results comparable it was decided not to adjust the mix compositions.

Some of the results obtained during this investigation can be seen in the set of graphs in Figure 1. From the first graph it can be seen that the use of recycled aggregates can have a significant effect on the density of the concrete produced. The mixtures containing the building rubble are more than 15% lighter than the mixture containing dolomite as coarse aggregate and with an own weight in the region of 2100 kg/m^3 the effect of recycled aggregate density definitely has to be taken into account even during the design of the structures containing recycled aggregate. From the graph it can be seen that the mixtures containing strong and medium strength recycled concrete with a free water/cement ratio of 0,5 have lower densities indicating a lack of compaction caused by the low workability. All the other mixes seem to be sufficiently compacted.

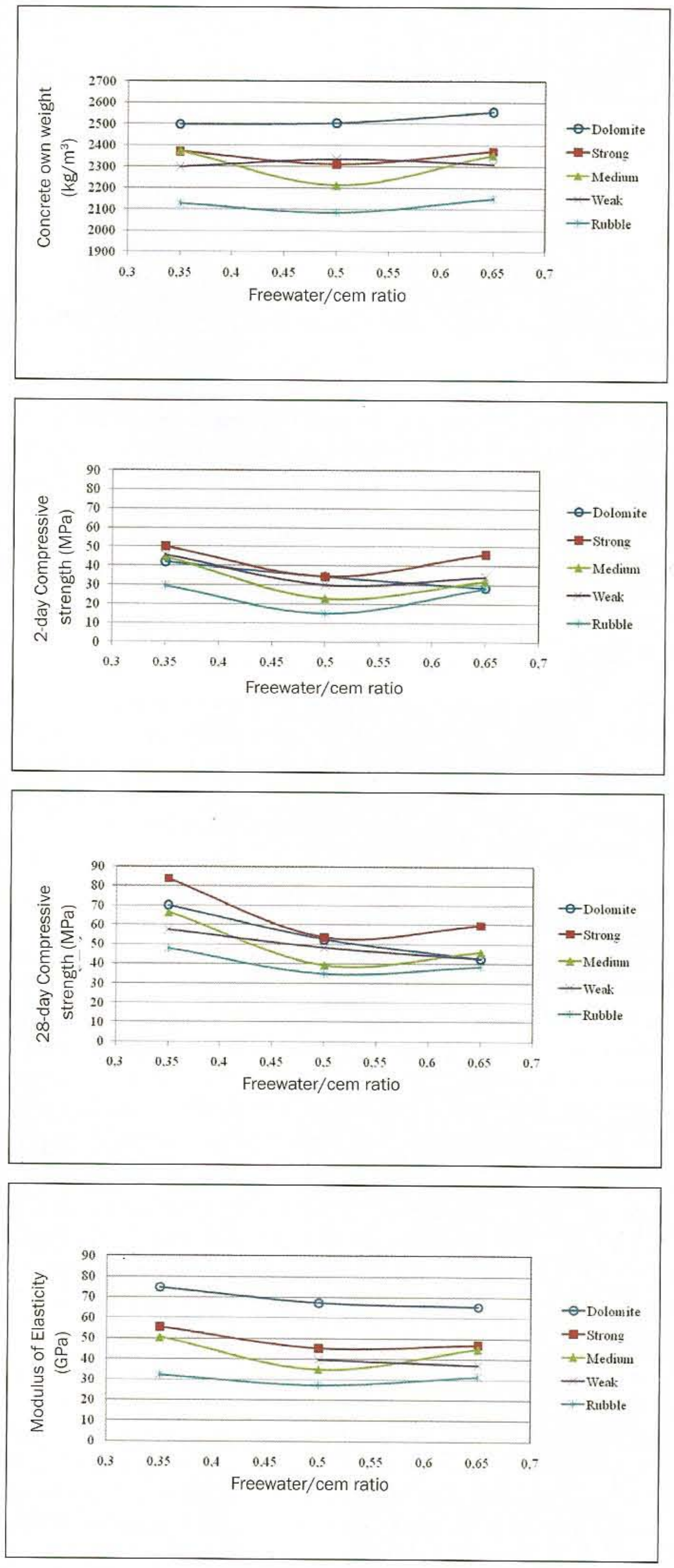

Figure 1: Concrete properties

The second and the third graph in Figure 1 give information on the effect of recycled aggregate quality on the compressive strength development. The early age strength measured two days after casting is, as expected, affected by the free water/cement ratio, with lower water/cement ratios in the normal concrete resulting in higher strengths.

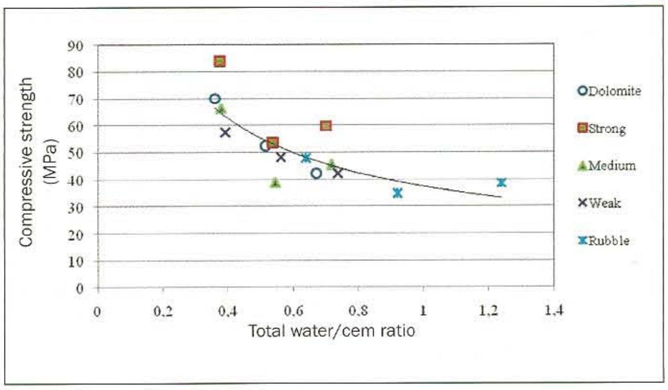

Figure 2: Effect of total water/cement ratio on 28-day compressive strength

It is however interesting to note that the recycled concrete mixes yield early age strengths equivalent to that of the normal concrete at low water/cement ratios and higher strengths than that obtained for normal concrete at high water/cement ratios. The relatively high early age strengths obtained with recycled concrete can be attributed to the un-hydrated cement that would be exposed during the crushing of the recycled concrete and which is now in contact with water and can contribute towards the hydration process.

As expected, the majority of the recycled aggregates yield lower strength concrete than the normal aggregate after 28 days. The only exception is the mixes made with recycled high strength concrete as these mixes yield higher strengths than those obtained from mixes containing dolomite.

The higher than expected strength of these mixes can again be attributed to the un-hydrated cement that would have been present in the relatively young concrete that was used to produce the aggregate. It is worth noting that the effect the recycled aggregates has on the strength of the concrete is more noticeable at the lower water/cement ratios with the concrete containing building rubble only reaching 68% of the strength obtained with normal concrete. As expected, the lack of compaction for the two mixes with a water/cement ratio of 0,5 had a negative effect on the strength of the concrete.

The modulus of rupture of the mixes varied between 15,7% and 11,4% of the compressive strength, which is in the range that is deemed typical for normal concrete. The mixes containing the dolomite did however have the higher ratios and the mixes containing the building rubble the lower ratios.

The fourth graph in Figure 1 gives an indication of the stiffness or modulus of elasticity of the concrete and it is clear the use of recycled aggregates does result in a significant reduction in the modulus of elasticity. In structures where large deflections are expected, the use of recycled aggregates in concrete should be carefully considered, but all the stiffness values recorded for the recycled aggregate concrete fall well within the modulus of elasticity range normally assumed by design engineers.

DISCUSSION

The 28-day strength results as recorded in Figure 1 seem to indicate that it is not possible to predict the strength of concrete containing recycled aggregates. Water/cement ratio graphs are used when a concrete mix composition is designed and it is therefore essential that suitable methods be used to design the mixes. If we add the water that was required to fill the voids in the aggregates during the pre-wetting of the aggregates to the free water content of the mixes the actual total water contents of the mixes can be calculated.

The 28-day strengths of all mixes were plotted as a function of the total water/cement ratio in Figure 2 and it is clear that this ratio holds true – regardless of the type of aggregate used. The strengths obtained from recycled high strength concrete can be seen as the only outliers, and the higher strengths can be explained by the presence of un-hydrated cement in the crushed material. This graph does however prove that it would be possible to design a recycled concrete mix using a standard water/cement: strength graph if the extra water required as a result of the aggregate void content were taken into account.

CASE STUDY

The results of a case study conducted a number of years ago [6] is included in Table 2 to give an indication of a true comparison of the properties of concrete made with good quality recycled aggregate. In this study old railway sleepers that were removed from railway lines were crushed and the crushed material was used to replace 100% of the coarse aggregate in a concrete mixture. A reference mixture was cast using dolomite as aggregate and the mix composition of the two mixes can be seen in Table 2.

The comparison in strength development for the two mixes can be seen in Figure 3 and it is clear that the trend is similar, with the recycled aggregate concrete yielding marginally higher strengths early on, but lower strengths at later ages. The modulus of rupture, split cylinder strength and modulus of elasticity as indicated in Table 2 show only a marginal decline in the recorded properties and the marginal loss in performance is deemed a small price to pay

Table 2: Comparison of concrete properties

	Natural Aggregate Concrete (NAC)	Recycled Aggregate Concrete (RAC)
Mix Composition	**kg/m^3**	**kg/m^3**
Cement (Cem I 42.5 R)	472,5	472,5
Fly Ash	105	105
Water	10	210
Fine aggregate – dolomite	677	677
Coarse aggregate – dolomite	1015	
Recycled coarse aggregate		1015
Water/cement ratio	0,4	0,4
Slump (mm)	50	10
28-day Compressive Strength (MPa)	71,7	65,9
28-day Modulus of Rupture (MPa)	8,3	7,8
28-day Split cylinder strength MPa)	3,4	3,1
Modulus of Elasticity (GPa)	52,1	50,6
Porosity (%)	12,8	13,9
Sorptivity (%)	0,53	0,61

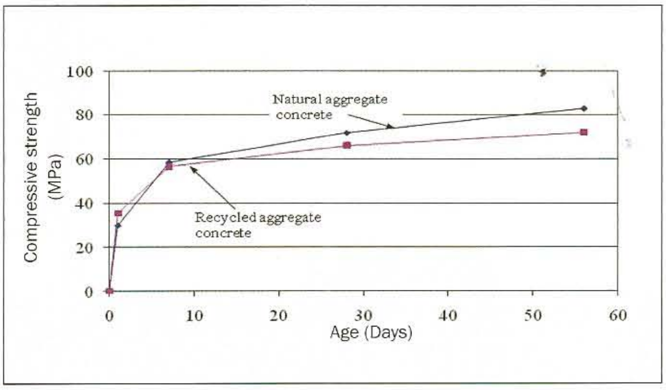

Figure 3: Strength development comparison

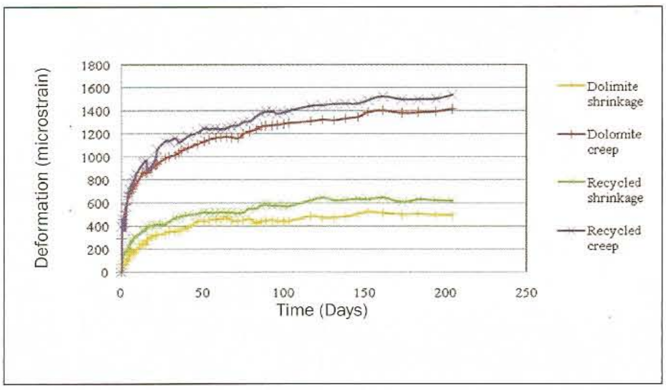

Figure 4: Drying shrinkage and creep comparison

for the total replacement of coarse aggregate with waste material. The porosity and sorptivity values as indicated are indicative of the long term durability properties that were measured and again the insignificant decrease in quality should not have a significant effect on the long-term durability of the concrete.

The most significant difference in behaviour that was recorded was the long term deformation as measured with drying shrinkage and creep specimens. Water cured samples were placed in a climate room set at 65% Relative Humidity and 25°C and allowed to dry naturally. A constant load resulting in a stress of 10 MPa was placed on the creep cylinders. The drying shrinkage and creep deformation recorded can be seen in Figure 4. Both the drying shrinkage and the creep of concrete increases with the use of recycled aggregates and the effect of increased long-term deformation should be taken into account when the decision is made to use recycled aggregates.

CONCLUSION

It is possible to make high quality concrete using large volumes of high quality recycled aggregate. Low strength concrete or building rubble should not be used to manufacture high strength concrete as the high water absorption of the aggregate will result in a significant increase in water content, thus causing an increase in cement content and cost. It is important to ensure that the quality of the recycled aggregate remains relatively constant and therefore it would, in the long run, be sensible to stream the material intended for recycling at source, thus ensuring uniform recycled aggregate quality. If a reliable source of high strength concrete is used as source for recycled aggregate concrete, the coarse aggregate in the concrete can be completely replaced with recycled material without any significant negative effect on the short-and-long-term concrete properties.

The fines produced when the recycled aggregates are manufactured can be used to replace a relatively large percentage (more than a third) of the fine aggregate without unacceptable negative consequences.

By following well established guidelines, South African contractors will be able to successfully use recycled aggregates if the use is not limited by the unnecessary implementation of strict specifications that are not based on performance. It is however essential that not only the effect of every source of recycled aggregate on the properties of the concrete produced should be established before use, but also that the consistency of the waste source and the aggregates produced should be determined before use and assessed on a continual basis.

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