INFLUENCE OF RECYCLED AGGREGATES OF DIFFERENT SOURCES ON CONCRETE: PART 1 - STRENGTH EFFECT

Ekolu S.O[a], Makama L.N and Shuluuka W.P

School of Civil and Environmental Engineering, University of the Witwatersrand, Private Bag WITS 2050, Johannesburg, RSA. [a]Stephen.Ekolu@wits.ac.za

Biography

Dr. Stephen Ekolu completed his first degree in civil engineering from Makerere University then worked as a construction engineer and later as a civil engineer specializing in construction materials and project management. In 1997, he obtained M.Sc with Distinction from University of Leeds, United Kingdom and was awarded a Ph.D from University of Toronto, Canada in 2004. Dr. Ekolu has conducted teaching and research at Universities in Uganda, Canada, and is a Lecturer of construction materials engineering at University of the Witwatersrand, South Africa. His areas of interest are materials aspects of concrete, cement extenders, concrete repair, concrete durability and service life, waste utilization in concrete.

This work is based on the final year investigation project of Wilson P. Shuuluka and Lebogang N. towards BSc degree in civil engineering.

Abstract

Different types of recycled aggregates consisting of crushed concrete, recycled rubble stone and crushed clay brick were used as 100% coarse aggregates to prepare concrete mixtures of water/cement ratios of 0.6 and 0.45. Crushed natural dolomite stone was used a control. The various concretes were tested for concrete properties of compressive strength, split tensile strength, the Youngs modulus of elasticity and abrasion resistance. It was found that recycled aggregates reduce the workability of concrete mixtures. Use of recycled aggregates of concrete origin also exhibits reduction in compressive strength and split tensile strength by up to 35%. With high strength concrete mixes of at least 50 MPa, the strength losses reduce to negligible levels in some cases. Crushed brick stones gave much higher split tensile strength than all the other recycled stones. The relationship between elastic moduli and compressive strength for concretes made with normal aggregates does not appear to directly apply to concretes made using recycled aggregates. Crushed brick also gave high abrasion resistance similar to the performance of the control dolomite stone and better than the other recycled aggregates.

1. INTRODUCTION

Recycling of concrete is an effort towards sustainable development using concrete. The benefits are economical, ecological and environmental. Reduced use of landfill space for waste dumping and conservation of natural rock resources are achieved; and some cases, concrete recycling for use as aggregates may result in cost savings for construction projects. Concrete recycling is a well exploited practice in some Western countries, with large proportions of concrete waste being re-used. Japan, USA, Germany and Belgium recover 80-90% of construction and demolition waste with countries such as Netherlands and Switzerland achieving near 100% recovery. Most recycled concrete is used in road base and sub-base as their use is quite beneficial in achieving improved compaction with less requirement for cement. Research has also shown that the use of recycled concrete aggregate for structural applications is viable, the resulting properties being largely dependant on the quality of the waste source. Some guidelines limit the use of recycled aggregates at 10 to 45% of the total aggregate content in order to avoid adverse effects on concrete properties (WBCSD, 2006).

In South Africa, recycling of concrete is yet small with plants for recycling demolition waste operating in Johannesburg and Cape Town. A large proportion of demolition waste in the country is usually dumped at landfills. With growing infrastructure and population, the promotion of concrete recycling in future is important. However, very little research work has been done on recycling of concrete in South Africa.

1.1 Characteristics of recycled aggregates

Recycled concrete aggregates are typically produced from parent concrete by crushing using mechanical means. Some of the aggregates may be more angular than others depending on their mineralogy. Generally, the roughness of aggregate surface texture is greater with increase in angularity, and in turn have higher water demand and generally lower workability. Tabsh and Abdelfatah, 2009 reported 10% additional water content in order to maintain the same level of slump when recycled aggregates were used. Recycled aggregates from concrete usually contain adhered hydrated cement particles which may affect the aggregate/paste bond or interfacial transition zone, increasing the porosity of concrete (Gomez-Soberon, 2002, Olorusongo and Padayachee, 2002). Aggregate toughness may reduce due to internal fracture associated with residual stresses experienced by the material during service, in addition to effects of crushing of the parent material.

While concrete is generally inert, recycled aggregates might contain contamination from environmental exposure such as chloride ions from marine environment or de-icing salts, and inter-mixing of concrete with other building materials during demolition, such as sulphates from gypsum boards.

1.2 Past studies on recycled aggregates

From world wide literature of scientific research, a general understanding of the characteristics of recycled aggregates is emerging but in all cases local testing is considered essential before recommendation of any sources for re-use in concrete. Recycled aggregates tend to give reduced strengths compared to their natural counterparts. This can be attributed to adherence of hydrated cement and other foreign particles as well as reduced toughness emanating from the residual stress sustained by the concrete during its service. Tabsh and Abdelfatah, 2009 reported that the use low strength parent concrete source produces recycled aggregate that will cause strength reduction, but high strength parent concrete of at least 50 MPa produces aggregates that give the same strength levels as their natural aggregate counterparts. While high strength parent concrete sources may be available, there may not be as much in quantities as the medium strength concretes predominantly used in concrete structures. Strength loss in the range of 10 to 20% is reported in the literature (Tabsh and Abdelfatah, 2009, Ajdukiewicz and Kliszczewicz, 2002, Kearsley and Mostert, 2010) with regard to use of recycled coarse aggregate. The creep, shrinkage and abrasion properties of concretes also increase with use of recycled aggregate (Sagoe-Crentsil, et al., 2001).

In this study, recycled stone aggregates of different types and sources are characterized then used to prepare concretes of varied grades. Tests conducted include slump, compressive strength, split tensile strength, Young's modulus of elasticity and abrasion resistance.

2. EXPERIMENTAL

2.1 Recycled aggregate sources

Crushed dolomite aggregate used as control, and three recycled aggregate types were used in the study. One of the recycled aggregates was a commercially recycled stone obtained from a plant in Johannesburg that processes rubble for use as fills in civil works. The other recycled aggregates were prepared from concrete chunks and fired clay bricks recovered from a nearby landfill. These were crushed using a laboratory aggregate crusher to produce 19 mm aggregates shown in Figure 1. The aggregate gradings of the commercially recycled rubble stone and crushed dolomite were the same and met the requirements for SABS 1083. Figure 2 shows that the laboratory crushed concrete and brick aggregates had higher finer contents of 6.7 to 13.2 mm sizes compared to the commercial sources. The densities and water absorption characteristics were determined and used to make adjustments in the mix design.

2.2 Concrete mixtures

Concretes made with recycled stone aggregates were prepared in water/cement ratios (w/c) of 0.6 and 0.45, and corresponding cement contents of 350 kg/m^3 and 430 kg/m^3. No partial replacements for recycled aggregates were made. To isolate the influence of recycled aggregates, the same type of crusher sand was used in all mixes. For each mix, nine (9) cubes of 100 mm size were cast for compressive strength, tensile strength and abrasion tests while 150 ϕ x 300 mm cylinders were made for determination of the modulus of elasticity in accordance with ASTM C 469. The abrasion resistance test was done as per ASTM C 944 method. No chemical admixtures were used in the concretes.

3. RESULTS AND DISCUSSION

3.1 Workability and compressive strength results

Figure 3 shows that recycled aggregates generally reduce the workability of concrete mixtures. Crushed brick stone exhibited the greatest effect and may be related to its surface characteristics causing mechanical interlocking of particles and resisting rheological flow. To maintain the same slump would require higher water contents for mixes containing recycled aggregates which in turn would reduce the strengths. It is therefore imperative that when recycled aggregates are to be used in concrete, relatively higher w/c's and cement contents will be required to achieve design strength targets compared to concretes made with normal crushed aggregates.

The control dolomite aggregates gave 28-day compressive strength results of 50 MPa and 32 MPa for the 0.45 w/c and 0.6 w/c mixes respectively. All the recycled aggregates showed strength reduction of the concretes. The strength losses were greater in the order of crushed concrete, recycled rubble stone, and crushed brick as given in Figure 4. The proportions of reduction in compressive strengths ranged from 18% to 35% for recycled aggregate of concrete origin, and 35 to 50% for crushed brick stone, as shown in Table 1. It can be seen that the strength reductions were significantly lower for the high strength grade of 50 MPa concrete compared to the strength losses for 30 MPa concrete. This may be attributed to the higher cement content used in the 0.45 w/c concretes whose greater hydration products may help to mitigate the adverse effects of aggregate defects on physical properties, especially at the aggregate/paste interface.

Dolomite

Crushed concrete

Recycled rubble stone

Crushed bricks

Figure 1 Recycled stone aggregates from various sources

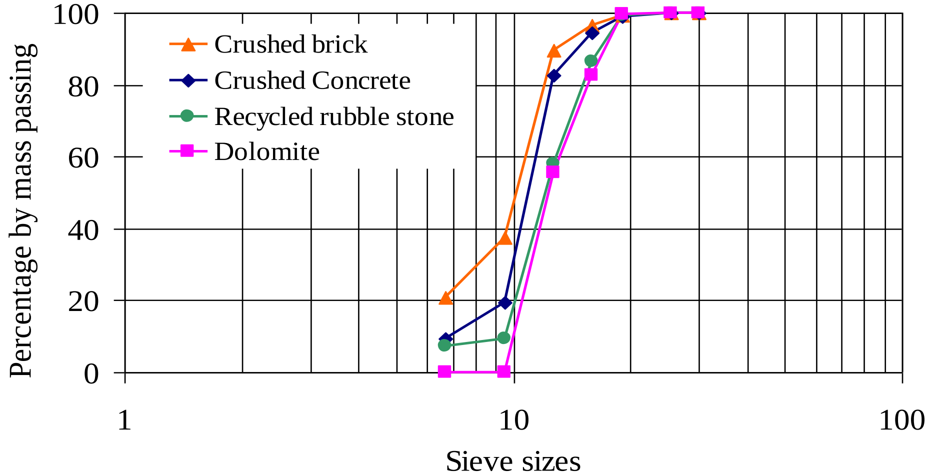

Figure 2 Grading of recycled stone aggregates

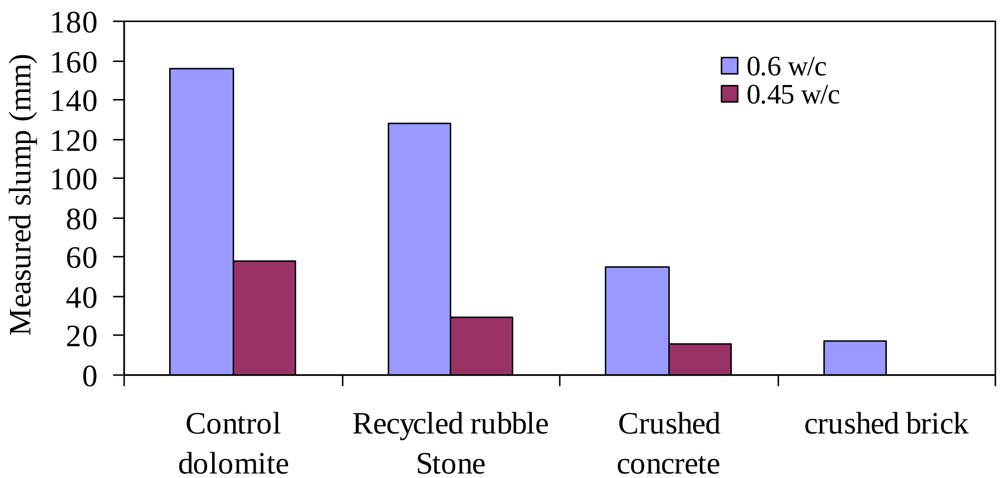

Figure 3 Compressive strength of concretes made using recycled stone aggregates

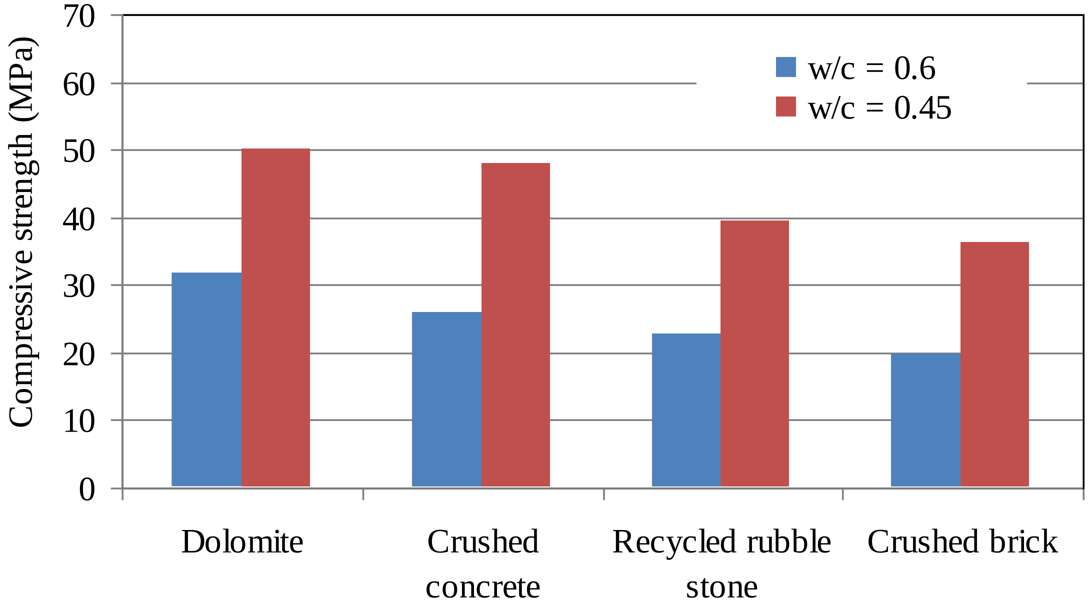

Figure 4 Compressive strength of concretes made using recycled stone aggregates

Table 1 Compressive and tensile strength losses due to use of recycled stone aggregates

Mix	Compressive strength reduction (%)			
	Dolomite (control)	Crushed concrete	Recycled rubble stone	Crushed brick
0.6 w/c	Datum	18.4	35.2	53.5
0.45 w/c	Datum	3.9	21.8	35.0
	Split tensile strength (%)			
	Dolomite (control)	Crushed concrete	Recycled rubble stone	Crushed brick
0.6 w/c	Datum	13.8	30.8	13.8
0.45 w/c	Datum	20.2	25.0	19.2

3.2 Split tensile strength results

The split tensile strengths determined from 100 mm cubes also showed strength loss as a result of using recycled aggregates but their tensile strength behaviour was different from their effect on compressive strength. As expected, the tensile strengths of 0.45 w/c mixes were higher than those of 0.60 w/c mixes, as shown in Figure 5. But unlike the case of compressive strengths, the reductions in tensile strengths were higher for the 0.45 w/c concretes compared to the corresponding reductions in the 0.6 w/c concretes. In all cases the rubble stone gave the highest loss of 25 to 30% while losses due to crushed concrete and crushed brick were in the range to 13 to 20% (See Table 1). It is interesting to note that the clay brick that gave the greatest compressive strength loss, showed relatively high tensile strength similar to the values of the control dolomite and crushed concrete stones. This effect may have resulted from the very rough surface texture and angularity of the fractured clay stones that could generate mechanical interlocking of particles.

3.3 Modulus of elasticity

The Young's moduli of elasticity of concretes made using recycled aggregates reduced in a similar manner as observed with compressive strengths. The stress-strain curves given in Figure 6 for 0.45 w/c concretes, show the behavioural influence of using recycled aggregates. Similar curves were obtained for the 0.60 w/c concretes. The moduli of elasticity of concretes made using crushed brick, recycled rubble stone, and crushed concrete were respectively about 40 to 50%, 60 to 70% and 75% of the modulus of control dolomite.

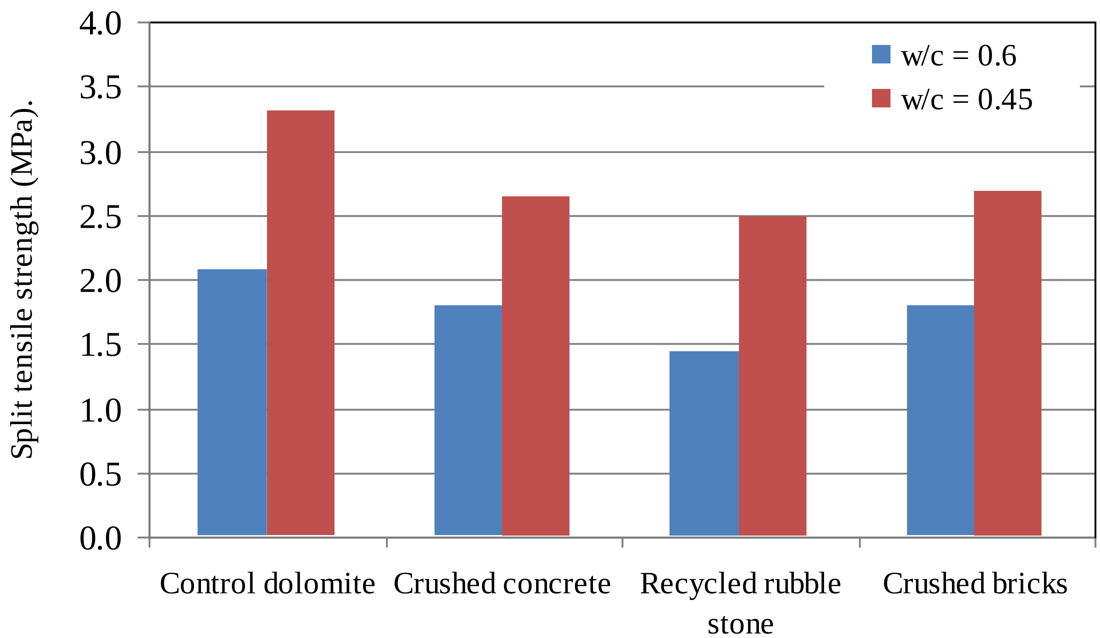

Figure 5 Tensile strengths of concretes made using recycled stone aggregates

In Figure 7, it can be seen that there is a strong relationship between the Young's modulus of elasticity (E) and compressive strength (f_{cu}), as expected. The graph also shows a plot of the equation, $E = 4.7\ f_{cu}^{0.5}$, typically used to roughly estimate the elastic modulus from compressive strength of concrete. It is clear that the fitting of the equation to data of recycled aggregates is poor.

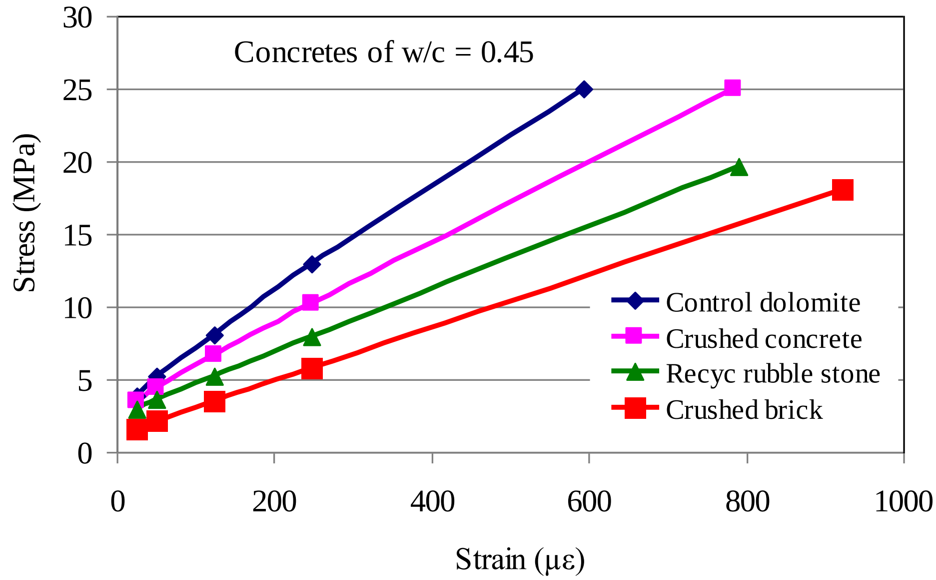

Figure 6 Stress-strain curves of 0.45 w/c concretes made using recycled stone aggregates

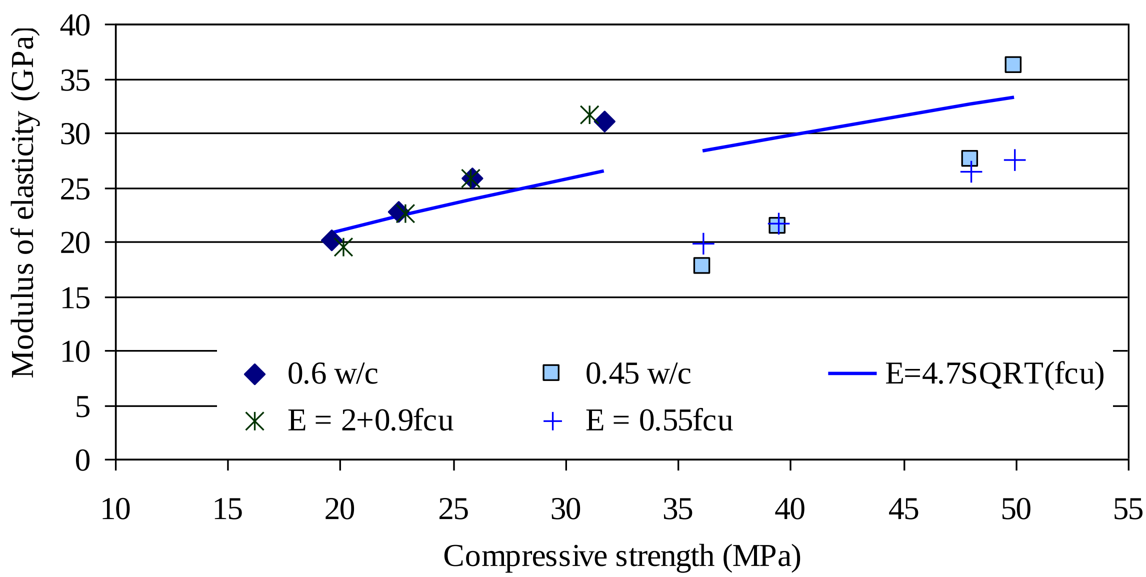

Figure 7 Relationship between compressive strength and elastic modulus of concretes made using recycled stone aggregates

For South Africa aggregates, the typical expression relating elastic modulus and compressive strength is of the form $E = K_o+\alpha f_{cu}$, where K_o is stiffness factor for the aggregate and α is strength factor. For normal aggregates, K_o lies between 18 to 30 and α ranges from 0.15 to 0.40 (Alexander and Davis, 1992). This form of expression was applied on the E-f_{cu} data for recycled aggregates. It was determined that $K_o = 2$, $\alpha = 0.9$ adequately fitted data for 0.60 w/c concrete and $K_o = 0$, $\alpha = 0.55$ fitted the data for 0.45 w/c concrete. No single expression was found to fit data for both 0.45 w/c and 0.60 w/c concretes. It can be seen that the (K_o, α) values are way outside the range of values for normal aggregates. These results again indicate that while the form of E-f_{cu} relationship for recycled aggregates may be the same as that of normal aggregates, the actual expression relating data for concretes made with recycled aggregates might not apply to that for normal aggregates.

3.4 Abrasion resistance

The use of recycled aggregates of concrete origin tends to reduce abrasion resistance regardless of the strength grade of concrete, as shown in Figure 8. The recycled aggregates of brick sources gave good performance in abrasion resistance giving the same results as the control mix made of the dolomite aggregate. The ceramic characteristics of fired clay exposed to high temperature during brick production could have influenced the mineralogical characteristics of clay, improving the wear resistance of the aggregates derived.

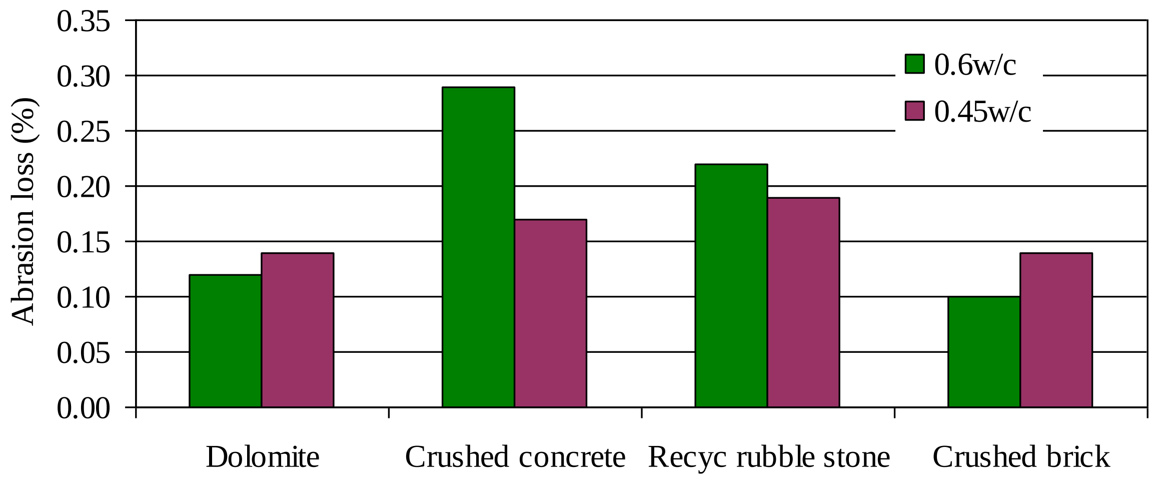

Figure 8 Abrasion resistance of concretes made with recycled stone aggregates

CONCLUSIONS

In the foregone investigation, recycled South African aggregates have been examined for their influence on strength properties of concrete. The four stone types investigate consisted of crushed dolomite natural aggregate as control, commercially available recycled rubble stone, crushed concrete, and crushed stone from fired clay bricks. Concrete mixes of 30 MPa and 50 MPa strengths were used in the study. It was found that all recycled aggregates significantly reduced the workability of concrete.

Results show that use of recycled aggregates of concrete origin reduced strength by up to 35% but the strength loss falls to negligible levels when the aggregates are used in concretes of high strength of at least 50 MPa. Stones of brick origin relatively gave higher strength losses. For recycled stone aggregates of concrete origin, similar observations were found for tensile strengths as in compressive strength. But for recycled brick, relatively high tensile strengths were obtained, deviating from the pattern observed with the other aggregate types.

The Young's modulus of elasticity also reduced in a manner consistent with observations for compressive strength reductions. The relationship between the compressive strength and elastic modulus for normal concretes does not appear to apply for concretes made with recycled aggregates. While crushed concrete and recycled rubble stones gave lower abrasion resistance, the crushed brick showed high abrasion resistance similar to the control dolomite stone.

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