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CONSTRUCTION POTENTIAL OF RECYCLED MASONRY FOR LIGHTWEIGHT CONCRETE

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A sustainable and developing building industry requires large quantities of raw materials such as aggregates and crushed rocks. However, sourcing natural aggregates is becoming more problematic due to environmental impacts. Hence, the use of secondary materials, such as recycled aggregate can reduce the amount of natural aggregates required. Lightweight concrete is frequently used by the building industry, and it is commonly produced with natural lightweight aggregates such as scoria, which results in high production costs. Preliminary tests on recycled aggregates showed that recycled masonry has a similar specific gravity as scoria and relatively good strength. Hence, crushed masonry can be used to replace natural lightweight aggregates. This paper discusses the use of partial or total replacement of normal-weight aggregates with recycled lightweight aggregates, and its effects on the strength and elastic properties of concrete. It is shown that concrete mixes with recycled aggregates generate comparable results to mixes with scoria, but at lower production costs.

Keywords: Aggregates, Construction waste, Demolition waste, Crushed brick, Elastic properties, Scoria, Strength properties.

1 INTRODUCTION

Concrete has long been one of the most widely-used construction materials due to its versatility, strength, sustainability and economic advantages. The versatile nature of concrete allows it to be designed for specific purposes by altering the proportions and materials of its constituents. In the last decade or so, the use of recycled aggregates has become common practice to conserve natural resources, reduce solid waste to landfill and minimize environmental impacts (Tam and Tam 2006).

Construction and demolition (C&D) sites are a continuous source of significant quantities of solid wastes. Although worldwide governmental policies, environment laws and reduce, reuse and recycle practices have improved (Lymbakiya et al. 2000, Tam and Tam 2006), there is still more work to be done to minimize the amount of solid waste (SW) produced and taken to landfills. For example, from 2009-2010 in Australia masonry materials accounted for 37% of the waste generated, representing the largest contributor to SW produced (ABS 2013). Out of 19.8 million tonnes of masonry materials, 71% was C&D waste, with only 55% of masonry waste being recycled (ABS 2013). Masonry materials include asphalt, bricks, concrete and other masonry. Crushed bricks are often supplied as mixed masonry or building rubble, which are relatively simple to process (Hyder Consulting et al. 2011).

Masonry materials are mainly used in pavement applications due to specifications that support their use, also the higher disposal costs and scarcer availability of natural aggregates (Hyder Consulting et al. 2011). Lymbakiya et al. (2000), Ionescu (2010) and Cavalline and Weggel (2013) reported that recycled masonry can successfully be used in concrete production as replacements for natural aggregates. Furthermore, preliminary investigations performed at La Trobe University showed that crushed bricks also have the potential to be used as aggregates. The findings of an ongoing study into the use of crushed bricks from a local supplier (All Stone Quarry) as either a partial or total aggregate replacement for the production of lightweight concrete are reported in this paper.

All Stone Quarries (ASQ) is located in Eaglehawk, Central Victoria. Each year, ASQ receives approximately 37,000 tonnes of masonry debris from local demolition operations, of which brick rubble is about 17,000 tonnes and the remainder concrete debris. From the brick rubble received, ASQ produces about 40% coarse (20 mm) crushed brick aggregates and 60% fine (finer than 14 mm) crushed-brick aggregates. Coarser aggregates are currently used for drainage purposes, whereas broader-gradation aggregates are mainly used for driveways. ASQ is currently considering using crushed bricks for concrete production to increase its efficiency.

2 MATERIALS REQUIREMENTS

Aggregates make up about 75% of the concrete volume, and they play a vital role in determining the properties of concrete. Neville (1995) reviewed the properties of aggregates that highly affect the behavior of both fresh and hardened concrete, namely strength, hardness, toughness, durability, porosity, volume change, grain shapes and texture, chemical reactivity, and relative density. Past research suggests crushed bricks have favorable properties, and hence they can be used as a partial or total replacement for natural aggregates to produce lightweight concrete (Cavalline and Weggel 2013).

Equal amounts of pull-out failure and fracturing of the coarse aggregates on the shear surface indicate a good concrete mix (Neville 1995). Hence, aggregates that have angular grains, with a rough surface texture and a broad gradation, ensure minimum void space in the concrete matrix. Proportions of flaky and elongated particles should be limited to avoid potential fracture planes in the concrete. Further, aggregates with high water absorption should be avoided to ensure a quality concrete (Neville 1995).

3 EXPERIMENTAL PROGRAM

The physical characteristics of the supplied materials were determined in accordance with relevant Australian Standards (primarily AS 1012, AS 1289, AS 2758) to provide a reasonable indication of their mechanical properties. The governing factors were compliance with current specifications and the economic feasibility of obtaining the optimum material.

3.1 Concrete Aggregate

Considering the economic aspects, it was decided that the aggregates be used as supplied, with no additional crushing, sieving or washing. ASQ supplied coarser aggregates (scoria and recycled coarse brick) in separated fractions, whereas the finer aggregate (recycled fine brick) was in a blended state. Hymix Quarry in Axedale (HQA) supplied the coarse basalt in fractions and washed river sand in a blended state. The supplied aggregates were combined for a target Gradation 2 for aggregates for concrete production (C&CAA 1976, AS 2758.1 2014) as follows:

- HQA coarse basalt and blended washed river sand (B-CA + BWRS-FA)
- ASQ coarse scoria and HQA blended washed river sand (Sc-CA + BWRS-FA)
- ASQ coarse recycled brick and HQA blended washed river sand (Br-CA + BWRS-FA)
- ASQ coarse and fine recycled brick (Br-CA + Br-FA)
- HSQ coarse basalt and ASQ fine recycled brick (B-CA + Br-FA).

Table 1 presents the gradation characteristics of the five combinations. Fines (grains < 0.425 mm) from the two sources were tested for any clay content. A summary of the consistency tests (AS 1289 2005) and the clay and silt contents (AS 1141.33 1997) is presented in Table 2. It was found that the finer fractions classify as non-plastic/low plasticity silts. In addition, the physical properties of both coarse and fine aggregates were determined in accordance with the relevant specifications (AS 1141.6.1 2000) and they are summarized in Table 3. As expected, scoria and recycled brick (CA and FA) showed significantly higher water absorption when compared with the currently-used aggregates, and this was accounted for in the mix design. The scoria and recycled brick are 20% to 30% lighter than the basalt and blended washed river sand, which results in a reduced dead load for a concrete structure.

3.2 Concrete Strength

The quantities for the five concrete mixes were based on a nominal characteristic compressive strength of 32 MPa and are listed in Table 4. A 50 mm slump was used in the mix design, and most of the aggregates were used in air-dried condition except scoria, which was used in as-supplied condition (6.7% moisture content).

Table 5 summarizes the strength and density of the concrete at 28 days. All alternate aggregate mixes showed lower compressive strength when compared with the control batch, with a reduction between 6.6% (B-CA + Br-FA) to 22.6% (Br-CA + Br-FA). This correlates well with the monitored reduction in concrete density. The measured indirect tensile and flexural strengths did not show conclusive trends, although they were within the expected magnitude range.

Table 1. Grading characteristics of combined aggregates.

Material	D_{10} (mm)	D_{30} (mm)	D_{60} (mm)	C_u	C_c
B-CA + BWRS-FA	0.51	3.75	8.20	16.1	3.4
Sc-CA + BWRS-FA	0.26	1.96	8.83	34.0	1.7
Br-CA + BWRS-FA	0.41	2.90	11.05	27.0	1.9
Br-CA + Br-FA	0.85	5.71	10.34	12.2	3.7
B-CA + Br-FA	0.53	3.60	7.80	14.7	3.1

Table 2. Consistency characteristics and silt content in fine aggregates.

Material	Liquid limit (%)	Plastic limit (%)	Plasticity index (%)	Linear shrinkage (%)	Silt content (%)
BWRS-FA	18	14	4	2	6
Br-FA	19	16	3	1	7

Table 3. Physical properties of aggregates used.

Material	Water absorption (%)	Particle density SSD (t/m^3)
B-CA	2.23	2.72
Sc-CA	17.7	1.85
Br-CA	7.0	2.20
BWRS-FA	0.6	2.61
Br-FA	4.6	2.44

Table 4. Proportions used for the mix design.

Mix type	Cement (kg)	Water (kg)	Fine aggregates(kg)	Coarse aggregates (kg)
B-CA + BWRS-FA	370	200	620	1090
Sc-CA + BWRS-FA	370	196	620	680
Br-CA + BWRS-FA	370	216	620	950
Br-CA + Br-FA	370	258	530	950
B-CA + Br-FA	370	208	530	1090

Table 5. Average properties for 28 day-old concrete.

Mix type	Compressive strength (MPa)	Flexural strength (MPa)	Indirect tensile strength (MPa)	Density (kg/m^3)
B-CA + BWRS-FA	53.0	5.9	3.5	2400
Sc-CA + BWRS-FA	42.0	6.7	3.3	2140
Br-CA + BWRS-FA	43.0	5.6	3.3	2240
Br-CA + Br-FA	41.0	5.9	3.2	2180
B-CA + Br-FA	49.5	6.0	3.8	2320

3.3 Elastic properties of concrete

The elastic properties of the concrete were determined from tests performed in accordance with Australian Standards (AS1012.17 2014), summarized in Table 6. The computed values of the modulus of elasticity employed the empirical relationship recommended by the Australian Standard (AS3600 2009), namely:

$$E_{cj} = \rho^{1.5} \times \left(0.024 \times \sqrt{f_{cmi}} + 0.12\right) \quad (1)$$

where E_{cj} is the mean value of modulus of elasticity (MPa) at a certain age, ρ is the density of concrete (kg/m^3) and f_{cmi} is the mean value of the compressive strength (MPa) at the relevant age. The computed and measured values of the modulus of elasticity compared quite well, with the former being somewhat lower (6-18%). In addition, it should be noted that the trends observed from the strength tests were replicated by the elastic properties. A higher strength is correlated with a higher modulus of elasticity and a lower Poisson's ratio.

Table 6. Elastic properties for 28 day-old concrete.

Mix type	Elastic modulus (MPa)		Poisson's ratio
	Measured	Empirical	
B-CA + BWRS-FA	33000	33000	0.15
Sc-CA + BWRS-FA	28000	26000	0.17
Br-CA + BWRS-FA	23000	29000	0.12
Br-CA + Br-FA	29000	27000	0.18
B-CA + Br-FA	38000	32000	0.14

3.3 Durability of Concrete

There is general agreement that there is an indirect correlation between the water permeable voids present in the hardened concrete and its durability. Hence, the water absorption and the apparent volume of permeable voids were determined from tests performed in accordance with Australian Standards (AS 1012.21 2014) and the results are presented in Table 7. As expected, the use of porous aggregates resulted in an increase in the apparent volume of permeable voids (AVPV). Concrete produced with scoria showed the highest AVPV, followed closely by the concrete prepared with recycled brick aggregates. It is interesting to note that the Br-CA + Br-FA batch showed the highest water absorption in 24 hours. This indicates that this concrete is not suitable for wet areas.

Table 7. Apparent volume of permeable voids for 28 day-old concrete.

Mix type	Immersed absorption (%)	Boiled absorption (%)	Apparent volume permeable voids (%)
B-CA + BWRS-FA	6.8	7.0	16.1
Sc-CA + BWRS-FA	9.8	11.7	22.2
Br-CA + BWRS-FA	8.5	9.0	18.3
Br-CA + Br-FA	10.6	10.9	21.3
B-CA + Br-FA	8.1	8.3	18.0

4 CONCLUSIONS

The effects of light aggregates (scoria and recycled brick) used for lightweight concrete production were discussed in this paper with following conclusions:

The use of scoria as a CA resulted in the lowest density concrete of the five batches, with the strength, elastic properties and durability of the concrete reduced.

Similar outcomes were obtained when the concrete was produced with coarse and fine recycled brick aggregates. The only advantage is the lower cost of production of aggregates from recycled brick in comparison with the cost for scoria.

Partial replacement of natural aggregates (i.e., replacing B-CA with Br-CA or replacing BWRS-FA with Br-FA) appears to be a suitable solution for lightweight concrete. Concrete from Br-CA + BWRS-FA and B-CA + Br-FA mixes produced concrete with acceptable strength and elastic properties, although slightly lower than the currently used mixes, B-CA + BWRS-FA. Hence, their use may result in a less durable concrete due to a slightly higher volume of permeable voids. Furthermore, the cost of production of concrete with recycled brick aggregates is lower than that of normal-weight concrete while providing environmental benefits. The durability of concrete may possibly be improved if water-repellent admixtures are added to the mix. Future research is required to study this aspect.

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