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Foundry Sand Utilisation in Concrete Production

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ABSTRACT

This paper reports results on the properties of concrete containing waste foundry sand (WFS). Fine aggregate was replaced with 0-100% WFS. The water to cement for all mixes was kept constant. Fresh and hardened properties of concrete were investigated. Hardened properties included water absorption, strength, ultrasonic pulse velocity (UPV) and length change. Testing on hardened properties was mainly conducted at 14, 28 and 56 days. The results show that the workability of concrete reduces with the increase as the WFS increases which was attributed to the larger surface area of WFS compared with the fine aggregate used. Although the compressive strength and UPV decreased with the increase in WFS, an adequate strength was achievable even when all the fine aggregate was fully replaced with WFS. As may be expected, an increase in compressive strength is associated with a decrease in water absorption. Furthermore, there is an increase in shrinkage as the content of WFS is increased. Attempts were made to correlate the various properties investigated.

INTRODUCTION

The UK has the highest amount of waste in all of Europe and recycles the least. Of the waste created in the U.K over 75% of the U.K's waste goes directly to landfill [Collins, 1997]; over 60% of this waste could actually be recycled. This gives a huge shortfall in the amount of waste that could be recycled or reused. The UK has the capabilities to recycle much more of its industrial waste. There is increasing pressure from the government through increased landfill levies to reduce the material sent to landfill. The use of recycled/secondary aggregates for construction has increased by 94% from 1989 to 2002 [DEFRA, 2008] shows the construction industry is changing and has made substantial progress in the right direction.

The construction industry consumes 400 million tonnes of materials per year [Bond, 1998]. Concrete is one of the most frequently used materials in the construction industry which is made up predominantly of aggregate. The British ready mixed concrete industry supplied an estimated 72 million tonnes [Guthrie and Mallet, 1995] with a current value of about £1.5 billion. The fine aggregate used in concrete is normally mined virgin sand and sources where it can be extracted in the U.K are diminishing. The cost of virgin sand is around £5.70 per tonne [Rugby cement, 2007] and reflects on the price of ready mixed concrete. If the materials used in the process could be sourced from waste, this would reduce the cost of ready mixed concrete and greatly aid construction companies in implementing sustainable construction by reducing waste and increasing recycling.

Department for Communities and Local Government has noted that over one million tonnes of foundry sand waste is created each year and only 0.3 Million tonnes is reused therefore there is a large amount of material that potentially be exploited. A potential alternative for fine aggregate in concrete is to utilise waste foundry sand (WFS). If WFS is a viable replacement for fine aggregate in concrete and its reuse would reduce the amount of waste sent to landfill.

The reuse of foundry sand in concrete is already commonplace in many parts of Europe and North America and is becoming more appealing to foundries in the UK as landfill levees rise. At present the low rate for landfill is £2.00 per tonne rising to £2.50 per tonne in April 2008.

Naik et al. [1994] conducted an investigation into the properties of fresh and hardened concrete containing waste foundry sand from ferrous foundries. The results showed that mixes containing foundry sand gave a much lower slump values. The lower slump values were attributed to the presence of binders that increased the water demand. In comparison the foundry sand mixes gave lower slump values than the control mix but higher than waste foundry sand. This showed that the lower slump values of mixes containing waste sand was not completely explained by the presence of binders but also the sand itself. Clean foundry sand has a higher absorption rate than building sand and also finer particles both factors increase water demand and reduce slump values.

Khatib and Ellis [2001] investigated a wider spread of mixes with different types of foundry sand; fine sand, blended sand and spent sand. As the amount of foundry sand increased, the compressive strength of the concrete reduced, this was found to be nearly linear decrease for all levels. The waste sand displayed similar compressive strength as mentioned by Naik et al [1994]; lower than the control and decreased linearly with replacement levels increased. The blended sand mixes decreased the compressive strength as the amount of blended sand replacement increased.

All types of sand displayed themselves to have increased shrinkage with the greater the replacement of sand. The clean sand gave shrinkage levels most comparable to the control. The blended sand mix showed shrinkage levels higher than both the control and clean sand although the rate of shrinkage occurred was similar to the control. The waste foundry sand gave the highest shrinkage values and also the fastest shrinkage rate. All other sands showed a gradual shrinkage whereas the waste sand shrunk at an accelerated rate for the first 20 days then the shrinkage rate levelled out to a similar rate as the other mixes.

Naik et al. [2004] reported that substitution of part of the sand with used foundry sand in concrete mixtures caused a small reduction in strength. Bakis [2006] performed a study into the reuse of waste foundry sand in asphalt concrete production by partially replacing a fine aggregate with waste foundry sand. The results showed that replacement of 10% aggregates with waste foundry sand was found to be the most suitable for asphalt concrete mixtures as higher replacement levels caused reduction in strength beyond tolerances. Naik et al. [2003] conducted the tests for abrasion of concrete with foundry sand. They found that partial replacement of cement with UFS resulted in considerable reduction in strength and increase in abrasion. Naik et al. [2004] conducted experiments into the use of foundry sand in concrete blocks as a partial replacement for fine aggregate.

In the UK the use of foundry sand in construction is not wide spread. Therefore this paper reports some results on the properties of concrete containing foundry sand from a UK foundry. Properties included; compressive strength, ultrasonic pulse velocity and absorption.

EXPERIMENTAL

The cement used was Portland cement (PC) and the sand (fine aggregate) used complied with class M of BS 882: 1992. The coarse aggregate was 10 mm nominal size. The waste foundry sand (WFS) was obtained from a foundry in the WestMidlands. The particle size distribution of sand and WFS is given in Tables 1 and 2 respectively.

Table 1: Sieve analysis of sand

Sieve Aperture	Retained(g)	Retained (%)	Cumulative Retained (%)	Cumulative Passing (%)
10mm	0	0	0	100
5mm	23.2	2	2	98
2.36mm	116.6	12	14	86
1.18mm	51.9	5	19	81
600 µm	113.3	11	31	70
300 µm	588.9	59	89	11
150 µm	85.6	9	98	2
75 µm	20.5	2	100	0

Table 2: Sieve Analysis of waste foundry sand (WFS)

Sieve Aperture	Retained(g)	Retained (%)	Cumulative Retained (%)	Cumulative Passing (%)
10mm	0	0	0	100
5mm	0	0	0	100
2.36mm	0.4	0	0	100
1.18mm	0.7	0	0	100
600 µm	8.2	1	1	99
300 µm	70.1	7	8	92
150 µm	871.1	87	95	5
75 µm	54	5	100	0

Six mixtures were used to conduct this study. The control mix (M1) had a proportion of 1 (cement): 2 (fine aggregate): 4 (coarse aggregate) and did not include WFS. In mixtures M2-M6, the sand was replaced with 20%, 40%, 60%, 80% and 100% WFS (by mass) respectively. Details of mixtures are given in Table 3. The water to binder ratio for all mixes was maintained constant at 0.50.

Specimens were cast in steel moulds. Cubes of 100mm in size were used for the determination of compressive strength and for water absorption specimens of 100mmx100mmx50mm in size were used. Prisms of dimensions 100mmx100mmx250mm were used for the determination of ultrasonic pulse velocity (V) and shrinkage. After casting specimens were covered and left in the laboratory at for 24 hours. After that demoulding took place and specimens for strength and absorption were placed in water. The specimens for shrinkage and V were left in a chamber at 20±1C and 60% RH. Testing was conducted at 7, 14, 28 and 56 days.

Table 3: Details of mixtures

Mixture Number	WFS* (%)	Mixture constituents (kg/m^3)				
		Cement	Free Water	Coarse Aggregate	Sand	WFS*
1	0 (Control)	320	160	1278	639	0
2	20	320	160	1278	511	128
3	40	320	160	1278	383	256
4	60	320	160	1278	256	383
5	80	320	160	1278	128	511
6	100	320	160	1278	0	639

* Waste foundry sand (% by mass of sand)

RESULTS AND DISCUSSION

Table 4 presents the slump values for the various concrete mixtures. There is systematic loss in workability as the foundry sand content increases. The slump dropped approximately in a linear manner from 200mm for the control mix (0% WFS) to zero for mix containing 80% and 100% WFS as replacement of sand. This decrease is largely due to the increased fineness of fine aggregate as the percentage of WFS increases.

Table 4: Slump of concrete mixes

Mixture	Slump (mm)
0% WFS (Control)	200
20% WFS	160
40% WFS	100
60% WFS	40
80% WFS	0
100% WFS	0

Figure 1 shows the ultrasonic pulsed velocity (UPV) for concrete containing various amounts of foundry sand as partial replacement of the sand at the age of 7, 28 and 56 days. The UPV values for all mixes increases with the increase in curing time. Also there is a systematic decrease in UPV with the increase in foundry sand content. The compressive strength at 28 days of curing for concrete with varying percentages of foundry sand is shown in Figure 2. The compressive strength of concrete also decreases with increasing amounts of WFS. This decrease is systematic in that the strength of the control mix (0% WFS) is 43.6 N/mm^2. At 60% WFS, the strength dropped to 32.9 N/mm^2 and at 100% WFS the strength is nearly half of that of the control.

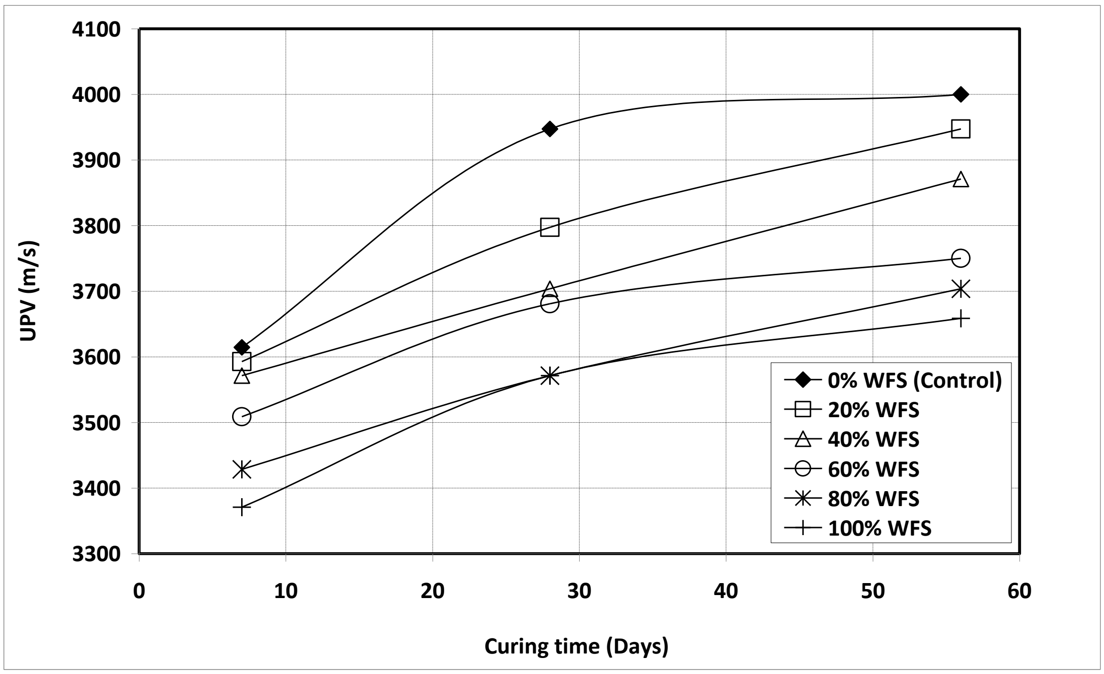

Fig. 1. Influence of WFS on ultrasonic pulse velocity (UPV) of concrete

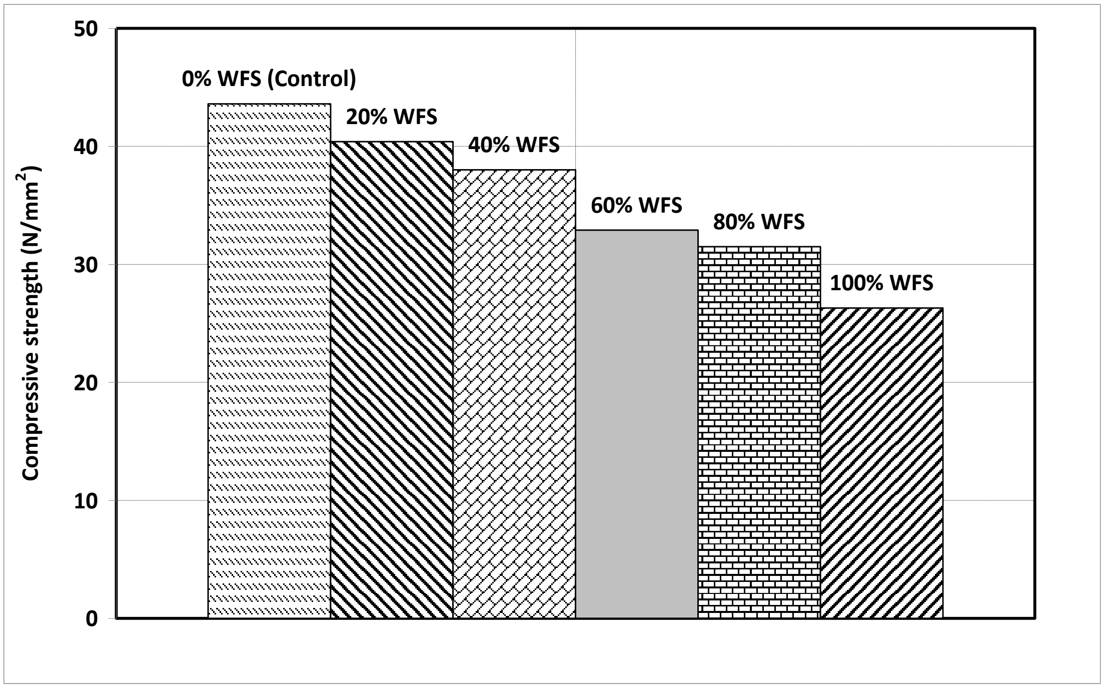

Fig. 2. Influence of WFS on the 28 days compressive strength of concrete

Figure 3 shows the water absorption at 28 days of curing for concrete incorporating different WFS contents. The mass of water absorbed was conducted after 0.5 hour, 1 hour, 2, 4 and 72 hours of full immersion in water. The control mix shows the least water absorbed and generally the water absorption increases as the WFS in the concrete increases. An increase in water absorption is associated with a decrease in compressive strength and UPV.

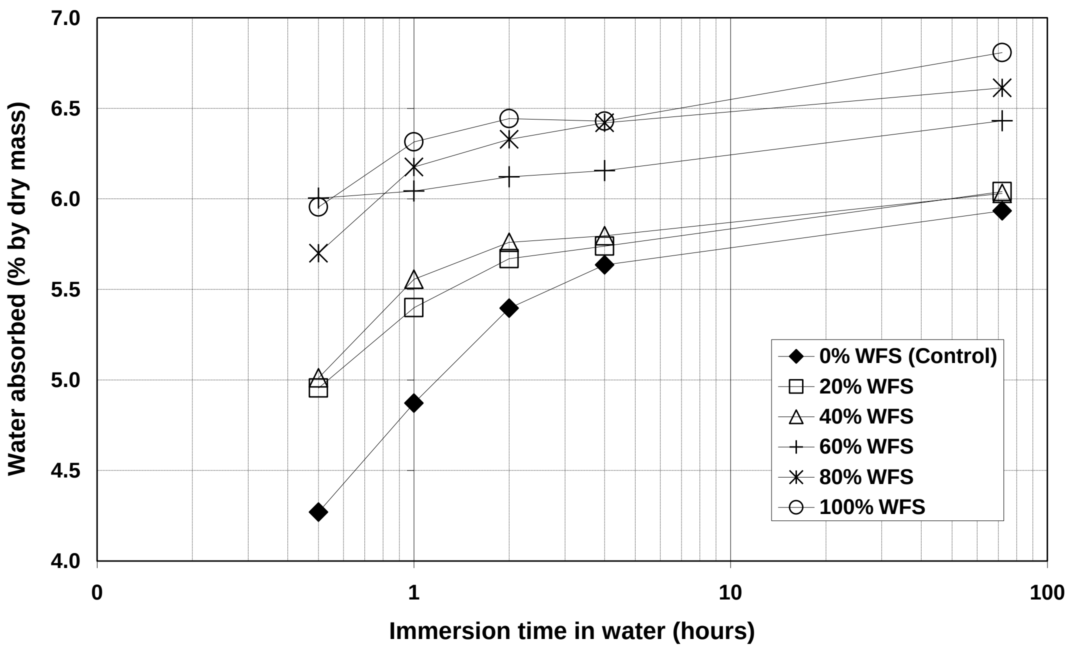

Fig. 3. Influence of WFS on water absorption of concrete at 28 days of curing

Table 6 presents the shrinkage values at 56 days of air curing. The data indicate that shrinkage increases as the WFS in the concrete increases and this increase is systematic. For example at 100% sand replacement with WFS, the shrinkage at 56 days is twice as much as the control mix (i.e. 0% WFS).

Table 5: Shrinkage at 28 days of curing

Mix	Shrinkage (microstrain)
0% WFS (Control)	-221.4
20% WFS	-243.3
40% WFS	-304.3
60% WFS	-337.5
80% WFS	-367.5
100% WFS	-442.5

CONCLUSIONS

The incorporation of waste foundry sand in concrete causes a systematic decrease in workability, ultrasonic pulse velocity and strength and an increase in water absorption and shrinkage of concrete. However, an acceptable concrete strength can be achieved using foundry sand.

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