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RECYCLED CONCRETE AS A SOURCE OF AGGREGATE

by

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The use of crushed waste concrete as concrete aggregate began in Europe at the end of World War II. Depletion of supplies of high-grade conventional aggregates in certain regions, the need for better methods of solid-waste disposal, and energy conservation have contributed to a new interest in this technology. Both earlier and recent research indicate that crushed old concrete will have higher absorption and yield concrete of lower strength at equal water-cement ratio and slump than concrete made with similar aggregate not previously used.

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20. ABSTRACT (Continued).

Where the original concrete was of low resistance to frost action, concrete made using it as aggregate had improved frost resistance. It is concluded that recycling concrete for use as aggregate in new concrete is feasible and may become routine.

PREFACE

This paper was prepared for presentation in the Session on "Living with Our Available Materials in the Energy Shortage" at the 1976 American Concrete Institute, Philadelphia, Pennsylvania, 1 April 1976.

This paper was approved for presentation and publication by the Technical Director of the U. S. Army Engineer Waterways Experiment Station (WES).

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This paper was prepared by Alan D. Buck, Research Geologist, Petrography and X-Ray Branch, Engineering Sciences Division, Concrete Laboratory.

Director and Technical Director of WES during the preparation of this paper were COL G. H. Hilt, CE, and Mr. F. R. Brown.

CONTENTS

RECYCLED CONCRETE AS A SOURCE OF AGGREGATE*

by Alan D. Buck**

Synopsis

The use of crushed waste concrete as concrete aggregate began in Europe at the end of World War II. Depletion of supplies of high-grade conventional aggregates in certain regions, the need for better methods of solid-waste disposal, and energy conservation have contributed to a new interest in this technology. Both earlier and recent research indicate that crushed old concrete will have higher absorption and yield concrete of lower strength at equal water-cement ratio and slump than concrete made with similar aggregate not previously used. Where the original concrete was of low resistance to frost action, concrete made using it as aggregate had improved frost resistance. It is concluded that recycling concrete for use as aggregate in new concrete is feasible and may become routine.

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* Prepared for presentation in Session on "Living with our Available Materials in the Energy Shortage" at the 1976 American Concrete Institute Convention, Philadelphia, Pa., 1 April 1976.

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Introduction

When an urgent rebuilding need was faced in Europe after World War II, there was a massive job of recycling waste material, especially building rubble, into new concrete construction with generally good success. As soon as the need for this action was satisfied such recycling was generally abandoned.

Several comprehensive surveys [1-3] during the past 10 years have dealt with the subject of aggregate supplies and needs and the possible use of waste materials as aggregates in this country. In general, these surveys indicated the following:

a. Considered as a whole, the US at present has adequate supplies of materials suitable to be processed for use as aggregates.

b. Some regions, usually including large urban areas, already have a problem in obtaining adequate aggregate supplies.

c. Since the needs for aggregates are expected to keep increasing, present shortages will become more acute and additional shortages will develop.

d. Replacements for conventional aggregates should be sought and used.

Thus, in the United States, we have come full circle to the point where Europe was 30 years ago. We have a need to recycle. Fortunately we do not also have the mess they had. Furthermore we in the United States are not alone in this need for other countries, especially Great Britain[4] and Canada,[5] share our problem.

Supplies and Usage

It has been estimated that a total of about 20 million tons of building rubble becomes available each year,[3] but no estimate of the amount of discarded pavement is known to have been made. It must be a very substantial amount. Past practice has been to use these wastes as landfill or riprap or not at all. When Buck [6a, c] reported in early 1973 on the potential for recycling of portland-cement concrete, the only then current US recycling uses he had found were as base-course material. [7, 8] The American Concrete Paving Association reported in October 1975, [9] a plan to use crushed old concrete in new concrete for paving in Iowa in 1976. This is the first full scale use that I have heard about in the USA. Concrete has been recycled and used as base course in Washington, DC, [13] Texas, [7] Southern California, [8] and Minneapolis, Minn. [14] These reports are not summarized since this paper deals with the use of recycled concrete as concrete aggregate.

Processing

Initial breakup of in-place pavement has been accomplished with conventional demolition equipment. Crushing has usually been done with portable crushing plants. These operations may require a crew to cut reinforcing bars or wires to free the concrete fragments between initial breakup and loading or other movement. During the crushing operation one or two men can remove steel or other scrap from conveyor belts after initial crushing. Problems have been the usual ones of dust and noise plus removal of steel.

New Equipment

The Building Research Establishment in England has described [10] a novel machine called the Nibbler for quiet breakup of old concrete. It can break up to 65 yd^2/hr (53 m^2/hr) of 10-in. (approx. 25-cm) thick concrete. Its breaking mechanism is similar to that used by a person breaking a bar of chocolate.

The use of adjustable hydraulic breaker machines for demolition of concrete structures in Japan has also been reported. [11] Such machines are reported to be quiet, clean, and free from shock. A road planer that cuts a 31-in. (79-cm) wide swath 4 in. (10 cm) deep through concrete at a rate of 8 to 10 ft (approx. 2-1/2 to 3 m) per minute and produces concrete chips has been introduced. [12]

Research on Concrete Recycled as Concrete Aggregate

Gluzhge(15) reported on work with waste concrete in Russia in 1946. His conclusions were: (a) New concrete will be no better than the waste concrete that is used as aggregate. (b) The use of concrete fines as sand requires an undue increase in the cement content of a mixture. (c) Compressive strengths are lower when concrete is used as aggregate. (d) The specific gravity of crushed concrete aggregate tends to be lower than that of natural aggregates. (e) The cement factor can be lowered if the crushed concrete aggregate is moistened, not saturated, before use. (f) For equal compressive strengths, the flexural strength of mixtures with crushed concrete aggregate is higher than for control mixtures. (g) Mixtures with crushed concrete aggregate stiffen rapidly but consolidate well with vibration.

Graf reported(16) studies of the recycling of building rubble in Germany in 1948. This work included the effects of the addition of different amounts of gypsum. He also worked with the effects of adding gypsum in different sizes to rubble and processing to remove this contamination from rubble. His data for the effect of different amounts of gypsum on the length-change of specimens are shown in Table 1. He found that 1.5 percent added SO_3 resulted in excessive expansion during moist curing or combined moist and dry curing; these specimens showed cracking by an age of 7 days. He concluded that 1 percent SO_3 was a maximum permissible value. The period of dry curing was beneficial in reducing expansion. The addition of powdered gypsum appeared to cause more and faster reaction than the addition of gypsum grains between 1 and 7 mm in size. Gypsum tends to concentrate in the finer material. Large pieces of gypsum were picked out of the rubble before it was crushed.

There were a number of other papers in the European literature but none of these deal significantly with the use of crushed concrete as concrete aggregate.

Ploger[17] recycled two concretes into aggregates. One concrete contained a natural gravel and the other a traprock coarse aggregate. He made three mixtures; one contained coarse and fine aggregate from the natural gravel concrete; each of the others contained one of the recycled concretes as coarse aggregate with a natural sand. The approximate 90-day compressive strength of each old concrete and the absorption of the aggregates he produced by crushing are shown in Table 2. He measured compressive strength and strain for each of his concrete mixtures at 28 days. His curves for compressive strength versus water-cement ratio and cement factor are shown in Figures 1 and 2. He pointed out that these curves were quite similar to those obtained from concretes of normal composition. Ploger's strength values for the two curves containing some or all recycled natural gravel concrete were similar for equal water contents and the strength of the mixture containing the recycled traprock concrete was substantially higher (Figure 1). His data tend to suggest a lower strength for recycled mixtures compared to the original concretes (Figures 1, 2), but this is not clearly shown in the absence of a control mixture.

Buck [6a, c] originally recycled concrete that contained siliceous aggregates and concrete that contained carbonate-rock aggregate. His concrete mixtures were like Ploger's in that they contained all recycled concrete as aggregate or included a natural sand as fine aggregate. Buck studied compressive strength, frost resistance, and volume stability in this work using a constant water-cement ratio. His data for compressive strength of his old concretes and absorptions and specific gravities of his crushed concretes are also shown in Table 2; these data show that aggregates made from old concretes tend to have high absorption and low specific gravity. His compressive strength data to 90 days are shown in Figures 3 and 4. The lower compressive strength of mixtures containing recycled concrete as aggregate is shown by these two figures. His data for frost resistance from laboratory freezing-and-thawing tests are shown in Table 3; the improved frost resistance of the two mixtures containing recycled chert-gravel concrete is clearly evident; there was no appreciable

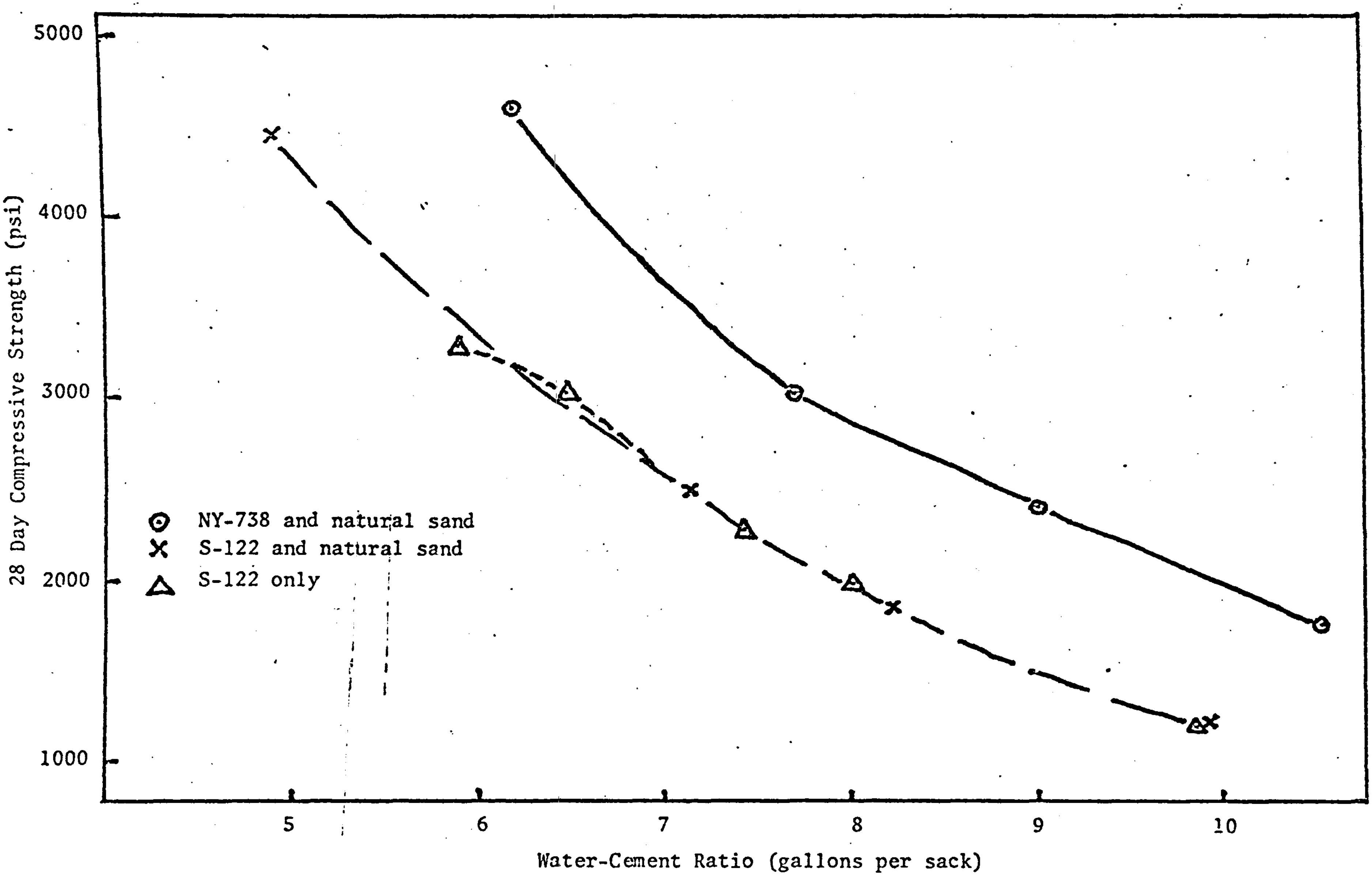

Figure 1. Comparison of Water-Cement Ratio Compressive Strength Curves (modified after Ploger, reference 17).

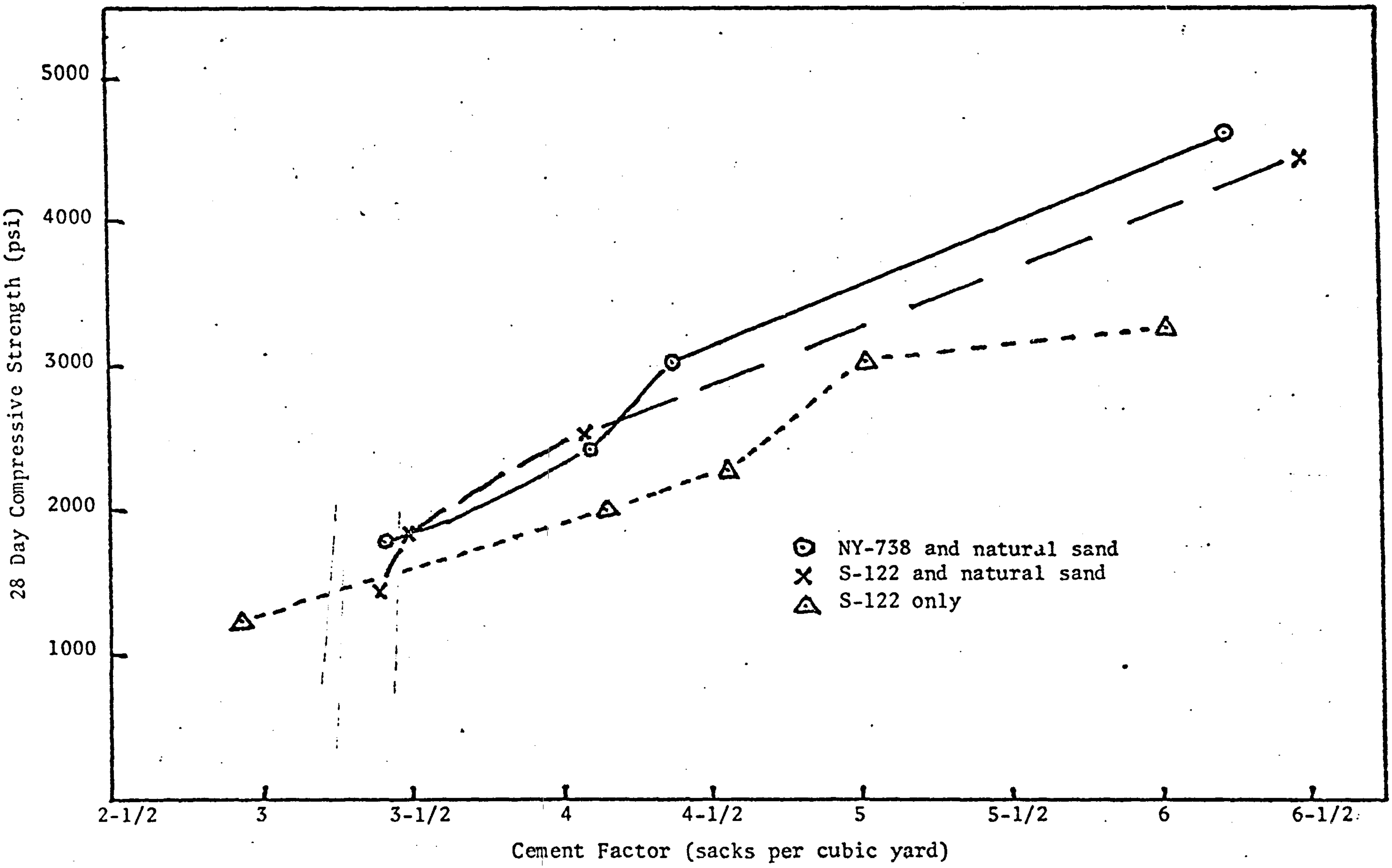

Figure 2. Comparison of Cement Factor Compressive Strength Curves (modified after Ploger, reference 17).

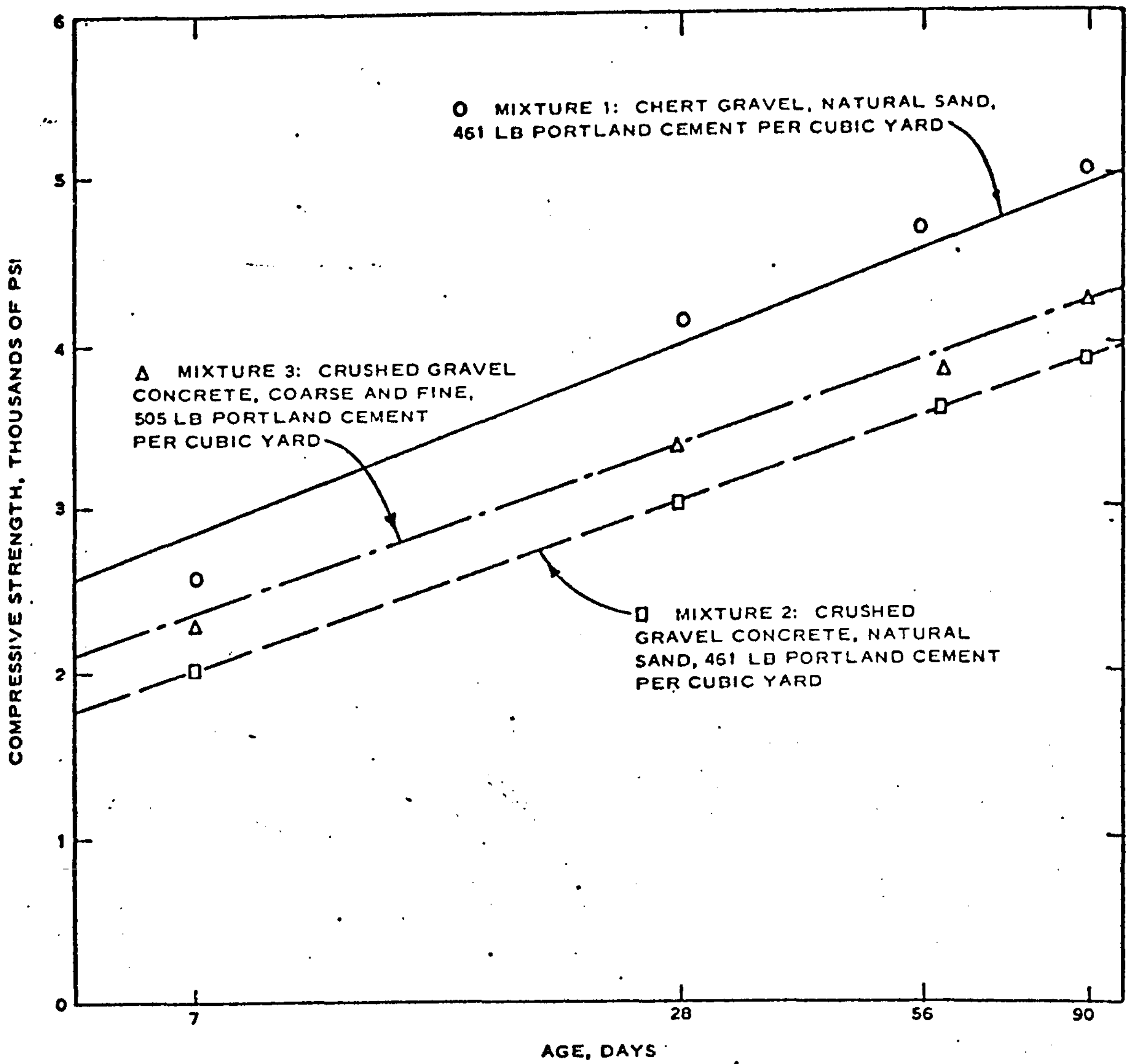

Figure 3. Compressive Strength Data for Three Concrete Mixtures (after Buck, reference 6a).

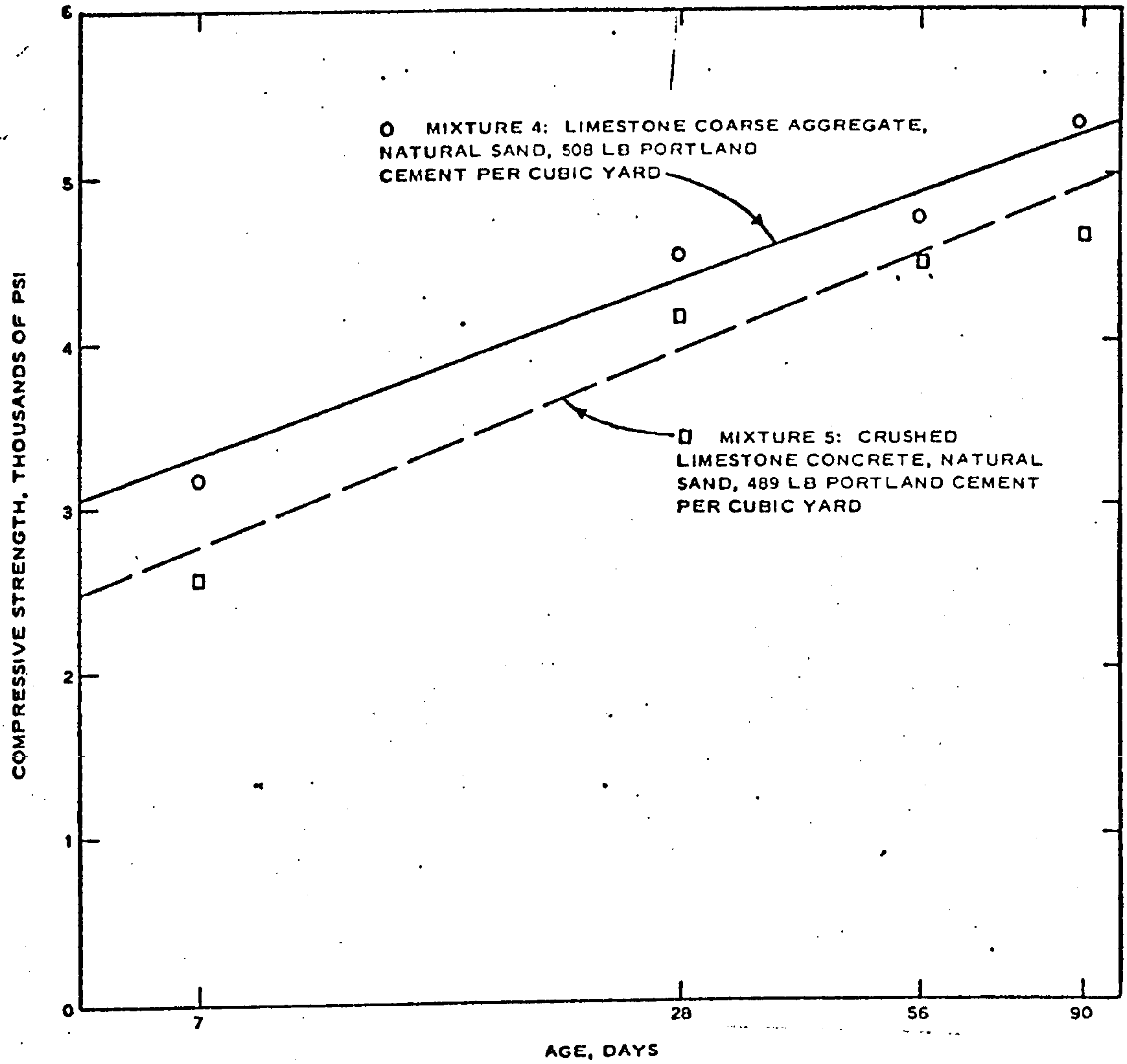

Figure 4. Compressive Strength Data for Two Concrete Mixtures (after Buck, reference 6a).

effect for the mixture that contained recycled carbonate-rock aggregate concrete. His data for volume change during moist storage or with temperature changes showed similar results for recycled and control mixtures.

In later work, Buck[6b] studied the effect of recycling low strength concrete into aggregate, how to increase concrete compressive strength, and effects of sulfate contamination. The latter was to simulate use of materials from demolished buildings.

He again used a constant water-cement ratio for seven of his nine mixtures. The water-cement ratio for two mixtures was reduced by the use of a water-reducing admixture and because of the addition of fly ash. Tests included compressive strength, frost resistance, and length-change. His data for two additional recycled concretes are shown in Table 2. The overall range in compressive strength for the six old concretes shown in Table 2 is from 1860 to 8000 psi (13 to 56 MPa). His compressive strength data for nine mixtures are shown in Table 4. The strength values for mixture 6 range from 2580 at 7 days to 4710 psi (18 to 33 MPa). It is thus indicated, contrary to the results reported by Gluzhge,[15] that the strength of concrete made using crushed concrete as aggregate can be higher than that of the concrete that was crushed.

Mixture 11 (Table 4) was made using similar materials to those used in mixture 3 (Fig. 3), but at a lower water-cement ratio and higher cement content. The decreased water-cement ratio was achieved by the use of a water-reducing admixture. The comparative strength results as given below indicate the range in strengths obtained using recycled materials with minor differences in mixture proportions.

	Mixture 3	Mixture 11
W/C, by wt	0.49	0.45
Cement Content, lb/yd^3	505	585
Compressive Strength, psi		
7d	2300	3500
28d	3400	5090
56d	3810	5280
90d	4280	5620
180d	4520	5720
365d	--	6590
2-1/2 yr	4390	--

Frost resistance data were similar to Buck's earlier results for recycling natural gravel concrete (Table 3). Buck's work[6b] showed that 5 percent gypsum by weight of total aggregate was sufficient to produce harmful internal expansion in concrete made with a cement containing over 5 percent C_3A, when the concrete specimens were stored moist. When the specimens were allowed to dry expansion was reduced (Table 5). Neither the use of a cement with moderate C_3A content (6 percent calculated) nor the use of fly ash was effective in preventing excessive expansion. Previous work in Europe on broken brick aggregate has been summarized by Lea[18] as follows:

"There is a risk with some crushed brick aggregates that the sulphate content may be undesirably high. This can arise from the use of bricks that have a high calcium sulphate content or of rubble from demolished buildings that is contaminated with gypsum plaster. Rubble from demolitions can be screened, as has been done in Germany, to remove all material below about 1 inch size, since this contains the higher amounts of sulphates, and the larger material crushed and graded for use as aggregate. In other cases it may be sufficient to reject only the sand size fraction.

"A limit of 1 percent has been imposed in some countries, e.g. Germany, on the SO_3 content of brick aggregates, but Gaede[2] has suggested that this value ought to be varied with the cement content of the mix. With progressive additions of gypsum to an aggregate he found a critical range of SO_3 contents over which the strength dropped rapidly and then remained more or less constant at the reduced value as further gypsum was added. Concretes made with Hochofen cement suffered less reduction in strength than those with Portland cement. He concluded that the limit of 1 percent SO_3 ought to be reduced to below 0.5 percent. These tests were made, however, by adding finely ground gypsum or magnesium sulphate to a gravel-sand aggregate and in consequence the effect of the sulphur trioxide was probably exaggerated. The results obtained by Newman[1] gave no indication of any serious deleterious effects for sulphur trioxide contents of up to 1 percent in brick aggregates in concrete mixes as lean as 1 : 2½ : 7½ by volume. The sulphate in this case was present in the bricks and not as contamination with gypsum plaster to which Gaede's results might apply more closely."

[1]A. J. Newman, J. Instn munic. Engrs 73 (2), 113 (1946).

[2]K. Gaede, Dt. Aussch. Stahlbeton 109 (1952; 126 (1957).

Results

a. The aggregates produced had lower specific gravity and higher absorption than is typical of conventional aggregates.

b. The use as aggregate of crushed concrete having compressive strengths less than 2000 psi (14 MPa) need not have a detrimental effect on the strength of the new concrete in which it is used.

c. The use of crushed concrete as aggregate imposed no problems with respect to workability.

d. The compressive strength of concrete containing recycled concrete aggregate is lower by as much as 1100 psi (8 MPa) than that of concrete of the same water-cement ratio and similar conventional aggregates. Equal strengths can however be obtained by using appropriately reduced water-cement ratios.

e. The fines produced by crushing old concrete may be used as fine aggregate without modification of grading. With the fines that have been studied, the concrete mixture required 75 to 100 lb (34 to 46 kg) more cement per yd^3 ($0.8\ m^3$) than if natural sand of specified grading were used.

f. The frost resistance of concrete containing recycled concrete, where chert gravel was the original aggregate, was increased by a factor of five or more in laboratory freezing-and-thawing tests. This is assumed to be the result of a reduction in frost susceptibility of the porous coarse aggregate particles.

g. Inorganic, nonmetallic residues from demolition of buildings may be recycled for use as concrete aggregate if the sulfate content is controlled to prevent deleterious expansion due to sulfate reaction.

Discussion

a. This paper has been prepared under the assumption that the need for new aggregate sources exists and will increase.

b. Conventional equipment can and has been used to process old concrete into recycled aggregate. New equipment has already been developed that will assist in this processing.

c. Limited laboratory research and field experience have shown that recycling of concrete is feasible. The laboratory data indicate that the recycled material is adequate for use as concrete aggregate.

The desirability of recycling concrete as a conservation measure and to reduce the quantity of solid waste generated annually is readily apparent. The effect of doing this on energy conservation is less evident but just as real. Since the need for processing will remain common to conventional aggregates and to recycled concrete, the energy reduction will come largely through elimination or reduction of transportation costs both in terms of delivery of aggregate to concrete making plants from aggregate sources and in terms of removal of old concrete from where it is found to a disposal area.

While the cost of the crushing and sizing operation <u>may</u> be higher for recycling concrete into aggregate than for producing conventional aggregates, all costs should be considered. It is believed that in many cases there will be reduced transportation costs.

It is predicted that the momentum for recycling of concrete that is building will culminate in its being a routine procedure and future generations will marvel that it wasn't always that way.

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Table 1

Length-Changes of Concrete Specimens with Added Sulfate

(Data from Reference 16)

Mixtures	Length-Change, Age 28 days	65 days	8-1/2 months
Continuous Moist Curing			
without admixture of gypsum	+0.02	+0.01	-0.02 mm/m
with 1% SO_3 (2) (admixed)	+0.6	+0.7	+0.6 mm/m
with 1.5% SO_3 (admixed)	+5.8	+9.4	+9.4 mm/m
with 2.5% SO_3 (admixed)	+23.6	+23.6	+23.6 mm/m
After 7 days moist, then dry curing			
without admixture of gypsum	-0.5	-0.7	-0.8 mm/m
with 1% SO_3 (admixed)	-0.1	-0.2	-0.3 mm/m
with 1.5% SO_3 (admixed)	+3.7	+3.6	+3.5 mm/m
with 2.5% SO_3 (admixed)	+5.6	+5.5	+5.4 mm/m

(a) Admixtures were in percent by weight of aggregate used;
1 percent SO_3 = 2.1 percent gypsum ($CaSO_4 \cdot 2H_2O$)

Table 2

Compressive Strengths of Waste Concretes

and Physical Properties of Aggregate Produced from Them

Concrete Samples	Average Compressive Strength, psi	Absorption, Percent		Specific Gravity	
		Coarse Aggregate	Fine Aggregate	Coarse Aggregate	Fine Aggregate
S-122* (natural gravel and sand as aggregate)	5060 (90 day) Used at about 122-day age	6.0	10.5	nd**	nd
NY-738* (trap rock coarse aggregate; the fine aggregate was mixed crushed and natural sand)	4870 (90 day) Used at about 188-day age	4.5	nd	nd	nd
Driveway waste (natural chert gravel aggregate)†	6000 (8 years old)	4.5	7.9	2.42	2.33
Discarded beam (carbonate coarse aggregate)†	8000 (9-1/2 months old)	3.9	nd	2.52	nd
Discarded beam (granitic coarse aggregate)†	1860 (2-1/2 years old)	2.3	7.9	2.59	2.36
Concrete panels (natural chert gravel aggregate)†	3300 (8 months old)	4.4	7.5	2.36	2.27

* After Ploger, reference 17.
** Not determined.
† After Buck, references 6a-c.

Table 3*

DFE_{300} of Concrete Beams in Accelerated Freezing and Thawing**

Average†	Mixture No. 1. Control, Chert-Gravel and Natural Sand	Mixture No. 2. Crushed Chert-Gravel Concrete Coarse Aggregate and Natural Sand	Mixture No. 3. Crushed Chert-Gravel Concrete Coarse and Fine Aggregate	Mixture No. 4††. Control, Limestone Coarse Aggregate and Natural Sand	Mixture No. 5††. Crushed Limestone Concrete Coarse Aggregate and Natural Sand
	DFE_{300}	DFE_{300}	DFE_{300}	DFE_{300}	DFE_{300}
Round 1	4	28	30	62	45
Round 2	4	22	28		
Round 3	2	19	25		
Combined	3	23	28		

* After Buck, references 6a, c.
** Tested in accordance with CRD-C 114, Handbook for Concrete and Cement.
† The values by round are for three beams; the combined value is the average of nine values.
†† Only one round was made

Table 4 ††

Compressive Strength of Nine Concrete Mixtures*

Mixture	Compressive Strength, psi, at Ages Shown					
	7-day	28-day	56-day	90-day	180-day	365-day
Mixture 11: Recycled coarse and fine WES-42 CON-1(2), 1(2)(S). Water-reducing admixture used. Average**	3500	5090	5280	5620	5720	6590
Mixture 6: Recycled coarse and fine WES-42 CON-3, 3(S). Average**	2580	3610	4180	4140	4270	4710
Mixture 7: Chert gravel, CRD-G-42, and natural sand, WES-1S-4(50). Average**	2580	3840	nd†	4640	3350	4600
Mixture 13: Remake of 7 and control for 12. Average**	2650	4080	4390	4920	5660	5760
Mixture 12: Recycled coarse and fine WES-42 CON-4, 4(S). Average**	2510	3470	3950	4940	4730	5580
Mixture 8: Recycled coarse and fine WES-42 CON-1(2), 1(2)(S) plus added sulfate, low C_3A cement. Average**	1940	2910	nd†	3460	3580	4750
Mixture 9: Recycled coarse and fine WES-42 CON-1(2), 1(2)(S) plus added sulfate, high C_3A cement. Average**	1730	2270	nd†	2770	2790	3150
Mixture 10: Recycled coarse and fine WES-42 CON-1(2), 1(2)(S) plus added sulfate, high C_3A cement, and fly ash. Average**	1460	2110	nd†	2980	2880	4330
Mixture 14: Remake of 10 with more fly ash. Average**	1700	2490	3240	3730	4880	5460
Accelerated curing. Average**	4380	4800	4840	5260	5660	6160

* Tested in accordance with CRD-C 14, Handbook for Concrete and Cement.
** Usually three 3- by 6-in. cylinders; occasionally two or five specimens.
† Not determined.
†† After Buck, reference 6b.

Table 5**

Length-Change of Five Concrete Mixtures†

	Length-Change of Bars at Indicated Ages, %††								
	7 Days	14 Days	21 Days	28 Days	56 Days	90 Days	180 Days	365 Days	About 3 Years
Control Mixture 3: Recycled coarse and fine WES-42 CON-1, 1(S). Low C_3A RC-635. Average of two bars.				0.007		0.010			0.016
									About 1-1/2 Years
Mixture 8: Remake of 3 with added sulfate. Average of three bars.	0.018	0.024	0.029	0.035	0.048	0.055	0.069	0.091	0.100
Mixture 9: Recycled WES-42 CON-1(2), 1(2)(S), high C_3A cement. Average of three bars.	0.024	0.035	0.041	0.048	0.077	0.104	0.170	0.328	*
Mixture 10: Remake of 9 with some fly ash. Average of three bars.	0.028	0.039	0.046	0.055	0.087	0.114	0.175	0.285	*

(Continued)

Table 5**(Concluded)

Length-Change of Five Concrete Mixtures†

	Length-Change of Bars at Indicated Ages, %††								
	7 Days	14 Days	21 Days	28 Days	56 Days	90 Days	180 Days	365 Days	About 1-1/2 Years
Mixture 14: Remake of 10 with more fly ash. Average of four bars.	0.019	0.031	0.042	0.046	0.067	0.084	0.117	0.133	
Accelerated curing. Average of four bars.	0.049	0.060	0.065	0.065	0.074	0.076	0.084	0.098	
Outdoor exposure. Average of four bars.	-0.008	0.016	0.013	0.029	0.048	0.045	0.049	0.048	

* Discontinued.
** After Buck, reference 6b.
† Moist storage unless indicated otherwise.
†† Values are positive unless preceded by minus sign.

In accordance with ER 70-2-3, paragraph 6c(1)(b), dated 15 February 1973, a facsimile catalog card in Library of Congress format is reproduced below.

Buck, Alan D
Recycled concrete as a source of aggregate, by Alan D. Buck. Vicksburg, U. S. Army Engineer Waterways Experiment Station, 1976.
17 p. illus. 27 cm. (U. S. Waterways Experiment Station. Miscellaneous paper C-76-2)
CTIAC Report No. 19.
References: p.16-17.

1. Aggregates. 2. Recycled concrete. (Series: U. S. Waterways Experiment Station, Vicksburg, Miss. ~~Miscellaneous paper C-76-2)~~
TA7.W34m no.C-76-2