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Technical and Economic Analysis for Optimum Condition of Aggreate Recycled from Unused Ready-Mixed Concrete

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Abstract
The objective of this study is to find the optimum condition of aggregate recycling from unused ready-mixed concrete in order to reduce the quantity of waste concrete and the expenses of waste treatment. Moreover, the environmental impact from the abolition of waste concrete can also be reduced, and the economic aspect of such reduction has been analyzed. According to the testing quality on attribute of gradation and dust volume of gravel and sand derived from unused ready-mixed concrete, the property testing result met the standard range and was suitable for using as a concrete production material. The experimental design was conducted to find the optimum proportion of recycled and new gravel and sand. The proportion of recycled gravel and sand at the percentage of 0, 20, 40, 60, 80, and 100 were varied. From the result of this experiment, the optimum percentage of recycled gravel and sand should not exceed 60 percent. As for the economic feasibility study at the 10 years of project life and a minimum attractive rate of return of 20 percent, the incremental investment analysis revealed the net present value at $US 86,000 whereas the internal rate of return of the incremental investment was 50.88 percent per year. The payback period was 2 years and 11 months. Regarding the sensitivity analysis, it showed that changing of gravel and sand price in the range of +/-25 percent would only slightly influence the internal rate of return, which did not affect the investment decision. Thus it could be derived from the result of this study that the recycling of aggregate recycled from unused ready-mixed concrete, at optimum condition, was technically and economically feasible for investment.

Keywords
Aggregate recycled from unused ready mixed concrete, Technical and economic analysis, Ready mixed concrete, Aggregate recycling, Unused ready mixed

1. Introduction

As a consequence of economic growth in Thailand, the construction industry, both in government and private sectors, tends to grow accordingly. Cement concrete is a leading material resource for construction because of its strength, its ability to be molded into any shape, its resistance to fire and weather, and the availability of raw materials from which it is made. Concrete is made by mixing selected proportions and qualities of cement, sand, gravel and sometimes other aggregates. Water is added and the soft mixture is formed into desired shapes. Water and cement interact chemically to form a solid mass, binding the ingredient particles together. While the mixture remains soft, it can be shaped before becoming hardened. Cement products are widely used in many forms such as portland cement for concrete mixing at construction site, pre-cast concrete products, and ready-mixed concrete.

Ready-mixed concrete has made a major contribution to the construction industry in terms of its consistent quality, modernization, and construction efficiency as well as time and cost saving. Whilst the production of ready-mixed concrete has a low impact on the environment, the problems have been raised regarding to the disposal of returned concrete. As the ready-mixed concrete is to be used within maximum 3 hours after production, during operating hours, it is common practice for the residual ready-mixed concrete to remain in the truck drum to be incorporated into the next concrete load. When the next load delays or may not be made within the acceptable hours, facility operators normally use retarding agents to slow down the hydration. However, should incorporation into the next load not be possible, the return concrete must be discharged from the truck drum and washed out of the mixer drum in order to avoid the risk that a residue concrete may set if it is allowed to remain in the drum for too long. Such unused concrete is generally disposed of by one of the following methods: (Ottl, 2000) production of other pre-cast concrete products, on-site use in paving yard surfaces or as site fill and recycle into cement manufacturing process.

The production of concrete at a ready-mixed batching plant involves a) accurately weighting the required quantity of each constituent materials b) mixing them together either in the drum of a mixer truck or a static pan-mixer and c) transporting to customers at construction sites. At the end of the operating day, return of excess concrete left in the truck drum has to be washed off. Most of the ready-mixed concrete plants have paved process area in order to allow collection of contaminated process water and surface runoff from truck loading, truck wash off and drum washout area, which provide collection of runoff and leach ate from sludge storage and drying piles. The concrete process water is caustic and typically has high pH value ranging between 11 to 12. The wastewater is decanted from the collection basin for wastewater treatment. Since drum washout uses significant amount of water, recycling or reuse has great benefit for water use reduction (Sealey *et al.*, 2001). In addition, as the solid waste is allowed to dry, it can be removed for use as landfill material.

The ready-mixed concrete consists mostly of natural aggregates, which are sand (38 wt%), gravel (35.8 wt%), and the mixture of cement (10 wt%), fly ashes (3.3 wt%), plasticizer and water (7 wt%). The unlimited and uncontrollable utilization of these nonrenewable natural resources produce sensitive impact to world ecology and environment. Many regulating bodies throughout the world are implementing measures, which actively promote environmentally sound and economically viable routes to convert waste into a valuable resource for industrially sustainable development of the country. As the ready-mixed concrete industry in Thailand is highly competitive, producers who have successfully reduced the quantity of waste by utilizing more efficient technology and management techniques would have greater commercial advantage.

The objective of this study is to find the optimum condition of aggregate recycle from unused ready-mixed concrete in order to reduce the quantity of such waste concrete and the expenses of waste treatment. Moreover, the environmental impact from the abolition of waste concrete can also be reduced, whereas the recycle of gravel and sand would help protect the natural resources and must be attributed to an economic value of the country (Cosgun and Esin, 2005). Technical, economic and environmental aspects have also been taken into consideration. The experiments were conducted at the first ready-mixed concrete company in Thailand, who received complete quality system approval from respective institutions. The company has more than 250 plants all over the country of which more than 1,500 truck drum services. The selected pilot plant is located at the central region of the country and has ready-mixed capacity of 180,000 cu.m. per year or 432,000 tons per year.

For the past 5 years, the residue concrete returned to the company has increased from 1.55% of production quantity in 2001 to 5.46% in 2005, which accounts for the waste treatment costs of $US 7,200 annually. Such unused concrete waste treatment costs also exhibit strong trend to increase in accordance with the growth of production as shown in Table 1.

Table 1: Unused Concrete Waste Treatment Costs

Year	Production Quantity (cu.m)	Concrete Waste		No. of Treatment (Time)	Treatment costs	
		(cu.m)	(%)		(US$)	US$/ 1,000 cu.m of production
2001	79,930	1,238	1.55	5	1,714	21.43
2002	81,538	1,284	1.57	5	2,142	26.29
2003	82,449	1,800	2.18	5	2,571	41.71
2004	84,384	4,170	4.94	9	5,142	60.86
2005	85,570	4,670	5.46	10	7,200	84.00

2. Experimental Procedure

As the quality of the ready-mixed concrete, in terms of workability for fresh concrete and the desired strength once the mixture has harden, depend upon the quality of aggregates and the proportion of the ingredients. The attribute of gradation and dust volume of gravel and sand from wash residue of unused ready-mixed concrete were tested for its specific surface area and percentage of dust and compared with the new gravel and sand at the acceptable range. The six proportions of mixed fresh concrete were prepared and tested for initial slump loss and stiffening to find the optimum proportion. The compressive strength and abrasive testing in terms of weight loss of concrete from each proportion at the age of 7 and 28 days were tested.

The experiments were conducted as following:

2.1 Ten samples of recycled gravel and sand from recycling wash residue of ready-mixed concrete were taken in the same day in order to compare with the new samples. The property testing was conducted in accordance with the American Society for Testing and Materials (2003). The ASTM C136 (method for sieve analysis of fine and coarse aggregate) and ASTM C117 (method for materials finer than 75 micrometer in mineral aggregate by washing) were conducted for attribute of gradation and dust volume respectively in comparison between recycled and new gravel and sand.

2.2 The concrete samples made from partly aggregate recycled from unused ready-mixed concrete at the cubic shape of 15x15x15 cc. were prepared. The six proportions of recycled gravel and sand at 0, 20, 40, 60, 80, and 100 wt% were mixed with the new gravel and sand. The compositions of mixed concrete are shown in Table 2. Five replications at each proportion from the same mixing lots were tested for initial slump loss and settling time properties at the stage of fresh concrete.

2.3 The compressive strength and abrasive resistance properties according to ASTM C 779 (Standard test method for abrasion resistance of horizontal concrete surfaces) were tested at the concrete age of 7 and 28 days. Mean and standard deviation for each set of experiment were calculated and compared with the acceptable range. The hypotheses were set in order to determine the effect of the six proportions to the compressive strength and abrasive testing.

2.4 Technical feasibility was concluded in order to find the optimum proportion.

2.5 The economic analysis of the optimum condition was performed by incremental investment analysis at the 10 years of project life and at a minimum attractive rate of return of 20%. The internal rate of return as well as the payback period of the incremental investment was also analyzed.

Table 2: Six Proportions of Recycled and New Aggregate

Proportion of Recycled Aggregate (%)	Composition of Mixed Concrete (kg.)						
	Cement	NG	RG	NS	RS	Water	Mixture
M1-0%	280	1,160	0	840	0	178	1.12
M2-20%	280	928	232	672	168	178	1.12
M3-40%	280	696	464	504	336	178	1.12
M4-60%	280	464	696	336	504	178	1.12
M5-80%	280	232	928	168	672	178	1.12
M6-100%	280	0	1,160	0	840	178	1.12

NG = New gravel RG = Recycled gravel
NS = New sand RS = Recycled sand

3. Results And Disscussion

3.1 Comparison Results between Recycled and New Gravel and Sand

The testing results of Specific Surface Area (SSA) and the percentage of dust in the recycled and the new gravel and sand were compared to the acceptable range. The results revealed no significant difference of the said properties between the recycled and new gravel and sand, and both were in the acceptable range as shown in Table 3. Thus the recycled gravel and sand might be possible for partial substitution of new gravel and sand.

Table 3: Property Comparison of Recycled and New Gravel and Sand

Property	Recycled		New		Acceptable Range
	Mean	Std.	Mean	Std.	
Sand					
SSA(cm^2/kg)	24,969	2,540	28,763	1,270	14,400-36,900
Dust (%)	2.80%	0.03%	2.45%	0.08%	Less than 3%
Gravel					
SSA(cm^2/kg)	2,652	175	2,686	146	2,400-3,300
Dust (%)	0.65%	0.04%	1.04%	0.10%	Less than 1.5%

3.2 Property Testing of Fresh Concrete

The six proportions, at five replications each, of mixed fresh concrete were tested for initial slump and slump loss as shown in Table 4 and Figure 1. The results revealed that the increase of recycled gravel and sand proportion would reduce the initial slumps and slump loss. The slump loss would result in higher requirement of water and reduction of the compressive strength. At the acceptable initial slump loss of 10-12.5 cm., the proportion of recycled gravel and sand should not be more than 60%

Table 4: Initial Slump Loss and Slump Loss

Time (Min.)	Initial Slump Loss and Slump Loss (cm)					
	M1-0%	M2-20%	M3-40%	M4-60%	M5-80%	M6-100%
0	12	11	10	10	9	8
15	10.5	9.5	9.5	8.5	7.5	7.5
30	9.5	8.0	8.0	7.5	5.5	5.0
45	8.0	7.0	7.5	6.0	5.0	4.5
60	7.0	6.0	6.0	5.5	4.5	4.0
75	6.0	5.0	5.5	3.5	2.5	3.0
90	5.5	3.5	3.0	2.0	0	0
105	2.5	0	0	0	-	-
120	0	-	-	-	-	-

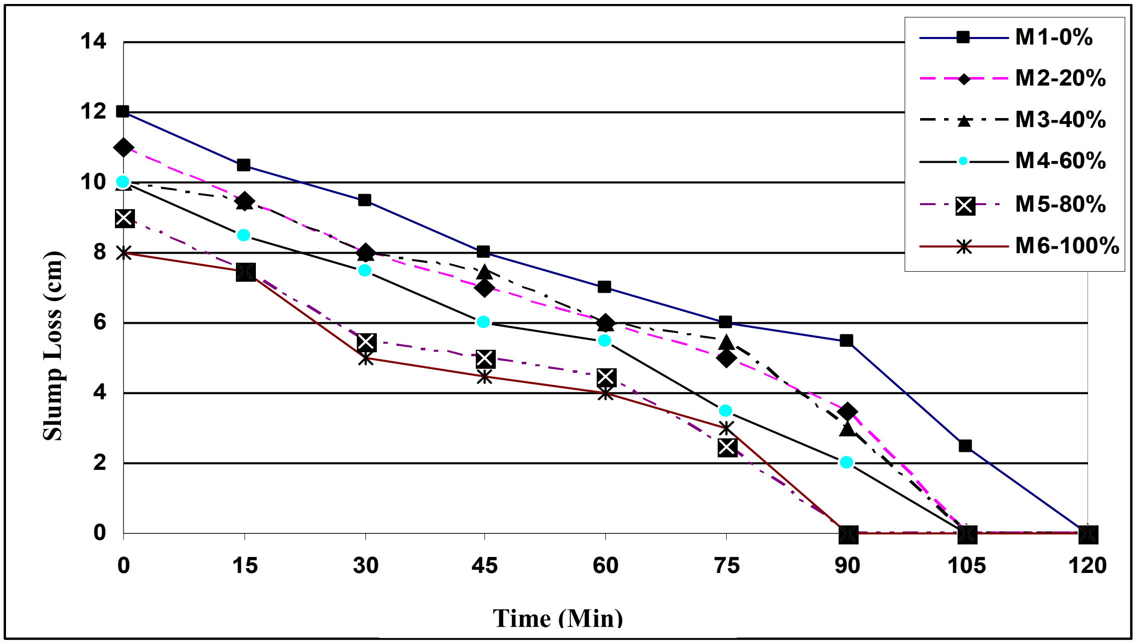

Figure 1: Relationship between Time and Slump Loss

For the result of stiffening and initial setting time, it revealed that the setting time was reduced as the proportion of recycled gravel and sand increased. Furthermore, the proportion of recycled aggregates more than 80% yielded more significant difference from the other proportions as shown in Table 5.

Table 5: Stiffening and Initial Setting Time

Proportion (%)	Setting Time (Hour)	
	Stiffening	Initial
M1-0%	6.38	7.43
M2-20%	6.22	7.21
M3-40%	6.14	7.11
M4-60%	4.75	6.57
M5-80%	4.34	5.41
M6-100%	4.09	5.13

3.3 Property Testing of Concrete at the Age of 7 and 28 days

The mean and standard deviation of compressive strength of concrete at the age of 7 days were 211.87 and 19.03 kg/cm^2, respectively, whereas such deviations at 28 days were 324.7 and 19.40 kg/cm^2, respectively. The increase of recycled gravel and sand proportion would reduce the compressive strength. The mean compressive strength of concrete at the age of 28 days at the proportion of 80% and more were less than the acceptable limit of 309 kg/cm^2. The hypothesis testing by Minitab software was conducted in order to determine the effect of proportions used on the compressive strength.

The results revealed that, at 5% significant level, the variation of proportion of recycled gravel and sand would affect the compressive strength as shown in Table 6 and Figure 2. The increase of proportion would reduce the compressive strength.

Table 6: Analysis of Variance of Compressive Strength

Source	DF	SS	MS	F	P
Proportion	5	9954.7	1990.9	49.59	0.000
Error	24	963.6	40.2		
Total	29	10918.3			

S = 6.336 R-Sq = 91.17 % R-Sq(adj) = 89.34 %

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                         Individual 95% CIs for Mean Based on Pooled Std.
Level  N    Mean  Std.  -------+---------+---------+---------+--
  0    5  342.60  6.73                                 (--*---)
 20    5  340.60  2.70                               (---*---)
 40    5  334.00  3.54                           (---*---)
 60    5  331.60  5.46                        (---*---)
 80    5  303.80  8.87       (---*--)
100    5  295.60  8.20  (---*---)
                        -------+---------+---------+---------+--
                             300       315       330       345
Pooled Std. = 6.34
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Figure 2: Individual 95% Confidence Intervals for Mean Based on Pooled Standard Deviation

As for the abrasion resistance in terms of weight loss, the hypotheses results at 5% significant level revealed the average weight loss between 7.00-7.90 gm as shown in Table 7 with no significant difference of average abrasion resistance between the six levels of proportion.

Table 7: Abrasive Testing in Terms of Weight Loss

Proportion	Recycled gravel and sand (%)	Average weight loss of concrete (gm)
M1-0%	0	7.80
M2-20%	20	7.00
M3-40%	40	7.20
M4-60%	60	7.50
M5-80%	80	7.20
M6-100%	100	7.90

From the above technical result, the utilization of recycled gravel and sand from unused ready-mixed concrete was technically feasible at the optimal proportion of recycled aggregates less than 60%.

3.4 Economic Consideration

For implementation of the unused ready-mixed concrete plant, the incremental investment cost was estimated at $US 65,715 with the following details:

3.4.1 Concrete recycling plant with gravel and sand separation system with the capacity of 12 m^3 per hour and 80% capacity utilization together with water supply system with the water consumption rate of 3 m^3 per hour, electrical control system and feeding conveyor at the total cost of $US 62,857.

3.4.2 Civil work for construction of concrete wash out area, waste water storage pit and aggregate storage was at the total cost of $US 2,858.

The source of finance of $US 65,714 was from the local commercial bank at the minimum loan rate of 12% per year and constant principle type of amortization of within 5 years. The annual debt service of principle repayment at $US 13,143 and interest at 12% of the debt balance at the beginning of each year were paid at the end of year.

The average incremental annual operation costs were at US$ 11,576.91 with the following details:

Electricity cost (11 KW)	US$ 499.29
Water cost (3 m^3 per hour)	US$ 909.47
Conveying cost	US$ 2,586.74
Maintenance cost	US$ 278.55
Labor cost	US$ 2,571.43
Interest	US$ 4,731.43

The sources of annual revenue at $US 37,757.67 were the cost saving of the recycling aggregate and the waste concrete treatment costs as follows:

The cost savings of 2,625.55 tons per year of gravel and 1,901.26 tons per year of sand were $US 20,483.79 and 9,627.44, respectively.

The cost saving of 87,014 tons per year of waste concrete treatment was $US 8,246.44.

The economic analysis at the optimum proportion of 60% recycling was performed by incremental investment cost analysis using present worth method, at the minimum attractive rate of return of 20% and at 10 years of project life. The pay back period as well as breakeven analysis were analyzed. All costs were estimated by constant basis at 2007.

At the 10 years of discounted cash flow and 20% minimum attractive rate of return the net present value before income tax was US$ 86,394.03 and the pay back period was 2 years and 11 months. The internal rate of return was 50.58%. During the first year of the project, the concrete waste was 5,658.52 tons and the breakeven point was 2,669.68 tons, which was equal to 47.18% of production volume. After 5 years of operation, the concrete waste increased to 6,117.96 tons per year which could reduce the breakeven point further to 1,195.35 tons per year, accounting for only 19.45%.

The sensitivity analysis for the variation of gravel and sand price in variation range of 25% would only slightly influence the internal rate of return and payback period. Hence, there was no significant change in decision making for investment

4. Conclusion

From the result of this study, it could be concluded that the recycling of unused ready-mixed concrete, at the proportion of not exceeding 60%, was technically feasible. The specific surface area and percentage of dust were comparable to the new gravel and sand and were in the acceptable range. The property testing of fresh concrete in terms of setting time at the age of 7 and 28 days in terms of compressive strength was also in acceptable range. The optimum proportion of 60% recycling yielded economically feasible return on investment with the internal rate of return of 50.58% and 2 years and 11 months payback period. The recycling of aggregate for concrete production could reduce the gravel and sand consumption, which was considered to be limited and nonrenewable natural resources crucial to the world ecology and the environment. However, partial utilization of recycled aggregate might cause some difficulty in raw material preparation for ready-mixed concrete and the homogeneity of the concrete quality. Also, the concrete wash out water, which was caustic and typically had high pH value ranging between 11 to 12 as well as contained dissolved solid (including sulfates and hydroxide from cement, oil, and grease) from equipment, could cause negative impact to the environment. The treatment process and recycling of concrete wash out water should be taken into consideration for further study.

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