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Recycled Aggregates Production Through Economic Perspectives

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Abstract: Construction and Demolition Waste (CDW), especially laboratory waste and concrete debris from construction, manufacturing errors, and demolition of existing structures, is posing challenges to the urbanization. As nowadays the aforementioned waste is disposed in landfills, this diminishes the development opportunity of cities. Although there are standards and research pointing out the application of recycled concrete aggregates in proper proportion, the theory has never been put into practice. This research aims to present feasibility of applying recycled aggregates through Bangkok's economic perspectives. It is found that the investment in recycled aggregate plants takes nine years of payback period. Besides, the sensitivity analysis suggests that implementing certain strategies, such as imposing a landfill tax increase and applying dumping fee will significantly shorten the payback period of recycling business.

Keywords: Recycle aggregate concrete, sustainable construction, construction waste

1. Introduction

Urbanization has fueled the continuous demand for infrastructure construction. According to the National Statistical Office [National Statistic Organization of Thailand, 2012], the number of building areas for construction approval in 2017 has increased by 14 percent compared to 2016. As a result, Construction and Demolition Waste (CDW) which makes up one-third of the total construction materials [Ghanbari et al., 2017] has also increased. Moreover, 60-80 percent of the waste is solid waste [World Economic Forum, 2016] which requires proper disposal. Normally, solid waste is disposed by being dumped in landfills in cities and sites near the construction without being sorted out properly, resulting in a limited land use.

Inspired to overcome the problem, the research presents the idea to take advantage of the recycled aggregates, especially those in cities where concrete debris from demolition of existing structure, the leftover concrete from the construction, and the laboratory waste are generated [Li et al., 2013]. This does not only relieve the problem, but also presents a potential approach to decrease transportation costs which are mainly accounted for the costs of crushed stones to be mixed in concrete [Coelho and de Brito, 2013]. The use of recycled aggregates is not something new as the research suggests that if used in right proportion, recycled aggregates can be used in concrete without the quality of concrete being affected compared to that of natural aggregates. Therefore, recycling concrete which has long been the main material in the construction poses a very intriguing question—the question that will lead to not only innovative but also necessary process [Curovic and Srije, 2016].

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There are two main challenges posed to aggregate recycling. First is the nature of recycled aggregates. Another challenge is that it requires a thorough cost-benefit analysis [Li et al., 2013]. Although there has been cost-benefit analysis of aggregate recycling conducted in many countries [Huang et al., 2002, Tam and Tam, 2006 and Duran et al., 2006], its effectiveness cannot be put into practice due to different business environments. Moreover, there is little relevant information available in Thailand.

This research focuses on the analysis of economic feasibility of recycled aggregate plants investment in Thailand as a case study.

1.1 Concrete from Recycled Aggregates

According to the study of using recycled aggregates in concrete [Otsuki et al., 2004, Dhir and Dyer, 2005 and Blengini and Garbarino, 2010], recycled aggregates affect the water absorption of concrete so dramatically that the permeability resistance of concrete reduces, and the shrinkage of concrete increases; however, if not over 20-30 percent of recycled aggregates are used, the quality of concrete in terms of fresh concrete workability is not affected compared to that of natural aggregates. The application of recycled aggregates has been widely accepted in many countries. In Thailand [Tam, 2008], the application of G1-quality coarse recycled aggregates is accepted in any concrete-related work while other levels of quality can be applied only in certain conditions with the highest compression.

1.2 Concrete Recycling Technology

In Taiwan and Italy, concrete waste from different sources is transported to recycled concrete plants in cities located within 15-25 kilometers from the sources where concrete waste is generated [Zhao et al., 2010 and Yoda, 2018]. The fact that the plants are located not so far away from the sources is the most effective way to help control transportation costs. As illustrated in picture 1, concrete waste is separated from easily sorted out materials, such as wood waste, tiles, and paper. Next step is to sort out reinforcing steel by using a jackhammer and break into small pieces. Next, the concrete waste is crushed into smaller pieces with the size not bigger than 80 millimeters and remaining tiny pieces of steel are sorted out by using a magnetic separator. After that, the aggregates are crushed into even smaller pieces while the coarse aggregates are separated from the crushed ones. Zhao et al [Nunes et al., 2007] found that the most effective power of jaw crusher is approximately 100-600 ton per hour.

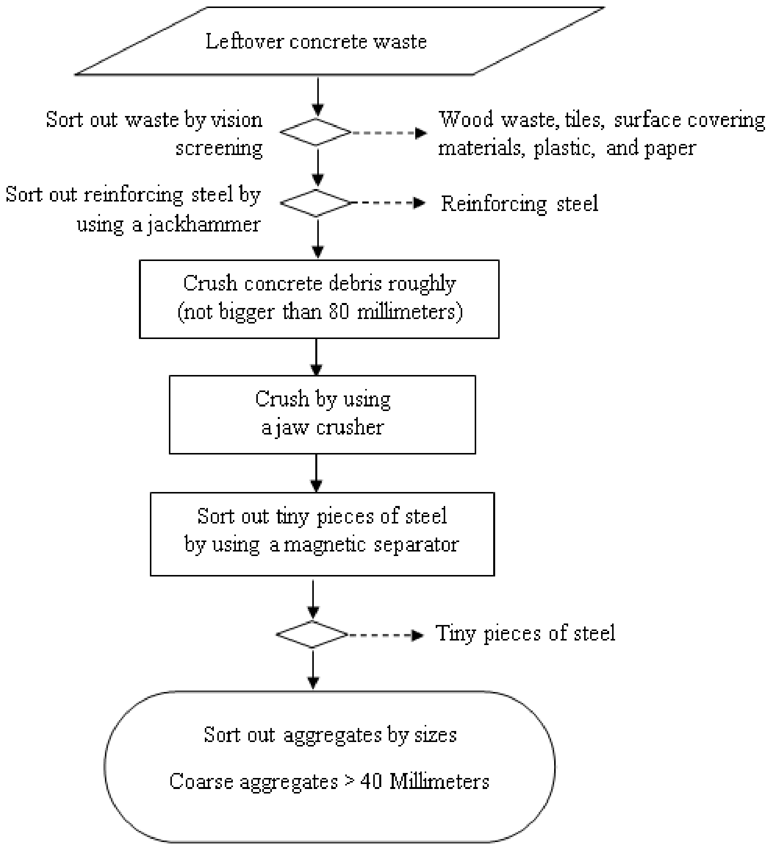

Fig. 1 - The process of aggregate recycling

In Japan, there is technology [Coelho and de Brito, 2013a] that requires mortar cracking through rotary drum mill wet process in order to reduce secondary interfacial transition zone which is a weak point in concrete produced from recycled aggregates [10].

1.3 Economics of Production

The cost-benefit analysis of investment in recycled aggregate plants requires a thorough consideration through various perspectives, including environment, society, and economy. According to the Trade Policy and Strategy Office, with a decline in natural aggregate sources, a higher demand for aggregates, and a higher production cost as well as higher transportation costs, the prices of crushed stones have increased by 23 percent in the past decade [18], resulting in higher possibility that the benefits of recycled aggregate plants in cities will outweigh their costs. Moreover, if the government implemented measures, such as imposing higher dumping fee as well as higher quarry tax concessions, and allocating subsidies to encourage sustainable industry, the possibility would be much higher.

2. Methodology

In this case study, the recycled aggregate plant in Bangkok with 150 ton per hour aggregate mining machine from Shanghai Sanme Mining Machinery is focused and studied.
As presented based on table 1, the life expectancy of a jaw crusher is expected to be 60 years [Trade Policy and Strategy Office, 2018]. Other details are categorized based on the following topics.

2.1 Income

The income is calculated based on the total production capacity with the prices of crushed stones at 565 baht according to the 2017's prices.

2.2 Fixed Cost

Fixed costs are expenses not based on the level of production, consisting of the costs of machinery, other equipment, land rental, and construction. The expenses are the same throughout the project.

2.3 Variable Cost

Variable costs are expenses that vary based on the level of the production, consisting of the costs of labor, transportation, fuel, and production leftovers.

2.4 Payback Period (PP)

Payback period refers to the amount of time it takes to recover the cost of an investment which can be calculated based on:

$$PP = \frac{C_0}{\sum C_i} \tag{1}$$

if

C_0 = Initial Investment

C_i = Annual Net Cash Flow

2.5 Internal Rate of Return (IRR)

Internal Rate of Return refers to the rate of return that sets the net present value of all cash flows from the investment equal to zero which can be calculated based on:

$$0 = -C_0 + \sum_{i=60}^{i=1} \frac{C_i}{(1+IRR)^i} \tag{2}$$

2.6 Sensitivity Analysis

Sensitivity Analysis refers to the study to determine how different values of an independent variable affect a particular dependent variable under a given set of assumptions. In this case study, the sensitivity analysis is applied to determine strategies government should implement.

Table 1 - Statement of cash flow in operating recycled aggregate plants in 60-year production period.

Types of Expenses	Description	Assumption	Net Present Value, NPV (Baht)	Percentage
Fixed Cost	Cost of Machinery with power of 150 ton per hour	- 7 years of depreciation (calculated by Direct Method)	3,221,001	1.56
		- Work 8 hours/day, 300 days/year [16]		
	Cost of Construction	- accounted for 50% of Machinery Costs [19]	1,184,192	0.57
		- Loan interest rate at 6% for 10 years		
	Cost of Land Rental	- Outer Bangkok areas	2,400,000	1.16
		- 4,000 square meters [16]		
		- Land rental at 600 baht/square meter/year [22]		
Variable Cost	Cost of Labor	- 6 Technicians	2,280,000	1.10
		- 12 Laborers		
		- 1 Manager		
	Cost of Fuel	- machines with power of 2.2 kWh/ton	1,686,960	0.81
		- 2.18 baht/kW electricity [23]		
	Cost of Maintenance	- accounted for 6% of production capacity [19]	12,204,000	6.00
	Cost of Materials and Cost of Disposal	- accounted for 79.56% of the total value of production [19]	161,825,040	78.17
	Cost of Transportation	- accounted for 8.75% of the total value of production [16]	17,797,500	8.60
Income	Sale Value	- Stone price at 565 baht/ton	203,400,000	

3. Results and Discussion

Two main perspectives which are payback period and sensitivity factors in encouraging the sustainable industry in Thailand are focused in the study. As for payback period, the net present value of the business has gradually increased from that of the earlier which suffers a net loss due to the costs of construction and machinery as illustrated in fig. 2. After seven- and ten-years depreciation of the construction and machinery respectively, the net value of the business has increased which eventually outweighs the total expenses. This means that the payback period of the recycled aggregate plants in Thailand takes approximately nine years with internal rate of return at 12.94 throughout the project. On the other hand, according to Zhao et al's research [Zhao et al., 2010] which was conducted in Chongqing in China, the payback period of the business requires 2.43 years while that of Coleho and de Brito's research which was conducted in Lisbon in Portugal is 2 years. This is because in Thailand the costs of stones are cheaper, and the costs of labor and transportation are less accounted for the total expenses compared to the mentioned research.

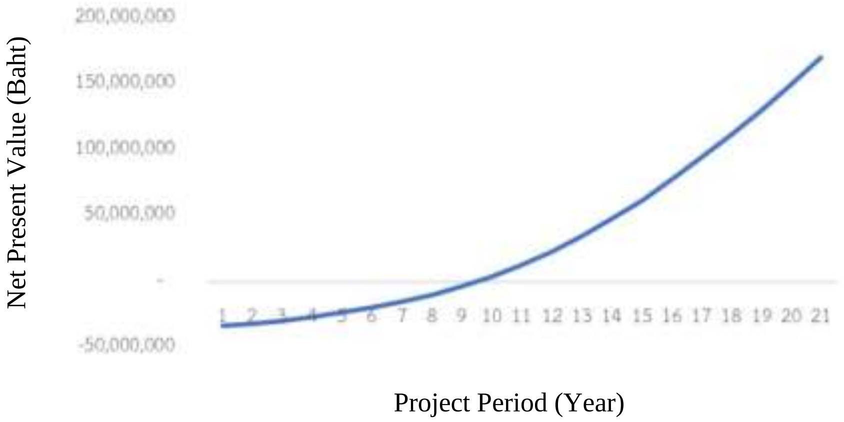

Fig. 2 - The payback period of recycled aggregates

Imposing higher dumping fee on construction businesses helps reduce the cost of recycled aggregates proportionally. Moreover, the shorter payback period is sensitive to imposing higher costs of transportation and allocating subsidies to encourage sustainable industry. As illustrated in picture 3, it is obvious that imposing higher dumping fee on construction businesses results in shorter payback period. If the cost of the aggregates can be reduced by 30 percent, the payback period will be less than 1 year.

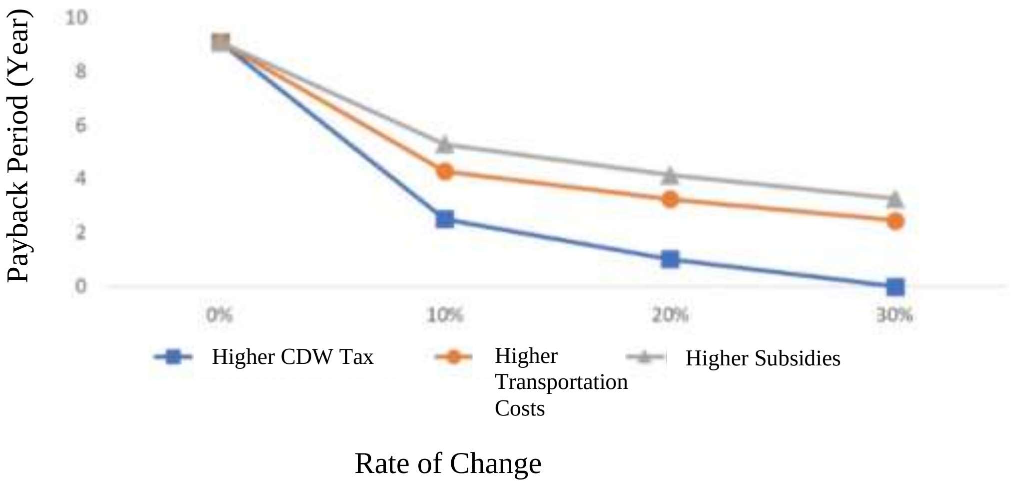

Fig. 3 - Sensitivity analysis of measures leading to shorter payback period

4. Conclusion

In Thailand, the use of recycled aggregates cannot be put into practice soon. Although there are studies of the nature of recycled aggregates, and the standards are about to set, the lack of conclusive studies of payback period is still a challenge. Therefore, this research focuses on recycled aggregates through economic perspectives and can be concluded as follows:

- Because the investment on recycled aggregates is still too high and requires payback period three to four times longer than that of investment in other countries, recycled aggregates might not be widely employed.
- The government needs to rigorously impose measures on dumping fee in order that the business can be sustainable and worth to be invested in. According to the sensitivity analysis, it is obvious that the shorter payback period is more sensitive to imposing higher taxes than other measures, such as imposing higher transportation costs and direct support of the recycle business.

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