Emergy Evaluation of Green Concrete Production Efficiency

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Abstract. By comparing the traditional concrete production mode with green concrete production mode, including recycled aggregate concrete production mode and fly ash concrete production mode, the system emergy flow of each production mode is analyzed, and the emergy analysis method for each mode is put forward.

1. Introduction

Since the beginning of the 21st century, China's concrete usage has been ranked first in the world for a long time. China Association of Concrete and Cement Products statistics the production and operation of ready-mixed concrete enterprises (groups) in China. The results show that the actual production of ready-mixed concrete enterprises (groups) in China totaled 1.645 billion m\(^3\) in 2015. In China, concrete products and components, concrete mixing stations and other construction methods are adopted, and about 2 billion m\(^3\) of concrete are used in national projects and infrastructure construction every year.

Concrete, as the most used building material in construction projects, has a great impact on ecological resources. In the early stage of construction, traditional concrete production enterprises invest a lot in economy and technology in order to pass environmental impact assessment (EIA), but after large-scale production, they lack necessary environmental protection measures such as dust and sewage discharge, noise isolation and so on. China produces a large number of concretes, some cities or regions adopt green concrete production to replace the traditional concrete construction site mixing, which has produced greater social and economic benefits in terms of productivity, quality, resources, and environmental protection and so on.

Green concrete is an environmentally friendly concrete material which can not only reduce the load on the natural environment in the production process, but also coordinate with the ecosystem on which human beings depend for survival, and be used in the practice of building activities.

Green concrete production has three meanings:

- Low resource consumption. Make the best use of industrial waste (fly ash, gangue, etc.), tailings, construction waste (waste concrete, waste bricks, waste mortar, etc.).
- Environmentally friendly. In the process of concrete production and construction, pollution should be reduced to the acceptable range of natural environment, or even zero pollution, without harmful effects on natural ecosystem.
- It can be recycled. The durability of concrete can be improved by using high and new material technology, so that waste concrete can be recycled as concrete aggregate.

Green building materials are the development direction of civil engineering construction materials. Green concrete technology has been developed for many years, but in the process of construction,
besides some pilot projects, the application scope of green concrete is still very small, which requires the necessary benefit analysis of green concrete, and the direct driving force to promote the development of green concrete.

According to the current construction technology level of green concrete, the main production modes of green concrete are: recycled aggregate concrete production mode, fly ash concrete production mode and recycling economy concrete production mode. The production process of green concrete involves the crushing, sorting, recycling, transportation of waste concrete, the processing of recycled aggregate, and the recovery, processing, adding and transportation of industrial waste (slag, fly ash) from other enterprises. As a complex industrial ecosystem, green concrete production has many units of input and output, including material flow, energy flow, information flow, labor flow, etc. When conducting benefit analysis, it needs to be treated in a unified dimension. The traditional method of benefit analysis is to convert input and output into money for comparative analysis. In the process of application, the accuracy and applicability of this method have certain limitations. The emergy analysis method is adopted in this study.

It is generally believed that the self-organization, transformation and information paper published by American ecologist H.T. Odum in 1983 in the Journal Science marks the establishment of emergy theory. Then Sweden, Australia, Italy and other countries carried out emergy research in the 1990s. Lan Shengfang, a Chinese scholar, first introduced emergy theory into China in the early 1990s. The popularization and application of emergy theory has received great attention in the domestic academic circles. The National Natural Science Foundation of China has supported dozens of emergy analysis projects successively, and carried out emergy analysis theories and methods from the aspects of country, region, city, nature reserve and agricultural development. However, the emergy analysis method used in the benefit evaluation of industrial production system is relatively few. In order to make the emergy analysis method suitable for the benefit evaluation of industrial ecosystem, this study used the emergy analysis method to analyze the production benefit of green concrete, fully considered the input and output value of the whole system, analyzed the distribution ratio of each production element in the green concrete production mode, and finally calculated the emergy analysis index.

The calculation of energy [1]:

\[ M = \tau \times B \]  

\( M \) is emergy, \( \tau \) is transformity, and \( B \) is available energy.

Indicators of emergy analysis [2] and calculation formulas:

EIR (Emergy investment ratio)

\[ EIR = \frac{F}{N+R} \]  

EYR (Emergy yield ratio)

\[ EYR = \frac{Y+W}{F} \]  

ELR (Environmental loading ratio)

\[ ELR = \frac{F+N}{R} \]  

ESI (Emergy sustainability index)

\[ ESI = \frac{EYR}{ELR} \]
Among them, F is the emergy of input material, energy flow and labor or service; Y is the emergy of production; W is the emergy of output waste; N is the emergy of non-renewable resources; R is the emergy of renewable resources.

2. Energy Value Analysis and Contrast of Green Concrete Production

2.1. Traditional concrete production mode
The emergy of input and output of traditional concrete production methods are shown in Table 1.

Table 1. Energy Value of Input and Output of Traditional Concrete Production

| Raw Material:             | unit | Input (Output) Quantity | Resource Quantity | Transformity (Sej/Unit) | Emergy (Sej) |
|---------------------------|------|-------------------------|-------------------|-------------------------|--------------|
| Cement                    | g    | 2.64 E+08               | 2.31E+09[3]       | 60.98                   |
| Sand                      | g    | 6.72 E+08               | 1.00E+09[4]       | 67.20                   |
| Aggregate (gravel)        | g    | 8.58E+08                | 1.00E+09[4]       | 85.80                   |
| Industrial Water Consumption | g   | 6.86 E+08               | 4.10E+04[5]       | 0.0028                  |
| Mechanical Agitation      | g    | 9.80E+05                | 6.70E+09[6]       | 0.66                    |
| Electricity               | j    | 2.41E+10                | 1.59E+05[4]       | 0.38                    |
| Traffic                   | t×m  | 6.92 E+05               | 2.81E+11[3]       | 19.45                   |
| Labor and Service         | $    | 4.45E+02                | 8.67E+12[3]       | 0.39                    |
| Concrete (annual output)  | g    | 1.63E+09                | 1.44E+09[3]       | 234.86                  |
building waste stacking [8]. The cost of recycled aggregate of construction waste may be slightly higher than that of natural aggregate when the cost of disposal is high, but if it can be disposed, broken and utilized locally in the demolition and reconstruction site, the cost can be reduced, or the relative value of recycled aggregate utilization will be higher when the cost of construction waste discharge is high and the local natural aggregate resources are scarce. In this study, recycled aggregate concrete produced by enterprises accounts for about 40% of the total concrete production.

2.3. Production Mode of Concrete Mixed with Fly Ash
The use of by-products as raw materials has many advantages, such as saving energy, reducing carbon dioxide emissions, environmental protection, and more importantly, these processed blends are very cheap [9]. Since the appearance of ground slag, fly ash can be used not only as cement mixture, but also as concrete mixing. Table 3 is the emergy calculation of concrete production mode with fly ash.

| Raw Material: | Input (Output) Quantity | Resource Transformity (Sej/Unit) | Emergy (Sej) |
|--------------|-------------------------|----------------------------------|--------------|
| Cement       | 2.64 E+08               | 2.31E+09[3]                      | 60.98        |
| Sand         | 6.72 E+08               | 1.00E+09[4]                      | 67.20        |
| Aggregate (gravel) | 5.12E+08            | 1.00E+09[4]                      | 85.80        |
| Fly ash      | 1.72E+07               | 1.40E+10[3]                      | 24.08        |
| Industrial Water Consumption | 6.86 E+08      | 4.10E+04[5]                      | 0.0028       |
| Mechanical Agitation | 9.80E+05        | 6.70E+09[6]                      | 0.66         |
| Electricity  | 2.41E+10               | 1.59E+05[4]                      | 0.38         |
| Traffic      | 6.92 E+05              | 2.81E+11[3]                      | 19.45        |
| Labor and Service | 4.45E+02         | 8.67E+12[3]                      | 0.39         |
| Concrete (annual output) | 1.65E+09       | 1.57E+099                       | 258.94       |

3. Emergy index calculation
The calculation results of emergy flow and index of traditional linear production mode, recycled aggregate concrete production mode and fly ash concrete production mode are shown in Table 4.

| Emergy flow and index                  | Traditional production mode | Recycled aggregate concrete | Concrete Mixed with Fly Ash |
|----------------------------------------|-----------------------------|-----------------------------|-----------------------------|
| **Emergy flow**                        |                             |                             |                             |
| Renewable Resources (R)                | 0.0028                      | 43.22                       | 24.08                       |
| Non-renewable resources (N)            | 213.98                      | 180.17                      | 213.98                      |
| External energy input (F)              | 20.88                       | 22.86                       | 20.88                       |
| **Emergy index**                       |                             |                             |                             |
| Emergy investment ratio (EIR)          | 1.34E-04                    | 0.53                        | 0.87                        |
| Emergy yield ratio (EYR)               | 11.46                       | 12.03                       | 12.63                       |
| Environmental loading ratio (ELR)      | 8.37 E+04                   | 3.02                        | 9.74                        |
| Emergy sustainability index (ESI)      | 1.37 E-04                   | 3.99                        | 1.30                        |
Both the production mode of recycled aggregate concrete and the production mode of fly ash concrete can reduce the energy input rate EIR and the environmental load rate ELR of the system. The ELR of recycled aggregate concrete production mode is the lowest at 3.02, which breaks through the previous disposal mode of waste concrete landfill, and recycles it as renewable material, and produces the least load to the natural environment.

The maximum ESI of recycled aggregate concrete production mode is 3.99. This shows that although the collection and sorting of waste concrete and the recovery and treatment of fly ash need to consume a lot of manpower and material resources, and increase the input of social and economic resources, the sustainability of green concrete production mode will be increased with the improvement of technical equipment level of production mode and the adoption of advanced management mode [10].

4. conclusion
Taking green concrete production mode as an example, the emergy analysis of various modes is carried out. The results show that the emergy evaluation method can measure the three modes of concrete production and their sustainability in an all-round way. The production mode of using fly ash and waste concrete greatly reduces the environmental load rate and improves the sustainability of the production system. With the increase of the proportion of recycled aggregate, the sustainable development ability of the system can be increased accordingly.

Acknowledgments
This paper is supported by Basic Research Project of Liaoning Higher Education Institutions, China (LJZ2017051), and Industry-Academia Cooperative Education Project of China’s Ministry of Education (201701061013).

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