Where Do Demolished Buildings Go?

This month's installment of our series introducing the varied activities of Japan's Building Research Institute (BRI) looks at some of the advanced recycling techniques the BRI has under development for waste construction materials, in particular concrete.

Figure 1: Production of concrete and the estimated generation of concrete waste

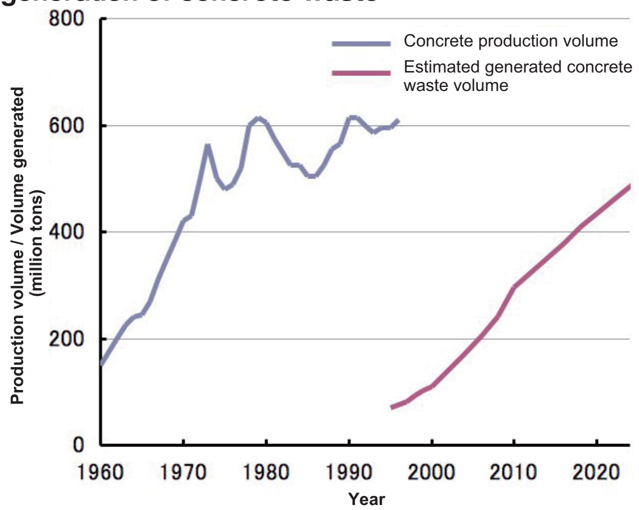
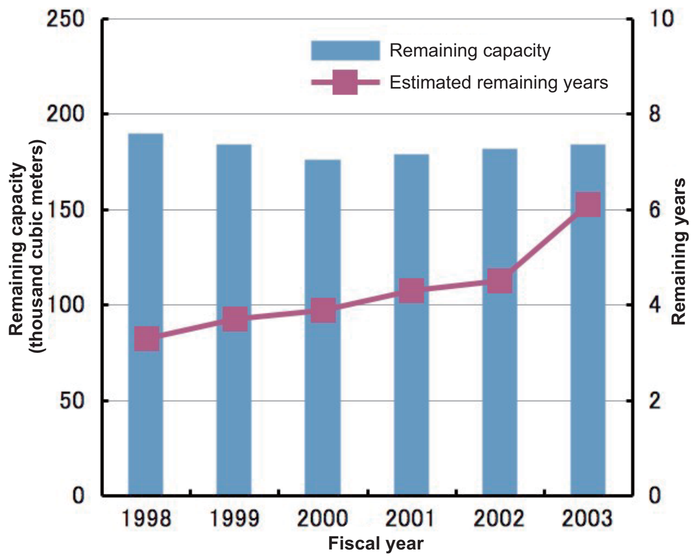


Figure 2: Remaining capacity and remaining years of final disposal sites



It is predicted that there will soon be a large amount of construction waste produced in Japan because the time is coming for when the buildings constructed during the period of rapid economic growth of the 1960s will be demolished and rebuilt. In addition, since buildings consist of a large amount of materials such as concrete, steel and wood, many resources and much energy are required for their construction.

Figure 1 shows the production of ready-mixed concrete and the estimated generation of concrete waste. Concrete production was at 150 million tons in 1960 and grew to nearly 600 million tons in 1973—an average annual increase of around 30 million tons. Since then production has been around 600 million tons. However, the amount of concrete waste generated has suddenly started to rise thirty to forty years after the economic growth period. The amount generated in 2000 was around 100 million tons, but it is predicted to climb to over 400 million tons in 2020.

Figure 2 shows the remaining capacity of final disposal sites and the estimated remaining years before they reach capacity. The capacity of final disposal sites has been very limited, so the remaining capacity steadily continues to remain almost unchanged. But thanks to progress in recycling technology, the remaining life of these sites has been growing longer. However, when considering the future increase in waste, even more advanced recycling techniques will need to be developed. In addition, since Japan is poor in natural resources, accelerating the use of recycled and unused materials becomes a big issue.

The Building Research Institute is developing and assessing recycling techniques for construction materials. The following are some recycling techniques for concrete, which makes up a large proportion of construction waste.

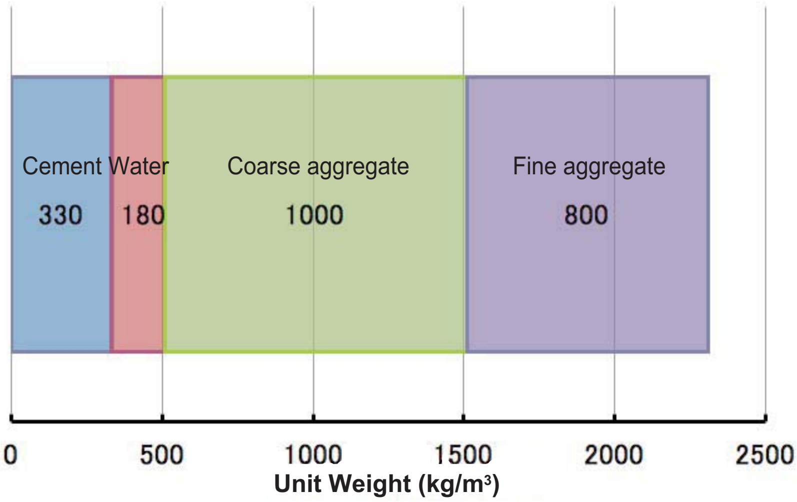
Composition of Concrete

Figure 3 is the typical composition of concrete. Concrete is mainly made up of cement, water and aggregate (coarse aggregate and fine aggregate), and weighs about 2,300 kg per cubic meter. This document describes recent topics in recycling technology for the materials that make up the greater proportion of concrete: cement and aggregate.

Regarding cement, this document describes the efforts to reduce CO_2 emissions and include large amounts of industrial waste and byproducts in cement produced in Japan, as well as the development of a new cement called eco-cement.

Regarding aggregate, this document describes recycled aggregate, which is extracted from the aggregate that comes from concrete waste generated from the demolition of concrete structures.

Figure 3: Typical composition of concrete



Cement and Recycling

Use of industrial waste and byproducts

The main ingredients in cement are limestone, clay and iron, however other than those, a large amount of industrial waste and byproducts are also used. **Table 1** shows the types and volumes of industrial waste and byproducts utilized by the cement industry. An unusually large amount of types and volumes of industrial waste and byproducts are used in the production of cement, and those which include calcium and silica are used as ingredients and mineral admixtures that make up a few percentage points of the ingredients in cement. In addition, organic materials are mainly used for thermal energy. The production of cement has been declining since its peak in 1996 when 99.267 million tons were produced, but in recent years the amount of industrial waste and byproducts used in the manufacture of cement has reached almost the same level, and the amount used per ton of cement is increasing.

Great efforts are also being made to reduce CO_2 emissions from the manufacture of cement in Japan. Through developments in the optimization of heating processes and use of waste heat, the consumption rate of kiln fuel in the manufacture of cement has been declining year by year, and has been held at a very low level even in comparison with foreign countries (**figure 4**).

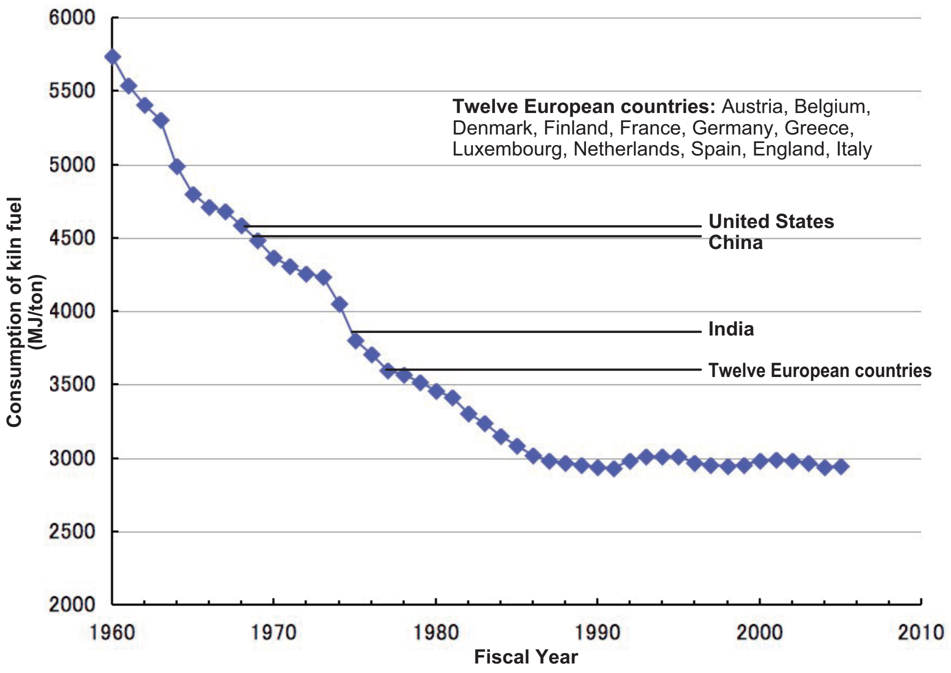
Even now cement is a textbook example of a material for a recycling-oriented society.

Table 1: Volume of industrial waste and byproducts used in cement production (FY 2009)

Type	Main use	Volume used (thousand tons)		
		FY 2003	FY 2006	FY 2009
Blast furnace slag	Raw materials, mineral admixtures	10,173	9,711	7,647
Coal ash	Raw materials, mineral admixtures	6,429	6,995	6,789
Sludge	Raw materials	2,413	2,965	2,621
Soil generated by construction	Raw materials	629	2,589	2,194
Byproduct gypsum	Raw materials (additives)	2,530	2,787	2,090
Others	Used mainly as raw materials	2,382	2,594	1,798
	Used mainly for thermal energy	2,632	2,633	2,633
	Other	378	615	518
Total		27,564	30,890	26,291
Volume used per ton of cement (kg/t)		375	423	451

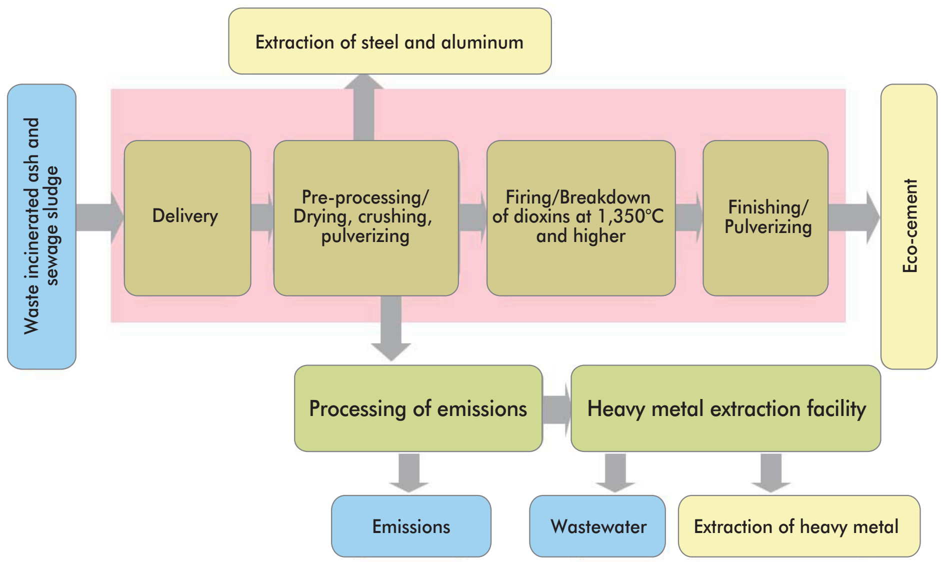
Source: Japan Cement Association

Figure 4: Consumption rate of kiln fuel during cement manufacture



Source: Japan Cement Association

Figure 5: Eco-concrete manufacturing process



Development of Eco-Cement

The term eco-cement combines the words *ecology* and *cement*. The reason that eco-cement is considered an ecological material is that around half of the material used for the cement during the manufacturing process is waste incinerated ash and sewage sludge (**figure 5**). In Japan, trash is first incinerated, and then once its volume is reduced, it is disposed of. But as mentioned earlier, it is becoming difficult to insure that there will waste disposal sites for it. For these reasons eco-cement is considered an ecological material from the dual perspectives of contributing to the conservation of limestone resources as well as to the conservation of waste disposal sites.

However, unlike typical cement, since there is little long-term strength development (**figure 6**), there is a strength deficiency in the long-term strength development of the compressive strength that has been expected until now. Also, because it includes a comparatively large amount of chloride ion, there is a high probability for the corrosion of rebar encased in concrete, so caution is required in the way that it is used. The Building Research Institute has conducted many experiments regarding the properties of fresh concrete, strength and durability of concrete made from eco-cement, and has developed guidelines for mix design and construction techniques when using eco-cement in building construction.

Aggregates and Recycling

As shown in **figure 3**, a large amount of aggregate is used in concrete. However, since there is a limit to natural high-quality aggregate, maintaining a continuous supply of it has become an important issue. The technology for appropriately handling the large amounts of concrete waste generated in the future is also necessary. Taking these things into consideration, technology has been developed for recycled aggregate extracted from aggregate from concrete waste generated from the demolition of concrete structures in Japan. **Photo 1** is an example of recycled aggregate, and **photo 2** is an example of a recycled aggregate manufacturing plant.

Recycled aggregate is relatively low quality when compared to natural aggregate, and much money and energy is required to manufacture high quality aggregate. Therefore, as for the manufacture of recycled aggregate, of course it will be manufactured at a high quality, but it is also important to maintain a quality that is appropriate for the use of the aggregate. The Building

Research Institute has developed quality standards for recycled aggregate based on its use, and has studied the methods for mix design for appropriate use. Based on these research results, three quality standards for aggregates have been established as part of Japan Industrial Standards (JIS): Recycled aggregate class H, recycled aggregate class M and recycled aggregate class L (**table 2**).

The technology for recycling construction materials is indispensable for creating a sustainable society. Technological development is making progress in Japan, and the recycling of materials as well as the use of recycled material is increasing. In comparison to virgin materials, however, they are lacking in performance, so it has become an issue of using the proper materials in the proper place. The Building Research Institute will continue to define quality standards and assessment methods for recycled materials, and make strides in R&D to provide methods for their appropriate use that meets each purpose.

Figure 6: Strength of eco-cement

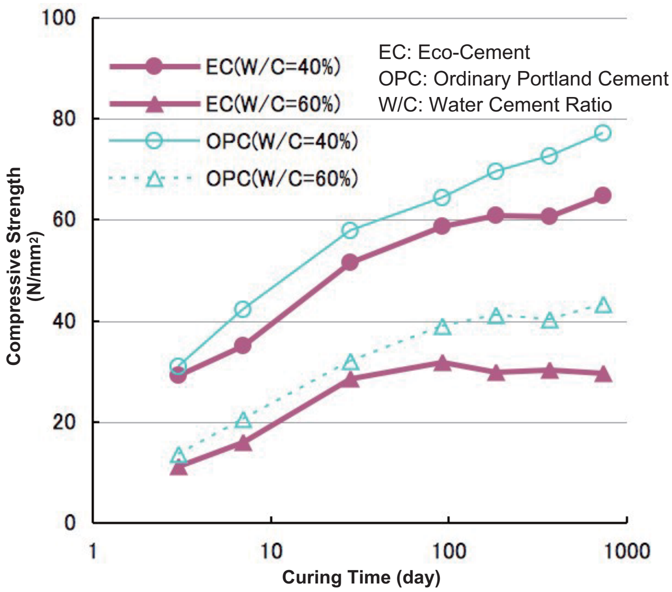


Photo 1: Recycled aggregate

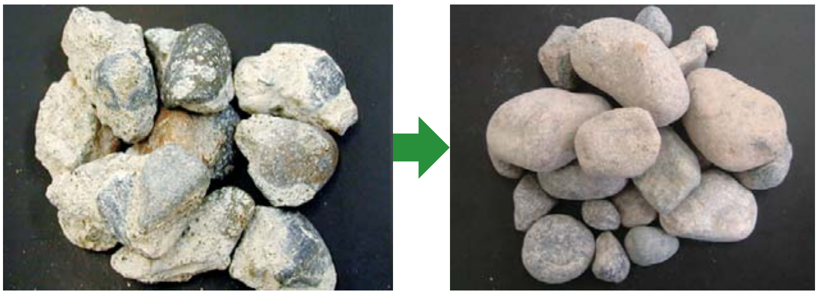


Photo 2: Recycled aggregate manufacturing plant

Table 2: Main uses and quality standards of recycled aggregate

Aggregate type (Natural aggregate)	Recycled aggregate class H	Recycled aggregate class M	Recycled aggregate class L	Crushed aggregate (Natural aggregate)
Standard	JIS A 5021	JIS A 5022 Annex A	JIS A 5023 Annex A	JIS A 5005
Main use	All buildings and public works (equivalent to natural aggregate)	Buildings and public works (only foundations and other areas that are not affected by drying shrinkage or freeze-thaw)	Roadbed material, backfill (for filling) concrete, concrete for leveling	All buildings and public works
Dry density (g/cm^3)	2.5 and greater	2.3 and greater	-	2.5 and greater
Water absorption ratio (%)	3.0 and lower	5.0 and lower	7.0 and lower	3.0 and lower