

Recycling Potential of Limestone Cutting Wastes in West Bank, Palestine

Mitsuo Yoshida and Suleiman Abu Mfarreh

Abstract - Cretaceous limestones are distributed almost all over the West Bank, Palestine, and these limestones are mined and widely used as stone materials for constructing local buildings and infrastructure. Moreover, the stone materials are exported surrounding countries as construction materials, which is one of the most abundant non-renewable natural resources in Palestine. A large amount of stone cutting waste and slurry are generated during the stone manufacturing process, but at present, these stone cutting waste and slurry are randomly dumped without being treated. However, if the generated limestone waste is properly sorted and treated, it can be recycled as concrete aggregate and/or other industrial commodities. In addition, it can be recycled as cement clinker, mortar plaster, and civil/agricultural use of quicklime. For sustainable development of Palestine, the stone resource is expected to be effectively and efficiently recycled.

Keywords – Cretaceous limestone, Stone cutting waste, Slurry, Recycle, Palestine

I. Introduction

Cretaceous limestones are widely distributed in the West Bank of the Jordan River, Palestine [1], and these limestones are mined and widely used as stone materials (the trade name is ‘Marble Stone’) for construction of local buildings (Fig.1).

According to the Union of Stone and Marble Industry in Palestine [2], the economic scale of the marble stone industry reaches US\$ 417 to 440 million annually, accounting for 25% of the revenues of the Palestine’s industrial sector and 4.5% of its gross national product (GNP). It accounts for not only domestic demand but also export items (annual export value of US\$ 60 million), which makes up 4% of the world’s stone production [3]. The major markets for Palestinian stone exports are Israel (85% of all exports), the United States of America, the European Union and the Arab States such as Jordan, Saudi Arabia, UAE, Kuwait and Qatar [3].

Although the international marketing potential is still restricted by insufficient skill and technology levels in Palestine [3], under present economic conditions, the stone industry is one of the most important natural resource industry sector in Palestine.



Figure 1: Limestone (the trade name: Marble Stone) in Bethlehem, West Bank, Palestine (Photo by Yoshida, 2017)

Most of the stone production is carried out by Palestinian small and medium-sized enterprises, operating throughout the West Bank but mainly concentrated near Hebron and Bethlehem [2]. Enterprises in the sector can be divided into three main categories depending on their specific activities: quarries (300 sites) that specialize in producing stone for construction are located exclusively in the West Bank; stone and marble processing factories (750 sites); and processing workshops (600 sites) [4].

The stone industry sector is labor-intensive, although use of heavy machinery and automation is increasingly becoming common. According to the estimation by International Trade Center of Palestine, current employment ranges between 15,000 and 20,000 employees [4].

In the limestone mining and industrial processing, a large amount of stone cutting waste is generated as industrial solid waste. The annual waste generation amount is estimated to be around 0.7 to 1 million tons [2][4]. Most of the limestone wastes are randomly dumped without any treatment, causing a deterioration of the environment, due to waste spill-over and dust rising particularly in the dry season. About 14% of the construction and demolition (C&D) waste is also derived from the stone material [5].

According to the National Strategy of Stone Industry Sector in Palestine [4], establishing “environmental waste management systems” and “developing the capacity of the sector to utilize waste to create new product offerings” (= stone waste recycling) have been set as the development-based challenges.

Based on this situation, there is a great need to reuse and recycle the stone cutting wastes and C&D waste for a sustainable management of limestone resource in West Bank, Palestine.

In this paper, we clarify the physical, chemical, and mineralogical properties of the stone cutting waste in

Mitsuo Yoshida
Environmental Research Laboratory, International Network for
Environmental & Humanitarian Cooperation, Nonprofit Inc., Tokyo
Japan

Suleiman Abu Mfarreh
Directorate of Joint Service Councils, Ministry of Local Government
State of Palestine

Bethlehem, Palestine, examine the possibility and demand for recycling, and propose a framework of the limestone resource recycling system that meets Palestinian conditions.

II. Materials and Methods

A. Materials

Samples of limestones and stone cutting wastes were collected from a stone cutting and processing plant of Al Jaber Stone Co., Bethlehem, West Bank, Palestine (Fig. 2) for mineralogical, chemical and physical analyses.

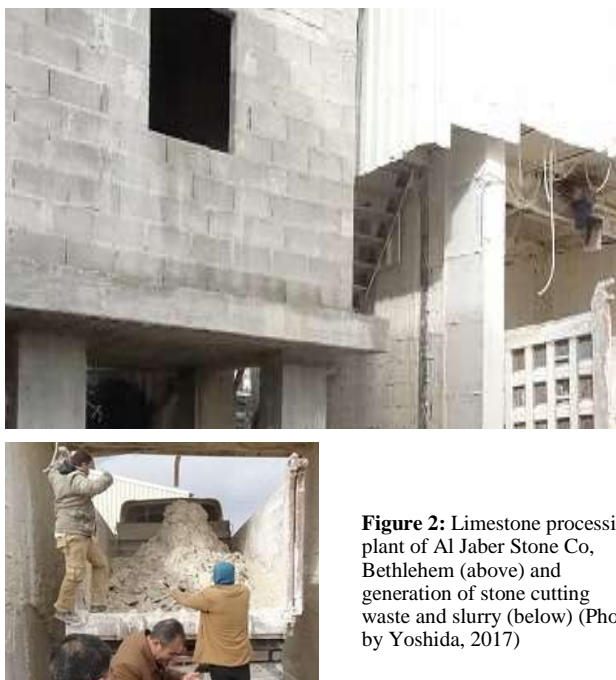


Figure 2: Limestone processing plant of Al Jaber Stone Co, Bethlehem (above) and generation of stone cutting waste and slurry (below) (Photo by Yoshida, 2017)

B. Analytical Methods

For petrological analysis, polarized microscopic observation of thin section was applied to limestone sample.

For mineralogical composition analysis, a powder X-ray diffraction (XRD) method was applied using a Shimadzu XRD6000 analyzer. The measurement conditions for XRD analysis are X-ray tube Cu cathode, counter monochromator, tube voltage 30 kV, tube current 20 mA, slit system: 1° - 0.3 mm - 1°, scanning speed 2°/min, preset time 1.5 sec, and the scanning range is 2 to 65°.

For chemical analysis of major elements, 9.0 g of lithium tetraborate ($\text{Li}_2\text{B}_4\text{O}_7$) and lithium metaborate (LiBO_2) are mixed with 0.9 g of stone cutting waste sample and melted at 1,050 to 1,100 °C to prepare a glass disc, which was used for the specimen of major element analysis. A wavelength-dispersed X-ray fluorescence analyzer, a PANalytical Axios Advance Sequential WD-XRF, was used for the measurement. For ignition loss measurement (LOI), a weight comparison method before and after 1,000 °C ignition was applied. For total carbon analysis, CO_2 coulometer measurement method was applied after the decomposition of stone cutting waste powder with a perchloric acid (HClO_4). For total sulfur analysis, the

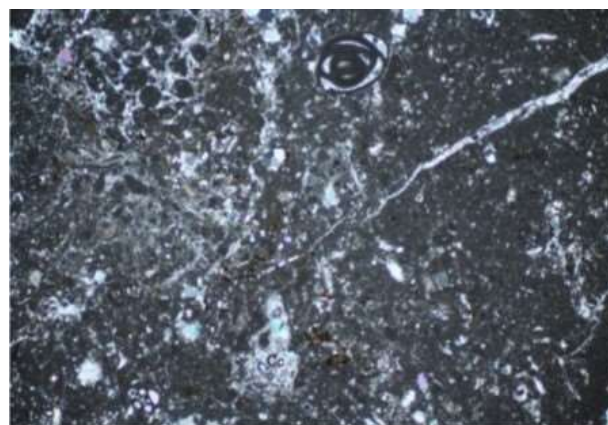
limestone powder sample was heated in an oxygen stream in a furnace at about 1,350 °C, and the generated gas was measured using a non-dispersion infrared absorption method (Leco carbon sulfur analyzer). For trace element analysis, an energy dispersive X-ray fluorescence analysis (ED-XRF; JSX-3100RII manufactured by JEOL) was applied using a powder sample of stone cutting waste.

For physical particle analysis, a sieving & particulate precipitation method were applied with three specimens and averaged. In the analysis, three specimens were arbitrarily measured from the stone cutting waste sample and the average was calculated.

III. Analytical Results

A. Petrology and Mineralogy

According to the results of polarizing microscope observation of the limestone samples, it is a biomicrite limestone consisting almost exclusively of carbonate minerals and containing a large amount of calcareous biological remains such as fossil foraminifera (Fig. 3).



Scale 1 mm

Figure 3: Microscopic picture of the thin section of limestone sample collected from Bethlehem. For: fossil foraminifera, CC: calcite.

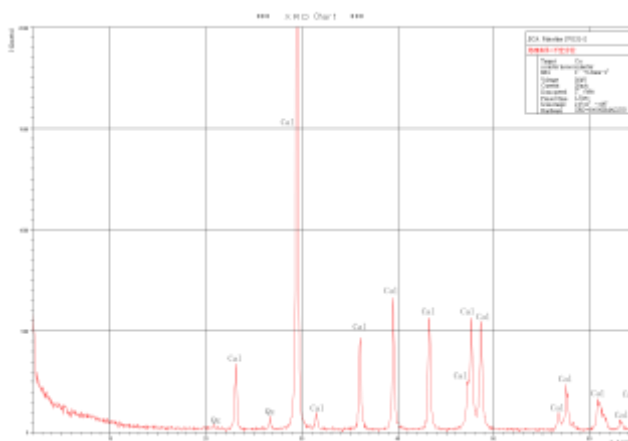


Figure 4: X-ray Diffraction (XRD) chart of the limestone powdered sample collected from a stone industry, Bethlehem. Cal: Calcite, Qz: Quartz,

According to the XRD analysis results of the limestone cutting waste sample, most of the minerals contained are calcite and a trace amount of quartz, and no dolomite

component has been detected (Fig.4). It indicates that the rock cutting waste is almost pure limestone powder.

B. Chemical Composition

According to the whole rock analysis of major elements, SiO₂ 1.49%, Al₂O₃ 0.28%, Fe₂O₃ 0.14%, CaO 54.04%, MgO 0.42%, Na₂O 0.01%, K₂O 0.05%, Cr₂O₃ 0.01%, TiO₂ 0.02%, MnO <0.01%, P₂O₅ <0.001%, SrO 0.02%, BaO 0.01%, S <0.01%, C 11.75%, and LOI is 43.1% (all are assuming CO₂). The molar ratio is Ca:CO₃ ≐ 1:1, and Ca and C are considered to be derived from calcite (TABLE 1).

TABLE 1: Result of Major Elements Analysis

	wt.%	molar weight	wt.%/molar weight	mol%
SiO ₂	1.49	60.085	0.02480	1.25
Al ₂ O ₃	0.28	101.961	0.00275	0.14
Fe ₂ O ₃ *	0.14	159.692	0.00088	0.04
CaO	54.04	56.079	0.96364	48.58
MgO	0.42	40.304	0.01042	0.53
Na ₂ O	0.01	61.979	0.00016	0.01
K ₂ O	0.05	94.203	0.00053	0.03
Cr ₂ O ₃	0.01	159.692	0.00006	0.00
TiO ₂	0.02	79.899	0.00025	0.01
MnO	<0.01	70.937	—	<0.01
P ₂ O ₅	<0.001	141.945	—	<0.01
SrO	0.02	103.901	0.00019	0.01
BaO	0.01	153.900	0.00006	<0.01
LOI**	43.10	43.990	0.9798	49.40
Total	99.59			
LOI**	43.1	43.99	0.97980	49.40
Total	99.41	—	1.98354	100.00

*Total Fe as Fe₂O₃ ** LOI = CO₂

According to the analysis of trace elements such as heavy metals by an ED-XRF, the concentration is as follows: Br 4.3 ppm, Rb 4.5 ppm, Sr 160.2 ppm, Y 2.7 ppm, Zr 31.8 ppm, Pb 5.6 ppm, Ba 79.0 ppm, Cr 12.6 ppm, Ni 21.8 ppm, Cu 12.0 ppm, and Zn 21.0 ppm. The concentration of five elements, As, Se, Hg, Cd, and Sn, were below the lower limit of detection.

The analytical results indicate that the samples of limestone and stone cutting waste contain only a trace amount of heavy metals as impurities and are not hazardous for using construction materials.

C. Physical Properties of Stone Cutting Waste

According to the results of particle size analysis of stone cutting waste and slurry, the average density of particles is

Ps = 2.175 g/cm³, and the particle size includes medium sand (0.2 %) and fine sand (2.4 %), but most of them are silt size (39.8%) and clay size (57.6%). The slurry sample contains a maximum particle size of 0.85 mm, but fine particles account for 97.4%.

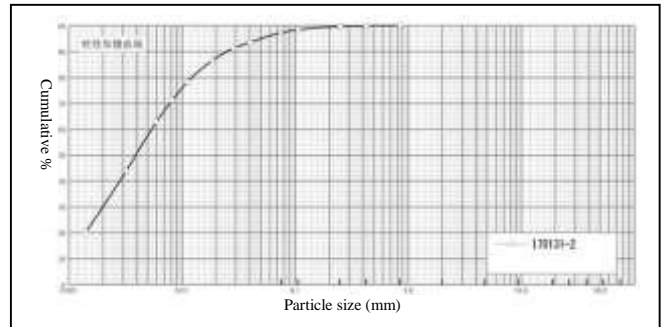


Figure 5: Cumulative curve of particle size of the stone cutting waste

IV. Recycling Strategy of Limestone Waste

Almost all of the stone-cutting wastes generated are dumped without being utilized except for some reuses in the Gaza Strip. Limited capacity of the remaining volume of the final waste disposal site in Palestine and the closure of random open dump sites are urgent issues. Therefore, reduce, reuse, and recycle (3Rs) of stone-cutting waste and C&D waste are crucial issue not only in terms of effective utilization of stone resources, but also in terms of proper waste treatment and minimization of waste volume flowing into landfills.

Another problem is that when these stone wastes are dumped into regular waste collection containers and enter the ordinal waste collection and transportation channel, they damage collection vehicles and equipment. Therefore, it is necessary to establish a system for properly collecting, transporting, and recycling these stone wastes.

There are several possibilities for reusing and recycling stone waste and slurry, considering the current socio-economic conditions and market demand in Palestine.



Figure 6: Crushing and sorting plant of C&D waste containing limestone in Gaza Strip (Photo by Yoshida, 2015)

A. Cement

The first is recycling as a material for cement clinker in cooperation with the cement industry. According to the results of present study, the sample from Bethlehem is almost pure limestone powder with no dolomite component, and the concentration of harmful heavy metals is also low, so it can be used as a material for cement production.

The Palestinian market consumes currently around three million tons of cement per year at a cost of around US\$ 300 million US dollars, while this is expected to increase five million tons per year within five years. A construction of a new large-scale cement factory is under the discussion in the West Bank, which is the first time in Palestine [6] [7]. It is possible to use the stone cutting waste as a cement clinker in collaboration with the cement factory, and considerable demand can be expected for the cement product.

B. Aggregate for Concrete

The second is to directly utilize the stone cutting waste as an aggregate (coarse grain part) or mortar (fine grain part) of concrete. The method of using limestone fragments and crushed stone waste as concrete aggregate has been put to practical use in other areas. It was reported that under sufficient predetermined conditions, mixing of stone cutting waste improve the concrete performance [8].

In any parts, appropriate waste sorting at the source of stone waste is a prerequisite for effective and efficient reuse and recycling (Fig.6)

The slurry waste generated from stone cutting industry could be used in producing artificial stones with reasonable compressive strength and absorption compared to natural stones. The compressive strength increases with cement ratio, level of compaction pressure and curing time [9].

Stone powder wastes generated during stone cutting process can be used as plaster mortar, a material for repairing, repairing, and reinforcing old buildings, historic buildings, and outdoor monuments [10]. A certain demand for plaster mortar can be recognized in Palestine.

The slurry generated from the stone cutting processes can be regarded as a source of water used in concrete mixes. Using slurry sludge as a source of water in concrete production has insignificant effect on compression strength, while it has a sharp effect on the slump values. It was reported that maximum of 25% of the total volume of water in the slurry could be used for the production of concrete [11].

As mentioned above, there are many technically conceivable methods for reusing/recycling stone cutting waste and slurry as an aggregate of concrete.

C. Quicklime and Others

The third is reuse as a roadbed improver or soil fungicide. Since most of the stone cutting waste consists of limestone powder, it can be calcined to form quicklime (CaO). This quicklime can be used to strengthen the roadbed in road construction, to prepare sand-lime briquettes [13]. In the construction of infrastructures such as highway embankments or earth dams, loose fills are required to be

compacted to increase the density and improve their strength properties.

Sometimes, existing soil deposit may need to be improve in order to enhance its engineering performance. Compaction is the most common method of soil improvement, and stone cutting waste is sometimes applicable for enhancing the compaction [12].

The quicklime can also be used as a soil fungicide (agricultural chemical) with Bordeaux Mixture with chemicals in agriculture, and demand in Palestinian domestic agriculture can be expected.

D. Environmental Management

Stone cutting industry is one of the major environmental pollutants in Palestine. In considering the recycling of stone cutting waste, it is required to plan appropriate measures to protect public health and the environment.

The environmental pollution can be found in excavating process of limestone rocks in quarries and transporting them to stone cutting plants. The mining and transporting process is usually associated with air, noise and dust contamination [14]. In and around stone cutting plants, rock blocks are cut into different sizes and shapes, where dust stone cutting waste and slurry are generated. The plant also consumes a large amount of water and generates wastewater. Water pollution often occurs when wastewater treatment is not properly applied.

Therefore, proper environmental management of stone cutting industries is required to reduce adverse impacts on the residential and agricultural land, and protection of groundwater quality for drinking [15].

Palestinian stone industry sector is weak and the performance of stone firms working within a cluster is very low. However, when they work in a cluster of industries, they can enhance the competitiveness [16]. Working in a cluster has been shown to promote productivity, innovation and competition in a number of ways, e.g., the reduced cost of sharing resources, the critical mass created by having a pool of specialized skills, expertise and value-added products. The cluster is expected to enhance the environmental management system under the collaboration and cooperation among industries.

E. Proposed Recycling System

The solid waste management policy directed toward the promotion of sorting and recycling of stone cutting waste and slurry according to the National Solid Waste Management Strategy (2017-2022). Based on the institutional setting and policy position, a framework of recycling system of stone cutting waste as well as stone materials in the C&D waste is proposed as shown in Fig.7.

There are basically three domains in the recycling system; waste generation domain, eco-concrete industries domain, and material recycling industries domain (see the parts surrounded by broken lines in Fig.7). The part of cement industry is also possible option but it depends on the realization of development plan for constructing a new cement factory.

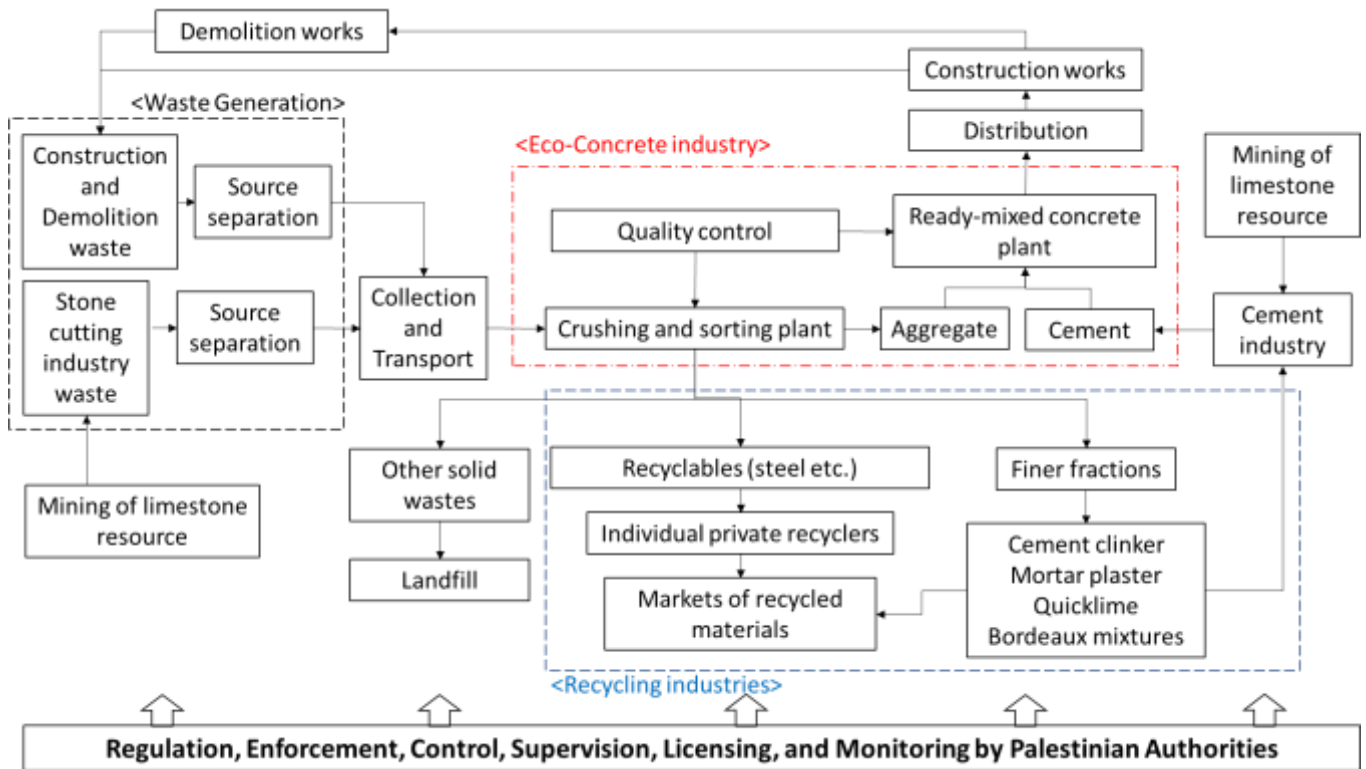


Figure 7: Outline of the proposed recycling system of limestone resource in Palestine.

v. Conclusions

The stone industry sector in Palestine is economically and socially very large, and the amount of industrial waste generated by this sector is also very large.

As shown in this study, the stone cutting waste itself is non-hazardous and potentially recyclable, thus effective and efficient recycling of the stone cutting waste can be realized if appropriate treatment facilities is established.

There are multiple technical options for recycling of stone cutting waste and slurry, and which technology should be selected must be determined by local conditions, economy, and demand. For that purpose, it is necessary to carry out a feasibility study and a demonstration project after identifying business partners.

Under the legal system, a new bylaws (Bylaw on Solid Waste Management, draft Bylaw on Construction & Demolition Waste Management) clearly stipulates the responsibility of the waste generator for the treatment and disposal of rock cutting waste and also construction and demolition waste.

A feasibility study for stone cutting waste recycling is necessary to implement under a cooperation between public and private sector. Active participation of the private sector is expected.

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About Authors:



Mitsuo Yoshida is the JICA Chief Advisor and Expert of the MoLG-JICA Project for Capacity Development in SWM in Palestine Phase-II and III. He is working for JICA and the International Network for Environmental and Humanitarian Cooperation, Nonprofit Inc., Tokyo, as the Director/CEO.



Suleiman Abu Mfarreh is the Director General of Directorate of Joint Service Councils, Ministry of Local Government, State of Palestine, and a Member of National Team of Solid Waste Management. He is conducting the MoLG-JICA Project for Capacity Development in SWM in Palestine Phase-II/III, as the Project Manager.