NIPPON STEEL & SUMITOMO METAL TECHNICAL REPORT No. 109 JULY 2015

UDC 669 . 184 . 28 : 631 . 87 : 634

Technical Report

Reforestation Efforts with Steelmaking Slag and Artificial Humus

Koichi TORII* Kenji TANAKA
Takashi OKADA Koichi IKEDA
Takuji HAMAZAKI Masato JIMBO

Abstract

"Artificial mineral" is developed in order to recovery deserted forests, in which nutrient salts are leached. It's made of artificial humus and steelmaking slag, are useful materials in different industries. Artificial humus is acid organic material which soaked woody chip in pyroligneous acid. Woody chip and pyroligneous acid are useful materials in forest industry. On the other hand, Steelmaking slag is alkali inorganic material, includes a lot of useful mineral for plant. It is also useful materials in steel industry. The combination of them creates new value to elute and chelate necessary minerals for plant. "Artificial mineral" is new material to recovery oligotrophic environment. It can be applied to various oligotrophic environments by changing the composition to adjust pH. The range of application is not only reforestation but also urban greening, agriculture and so on. It has possibilities and superior technology.

1. Introduction

Japan has a land area of 37800000 ha, 66% (25000000 ha) of which is covered with forests. They are further subdivided into natural forests (34%), and man-made forests (27%), aimed to secure building materials, and so on. Artificial forests of cedars and cypresses have been maintained by processes such as thinning and lopping from the time the young trees are planted till the time they grow and are lumbered.

Forests have long been regarded merely as a lumber production site. In recent years, however, they have come to be demanded to play various other roles, too—helping to curb the global warming, conserving water resources, affording places of recreations, preventing natural disasters. According to the Opinion Survey on Forests and Life published by the Cabinet Office in December 2011, forests are increasingly expected to help prevent natural disasters such as landslides and floods (**Table 1**).

Well-kept forests always receive moderate sunshine and have plenty of understory vegetation. Recently, with the increase in imports of inexpensive foreign lumber as well as the aging of forest workers and the dwindling number of their successors, increasing number of man-made forests are being deserted or becoming desolate (**Photo 1 (a)** and **(b)**).

In well-maintained forests, the fallen leaves and twigs and the understory vegetation are decomposed into humus by organisms living in the soil. In addition, the rock-forming minerals of base rock are weathered into clay mineral, which combines with humus to form a clay-humus complex. It then forms soil in combination with sand, gravel, and silt (**Fig. 1**). However, if the forests are not properly maintained by thinning, lopping, and so on, their light environment deteriorates, and their understory vegetation degenerates. Besides, the soil organisms that decompose the fallen leaves and twigs decrease in number. As a result, the "humus" that retains the "clay mineral" that is indispensable for the growth of plants is not formed. Furthermore, under the influence of rain, the soil continually becomes acidic, causing the clay mineral to be leached. As a result, quite a few forests have become desolate, causing such natural dis-

Table 1 Function expected for forest

Expected function	Ratio (%)
To prevent disasters such as landslide, flood	48.3
To forestall global warming by carbon dioxide absorption	45.3
To retain water resources	40.9
To clean up air and to reduce noise	37.3
To provide comfortable and peaceful environment	27.2
To produce wood for housing-related material, furniture and paper	23.6

* Head of By-products Recycling Technical Dept., Environment & Energy Div., Wakayama Works
1850 Minato, Wakayama City, Wakayama Pref. 640-8555

Photo 1 (a) Healthy forest in Okuizumo, Shimane Pref.

Photo 1 (b) Deserted forest at Okuizumo, Shimane Pref.

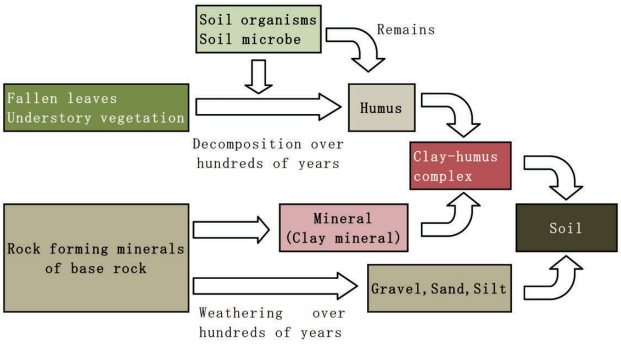


Fig. 1 Formation of forest soil

asters as surface layer collapses and landslides.

Under such conditions, with the aim of restoring desolate forests, we have come up with an "artificial mineral" that supplies the required minerals to these forests using raw materials, which occur in the fields of forestry and steelmaking.

2. Contents and Characteristics of Developed Technology

The developed technology is called artificial mineral, which utilizes steelmaking slag to neutralize acidified forest soil and utilizes artificial humus to retain minerals eluted from the soil and supply them to the plants when needed. The artificial humus is prepared by curing wood chips in naturally obtained vinegar. It is an acid material capable of retaining the various minerals required of plants. Steelmaking slag is lime that is first input to the steelmaking process, and then cooled and solidified. It is an alkaline material containing large proportions of minerals (Ca, Si, P, Fe, and so on) required of plants.

2.1 Composition

2.1.1 Artificial humus

Humus is capable of retaining various minerals and adjusting the pH of soil. It is made of decayed animals and plants decomposed and recomposed by soil organisms. The formation of a humus layer of only 1 cm takes more than 100 years. Once it is lost, it is hard be restored. However, it is possible to substitute peat moss, grass coal, peat, or other overseas resources that are similar in properties to humus. However, in view of high costs of transportation, they are uneconomical. Besides, since their nutrients are leached out in a few years, they need to be renewed periodically. After all, they are mined resources, which are exhaustible. As an organic material available domestically, composted bark is available. However, it is incomplete humus deposited and fermented only for a short period of time, say, one to two years. Under such conditions, there was a demand for a more humified material available domestically. Making humus artificially has long been studied. As a recent example, Kumada prepared man-made humus in his laboratory.[1]

On the basis of the above result, a method for manufacturing artificial humus (**Photo 2**) on an industrial-scale was established.[2] Produced by curing wood chips in naturally obtained vinegar for a short period of time, the artificial humus is an acid material comparable in performance with natural humus.

The degree of humification of the artificial humus is higher than that of bark compost (**Fig. 2**). Like natural humus, the artificial humus is capable of retaining minerals and adjusting the pH of soil. However, since the artificial humus itself contains only small amounts of minerals, it is necessary to add minerals to it so as to enhance its functions.

Photo 2 Artificial humus

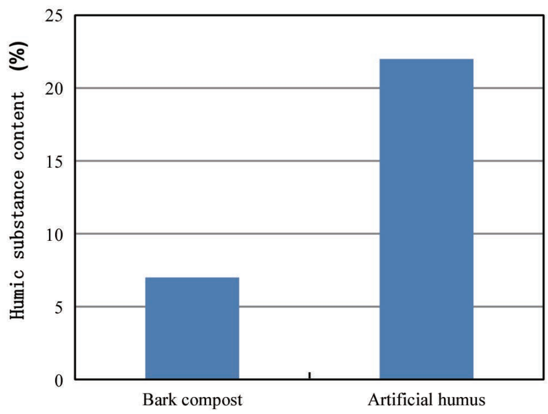


Fig. 2 Comparison of humic substance content between bark compost and artificial humus

2.1.2 Steelmaking slag

Steelmaking slag consists mainly of lime that is first input to the steelmaking process, and then cooled and solidified. Since the lime comes from natural limestone, steelmaking slag is similar in composition to natural limestone and contains considerable proportions of minerals (Ca, Si, P, Fe, and so on) that are required of plants (**Table 2**, **Photo 3**, and **Fig. 3**).

With the aim of studying the types of minerals eluted from steelmaking slag, we performed a continuous water flow test in which pure water was continuously passed through a column chromatograph tube filled with steelmaking slag, and the pH and eluate composition of the extract was collected at a prescribed liquid–solid ratio (quantity of passed water (g)/quantity of slag (g)) were measured. Ca^{2+} and Mg^{2+} were analyzed by ion chromatography, T-Si and T-P by ICP-AES, and Fe^{2+} by absorptiometry. The test results are shown in **Fig. 4**. The results of an Electron microprobe analysis of slag samples before and after the test are shown in **Table 3**.

An examination of the minerals eluted from the steelmaking slag showed that the elution of Ca was predominant and the eluate was highly alkaline. Although the elution of Si was slightly observed, the concentrations of P, Fe, and Mg were under their analytical limits. From these results, it was confirmed that since the steelmaking slag itself was alkaline, minerals could hardly elute from it.

Table 2 Compositions of steelmaking slag

	Composition (%)				
	CaO	SiO_2	P_2O_5	T.Fe	MgO
Steelmaking slag	42.1	20.0	4.3	8.8	1.9
ex) Andesite	5.8	59.6	–	3.1	2.8

2.2 Mechanisms of the artificial mineral

It was found that the artificial mineral utilizing the alkalinity of steelmaking slag can be used to improve the acid soil of desolate forests. Since the artificial mineral retains its alkalinity for a long period of time, it need not be renewed for several years. Used in combination with the artificial humus, the artificial mineral permits adjusting the pH of soil to facilitate the elution and retention of minerals required of plants. Thus, it should become possible to supply plants with the right minerals at the right time (**Fig. 5**).

2.2.1 Optimum pH for desolate forests

For the soil to be able to hold the minerals required of plants in a balanced manner, it is necessary that the soil have cation–anion exchange capacity. In this regard, the optimum pH value of the soil is around 6 [3] (**Fig. 6**). The results of examinations of forest soils that have been conducted in Shimane and Nagasaki prefectures show that in the case of desolate cedar and cypress forests that have not

Photo 3 Steelmaking slag

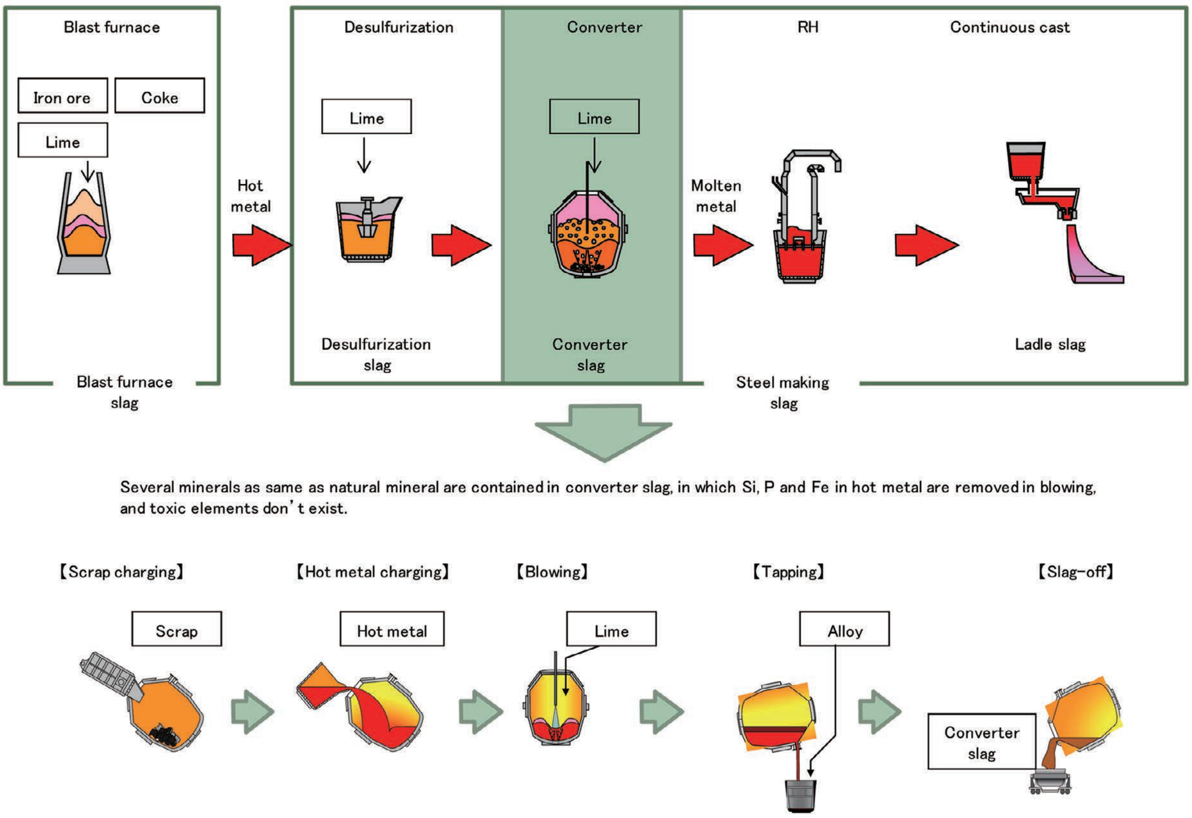


Fig. 3 Process of steel making slag

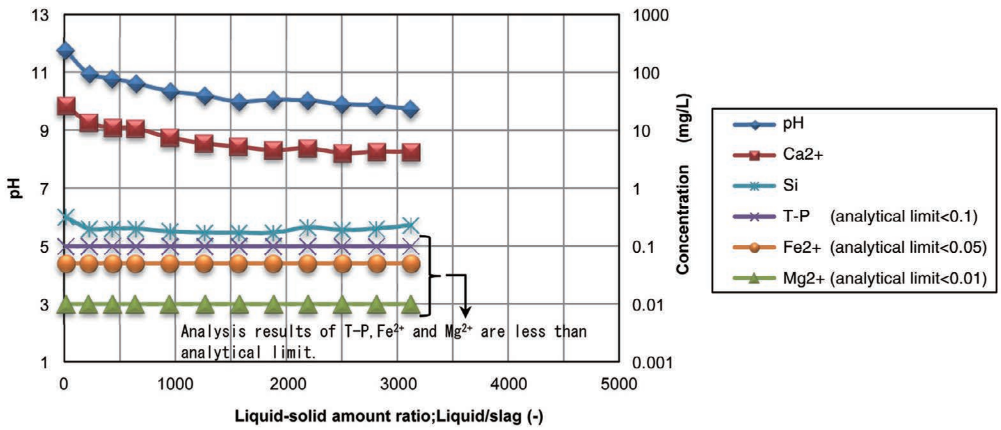
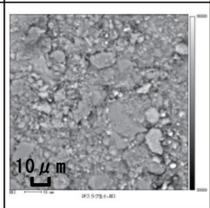
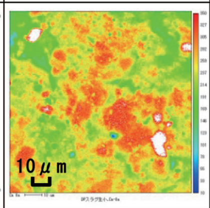
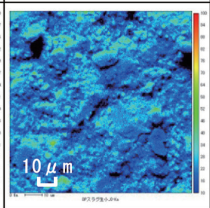
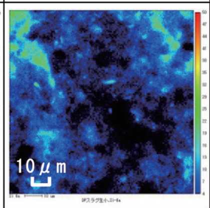
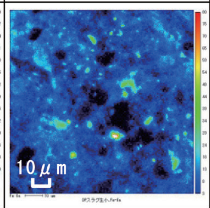
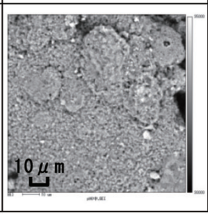
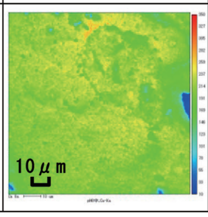
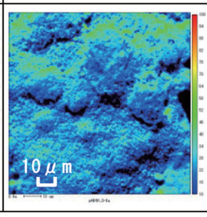
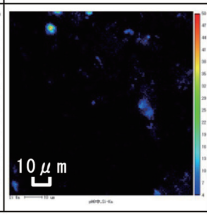
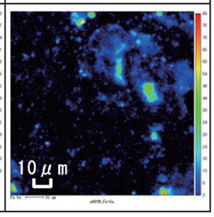


Fig. 4 Dissolution test result of steelmaking slag

Table 3 EPMA result of steelmaking slag before or after solution test

	SEM	EPMA			
		Ca	O	Si	Fe
Before solution test					
After solution test					

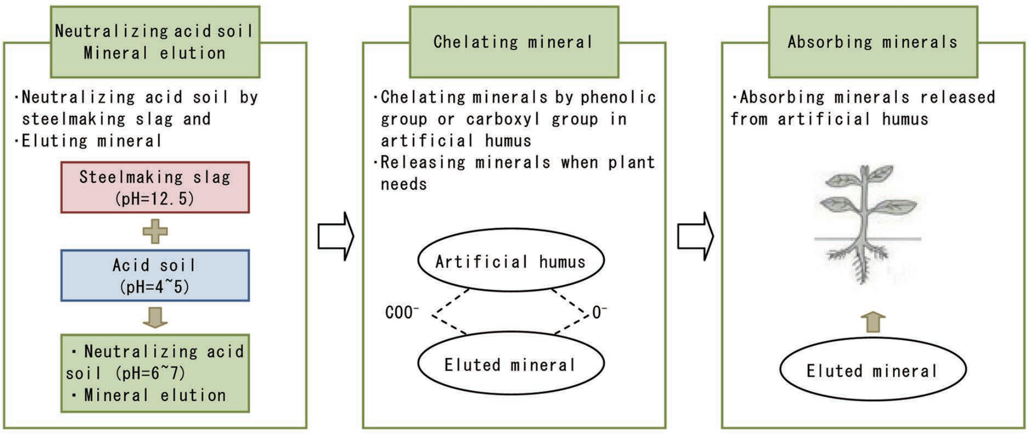


Fig. 5 Mechanism of artificial mineral

been properly managed (e. g., thinning), the soil is strongly acidic, the pH value is below 4.4, which is far lower than that of the acid secreted by plant roots for absorbing minerals from the soil.

2.2.2 Adjustment of pH and minerals eluted

With the aim of studying the relationship between the minerals eluted from steelmaking slag and the pH of soil, we performed a mineral elution test using pH-adjusted specimens having different artificial humus–steelmaking slag ratios. Test results are shown in **Fig. 7**. In addition to Ca and Si, the elution of P, Fe, and Mg from the pH-adjusted specimens was confirmed.

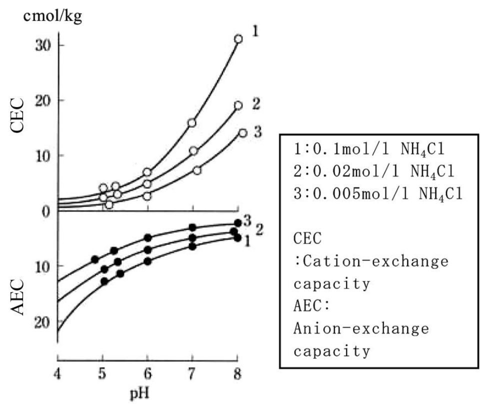


Fig. 6 Influence of solution concentration to charge characteristic in andosol

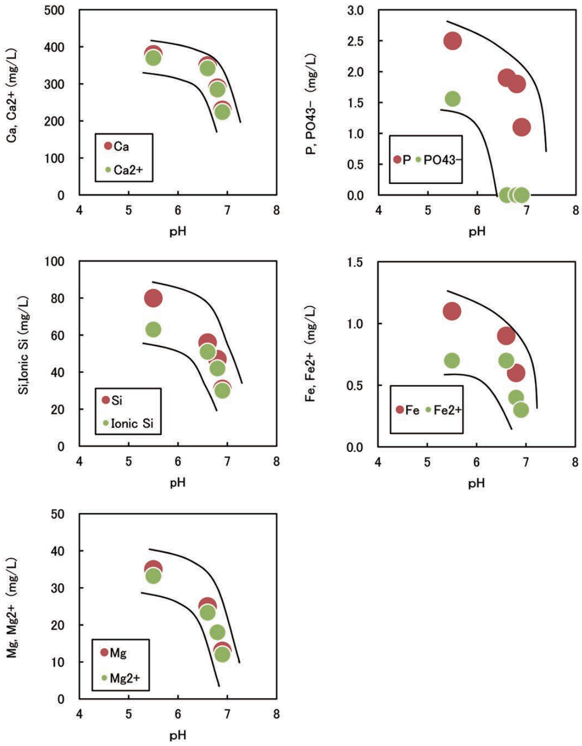


Fig. 7 Result of mineral dissolution test

3. Verification Tests

3.1 Iinan-Cho, Shimane Prefecture

In a forest of Iinan, Shimane prefecture, converter slag was scattered over a culture medium at rates of 0.0, 2.5, 5.0, 7.5, and 10.0 vol% per 2-cm-deep top layer to make a chemical analysis of the soil and measure the planting rate of understory vegetation. The scattering of the converter slag increased the mineral contents of the soil and improved the planting rate from 25% to 100%[4] (**Table 4**, **Photo 4 (a)** and **(b)**). The activity was carried out as part of environmental learning planned by a local primary school (**Photo 5**), which has contributed to the enlightenment on environmental conservation in the locality.

3.2 Cypress forest around Mt. Shinmoe in Miyazaki Prefecture

In a national forest around Mt. Shinmoe in Miyazaki prefecture, we performed an acid reduction test of the soil covered in volcanic ash. The amount of steelmaking slag scattered was 0, 2, 4, and 6 L per square meter. The soil was subjected to a chemical analysis, and the planting rate of the underway vegetation was measured. The application of steelmaking slag increased the soil pH value and improved the soil electric conductivity to over 120 μS/cm, which is suitable for the germination and growth of plants (**Table 5**, **Photo**

Table 4 Result of soil chemical analysis and planting rate at cedar forest in Iinan, Shimane Pref.

		Converter slag distribution ratio (vol%)				
		0.0	2.5	5.0	7.5	10.0
pH		5.1	6.8	6.8	7.3	7.2
Humic substance content (%)		6.9	5.8	4.4	4.3	6.0
Ca (mg/100g)		132	905	7151	346	1159
Mg (mg/100g)		21.3	53.8	46.4	80.8	65.2
Bivalent iron (ppm)		6.0	17.5	25.3	47.3	62.8
Planting rate (%)	Beginning	5	5	5	3	25
	Half a year later	7	30	50	50	100

Photo 4 (a) Beginning (planting rate 25%)

Photo 4 (b) Half a year later (planting rate 100%)

Photo 5 Extracurricular study for distributing artificial mineral in deserted forest

Table 5 Soil chemical analysis of national forest in Shinmoe, Miyazaki Pref.

	Control	Experiment		
		①	②	③
Steelmaking slag (L/m^2)	0	2	4	6
pH	4.5	6.3	6.2	6.1
Electric conductivity ($\mu S/cm$)	48	90	130	125

Photo 6 (a) Before experiment

Photo 6 (b) 4 months later in control

Photo 6 (c) 4 months later in experiment ②

6 (a)–(c)).

4. Application Example

To the present, as a measure to prevent the outflow of scoria in Oyamacho, Shizuoka, an area of 2 000 m^2 has been revegetated with artificial mineral composed of 10 vol% artificial humus, 86 vol% bark compost, and 4 vol% steelmaking slag (**Photo 7**). Scoria, which is volcanic ejecta, has high fluidity and small mineral-retaining capacity and contains few minerals (**Table 6**, **Photo 8 (a)–(c)**). Therefore, it was difficult to prevent the outflow of scoria by means of vegetation of the surface soil (revegetation work). In fact, there was no alternative but to apply the conventional hillside foundation work

Photo 7 Scoria deposition in forest

Table 6 Soil chemical analysis and planting rate at Koyama, Shizuoka Pref.

	Before	3 months later
pH	7.0	7.8
Electric conductivity ($\mu S/cm$)	0.02	0.24
Cation-exchange capacity (meq/100g)	4.6	23.1
Planting rate (%)	0	40

Photo 8 (a) Before construction

Photo 8 (b) Under construction

Photo 8 (c) After construction

Table 7 Comparison between conventional work and developed work

	Convention Foundation works of erosion control afforestation	**Development** Seeding and planning works with artificial mineral
		
Economic efficiency (M¥/1 000 m^2)	4.8	3.0
Term (day/1 000 m^2)	30.7	9.0
CO_2 emission under construction (ton/1 000 m^2)	19.9	5.0

Table 8 Soil chemical analysis at Ebisu-higashi Park

	Before	After
pH	8.6	6.7
Electric conductivity (μS/cm)	0.08	0.13

method using steel frames. Artificial mineral has made it possible to improve the soil, allowing for revegetation. As a result, it was possible to cut the cost of work by about 40% per 1 000 m^2 and shorten the period of work by about 70%. In addition, the emission of CO_2 during execution of the work has been reduced 75% (**Table 7**).

5. Application to Other Fields

Our artificial mineral can be applied to various oligotrophic environments merely by varying the mixing ratio to adjust its pH. It is a promising technology that will find applications not only in forest restoration but also in park vegetation and agriculture.

5.1 Reforestation of Ebisu East Park in Tokyo

At the Ebisu East Park in Tokyo, the artificial mineral was plowed in 20 vol% per 10 cm of surface ground to make the soil suitable for the planting of turf. The artificial mineral was composed of 89 vol% bark compost, 9 vol% artificial humus, and 2 vol% steelmaking slag. Tifton turf was planted. Consequently, the soil became weakly acidic, and the soil electric conductivity improved (**Table 8**, **Photo 9 (a)–(c)**).

Photo 9 (a) Before construction

Photo 9 (b) Under construction (sodding)

Photo 9 (c) After construction

5.2 Kirari Farm Takagi in Miyakonojo City, Miyazaki Prefecture

At Kirari Farm Takagi in Miyakonojo City, Miyazaki, the artificial mineral was plowed in 2.5 vol% per 20 cm of surface farmland to plant spinach. The composition of the artificial mineral was 86 vol% bark compost, 10 vol% artificial humus, and 4 vol% steelmaking slag. Spinach was also sown in each of two separate sections plowed in with cow manure and bark compost to compare the weight per spinach leaf. As a result, the weight of the spinach harvested in the field with the artificial mineral was heavier than that of the spinach harvested in the field with cow manure or bark compost (**Photo 10**, **Fig. 8**).

5.3 Salty wind protection forest in Izumiotsu City, Osaka (Osaka Bureau of Port and Harbor)

The salty wind protection forest within the jurisdiction of Osaka Bureau of Port and Harbor in Izumiotsu City, Osaka was revegetated by applying 25 vol% artificial mineral per 50-cm-thick surplus soil from construction. The artificial mineral was 17 vol% mixture of bark compost and artificial humus and 8 vol% steelmaking slag.

Photo 10 Comparison of spinach (from left, cow manure, back compost and artificial mineral)

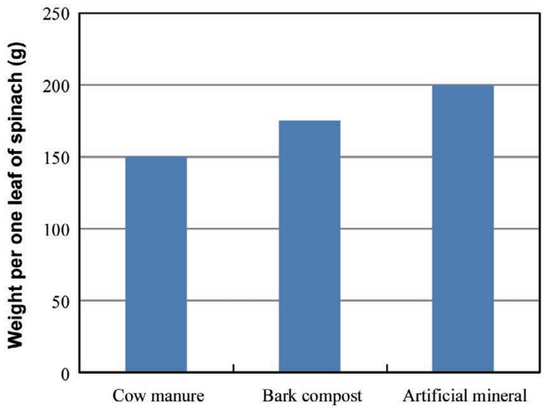


Fig. 8 Comparison of weight per one leaf of spinach among cow manure, bark compost and artificial mineral

The soil was made suitable for revegetation (**Photo 11 (a)** and **(b)**).

6. Conclusion

The artificial mineral described in this study combines an acid organic material (artificial humus), which is obtained by curing wood chips from forestry in naturally derived vinegar, and an alkaline inorganic substance (steelmaking slag), which is a byproduct of steelmaking containing many minerals useful for plants. It is a promising technology for forest restoration that permits retaining various minerals required of plants and supplying the plants with the right minerals at the right time. The artificial mineral can also be applied to various oligotrophic environments in both land and sea areas merely by varying the mixing ratio to adjust its pH.

Photo 11 (a) Before planting

Photo 11 (b) After planting

References

1) Kumada, K.: Journal of the Japanese Society of Soil Science and Plant Nutrition. 26 (1), 5 (1995)
2) Tanaka, K.: Professional Engineer CPD/FY 2010 Annual Meeting for Presentation of Achievements & Studies. Tokyo, June 2010
3) Matsunaka, T.: Basics of Soil Science. 1st Edition. Tokyo, Rural Culture Association Japan, 2003, p. 128
4) Torii, K. et al.: Materials and Processes. 25 (1), 344 (2012)

Koichi TORII
Head of By-products Recycling Technical Dept.
Environment & Energy Div.
Wakayama Works
1850 Minato, Wakayama City, Wakayama Pref. 640-8555

Koichi IKEDA
Senior Manager
Production & Technical Control Div.
Wakayama Works

Kenji TANAKA
Corporate Officer
General Manager of Forest Environment Div.
Japan Conservation Engineers Co., Ltd.

Takuji HAMAZAKI
Manager
By-products Recycling Technical Dept.
Environment & Energy Div.
Wakayama Works

Takashi OKADA
Corporate Officer
Wakayama Branch Manager, No.2 Sales Div.
Krosaki Harima Corporation

Masato JIMBO
Staff
By-products Recycling Technical Dept.
Environment & Energy Div.
Wakayama Works