

Corrosion Cost and Corrosion Map of Korea - Based on the Data from 2005 to 2010

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Corrosion of metallic materials occurs by the reaction with corrosive environment such as atmosphere, marine, soil, urban, high temperature etc. In general, reduction of thickness and cracking and degradation are resulted from corrosion. Corrosion in all industrial facilities and infrastructure causes large economic losses as well as a large number of accidents. Economic loss by corrosion has been reported to be nearly 1-6% of GNP or GDP. In order to reduce corrosion damage of industrial facilities, corrosion map as well as a systematic investigation of the loss of corrosion in each industrial sector is needed. The Corrosion Science Society of Korea in collaboration with 15 universities and institutes has started to survey on the cost of corrosion and corrosion map of Korea since 2005. This work presents the results of the survey on cost of corrosion by Uhlig, Hoar, and input-output methods, and the evaluation of atmospheric corrosion rate of carbon steel, weathering steel, galvanized steel, copper, and aluminum in Korea. The total corrosion cost was estimated in terms of the percentage of the GDP of industry sectors and the total GDP of Korea. According to the result of Input/output method, corrosion cost of Korea was calculated as 2.9% to GDP (2005). Time of wetness was shown to be categories 3 to 4 in all exposure areas. A definite seasonal difference was observed in Korea. In summer and fall, time of wetness was higher than in other seasons. Because of short exposure period (12 months), significant corrosion trends depending upon materials and exposure corrosion environments were not revealed even though increased mass loss and decreased corrosion rate by exposure time.

Keywords : corrosion map, corrosion cost, Korea

1. Introduction

Since corrosion of metals and materials occurs spontaneously and naturally, the corrosion costs to the various national economics are of great concern. The first study was reported in 1949 by Uhlig who estimated the total cost to the economy by summing materials and procedures related to corrosion control.¹⁾ The 1949 Uhlig report was followed in the 1970s by a number of studies in various countries, such as USA, UK, and Japan. The national study by Japan conducted in 1977 followed the Uhlig methodology. In USA, Battelle-NBS estimated the total direct cost of corrosion using an economic input/output method. Australia in 1983 and Kuwait in 1995 adopted the input/output method. In the UK, a committee chaired by

T. P. Hoar conducted a national study in 1970 using a method where the total cost was estimated by collecting data through interview and surveys of targeted economic sectors.²⁾ Direct corrosion cost was estimated as 3.1% to GDP (1998) of USA and many countries performed the study on corrosion costs.³⁾ Corrosion survey in Korea was first started in 1972;⁴⁾ This study was discussed under six sub-divisions, such as fertilizer plants and oil refinery, thermal power plants, water plants, general chemical plants, fiber plants and paper mills, and shipyard, port, and railroad facilities. Corrosion problem in fertilizer plants and oil refinery were considered as the most importance. Generally, main corrosion problems were: 1) water treatments in pipelines, heat exchangers, and boilers etc., 2) corrosion problem by fuels such as bunker C and coal etc., and 3) underground pipe lines by low soil resistivity, salt contents, and biological attack etc.

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Also, knowing the atmospheric corrosivity of a region or city of the country is considered of very important concern for major industrialists and investors who require knowledge of the corrosive impact of the atmosphere on materials such as carbon steel, galvanized steel, copper, and aluminum.⁵⁾⁻⁷⁾

The Corrosion Science Society of Korea in collaboration with 15 universities and institutes has started to survey on the cost of corrosion and to develop corrosion map of Korea since 2005. Present study focused on the survey on cost of corrosion by Uhlig, Hoar, and input-output methods, and the evaluation of atmospheric corrosion rate of carbon steel, weathering steel, galvanized steel, copper, and aluminum in Korea.

2. Experimental

Corrosion costs were surveyed using 3 methods; (1) Uhlig method⁸⁾ - the cost of corrosion in protection methods and services, (2) Hoar method⁹⁾ - the direct cost of corrosion in various sectors (based on surveys and experts judgments), (3) Input/output method¹⁰⁾ - a simplified general equilibrium model of an economy showing the extent to which each sector uses from the other sectors to produce its output and thus showing how much each sector sells to other sectors. The Korean economy was divided into 168 industrial sectors in input/output analysis.

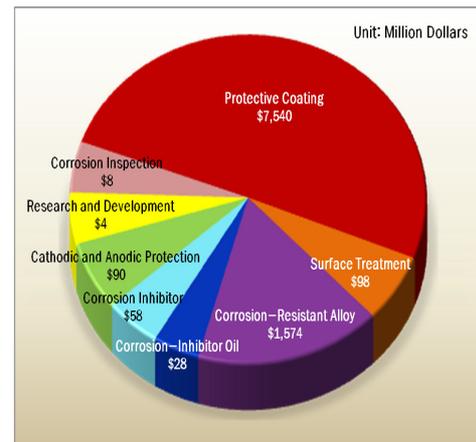
Investigation of atmospheric corrosion in Korea started since 2005; outdoor exposure tests have been performed at 21 sites around the nation. Test specimens were carbon steel, weathering steel, galvanized steel, aluminum, copper. During atmospheric corrosion tests, chloride ion concentration, sulfur dioxide deposition rates, temperature and relative humidity were measured periodically. Atmospheric

corrosivity of Korea was determined with ISO standards, ISO 9223, 9224, 9226.¹¹⁾⁻¹³⁾

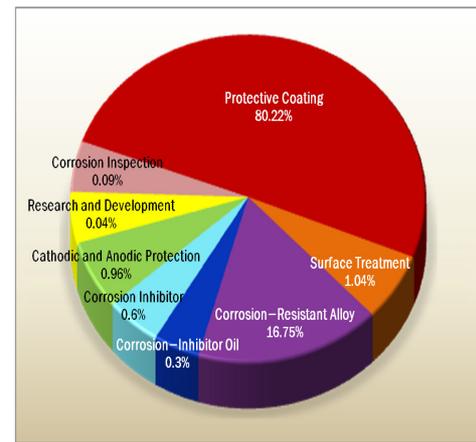
3. Results and discussion

In this study, Fig. 1 shows corrosion costs of Korea on the Uhlig method in terms of the percentage of the GDP in 2005. Surveyed fields were protective coating, surface treatment, corrosion-resistant alloys (ferrous and non-ferrous), corrosion-inhibiting oil, corrosion inhibitor, cathodic and anodic protection, research and development, and corrosion inspection. The protective coating covered 80% of total corrosion cost and its cost was 7,540 million dollars. Next was the field on corrosion-resistant alloy and corrosion cost was 1,574 million dollars. The others were 1.04% and less.

Fig. 2 shows corrosion costs in Korea on the base of Hoar method (2005). Surveyed fields were infrastructures,



(a)

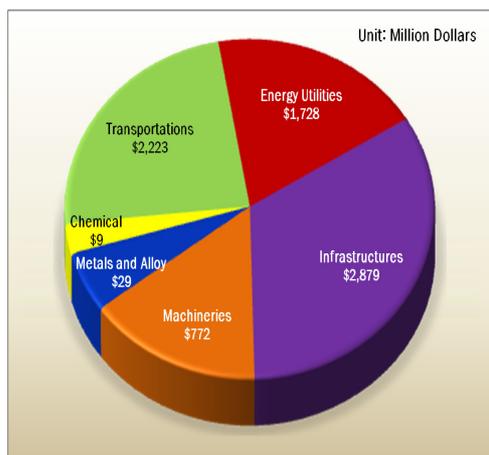


(b)

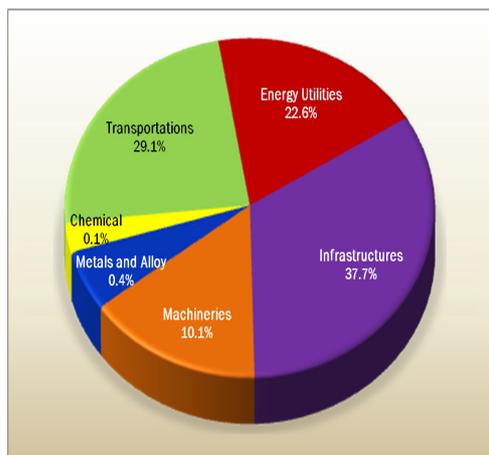
Fig. 1. Corrosion costs estimated by Uhlig method (2005); (a) in dollars, (b) in percent.

Table 1. Experimental specimens for outdoor exposure test

Specimens	Symbols	Surface conditions
Carbon steel	CS	As-received
Carbon steel(Sand)	CS(Sand)	As-sanded
Weathering steel	WS	As-received
Weathering steel(Sand)	WS(Sand)	As-sanded
Galvanized steel (Cutting plane exposed)	Gal-S	Hot dip galvanized
Galvanized steel (Electroplating after cutting)	Gal-S(P)	Electroplated
Galvarium (Cutting plane exposed)	Gal-V	Hot dip galvanized
Copper	Cu	As-received
Aluminum	Al	As-received



(a)



(b)

Fig. 2. Corrosion costs estimated by Hoar method (2005); (a) in dollars, (b) in percent.

machineries, metals and alloys, chemicals, transportations, and energy utilities. Infrastructure included architectures, housings, roads, waterways, ports. Machinery included general, electric, and electronic machineries. Metals and alloys included ferrous and non-ferrous. Chemicals included general chemicals and petroleum. Transportations included mobile vehicles, ships, electric train, railroads. Energy utilities included electrical utilities, gas distribution, and drinking water and sewer systems. The corrosion cost in infrastructures covered 37.7% of total corrosion cost and its cost was 2,879 million dollars. Next was on transportations and its cost was 2,223 million dollars. The third largest corrosion cost was estimated to be 1,728 million dollars (22.6%) in energy field.

Fig. 3 shows corrosion costs in Korea on the base of Input/output method (2005). In this method, Korean economy was divided into 168 industrial sectors. For each in-

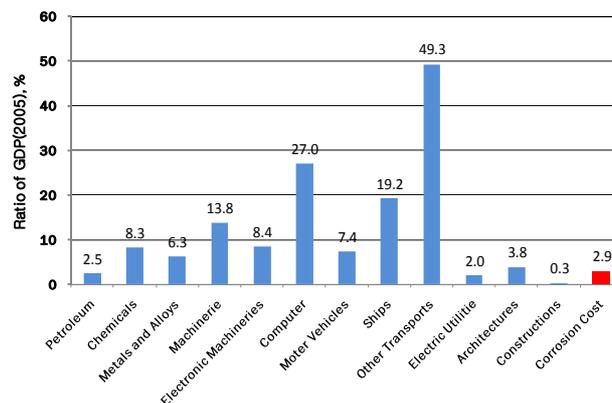


Fig. 3. Corrosion costs estimated by Input/output method (2005).

dustry sector, estimation was done on the costs of corrosion protection, as well as for the cost of repair and replacement due to corrosion. Data on corrosion costs collected by Uhlig and Hoar methods was used to analyze corrosion costs by input/output model. The total corrosion cost was defined as the increment of total cost incurred because corrosion exists. In this method, three worlds are defined; World I (real world of corrosion (2005), World II (hypothetical world without corrosion), and World III (hypothetical world in which the economically most effective corrosion prevention is practiced by everyone.¹⁾ In this study, major industrial sectors surveyed were petroleum, chemicals, metals and alloys, machineries, electronic machineries, computers, motor vehicles, ships, other transports, electric utilities, architectures, and constructions and corrosion costs of each sector were shown in Fig. 3. As can be seen in this figure, total corrosion cost of Korea was 2.9% of GDP in the year of 2005.

Outdoor exposure tests to determinate the corrosion rate by atmospheric corrosion were performed at 21 sites in Korea; 10 marine regions including industrial, 5 rural regions, and 6 urban regions. Also, atmospheric corrosivity of Korea was determined with ISO standards, ISO 9223, 9224, 9226.¹¹⁾⁻¹³⁾

Fig. 4 shows ISO categories of time of wetness in Korea. (a) is for 1 year (2008) and (b) is for 4 seasons. Time of wetness shows 3 to 4 in all exposure areas. As was expected, a definite seasonal difference was observed in Korea as in Fig. 4(b). In summer and fall, time of wetness was higher than in other seasons.

Fig. 5 shows corrosion rate and mass loss of (a) carbon steel (as-received) and (b) carbon steel (as-sanded) as a function of exposure time in Andong area. Mass loss of carbon steel (as-received) was highly increased by exposure time but its corrosion rate was decreased as shown in Fig. 5(a). Also, in the case of carbon steel (as-sanded), mass loss of carbon steel was highly increased by exposure

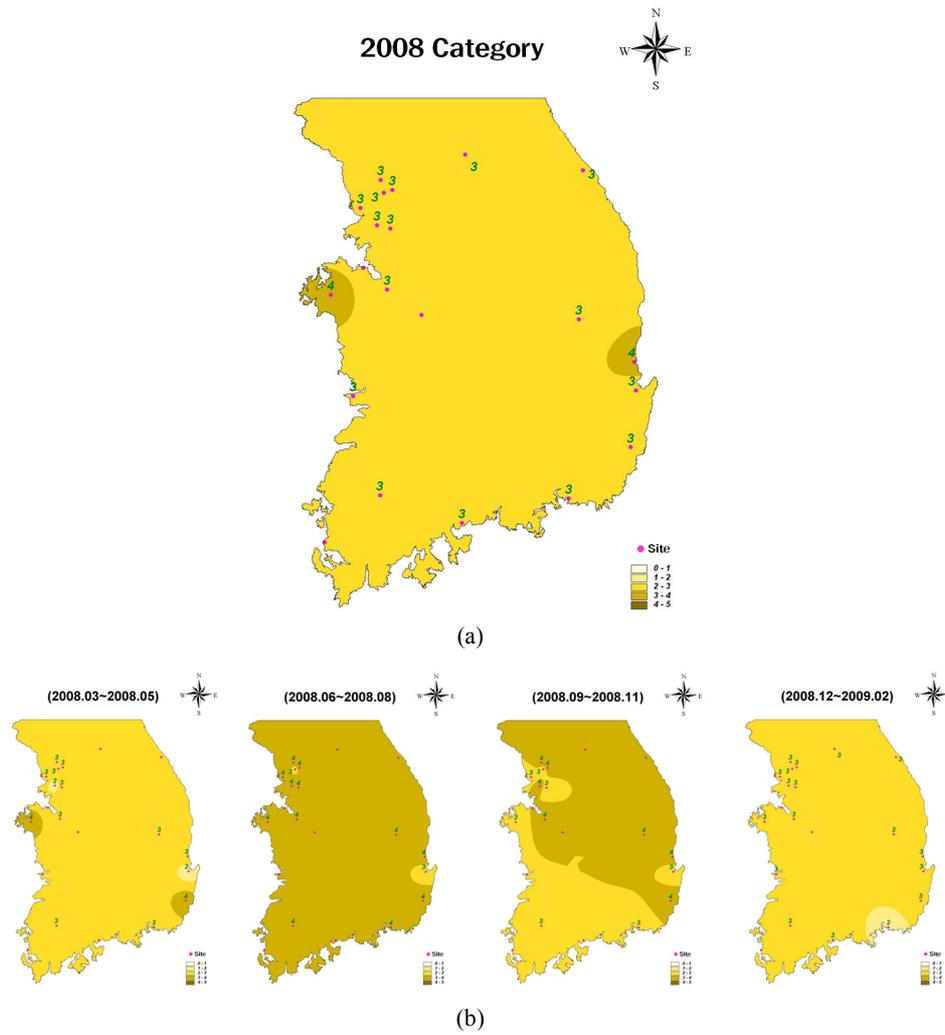


Fig. 4. ISO categories of time of wetness; (a) 1 year (2008), (b) 4 seasons.

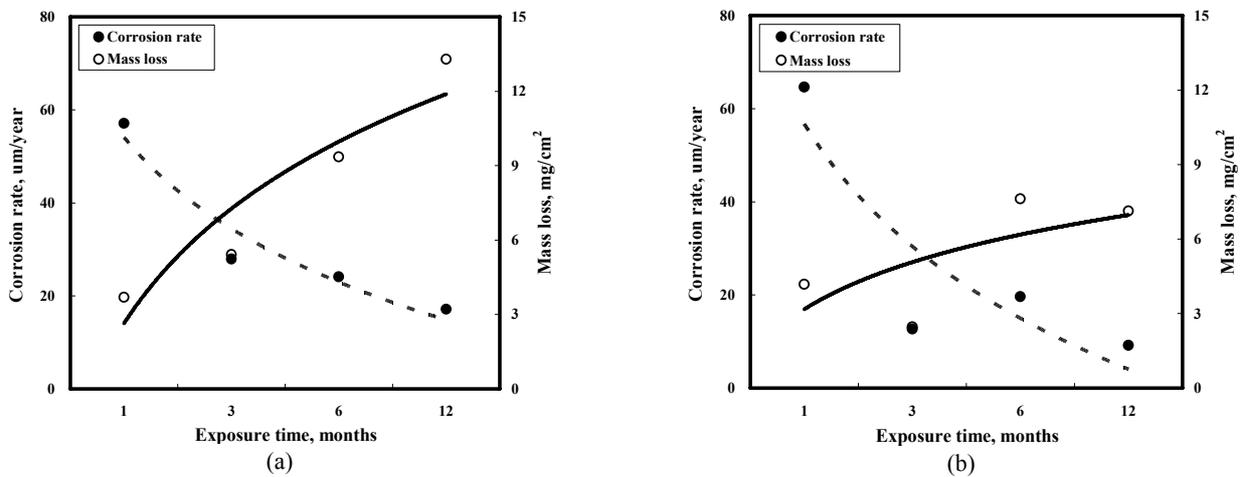


Fig. 5. Corrosion rate and mass loss of (a) carbon steel (as-received), (b) carbon steel (as-sanded) as a function of exposure time in Andong area.

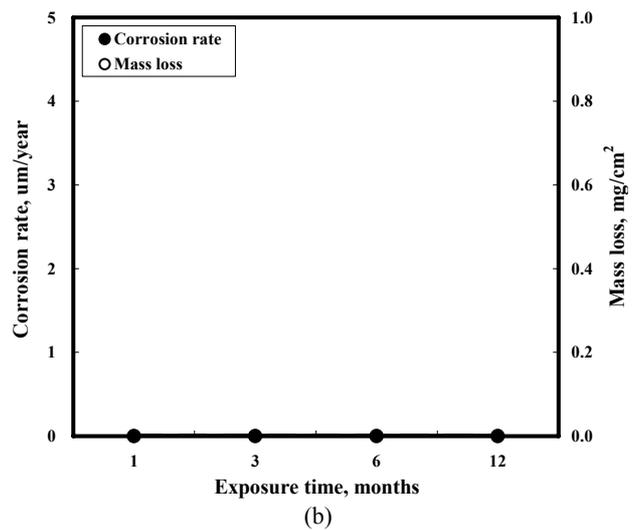
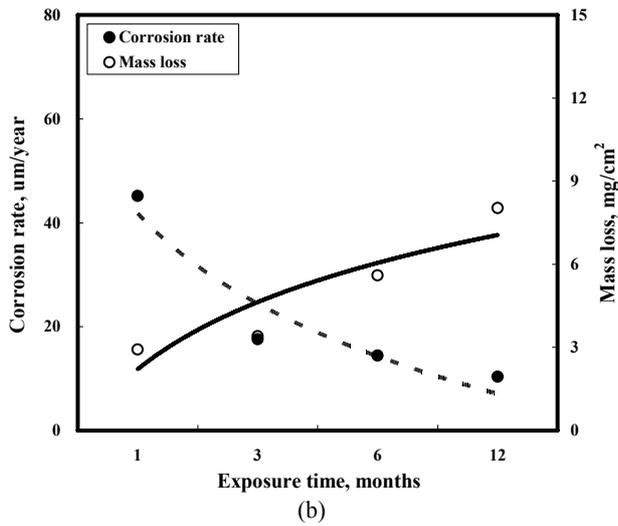
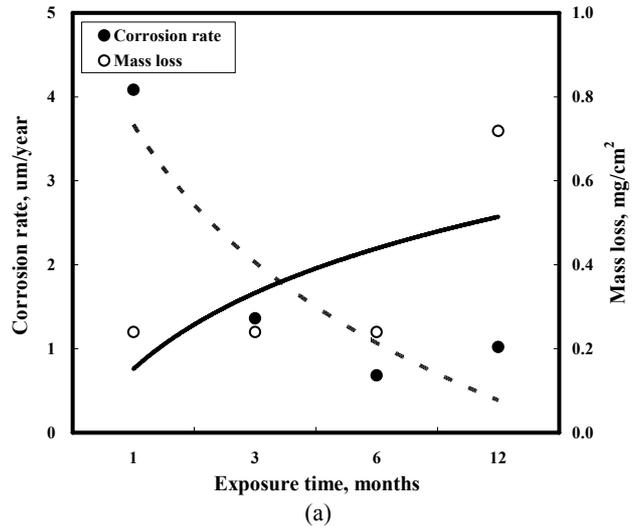
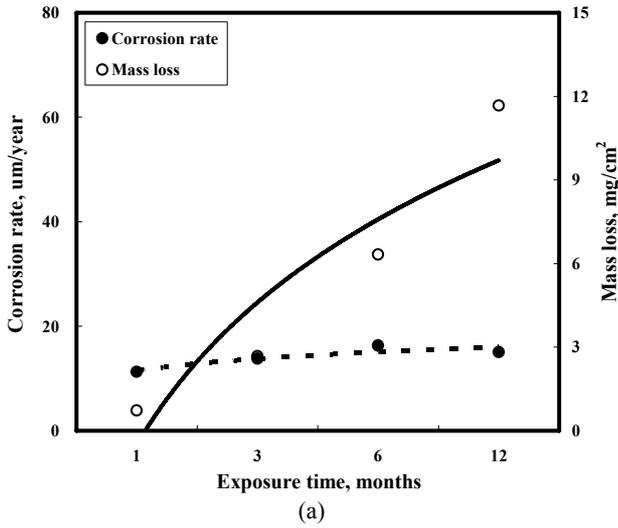


Fig. 6. Corrosion rate and mass loss of (a) weathering steel (as-received), (b) weathering steel (as-sanded) as a function of exposure time in Andong area.

time but its corrosion rate was decreased as shown in Fig. 5(b).

Fig. 6 shows corrosion rate and mass loss of (a) weathering steel (as-received) and (b) weathering steel (as-sanded) as a function of exposure time in Andong area. Mass loss of weathering steel (as-received) was increased by exposure time but its corrosion rate was almost constant as shown in Fig. 6(a). Also, in the case of weathering steel (as-sanded), mass loss of weathering steel was increased by exposure time but its corrosion rate was decreased as shown in Fig. 6(b).

Fig. 7 shows corrosion rate and mass loss of galvanized steels as a function of exposure time in Andong area; (a) is for hot-dip steel, (b) is for electroplated steel, and (c) is for galvarium. In the case of hot-dip steel (Fig. 7(a)),

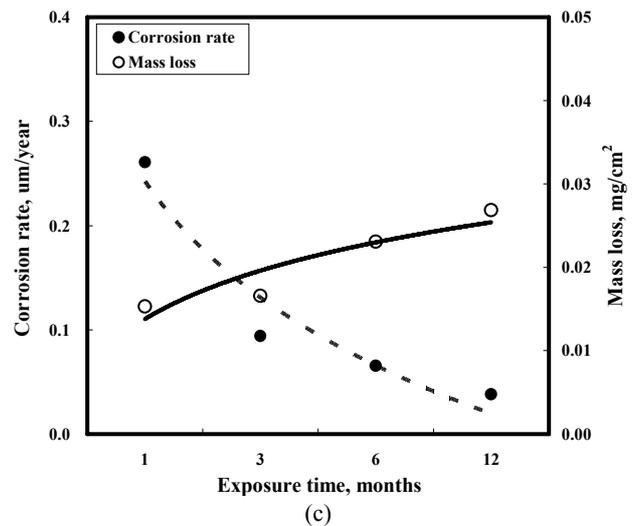


Fig. 7. Corrosion rate and mass loss of galvanized steels as a function of exposure time in Andong area; (a) hot-dip steel, (b) electroplated steel, (c) galvarium.

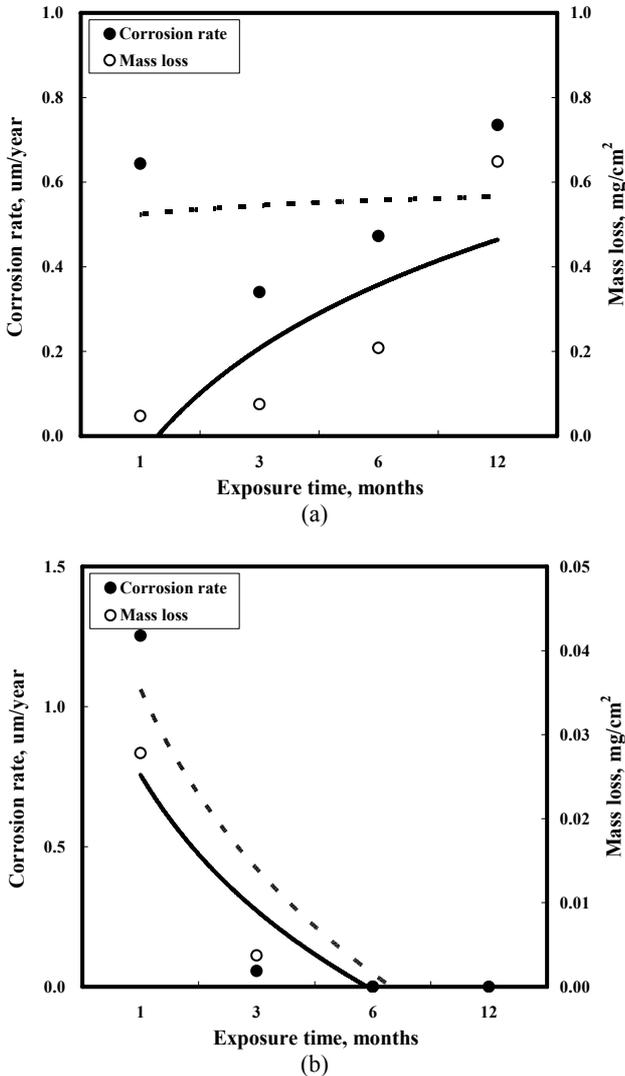


Fig. 8. Corrosion rate and mass loss of (a) pure copper, (b) pure aluminum as a function of exposure time in Andong area.

mass loss was slightly increased but its corrosion rate was decreased. However, mass loss of Zn-electroplated steel was nil until 12months as shown in Fig. 7(b). Also, mass loss was slightly increased but its corrosion rate was decreased in the case of galvarium (Fig. 7(c)).

Fig. 8 shows corrosion rate and mass loss of (a) copper and (b) aluminum as a function of exposure time in Andong area. Mass loss of copper was slightly increased by exposure time but its corrosion rate was almost constant as shown in Fig. 8(a). Also, in the case of aluminum, mass loss and corrosion rate were decreased by exposure time as shown in Fig. 8(b).

Fig. 9 shows corrosion maps based on the data collected for 12 months of (a) carbon steel (as-received), (a') carbon steel (as-sanded) and (b) weathering steel (as-received), (b') weathering steel (as-sanded). Corrosion map was plot-

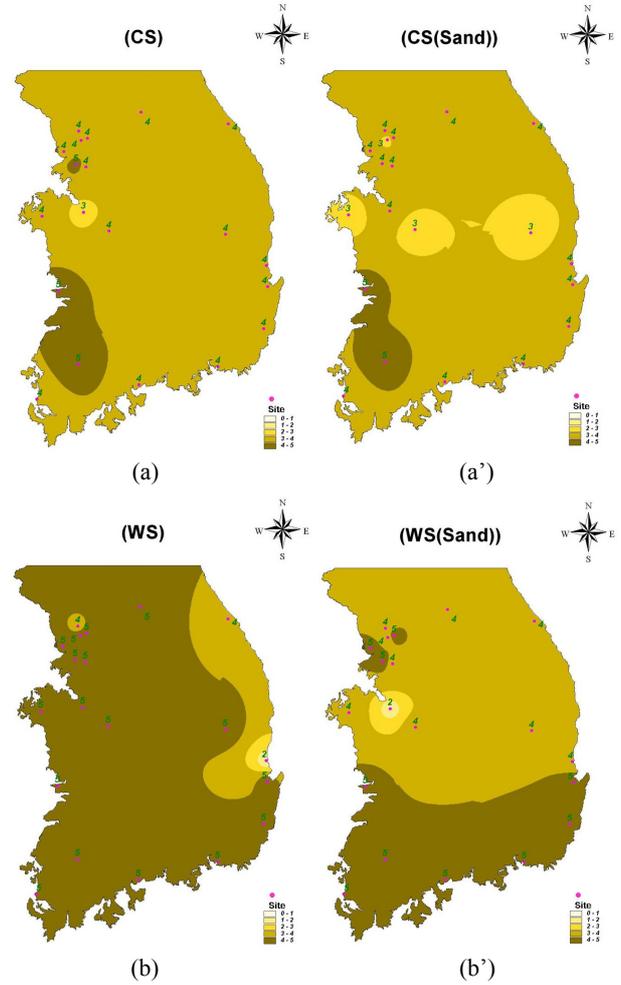


Fig. 9. Corrosion maps based on the data collected for 12 months of (a) carbon steel (as-received), (a') carbon steel (as-sanded) and (b) weathering steel (as-received), (b') weathering steel (as-sanded).

ted on the base of its corrosion rate according to ISO standards.¹¹⁾⁻¹³⁾

Fig. 10 shows corrosion maps based on the data collected for 12 months of (a) hop-dip steel, (b) Zn-electroplated steel, (c) galvarium. Also, Fig. 11 shows corrosion maps based on the data collected for 12months of copper and aluminum.

As shown in the above figures, because of short exposure periods, it should be considered that significant corrosion trends depending upon materials and exposure corrosion environments were not revealed. This work will be continued during 10years and each data will be revised too.

4. Conclusions

In this study, Uhlig, Hoar, and Input/output methods

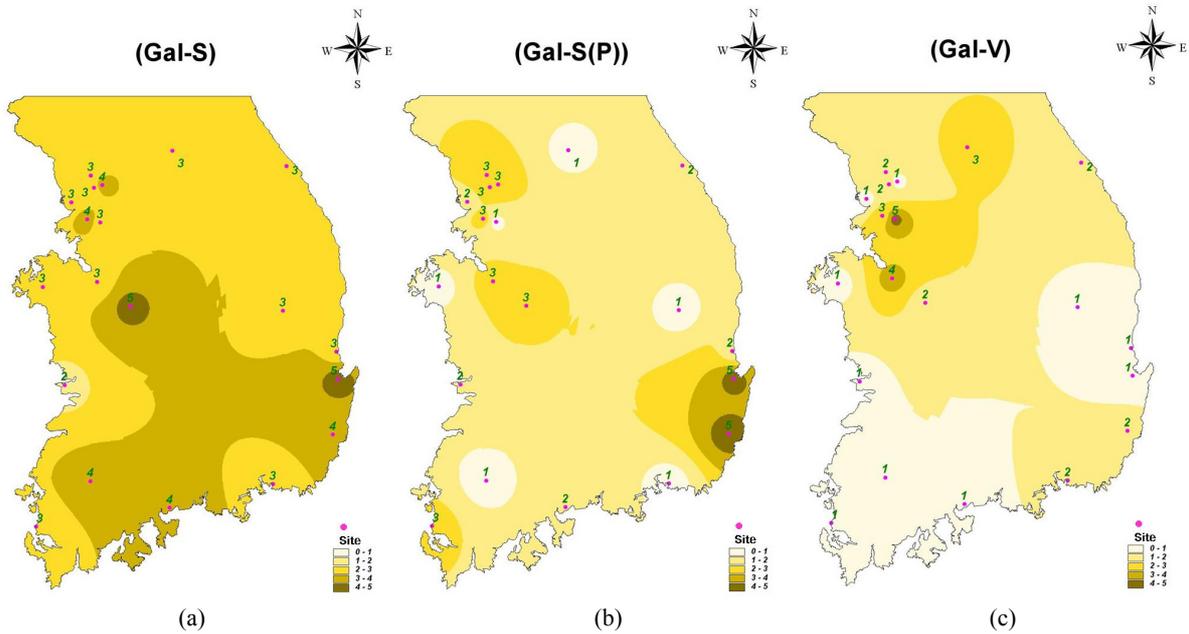


Fig. 10. Corrosion maps based on the data collected for 12 months of galvanized steels; (a) hot-dip steel, (b) electroplated steel, (c) galvarium.

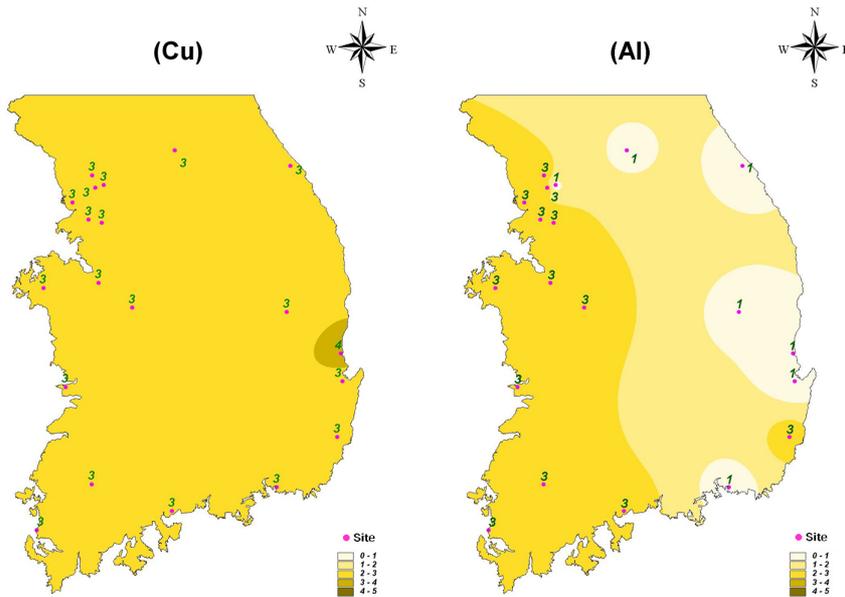


Fig. 11. Corrosion maps based on the data collected for 12 months of copper and aluminum.

were used to estimate the corrosion costs. The total corrosion cost was estimated in terms of the percentage of the GDP of industry sectors and the total GDP of Korea. According to the result of Input/output method, corrosion cost of Korea was calculated as 2.9% to GDP (2005).

Time of wetness was shown to be categories 3 to 4 in all exposure areas. As was expected, a definite seasonal difference was observed in Korea. In summer and fall,

time of wetness was higher than in other seasons. Because of short exposure period (12 months), it should be considered that significant corrosion trends depending upon materials and exposure corrosion environments were not revealed even though increased mass loss and decreased corrosion rate by exposure time. This work will be continued during 10years and each data will be revised too.

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