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Survey of National Corrosion Cost

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Previous national studies on costs of corrosion are reviewed and brief explanations are given of the Uhlig method, Hoar method and Input-output method that are employed for corrosion cost estimation. Total costs of corrosion of 11 countries are summarized and the results by Uhlig methods are compared especially for the recent studies from the U.S, Japan and China.

Keywords *: corrosion, corrosion cost, Uhlig method, Hoar method, Input-output method*

1. Introduction

The corrosion of materials and structures has a significant impact on the economy, including infrastructure, transportation, utilities, production and manufacturing. The common finding of cost of corrosion is that the annual corrosion costs ranged from approximately 1 to 5 percent of the Gross National Product (GNP) of each nation.[1)-7)] Corrosion is also known to be one of the major causes for accidents responsible for the massive casualties. The most worst accident may be the one in Bhopal, India in 1984, which occurred by the corrosion of the stainless steel tank wall and lead to the death of at least 3000 people.

For minimizing the impact of corrosion, proper strategies needs to be developed and the cost of corrosion in various industrial sectors should be determined by a systematic study. Through the survey on the cost of corrosion, avoidable and unavoidable corrosion cost can

Table 1. Examples of corrosion cost estimation by the Uhlig method

Control Methods/Services	Cost of Corrosion Estimation
Coating(painting)	Amount of total sale x Proportion used for corrosion protection x Cost for applying coating /Cost of material for coating (in construction, structure, marine transportation, trucks and rail road car, home appliances, road construction, machinery, metal goods, wooden products, government supplies, export etc)
Metal surface finishing	Amount of order(including import) in tin plate, tin free steel, galvanized steel, other surface treated steel, weathering steel, lining pipe, steel pile x price difference between mild steel
Corrosion resistant materials	Amount of order in ferritic and austenitic stainless steels x amount of order of titanium and copper alloys x price difference between mild steel x Proportion used for corrosion protection
Anti-rust oil	Amount of total sale of grease and lubrication oil x Proportion used for corrosion protection
Inhibitor	Amount of total sale in boiler water, cooling water, treatment on process side and anti-rusting for feed water
Anodic and cathodic protection	Amount of total sale
Research	Amount of total research fund related with corrosion
Corrosion control and monitoring	Amount of total sale(suppliers only) x proportion for corrosion protection

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be identified and information on proper corrosion control practices needed to be implanted can be obtained. Further, potential savings and recommendations can be included to realize the reduction in cost of corrosion.

2. Methods for estimating the cost of corrosion

Three methods are mainly used for the estimation of cost of corrosion though the methods have not been established yet. Brief explanations of these three methods will be given in the following sections.

1.1 Uhlig method[4)]

The total direct cost of corrosion was estimated by adding the cost of control methods and services. The corrosion control methods and services include protective coatings, metal surface finishing, corrosion-resistant materials, corrosion inhibitors, cathodic protection, and corrosion control and monitoring and corrosion research. Examples on how to estimate the corrosion cost[6)] are as listed in Table 1.

1.2 Hoar method[2)]

In Hoar method, the cost of corrosion is first determined for specific industry sectors and then extrapolated to calculate a national total corrosion cost. As in the Uhlig method, information is gathered by interviewing corrosion experts and by surveys on expenditures for corrosion protection practices. A typical form of questionaire for gathering information[6)] is as shown in Table 2. Major industries included for survey are energy, transportation, construction, chemicals, metals, and machinery industries.

Table 2. Forms used for corrosion cost estimation by the Hoar method

	corrosion cost by	Facility A	B	C	....
Construction	(a) corrosion resistant materials (b) coated or covered pipes (c) coating and lining (d) plating and metallic coating (e) inhibitors, rust-preventing oils and chemicals (f) cathodic and anodic protection (g) others.				
Maintenance	(a) corrosion resistant materials (b) coated or covered pipes (c) coating and lining (d) plating and metallic coating (e) inhibitors, rust-preventing oils and chemicals (f) cathodic and anodic protection (g) others				

1.3 Input-output method[1)]

The input-output method uses a simplified general equilibrium model of an economy showing the extent to which each sector uses inputs from the other sectors to produce its output. The Battelle-NBS study[1)] developed and used this method for the first time to estimate the cost of corrosion and defined the total cost of corrosion as "the increment of total cost incurred because corrosion exists. It developed three "worlds" for its analysis as follows: World I: real world of corrosion, World II: hypothetical world without corrosion, and World III: hypothetical world in which the economically most effective corrosion prevention is practiced. For the analysis, the Input/Output Matrix is developed showing how the changes of each sector influence the others, and finally how they influence the entire domestic industry, or GDP. The matrix can also be developed for an ideal world where corrosion does not exist. From the comparison of these two matrices, the cost of corrosion can be estimated.

Table 3. An example of input-output matrix

	Intermediate demand	Final demand	Total demand	Import	Gross domestic expenditure
Intermediate inputs	matrix A	matrix C			
Value added	matrix B				
Domestic production					

2. National studies on cost of corrosion

Cost of corrosion studies have been reported to be undertaken by 11 countries so far. The national costs of corrosion vary between 1.5 and 5.2 percent as shown in table 4. Several countries such as China, Japan, the United kingdom, and the United States have conducted more than once. The united states has undertaken three times, and the earliest one was reported in 1949. In this study, the total cost of corrosion was estimated by the Uhlig method, that is, by summing up materials and method costs related to corrosion control. The annual cost of corrosion to the United states was estimated to be $ 5.5 billion or 2.1

Table 4. National corrosion costs per annum.

	Country	Annual corrosion cost	Percent of GNP	Year
1	UK	£ 1.365 billion	3.5	1970
2	USA	$ 534 billion	6.0	1998
3	Japan	Y 9694.7 billion	1.9	1997
4	Australia	$ 2 billion	1.5	1982
5	USSR	$ 6.7 billion	2.0	1969
6	W. Germany	$ 6 billion	3.0	1969
7	Finland	$ 54 million	-	1965
8	Sweden	$ 77 million	-	1964
9	India	$ 320 million	-	1961
10	Kuwait	$ 1 billion	5.2	1987
11	China	$ 35.5 billion	-	2000

percent of the 1949 GNP.

A number of national studies in Japan, the United States, and the United Kingdom were then followed in the 1970s. In United States, the Battelle-NBS study in 1978 used an economic input/output model for estimating the cost of corrosion. This model was able to account for the direct effects of corrosion on individual industry sectors and the interaction among various industry sectors. This model was later adapted by studies in other nations, Australia in 1983, Kuwait in 1995 and Japan in 1997. The total cost of metallic corrosion per year in United States was estimated to be $82 billion, 4.9 percent of the GNP in 1975, and approximately 40 percent of this was estimated to be avoidable by the use of the most economically effective, presently available corrosion technology.

In the study conducted in 1970 by the United Kingdom, the cost of corrosion was estimated by Hoar Method.[2] In this study, the direct expenditures (costs to owner/ operator) was evaluated in each economic sector. Indirect costs (cost for user) were not included in the study. The cost of corrosion was estimated to be £1,365 million per annum, 3.5 percent of the gross national product of 1970, and approximately 20 to 25 percent of the total national corrosion costs was reported to be saved with better use of current knowledge and techniques.

In the cost of corrosion study conducted in 1975 in Japan,[3] the corrosion cost was estimated by the Uhlig and Hoar methods. Total costs by the Uhlig method were approximately 2.5 trillion yen (US$ 9.2 billion), whereas total costs by the Hoar method were approximately 1 trillion yen. The Uhlig method's estimate is 1.5 trillion yen higher then that of the Hoar method. The difference between the total cost estimates of the two methods is large and this was reported to be partially due to omissions of some costs by the second method and due to the difficulties and uncertainties in the investigation of the costs of corrosion.

Most recent studies were conducted by Japan in 1997, US in 1998 and China in 2001. In these studies cost of corrosion of each nation was determined by using all the three methods, that is, the Uhlig, Hoar and Input-output methods. Cost of corrosion in Japan[6] estimated by the Uhlig and Hoar methods for 1997 were reported to be 3,938 billion yen and 5,258 billion yen, respectively, which were equivalent to 0.77% and 1.02% of the GNP of Japan. The total cost including the direct and indirect costs estimated preliminary by the Input/Output analysis was more than 2 times larger than the direct cost estimated by the Uhlig method.

In the study[5] conducted by the US in 1998, the total direct cost of corrosion was determined in 26 industrial sectors. The total direct cost of corrosion was reported to be $276 billion per year, which is 3.1 percent of the U.S. gross domestic product(GDP). Indirect costs to the user were conservatively estimated to be equal to the direct costs. The overall cost was as much as 6 percent of the GDP the US in 1998.

In China,[7] the overall corrosion cost per annum estimated by the Uhlig and Hoar methods at 1997-2001 was found to be 204,827 and 228,843 million yuan respectively, which is equivalent to 2% of the gross national product of China. The total cost of corrosion including the direct and indirect cost estimated by Input/out put method to be more than 497.9 billion yuan per year.

3. Comparison of corrosion costs in national studies

Though the many national studies have been conducted on the cost of corrosion, it is difficult to compare and analyze the results directly. This is due to the fact that the studies were performed based on different categories and in different years. From the currently available data, the results from the U.S, Japan and china are compared.

The results shown in table 5 are collected from those by the Uhlig method, that is, estimation of the total annual direct cost of corrosion by adding the cost of control methods such as protective coatings, corrosion-resistant alloys, corrosion inhibitors, anti-corrosion oil, cathodic protection, R&D and corrosion inspection. As shown in this table, the most widely used method for corrosion protection is the application of organic coatings. The categories of research and development and education and

Table 5. Comparison of national corrosion cost[5)-7)](in billion dollars) estimated by the Uhlig method.

	USA(1998)		Japan(1997)		China(1997-2001)	
	cost	percent	cost	percent	cost	percent
Coating	35.0	67.82	21.9	58.4	19.498	76.15
Surface finishing	2.5	4.84	9.65	25.7	2.927	11.43
Corrosion Resistant Materials	7.5	14.53	4.22	11.3	3.128	12.22
Anti-corrosion oil	1.8	3.49	0.606	1.62	0.025	0.10
Inhibitor	1.066	2.07	0.428	1.14	0.012	0.05
Cathodic protection	0.146	0.28	0.207	0.55	0.012	0.05
R & D	3.1	6.0	0.397	1.06	-	-
Corrosion Inspection	0.5	0.97	0.091	0.24	-	-
total	51.606	100	37.50	100	25.602	100

training indicated unfavorably low numbers.

One more important point to be noted in national corrosion cost studies is preventive strategies developed for minimizing cost of corrosion. The preventive strategies from the 1998 U.S. study include: (1)increase awareness of large corrosion costs and potential savings, (2)change the misconception that nothing can be done about corrosion, (3)change policies, regulations, standards, and management practices to increase corrosion cost-savings through sound corrosion management, (4)improve education and training of staff in recognition of corrosion control, (5)advance design practices for better corrosion management, (6)advance life prediction and performance assessment methods, and (7)advance corrosion technology through research, development, and implementation. The conclusions from the 1997 Japan study suggested as preventive strategies to (1)develop technology in corrosion and corrosion prevention into technology for public infrastructure, (2)enlightenment and instruction on corrosion and corrosion prevention, and establishment of a qualification system, (3)create a network of experts and to utilize the corrosion center as the core center, (4)organize experts on corrosion and corrosion prevention, and exploitation of their knowledge.

4. Concluding remarks

The national costs of corrosion have been reported to vary between 1.5 and 5.2 percent or 6.0 percent of GNP when indirect cost is included, and an uncertainty of the estimation reported was ±30 percent for the total corrosion cost. Many national studies have been performed for corrosion control methods /services and industrial sectors, but based on different classification or categories, and it is difficult to compare and analyze the national corrosion costs directly. This bring out the needs for the development of unified or standardized method for estimation. Still, corrosion-related cost information from the private industry sectors was reported to be difficult to obtain directly. This stemmed from the fact that either the information was not readily available or could not be released because of company policies. This is expected to be the case for corrosion cost survey in Korea to be conducted for two years starting from 2006 and this obstacle needs to be surmounted for more accurate estimation of corrosion costs.

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