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Survey of Corrosion Cost in China and Preventive Strategies

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A national consultative project entitled "corrosion cost survey in China and preventive strategies" was funded by the Chinese Academy of Engineering in 1998. Soon afterwards, an expert group was organized jointly by the Institute of Metal Research, CAS and Chinese Society of Corrosion and Protection. The report on corrosion cost survey in China was published in 2003. According to this report the overall annual corrosion cost in China estimated by the Uhlig Method and Hoar Method at 1997-2001 was found to be 200.7 billion Yuan RMB and 228.8 billion Yuan RMB respectively, which is equivalent to 2% of the gross national product of China. However the total cost of corrosion including the direct and indirect cost was estimated to be more than 500 billion Yuan RMB per year in China. Among them, corrosion cost of infrastructure ranked in first comparing with other sectors. Although corrosion costs in some sectors, such as electric power, petrochemical, oil pipeline and railway in China has reduced in the past years, significant losses are still being encountered in most sectors of industries and cost-effective methods have not always been implemented. Both successful and unsuccessful cases in corrosion control and corrosion management were collected. As the investment in capital construction continues increasing rapidly in China, the maintenance and life extension of the infrastructures will become a big issue. The preventive strategies have been suggested

Keywords *: corrosion cost survey, Uhlig's method, Hoar's method, direct and indirect cost, preventive strategies*

1. Introduction

In the past, much work has been undertaken on the corrosion cost study in several countries since 1949, such as the United States, the United Kingdom, Japan, Australia, USSR, Germany, Sweden, India, Czechoslovak, Poland and Kuwait. The common finding was that the annual corrosion costs ranged from approximately 2 to 5 percent of the Gross National Product (GNP) of each nation. The indirect costs, due to corrosion damage, often are significantly greater than the direct costs and more difficult to estimate. The estimated avoidable corrosion costs varied widely with a range from 15 to 35 percent of the total cost.

As the investment in capital construction continues increasing rapidly in China, what is the current status of corrosion in China? A national consultative project entitled "corrosion cost survey and preventive strategies" was funded by the Chinese Academy of Engineering in 1998. The main result is reported in following

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2. Method of corrosion cost survey in previous studies

To estimate costs of corrosion we need to find an appropriate method for data collection in quantitative economical analysis. In previous studies, the Uhlig's method, the Hoar's method and the Battelle-NBS method were used

2.1 The Uhlig's method

"The Cost of Corrosion in the United States" study, led by H.H. Uhlig, was the earliest effort to estimate the costs of corrosion in 1949.[1)] In this study the calculation of corrosion costs was based on corrosion prevention methods from the production and services, such as paint and coatings, inhibitors, corrosion-resistant metals and cathodic protection used for corrosion prevention. This method is to estimate the total costs by summing up the cost for both the owner (direct cost) and the users (indirect cost) of corroded components. An advantage of the method is that the cost data are more readily available for well-defined products and services. For example the national costs of corrosion in US are presented in Table 2.

2.2 The Hoar's method

In the beginning of 1970's, the UK committee, led by

Table 1. Total annual corrosion cost

Country	Year	Total annual corrosion cost	Percent of GNP, %	Estimated potential savings, %	Method	Reference
USA	1949	$5.5 billion	2.1		Uhlig	1
	1975	$70 billion	4.2	15	IO	2
	1995	$300 billion	4.21	33	IO	3
	1998	$275.7 billion			IO	4
UK	1957	£0.6 billion			Vernon	5
	1969	£1.365 billion	3.5	23	Hoar	6
Japan	1975	2550.93 billion JPY			Uhlig	7
	1997	3937.69 billion JPY			Uhlig	8
USSR	1975	13014 billion Rouble			Only Metal Structure	9
	1985	40 billion Rouble				10
W.Germany	1968	19 billion Mark	3	25	D.Bhrens	11
	1982	45 billion Mark				12
Sweden	1986	35 billion Franc		20		13
India	1960	1.5 billion Rupee				14
	1984	40 billion Rupee				15
Australia	1973	0.47 billion AUD			Uhlig	16
	1982	$2 billion			IO	17
Czech	1986	15 billion Franc				18
Poland			6～10			19
Kuwait	1987	$1 billion	5.2			20

Table 2. Corrosion cost in US estimated by Uhlig's method in 1949

	ITEM	COST [$ X million]	PERCENT OF TOTAL CORR.COSTS
DIRECT COSTS	Paint	2,000	36
	Metallic coatings & electroplate	472	9
	Corrosion resistant metals	852	15
	Boiler and other water treatment	66	1
	Underground pipe maintenance and replacement	600	11
INDIRECT COSTS	Domestic water heater replacement	225	4
	Automobile internal combustion engine repairs	1,030	19
	Automobile muffler replacement	66	1

Table 3. Corrosion cost in UK estimated by Hoar's method in 1972

INDUSTRIAL SECTOR	ESTIMATED NATIONAL CORROSION COSTS	
	£ X million	%
Building and Construction	250	18
Food	40	3
General Engineering	110	8
Government Departments and Agencies	55	4
Marine	280	21
Metal Refining and Semi-Fabrication	15	1
Oil and Chemical	180	13
Power	60	4
Transport	350	26
Water	25	2
TOTAL	£ 1,365	100%

Chairman T P Hoar, issued its report entitled "Report of the Committee on Corrosion and Protection"[6] They made inquiries to examine each industrial sector in detail and calculated the cumulative total of direct losses arising from corrosion and corrosion prevention costs. These costs include direct costs of the industry and indirect costs sustained by the users of the product due to maintenance or replacement. Costs from interactions among sectors were not included.

For example the U.K. national costs of corrosion in major areas of industry are presented in Table 3.

2.3 The Battelle-NBS method

In 1975 the National Bureau of Standards and the

Battelle Columbus Laboratories jointly conducted the study for estimating the corrosion cost to the US.

The Battelle-NBS study (United States, 1978)[2] used an input/output (IO) framework to estimate the cost of corrosion for the U.S. economy. The input-output analysis was invented by Wassily Leontief, for which he received a Nobel Prize in 1973. IO is a general equilibrium model of an economy showing the extent to which each sector uses inputs from the other sectors to produce its output, and thus showing how much each sector sells to each other sector. The U.S. economy was divided into 130 industrial sectors in the input/output model. Industrial input-output, can be summarized in one chart which lists monetary transactions for each industry. Each industry sector needs to estimate the costs of corrosion prevention and the cost of repair and replacement due to corrosion. The study used a version of the Battelle National Input/Output (IO) Model to estimate the total corrosion cost. The total cost of corrosion was defined as "increment of total cost incurred because corrosion exists." The corrosion costs were estimated by calculating the GDP (Gross Domestic Product) for the following three "Worlds" and the IO model was constructed to describe these three "worlds". The study then determined the total national cost of corrosion as the difference between the GDP of World I and the GDP of World II.

World I: real world of corrosion

World II: hypothetical world without corrosion as a baseline

World III: hypothetical world in which the economically most effective corrosion prevention method was practiced where corrosion is ideally suppressed

Corrosion costs $\overset{GDP}{=}$ World II $\overset{GDP}{-}$ World I

Avoidable corrosion cost $\overset{GDP}{=}$ World III $\overset{GDP}{-}$ World I

Unavoidable corrosion cost $\overset{GDP}{=}$ World III $\overset{GDP}{-}$ World II

Avoidable costs of corrosion are the difference between the GDP of World I and the GDP of World III or "cost which are amenable to reduction by the most economically efficient use of available corrosion control technology."

Unavoidable costs of corrosion are the difference between the GDP of World II and the GDP of World III or "those which are not amenable to reduction by presently available technology."

This method calculates the total of direct and indirect costs and produces bigger values than those estimated by both the Uhlig and Hoar's methods.

The total US Corrosion Costs was estimated to be $70 billion / year in 1975 and total direct cost of corrosion in analyzed sectors, to be $137.9 billion / year and Extrapolated to U.S. Economy to be $275.7 billion / year in 1998.(4)

For example the US national costs of corrosion by major areas of industry are presented in Table 4.

Table 4. The US national costs of corrosion by major areas of industry

Sector names	Estimated corrosion costs	
	[$ Billion]	%
Production &Manufacturing	17.6	12.8
Utilities	47.9	34.7
Government, Nuclear waste storage, defence	20	14.6
Infrastructure	22.6	16.4
Transportation	29.7	21.5
Total	137.9	100

3. Corrosion cost in china

The first corrosion cost survey in China, had been made in 1979, but only including the corrosion losses in a few sectors of national economy, as shown in Table 5.

In 1986 a study on the corrosion cost for machinery industry was reported by Wuhan Institute for Materials Protection. According to the results of inquiring into 2816 enterprises the total corrosion cost in machinery industry was estimated to be 11.6 billion RMB per year, 5.64% of output value of machinery industry. Since then, almost three decades have passed, and the industrial structure has been drastically changed. Many new materials, manufacturing processes and cost effective corrosion protection techniques have been introduced to the industries for further lowering corrosion costs. Therefore, a national consultative project entitled "corrosion cost survey and preventive strategies" was funded by the Chinese Academy of Engineering in 1998. Soon afterwards, an expert Group was organized jointly by the Institute of Metal research, CAS and The Chinese Society of Corrosion and Protection. More than 30 experts, led by Professor Wei Ke, took part in this project. Questionnaires were sent to the

Table 5. Corrosion cost in some sector of China in 1979

Sector	Number of Investigated Enterprises	Corrosion Costs /10^3 Yuan	Percent of GNP / %
Chemical	10	79729	3.97
Oil refinery	13	7500	0.08
Metallurgy	30	6780	2.4
Chemical Fiber	17	3300	1.5

major industries concerned. When necessary, the meeting or visiting to the factories was conducted by the field experts. In fact, this was the first nationwide corrosion survey in China including most industry sectors. A report on corrosion survey in China was published in 2003. Since the authorized unit did not construct IO matrix, which represents the actual structure of Chinese economy, we have mainly used Uhlig's and Hoar's methods.

In the following, the use of both Uhlig's method and Hoar's method for determining the cost of corrosion in China is discussed. Obviously the prior studies of different countries have provided useful direction for investigation, including a set of industrial sectors and a list of corrosion control methods.

The following direct costs (cost to owner / operator of the structure) were included in the study:

- Replacement of equipment or buildings
- loss of product
- maintenance and repair
- corrosion control (such as inhibitors, organic and metallic coatings)
- material of corrosion not for structural integrity
- material of corrosion for product purity special processing for corrosion resistance

In addition, the current study especially focused on several individual sectors, which sustained more corrosion losses, such as:

- Oil and natural gas extraction, storage and petroleum pipeline
- Corrosion in chemical and petrochemical industries
- Offshore and marine corrosion
- Electric Power Group Corporations
- Railway and vehicles
- Automobile, car and bus
- Machine building industry
- Infrastructure, highway, bridge, port, building and construction
- Hydraulic power and water conservancy metallic facilities

We have also made inquiries and investigations to examine some typical enterprises in detail and calculated the cumulative total of direct losses arising from corrosion and corrosion prevention costs, such as:

- Corrosion in Luzhou Natural Gas Chemical Cooperation
- Corrosion in Yizheng Chemical Fiber Co.
- Shanghai Pharmaceutical enterprise group
- Daya Bay Nuclear Power station
- TV tower in natural environment.

Although corrosion costs in some sectors, such as electric power, petrochemical, oil pipeline and railway have fallen due to better understanding of corrosion, improvements in materials and protection methods, significant losses are still being encountered in most sectors of industries. Some effective modern anticorrosion method has not been widely used in China.

Table 6. Corrosion cost in China estimated by Uhlig's method (billion RMB)

Corrosion protection method	COST/Yuan billion	Proportion/%
Paints and protective coatings	151.8	75.63
Surface treatment	23.42	11.66
Corrosion resistant materials	25.03	12.46
Rust prevention oils	2	0.10
Inhibiters	1	0.05
Cathodic protection	1	0.05
Total	200.79	100.00

Table 7. Corrosion cost in China estimated by Hoar's method (billion RMB)

Sector	Corrosion Cost/ Yuan billion	Proportion, %
Chemical, Petrochemical, Pharmacy	30.00	13
Energy: Electric, Oil, coal, Atomic	17.21	8
Transpotation: Railway, Motor vehicle, Car, bus	30.39	13
Infrastructure, Building	100.00	44
Machinery and manufacturing	51.24	22
Total	228.84	100

The national costs of corrosion by major areas of industry in China are presented in Table 6 & Table 7

The overall annual corrosion cost in China estimated by the Uhlig's Method and Hoar's Method at 1997-2001 was found to be 200.79 and 228.84 billion RMB respectively, which is equivalent to 2% of the gross domestic product of China.

In addition to the above estimation, a preliminary analysis by comparing with the results of Input/output method from other countries was performed. The total cost of corrosion including the direct and indirect cost was estimated to be more than 400-500 billion Yuan RMB per year in China. Thus, Corrosion Cost in China is more than 5% GNP, and direct corrosion cost is more than 2% GDP, which is higher than developed countries. The estimated cost mainly depends on the cost of coatings, which occupied more than 70% in the total corrosion cost.

Corrosion cost of infrastructure, building and constructure, ranked first comparing with other sectors. The Uhlig's method shows that the estimated cost mainly depends on the cost of coatings, which occupied more than

70% in the total corrosion cost. The Hoar's method shows that the estimated cost of infrastructure in natural environment occupies more than 40% in the total corrosion cost. As the investment in capital construction increases rapidly in China, the maintenance and life extension of the infrastructures will become a big issue. With appropriate knowledge it is possible to foresee corrosion rate in the design phase. For a better saving the resources it is most important to disseminate the information of corrosion control to the country. With necessary measurement equipment it is possible to choose the optimal protection technology during the whole construction and exploitation period

4. Preventive strategies to reduce corrosion cost

Corrosion Cost in China is more than 5%GNP, and direct corrosion cost is more than 2% GNP, which is higher than that of developed countries. Modern corrosion prevention is not only composed of technical solutions but also includes ecological, economic, legal, educational, social, safety, and international cooperation aspects. Corrosion prevention should be treated as an important management problem requiring similar effort as in the cases of protection of the environment and health.

To achieve a substantial savings, a number of improvements would have to be made on a national scale:

1) An authoritative organization is essential to coordinate the actions in the scale of the whole country. We suggested to build a corrosion leading group under the National Commission of Science and Technology to coordinate the actions at every level such as owner, operator, user, government regulators, policy makers, engineers, designers, and general public.

2) Make more effort in better dissemination of the existing information of corrosion and pay more effort on corrosion-relative legislature, regulations and corrosion standards to avoid contradictory elements in competition for markets.

3) Draw up a national long term planning for corrosion control to build stabilized funding resources, improving technological platform and databases for research, development and implementation, such as. built a corrosion network, including database and expert systems for technical advisory and consulting services. Take every opportunity for large savings through more cost-effective use of currently available means to reduce corrosion.

4) As the investment in capital construction continues increasing rapidly in China, the maintenance and life extension of the infrastructures will become a big issue. Popularize an elementary knowledge of corrosion, improve education and training of staff are the most important task. The advanced methodologies such as LCC (lifetime cycle cost) and risk based inspection should be emphasized from design phase. A widely use of high performance coating, stainless steel, weathering steel, cathodic protection and computerized inspection is expected in the future, which also responds to the public concern about the environmental issues.

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