Corrosion Costs and Prevention and Control Strategies in China: Postprint

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Abstract

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Full Text

Corrosion Cost and Preventive Strategies in China

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Abstract

Material corrosion is a common phenomenon in production and daily life. Severe corrosion not only causes material failure but may also trigger unexpected catastrophic accidents. Understanding and recognizing corrosion problems is an essential requirement for safeguarding people' s lives and property. To this end, the Chinese Academy of Engineering conducted an investigation on corrosion costs in China. Data show that in 2014, China' s corrosion cost reached 2,127.82 billion RMB, accounting for approximately 3.34% of the country' s GDP that year. Corrosion problems are preventable and controllable. By implementing top-level designs for corrosion prevention, strengthening corrosion and protection research, developing new anti-corrosion technologies, promoting anti-corrosion standards and best practices, and raising public awareness of corrosion issues, China' s corrosion protection capabilities can be comprehensively enhanced.

Keywords: corrosion, cost, survey, prevention, strategy

The Strategic Importance of Corrosion Prevention

Material corrosion refers to the deterioration of materials through chemical or electrochemical reactions with their environment. This phenomenon is ubiquitous in both industrial production and everyday life. Serious corrosion not only leads to material failure but can also induce sudden, catastrophic accidents, profoundly impacting people' s lives and property. Understanding and addressing corrosion is therefore not merely a technical research imperative but an essential requirement for ensuring public safety.

Corrosion Prevention is a Matter of National Security. Corrosion-induced leaks of hazardous materials and structural collapses pose grave threats to public safety. On November 22, 2013, an explosion in a drainage culvert in Qingdao' s economic development zone killed 62 people and caused over 750 million RMB in direct economic losses. The State Council' s investigation identified the direct cause as "pipeline corrosion thinning and rupture at the intersection of an oil pipeline and a drainage culvert, resulting in crude oil leakage." Such incidents underscore the critical link between corrosion control and citizen safety.

Corrosion Prevention is an Economic Imperative. Every industry faces corrosion challenges, and effective control directly enhances productivity and cost management. In some developed countries, robust corrosion prevention measures have made rust a rare sight. Conversely, uncontrolled corrosion accelerates infrastructure aging, shortens equipment lifespans, and wastes the substantial resources and energy invested in their construction.

Corrosion Prevention Affects People' s Livelihoods. Corrosion-related leaks and emissions of toxic substances seriously impact daily life and public health. Drinking water pipe corrosion can deteriorate water quality, causing "red water," "black water," or discolored water incidents that compromise water safety.

Corrosion Prevention is an Environmental Priority. Overseas incidents of pipeline ruptures have caused massive oil spills, severely contaminating rivers, lakes, and hundreds of hectares of land, killing vegetation and wildlife. Corrosion in nuclear facilities can lead to radioactive material leaks, damaging biological organisms and even causing genetic mutations.

Corrosion Prevention Supports Resource Conservation. Corrosion causes premature retirement of facilities and equipment, indirectly wasting the raw materials and energy consumed during their construction. It also contributes to water, air, and soil pollution, further depleting precious resources.

Corrosion Prevention is Vital to the Belt and Road Initiative. As China assists Belt and Road countries in building infrastructure, it must address local corrosion challenges. This requires deeper understanding of corrosion environments along these routes to develop appropriate protection strategies, ensuring both project quality and China' s international reputation.

International Corrosion Cost Surveys

Corrosion cost surveys are essential tools for nations to assess economic and social impacts. By 2014, many countries had conducted such investigations, with the United States and Japan performing multiple surveys to analyze corrosion' s evolving impact across different development stages.

U.S. Corrosion Surveys. Uhlig [3] conducted the earliest national corrosion cost study in the United States, publishing "The Cost of Corrosion to the United States" in 1949, which estimated annual corrosion costs at $5.5 billion (2.1% of GNP). In 1975, the U.S. National Bureau of Standards (NBS) performed another comprehensive survey [4,5], introducing the Input/Output economic model to estimate corrosion costs across 130 industrial sectors. This study pioneered the division of total corrosion costs into avoidable and unavoidable losses. Between 1999-2001, CC Technologies, in collaboration with the U.S. Department of Transportation and NACE International, conducted the seventh U.S. survey [6].

Japanese Corrosion Surveys. In 1976, Japan' s Anti-Rust Technology Association and Corrosion Prevention Association conducted their first survey [7], estimating 1974 corrosion losses at 2% of GNP. A second survey in 1999 [8] calculated direct and indirect costs at 9.7 trillion yen (1.88% of GNP), noting that more detailed investigation might reveal costs reaching 3-4% of GNP. A third survey launched in 2016 continues this work.

U.K. Corrosion Survey. In 1969, Professor Hoar chaired the U.K. Corrosion Protection Committee [9], investigating corrosion costs across construction, food, engineering, government, offshore platforms, metal processing, petrochemicals, energy, transportation, and water environments. The 1971 report found annual corrosion costs of £1.365 billion (3.5% of GNP).

International IMPACT Survey. In October 2013, NACE International launched the IMPACT survey [10], a global corrosion study conducted with

DNV GL and APQC, involving enterprises and research institutions from China, Canada, India, and other nations. In 2014, the IMPACT project manager visited China, appointing Academician Hou Baorong as Chair of the China region.

China' s Corrosion Survey

China' s corrosion survey efforts began relatively late [11]. In July 1980, the Corrosion Discipline Group of the State Science and Technology Commission distributed corrosion management and cost survey forms to seven industries, including chemical and metallurgical sectors. In 1986, the Wuhan Materials Protection Institute surveyed corrosion costs in China' s machinery industry. In 1999, following recommendations from Academicians Ke Wei and Cao Chunan, the Chinese Academy of Engineering conducted a study on "Investigation and Countermeasures for Industrial and Natural Environmental Corrosion Problems in China."

The 21st century has brought profound economic changes. Since the 2008 global financial crisis, the world economic center has shifted further toward emerging economies [12]. During China' s 12th Five-Year Plan period (2011-2015), structural adjustment and transformation became priorities, with the service sector surpassing industry as the largest economic sector for the first time in 2012 [13]. Against this backdrop of deepening supply-side structural reform, China' s industrial structure and corrosion cost composition have continuously evolved.

To understand the nation' s corrosion status and industry-specific characteristics in this new era, and to develop strategies for reducing corrosion losses and ensuring critical infrastructure safety, the Chinese Academy of Engineering established the major consulting project "Investigation and Strategic Study on Corrosion Status and Control in China" in 2015. Led by the Institute of Oceanology, Chinese Academy of Sciences, and jointly conducted with the Chinese Society for Corrosion and Protection, University of Science and Technology Beijing, Beihang University, Nanjing Hydraulic Research Institute, and the Chinese People' s Liberation Army Armored Force Academy, this comprehensive survey covered five major domains: infrastructure, transportation, energy, water environment, and manufacturing/public utilities.

Survey Methodologies

Internationally recognized corrosion cost survey methods include the Uhlig method, Hoar method, and Battelle method [14].

Uhlig Method. This approach calculates total corrosion costs by summing expenses for corrosion prevention measures in production, manufacturing, maintenance, and repair, including coatings, surface treatment, corrosion-resistant materials, rust-preventive oils, inhibitors, electrochemical protection, corrosion research, and monitoring. In China' s 2014 survey, annual production of anti-corrosion products and sales of anti-corrosion technologies were calculated from government statistics, with unit costs obtained through expert consultation or data analysis, and overall market sizes estimated from manufacturer scales and market shares.

Hoar Method. This method examines and aggregates corrosion costs and protection expenses across industries through questionnaires, expert consultation, and field surveys, using statistical methods to estimate national costs. Since infrastructure and public utility corrosion data are often publicly available, while some enterprises don' t record or disclose such data, expert-assisted scientific estimation becomes crucial for specific industries. In China' s survey, questionnaires were distributed across typical economic sectors, supplemented by investigations of representative enterprises to estimate industry-wide costs based on their market shares.

Battelle Method. This Input/Output matrix approach calculates corrosion costs across economic sectors by comparing three "worlds" : World I (the real world with corrosion), World II (a hypothetical world without corrosion), and World III (a world with optimal corrosion control). Total corrosion cost equals the difference between Worlds I and II, subdivided into avoidable (Worlds I vs. III) and unavoidable (Worlds II vs. III) costs. Battelle' s method accounts for both initial investment and maintenance costs, while Uhlig' s only considers the former, and also addresses cross-industry cost overlaps.

Survey Results

Uhlig Method Results. The 2014 direct corrosion cost in China totaled approximately 1,063.91 billion RMB [11,15], with protective coatings representing the largest component, followed by corrosion-resistant materials and surface treatment expenses. Notably, corrosion monitoring costs were excluded due to data unavailability. Indirect costs—including production losses, reputational damage, environmental damage, and casualties—are typically 1-3 times direct costs. Conservatively assuming indirect costs equal direct costs, total 2014 corrosion costs reached 2,127.82 billion RMB, representing 3.34% of GDP, or about 1,555 RMB per capita [11,15].

Hoar Method Results. This method estimated 2014 corrosion costs across five major economic sectors at 1,109.02 billion RMB. Extrapolating from these sectors' GDP proportions yielded a national direct corrosion cost of 1,348.98 billion RMB—higher than the Uhlig estimate. This difference stems from Hoar' s inclusion of both investment and maintenance costs, and its accounting for inter-industry overlaps. Among the five surveyed domains, manufacturing and public utilities showed the highest direct corrosion costs.

Recommendations for Enhancing Corrosion Protection in China

1. Strengthen Top-Level Design and Management. Currently, no dedicated agency oversees national corrosion prevention strategy. Given its cross-industry importance, the Ministry of Science and Technology (MOST) should lead in establishing a corrosion protection leadership group with the National

Development and Reform Commission, Ministry of Industry and Information Technology, and State Administration for Market Regulation to coordinate top-level planning. A specialized institution should regularly monitor corrosion status and costs in key industries, enforce lifecycle corrosion management for major infrastructure, and establish regular reporting systems for corrosion control in critical facilities.

2. Establish R&D Programs and Drive Innovation. Corrosion protection is a common scientific challenge across all industries. MOST should organize expert teams to develop corrosion protection technology roadmaps, clarifying priorities and funding sources. National science and technology programs and key foundations should support fundamental research on corrosion mechanisms, numerical simulation, monitoring technologies, new materials, and long-term protection methods. Research bases, experimental stations, and information-sharing platforms should be established to meet domestic and international needs.

3. Develop Laws, Regulations, and Standards. A comprehensive legal and regulatory framework for corrosion protection safety must be established to strengthen management and oversight. Enterprises should be required to implement corrosion protection standards throughout engineering design, material selection, construction, operation, and maintenance. Standardization talent teams should be trained to understand both corrosion technology and standards development, with mandatory implementation in safety-sensitive industries.

4. Enhance Education and Public Awareness. The survey identified a severe shortage of corrosion protection professionals. National strategy must therefore prioritize education and outreach. University curricula should strengthen corrosion science education, while vocational schools should provide technical training. Public media and social campaigns should raise awareness among government officials, entrepreneurs, and students about corrosion hazards and the importance of prevention, promoting lifecycle cost concepts.

5. Promote Advanced Technology Integration and Application. After decades of development, China has established world-class corrosion research capabilities. Advanced protection technologies should be demonstrated, promoted, and applied to new and existing infrastructure, supporting China' s transformation from "Made in China" to "Quality China."

6. Support the Belt and Road Initiative. As President Xi Jinping stated, the Belt and Road should become an "innovation road" [17]. With increasing infrastructure cooperation along these routes, China must conduct forward-looking research on representative corrosion problems in typical countries and environments, enhancing the internationalization of China' s corrosion protection industry to support high-quality, sustainable development abroad.

Conclusion

Corrosion is an objective reality, but this does not justify neglect. Through deeper understanding of corrosion mechanisms, mastery of protection technologies, implementation of design management, and enhanced awareness, we can mitigate corrosion and improve infrastructure safety. This survey has clarified China' s current corrosion costs, marking a new beginning. Through national-level corrosion prevention strategies, China will comprehensively enhance its material corrosion protection capabilities across all sectors, providing strong support for achieving the Chinese Dream of national rejuvenation and meeting people' s aspirations for a better life.

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Note: Figure translations are in progress. See original paper for figures.