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Techniques in detect selective leaching in metal components

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Abstract: Selective leaching is a corrosion type in, in which certain element in an alloy is preferentially removed from a material, leaving behind a porous or weakened material that can affect its quality and structural integrity. Evaluating the quality of components affected by selective leaching often involves several inspection techniques and assessment methods to determine the extent and severity of degradation. In this paper, we will describe the main techniques that are used in detect selective leaching in metals and the advantages and disadvantages of each. In addition, visual indicators of the presence of selective leaching will be presented. Selective leaching can significantly affect the long-term operation (LTO) of a nuclear power plant (NPP) by compromising safety, structural integrity, and potentially leading to radioactive material release. Due to the fact, Selective Leaching Detection Program is a requirement of the current national regulatory authority, there is a need to know the techniques for early detection of defects and failures in Structures, Systems and Components (SSCs) due to selective leaching, enabling immediate corrections and minimizing resources and replacements. Hence, the importance of this paper to Angra 1 NPP. As a result of this work, it provides a guide that will deal with the fundamental techniques used for manage and mitigate the risks associated with this phenomenon.

Keywords: selective leaching, corrosion, NPP, LTO.

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Técnicas para a detecção de lixiviação seletiva em componentes metálicos

Resumo: A lixiviação seletiva é um tipo de corrosão, na qual determinado elemento de uma liga é preferencialmente removido de um material, deixando para trás um material poroso ou enfraquecido que pode afetar sua qualidade e integridade estrutural. A avaliação da qualidade dos componentes afetados pela lixiviação seletiva geralmente envolve várias técnicas de inspeção e métodos de avaliação para determinar a extensão e a severidade da degradação. Neste artigo, descreveremos as principais técnicas que são utilizadas na detecção de lixiviação seletiva em metais e as vantagens e desvantagens de cada uma delas. Além disso, serão apresentados indicadores visuais da presença de lixiviação seletiva. A lixiviação seletiva pode afetar significativamente a operação de longo prazo (LTO) de uma usina nuclear (NPP), comprometendo a segurança, a integridade estrutural e potencialmente levando à liberação de material radioativo. Devido à que o Programa de detecção de lixiviação seletiva é uma exigência da atual autoridade reguladora nacional á necessidade de conhecer as técnicas de detecção precoce de defeitos e falhas em SSCs devido a lixiviação seletiva, possibilitando correções imediatas e minimizando recursos e substituições. Daí a importância deste trabalho para a NPP de Angra 1. Como resultado deste trabalho, fornece-se um guia que abordará as técnicas fundamentais utilizadas para gerenciar e mitigar os riscos associados a esse fenômeno.

Palavras-chave: lixiviação seletiva, corrossão, plantas nucleares, extensão de vida útil.

1. INTRODUCTION

Selective leaching is a corrosion type in, in which certain element in an alloy is preferentially removed from a material, leaving behind a porous or weakened material that can affect its quality and structural integrity. Graphitization and dezincification are two common forms of selective leaching. Dezincification involves the selective removal of zinc from particularly brass alloy. Graphitization involves the selective removal of iron from particularly cast iron (iron-graphite matrix). Selective leaching occurs in aqueous environments, particularly acidic solutions. Occurs in other alloys, such as Aluminum Bronze (De-aluminification).

Selective leaching removes specific metals from an alloy, leading to changes in both its color and its mechanical properties. The primary effect of selective leaching is usually a change in the surface texture and a lightening of the color In copper-based alloys, this often results in noticeable reddish or reddish-brown appearance due to the predominance of copper, for example in brass (composed of copper and zinc).

This process can result in the compromising of NPP integrity. The aging mechanism caused by the corrosion, fatigue, wear, and embrittlement affects the ability of the Structures, Systems and Components (SSC) to perform its intended function.

Selective leaching can significantly affect the long-term operation (LTO) of a nuclear power plant (NPP) by compromising safety, structural integrity, and potentially leading to radioactive material release. Hence, the importance of this paper to Angra 1 NPP.

Evaluating the quality of components affected by selective leaching often involves several inspection techniques and assessment methods to determine the extent and severity of degradation.

In the context of the Angra 1 Nuclear Power Plant, it minimizes costs associated with emergency repairs or unplanned replacements of damaged SSCs. In addition, component failure due to selective leaching can lead to leaks of radioactive substances, which would prevent serious environmental impacts or mechanical failures.

In this paper, we will describe the main techniques that are used in detect selective leaching in metals and the advantages and disadvantages of each.

2. METHODOLOGY

The existing techniques used to detect selective leaching [1] are described as followings:

1. Visual Inspection: Visual examination is an initial step to identify visible signs of degradation caused by selective leaching. It involves observing surface changes, discoloration or the presence of various oxides on surface (physical condition). Particularly in raw water environments (e.g., river, lake, well, and ocean water sources), other surface oxides, debris, and scale can often obscure the component surface and mask indications of potential dealloying.

2. Mechanical Testing: Mechanical tests assess changes in the material's mechanical properties like tensile strength, ductility, or elasticity due to selective leaching. Any alterations can be indicative material's structural integrity. Hand tools (See Figure 1), such as flat head screwdrivers, picks and chisels are often used to scratch, scrape, and probe areas of the component's surface in an attempt to dislodge any corrosion product left intact due to shutting down. The mechanical test can be destructive or NDE. The choice between the two methods will depend on the type of material being tested. Common hardness testing methods include Brinell Hardness Test, Rockwell Hardness Test and Vickers Hardness Test.

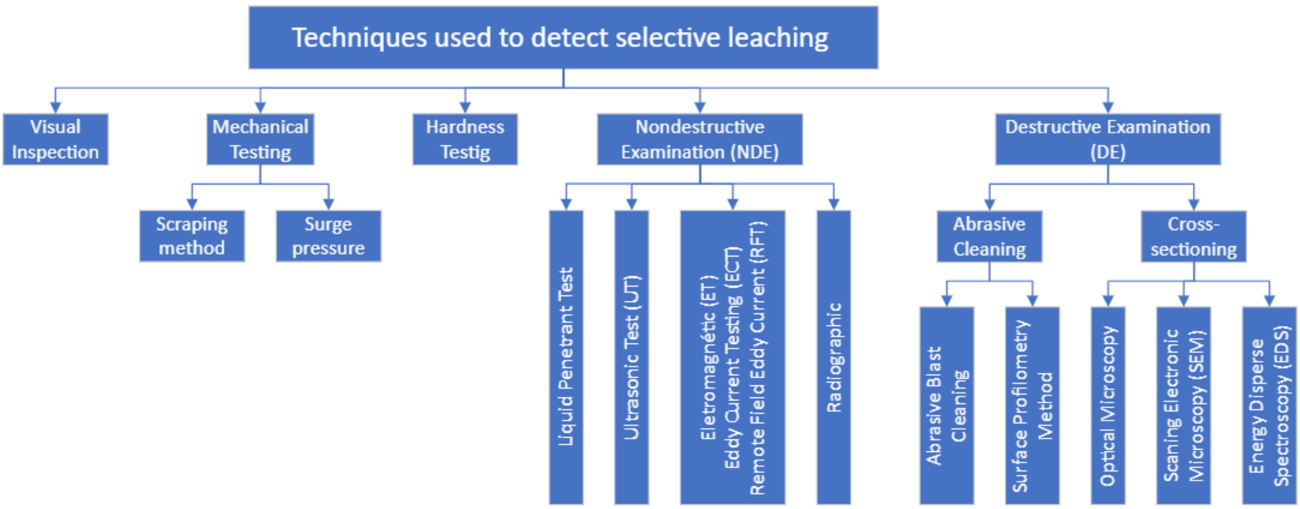
3. Nondestructive Examination (NDE): NDE techniques are used to identify internal defects, cracks, or discontinuities caused by selective leaching without causing damage to the material. These methods are crucial for assessing the material's internal condition. Some common NDE techniques are: Liquid Penetrant Test (LPT), Electromagnetic Testing (ET), Ultrasonic Testing (UT), and Radiographic Testing (RT). NDT methods do not damage the SSCs, allowing it to remain in operation after testing, which is particularly important for expensive or hard-to-replace components.
4. Destructive Examination (DE): DE involves damaging the material to measure the depth of penetration of dealloying through the component wall thickness or the remaining wall thickness of sound (unaffected) base material. Techniques like metallography (examining microstructures), fracture surface analysis, or chemical analysis of extracted samples can be employed. NDE has often been one of the most effective ways to determine if a component has experienced selective leaching degradation. Two main techniques used are: cross-sectioning and abrasive cleaning. Within the cross-sectioning techniques are: Optical Microscopy (OM), Scanning Electronic Microscopy (SEM) and Energy Dispersive Spectroscopy (EDS) and within the abrasive cleaning techniques are: the surface profilometry and abrasive blast cleaning between others. Destructive tests would only be applied in cases of components that were replaced and would no longer be able to remain in operation. While these techniques are expensive, their precision and the depth of information they provide make them essential tools in materials science

All are direct techniques in the context of material assessment and inspection (See Figure 2). They involve the direct application of physical phenomena (mechanical forces, eddy currents, ultrasonic waves, electromagnetic fields, physically abrading or wearing down the surface and cut) to directly interact with the material's surface and provide information about its internal structure, defects, flaws or material properties without altering the material itself. These techniques are essential in various industries for quality assurance, structural integrity assessment, and safety inspections.

Figure 1: Example of a small pick being used on the inner surface of a valve to remove dutile material.

Source: EPRI Report 3002016057 (2019) [2]

Figure 2: Techniques used to detect selective leaching [2].



Source: Authors

In Table 1 is presented the advantages and disadvantages of techniques used to detect selective leaching.

Table 1 : Advantages and disadvantages of techniques.

TECHNIQUE	ADVANTAGES	DISADVANTAGES
Visual Inspection	Economic, Inmediate identification of the visible signs of degradation in all accessible surface	Depend on the experience of inspector
Mechanical Testing	Assess the mechanical properties of the material	Can be NDE or DE, Necessary complementary test
Hardness Testing	Economic, Assess the changes in hardness of material	Necessary complementary test
NDE	No Damage the material	Expensive
DE	Provide detailed information of degradation	Damage the material

Source: Authors

DT does require skilled personnel and specialized laboratory setups, but the level of expertise and resources needed depends on the type of DT being performed. Generally less expensive per test but becomes costly when replacement of tested components is required, especially for expensive or critical items. Many nuclear plants have internal laboratories and their own personnel to carry out DT, especially for critical components. This can reduce costs and increase efficiency in quality control, as it is not necessary to employ third-party companies to perform these tests regularly for example, in Angra 1 NPP.

NDEs are more expensive due to the renting the required sophisticated equipment and because the external personnel require training to using the different tools and equipments and to interpret the collected information, making the cost per test higher. The external personnel require specialization and needs regulated certifications (such as, ISO 9712:2021) [3].

In most cases, DT can be cheaper for routine material testing, while NDT is more cost-effective for preserving valuable components or systems.

In summary, the visual indicators of the presence of selective leaching [1], [4] are:

- Loss of material

- Loss of appearance
- Loss of hardness (< 20 %)
- Depth of penetration
- Functional Requirements

The acceptable criteria of material loss due to corrosion can vary significantly depending on the industry, the specific material being used, and the intended application.

A more robust comparative analysis between the advantages and disadvantages of each method in the nuclear context will be the objective of future work.

The global nuclear industry has been working on applying the experience gained from the techniques in other industrial sectors in order to identify the effects of aging by selective leaching of SSC [1-2]. The designers of nuclear facilities have been using scientific research, technical report and guidelines, as well as national and international regulatory bodies in the nuclear sector such as the International Atomic Energy Agency (IAEA) and the Nuclear Regulatory Commission (NRC).

Materials susceptible to selective leaching and susceptible material-environment combination that contribute to selective leaching are presented in other paper [5].

2.1. Practices in nuclear scenario

In the nuclear scenario, techniques used to detect selective leaching are carried out in areas where there is no direct impact on the reactor operation or when the reactor is in a state of shutdown, that the systems are emptied, cleaned and the components are accessible, as for example: feed water tank, heat exchangers, steam generators, etc.

In the case of the directly irradiated SSCs, the tests must be carried out remotely using drones or the sample must be withdrawals, cleaned and decontaminated before testing to ensure that surfaces, SSCs are free of contamination.

NDTs are preferred in NPP because do not compromise the integrity of SSCs and allow the continuous monitoring and operation however, DEs are indispensable when a deep level of understanding of the structure and composition of the material is required.

3. RESULTS AND DISICUSSIONS

As a result of this work, it provide a guide that will deal with the fundamental techniques used for manage and mitigate the risks associated with this phenomenon, based on recent EPRI 3002026340 report (2023) [1].

Non-destructive evaluation (NDE) techniques such as visual inspection, mechanical testing and hardness techniques, can be complementary to destructive evaluation (DE) techniques for detecting selective leaching. By combining both NDE and DE techniques, a more comprehensive understanding of selective leaching can be achieved, allowing for better-informed decisions regarding maintenance, repair, and corrosion prevention strategies.

Applying these techniques:

- Reduces maintenance costs without the compromising safety,
- Minimize unscheduled plant shutdowns by identifying failures early on, enabling timely maintenance and repairs, and
- Increases the safety, efficiency and longevity of SSCs.

Summarizing the various techniques for detecting selective leaching in metal components within nuclear power plants is highly relevant. This paper provides valuable insights into the advantages and limitations of each method, guiding the selection of appropriate detection strategies. This, in turn, aids in the development of effective aging management programs, ensuring the continued safe operation of nuclear facilities.

Each technique must be chosen considering the type of material, the location of the damage, accessibility and inspection conditions and the expected severity of damage [6]. For example, for internal inspections of pipelines, the UT and RT are more used. For superficially located defects, the Liquid Penetrant Technique is more used.

4. CONCLUSIONS

The paper consolidates detection techniques for selective leaching for SSCs in a NPP and serves as reference material. It can serve as an accessible guide, both for professionals in the nuclear field and for those just starting out to study the selective leaching.

Combining these destructive and non-destructive techniques allows for a comprehensive assessment of the damage caused by selective leaching in metals. Non-destructive methods are generally preferred as they don't compromise the integrity of the material, but in cases where more detailed analysis is needed, destructive methods are used.

For the maintenance area, selective leaching detection techniques have invaluable practical value, as they help to anticipate problems, ensure the operational safety, efficiency and operational reliability of systems, comply with strict regulations and optimize resources. This directly contributes to the longevity, efficiency and safety of nuclear power plants. An efficient and predictive maintenance system provides a safer and more predictable environment for maintenance teams.

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CONFLICT OF INTEREST

All authors declare that they have no conflicts of interest.

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