Corrosion damage and periodic inspections on pressure devices and lifting equipments

F. Giacobbe, M. Platania, A. Sili, A. Iacino, A. Corso

This paper deals with requirements for service safety conditions of pressure devices and lifting equipments, according to the European and Italian Standards. Periodic controls and inspections are necessary to check corrosion damage and determine residual life, as showed for some significant case histories. As concern as pressure device, hydrogen induced cracking phenomena in steel walls of a demister, utilized to enhance the liquid droplets removal in a vapor stream, were detected by ultrasound measurements. The measured defect sizes were put in comparison with the required limits to verify if this device can be maintained in service. About lifting equipments, two different corrosion mechanisms were examined by detecting defects and measuring residual plate thickness: crevice, due to aggressive environment, at the interstitial of steel plates overlap in a welded and bolted joint of a gantry crane; lastly, crevice and corrosion fatigue of steel rail and plate in a double girder shipyard bridge crane, that was exposed for some decades to the daily aggressive action of direct solar radiation and sea salt, detrimental for the coating layer. In these two cases both defects size and plates thickness were considered with the aim of indicating treatments and restoration procedures of damaged components.

Keywords: Corrosion - Test and inspection - Non destructive testing - Environment and safety - Hygiene in workplace - Plant and equipment

INTRODUCTION

In lifting equipments, defined according to the UNI ISO 4306-1 Standard, corrosion may occur on structures or ropes and chains used for loads slinging and lifting [1].
Pressure devices, vessel and tube, designed to store liquid or gas at different pressure and temperature (Pressure Equipment Directive 97/23/EC - implemented in Italy with the Legislative Decree No 93/2000), may be affected by heavy stress state [2]. Moreover an irreversible and progressive decay of their properties, detrimental for structural stability [3][4]. Therefore manufactures, in order to protect workers, are required to choose materials and protection systems more suitable to maintain sound the above mentioned devices during service; moreover users are required to set up suitable systems of control and inspection [5].
In practice lifting equipments with a carried weight higher than 2000 N and vessels or pipes with internal pressure higher than 0.5 bar must be verified according to the current standards.

F. Giacobbe, M. Platania
INAIL – Territorial Department of Messina (Italy)
A. Sili
Department of Electronic Engineering, Chemistry and Industrial Engineering - University of Messina (Italy)
A. Iacino, A. Corso
Senior structural engineer

In this work some cases of inspections on corrosion damaged devices are examined and discussed on the basis of the Italian Laws [7][11].

Requirements for service

The European Directive No 89/655 and its subsequent amendments provide for the adaptation requirements of devices just put in service. This is the minimum technological level of security that employers must provide to assure workers safety [6].
For pressure devices, the Ministerial Decree No. 329/04 imposes requirements (controls and inspections) to verify the permanence of the essential safety conditions set out by the Legislative Decree No 93/00 (Pressure Equipment Directive - PED) during construction. Pressure equipments have to work in safe conditions, even if pressure, temperature and environmental conditions change.
The Ministerial Decree No 329/04 provides (articles 4 and 6) for devices verification before their startup. In the case of chemical and physical environmental conditions favorable to corrosion, it is necessary to highlight the solutions adopted to prevent and control the deterioration processes. Obviously users must take account of any requirements specified in the use and maintenance manual. Moreover the above said regulation requires, in order to control the stability level of devices, to check their integrity periodically every ten years. This check is based on non-destructive tests (eg. visual examination and thickness measurement by ultrasound) [7].
Concerning periodical retraining (art. 10 comma 3), the verification frequency should be changed in a restrictive

way, if the manufacturer requires, in the use and maintenance manual, a lower range of time between two controls, assuming possible corrosion phenomena. Devices that undergo corrosion have not to be excluded from periodic re-qualification (Article 11 paragraph 1, point a).
According to the Legislative Decree No 81/08, supplemented by the Legislative Decree No 106/09, employers must comply with safety requirements (Article 70); in addition, such devices must be used in accordance with regulations transposing the EU Directives and, if required by the Annex VII, they must be periodically verified with the prescribed frequency, in order to check the actual conditions of conservation and efficiency.
In particular, employers, as also required by the Art. 71, paragraph 8, of the above said Decree, shall ensure that:

a) Devices, whose safety depends on the installation conditions, must be inspected, after installation and before commissioning, moreover after every assembly in a new site or in a new plant position, in order to ensure a proper installation and a good service [8].
b) Devices exposed to conditions that can cause deterioration resulting in dangerous situations must be submitted to: 1) periodic inspections with frequencies determined according to the directions provided by the manufacturers, or by standards of good practice, or, in absence of the latter, derived from codes of good practice; 2) overtime controls to ensure the maintenance of good safety conditions, whenever occur exceptional events that can have detrimental effects on safety of commissioned devices, such as repairs, accidents, natural phenomena or prolonged periods of inactivity [9].
c) Control actions referred in a) and b) are addressed to ensure a good state of preservation and efficiency with the aim of maintaining devices in safety conditions during service. Controls must be performed by a competent staff [10].

Methods for performing periodic checks are set down in the Annex II of the Ministerial Decree April 11th, 2011 [11].
Results of additional investigations, carried out in agreement with technical standards, have to be highlighted in the case of periodic inspections concerning mobile cranes and bridges supported on motor-driven carriages. These inspections are addressed to identify any faults, defects or anomalies, that are produced during service of devices working for over 20 years, and to determine the residual life during which these devices can still operate safely with any new nominal weights.

CASE HISTORIES

Metals can be subjected to various types of corrosion, including stress corrosion due to the simultaneous effects of mechanical stress and environmental aggressiveness or to other particular conditions. For example, in the case of hydrogen induced cracking in pressure vessel, the hoop stress effects are enhanced by the results of atomic diffusion inside steel.
Frequently in metallic carpentry of lifting equipment corrosion process becomes faster due to specific surface conditions observed close to interstices, joints or other zones where geometry makes difficult the oxygen supply (crevice); in other cases corrosion fatigue phenomena also occur as a result of cyclic stress applications (corrosion fatigue).

Case A - Hydrogen induced cracking in a vessel

Hydrogen Induced Cracking (HIC) can be ascribed to hydrogen atoms diffusion inside steel from a H_2S wet environment. Diffusion takes place also at a low temperature if it is assisted by a concentration gradient.
Hydrogen, combining into molecules, gives rise locally to very high pressure. In particular hydrogen diffusion inside steel causes damage through different mechanisms, such as step wise cracking (SWC) [12], that, as shown in fig. 1, it is a failure mechanism characterized by cracks that follow paths of lower resistance and interconnect each other.
A demister, a device often fitted to vapor liquid separator vessels to enhance the removal of liquid droplets entrained in a vapor stream, has been examined. It consists of a steel vessel closed by two convex funds, with the following design data: pressure 7 bar, temperature 90°C; fluid: hydrocarbon + water steam; material: ASTM 516 Gr. 70 steel; thickness: 10 mm). The rules for design, fabrication, and inspection of pressure vessels are provided by a specific standard [13].
In the considered device, non-destructive testing, performed according to the Phased-Array ultrasonic method, showed the presence of defects inside material and allowed their positions and sizes evaluation [14]. Many indications of defects were found in the vessel mid-thickness. Due to their morphology, these defects can be ascribed to SWC, that results in cracks breaking through the vessel internal surface (fig. 2).
Technical assessments were performed according to the API 579-1 and ASME FFS-1-2007 Standards, with the aim of verifying if defects are acceptable or not. Pressure equipments with structural deteriorations are allowed to work, thanks to the Fitness For Service (FFS) procedure [15][16].
The damaged vessel was studied according to the Level 2 of Part 7 "Assessment of Hydrogen Blistering and Hydrogen Damage Associated with HIC and SOHIC", because there are defects appearing on surface.
For vessel verification, the following assumptions were made:

a) the most critical defect was studied, namely the one having the maximum size between all (in the circumferential or longitudinal direction, or along the thickness);
b) the studied defect was assimilated to an ellipse oriented along the thickness in the longitudinal direction, assuming the maximum measured depth as

Fig. 1 – Stepwise cracking due to hydrogen diffusion inside an ASTM A 516 Gr. 70 steel plate.

Fig. 1 – Frattura progressive dovuta alla diffusione di idrogeno all'interno di una lamiera d'acciaio ASTM A 516 Gr. 70.

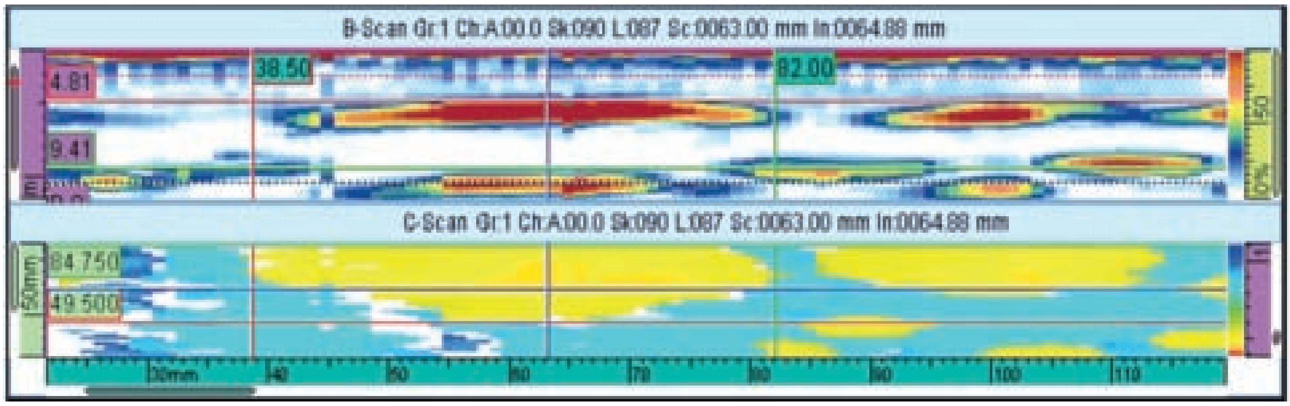

Fig. 2 – Ultrasound measurements performed by the Phased-Array method with linear scanning. B scan is the sectional view and C scan is the plan view. According to the colored scale, the measured crack was 43.5 mm long, 35.2 mm wide and has a depth of 4.8 mm with a wall thickness of 9.4 mm.

Fig. 2 – Misure con ultrasuoni effettuate con il metodo dell'allineamento di fase con scansione lineare. La scansione B è effettuata sulla sezione, la scansione C è nel piano. Secondo la scala a colori, la cricca è lunga 43.5 mm, larga 35.2 mm ed ha una profondità di 4.8 mm con uno spessore di parete di 9.4 mm.

the minor axis and the maximum longitudinal length as the major axis;

c) vessel was subjected only to the action of the internal pressure;

d) there were no secondary loads;

e) there were no other causes that could promote the defects growth (eg. sulfide stress cracking, fatigue, etc.).

Calculation, carried out following the API 579-1/ASME FFS-1-2007 code, gave the possibility to assess the pressure vessel stability according to defects [17]. The examined device can be considered stable with respect to the defect sizes indicated in the non destructive test report, performed according to the Phased-Array technique. Therefore, as specified by the Art. 12, Paragraph 2, of the Ministerial Decree 329/04, devices can be maintained in service (Tab. 1).

Case B – Crevice in a crane located in a power plant

Crevice is a corrosion mode typical of interstices, joints or other zones where geometry makes difficult the oxygen supply. Two stages can be distinguished: initiation and propagation. During the first one, generalized corrosion takes place near the interstices when the protective layer of metal (paint, zinc plating, passivating agents) begins to be damaged; here corrosion proceeds roughly uniformly.

	Defect deep [mm]	Defect length [mm]
Most critical defect size	2,4	84,7
Defect limt size	4,8	414,5

Table 1 - Most critical defect size and limit size in comparison.

Tabella 1 – Dimensioni più critiche del difetto in confronto con i valori limite.

During the propagation stage, in addition to general corrosion, an accelerated corrosion can be observed in correspondence of interstices.

An asymmetric gantry crane (lame), dating back to 1970, installed in a power plant and serving two groups of Rankin cycle turbo-alternator, was examined. It was located near the steam generator, not more than 250 m from the sea, and used only during the turbo-alternator scheduled maintenance. Photographs of the bolted and welded steel joint affected by crevice are given in fig.3.

The simultaneous presence of combustion fumes from boiler and sea salt made the environment very aggressive against the coating layer, favouring the onset of steel corrosion. Moreover bolts caused crevice phenomena:

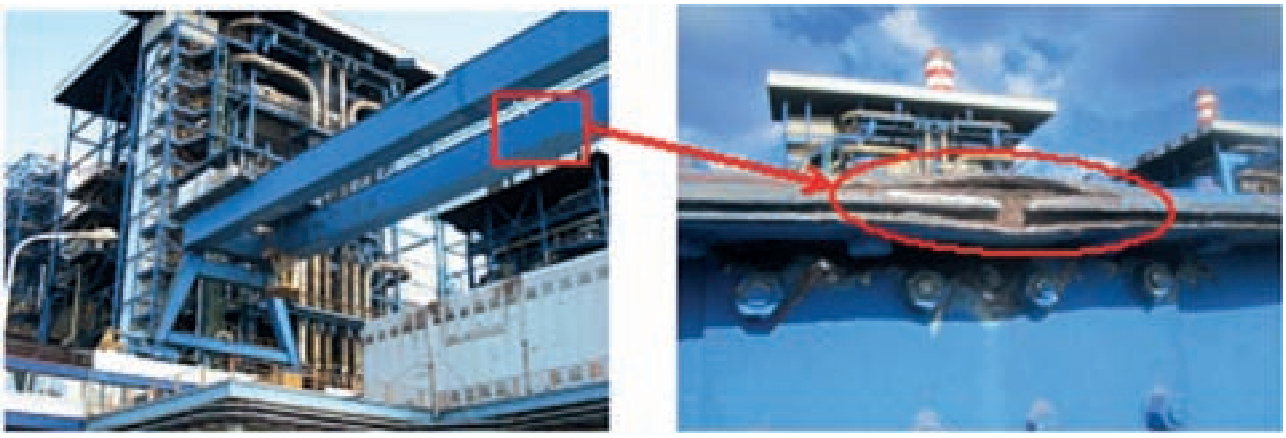

Fig. 3 – Gantry crane with indication of the joint affected by crevice.

Fig. 3 – Gru a ponte con indicazione del giunto affetto da crevice.

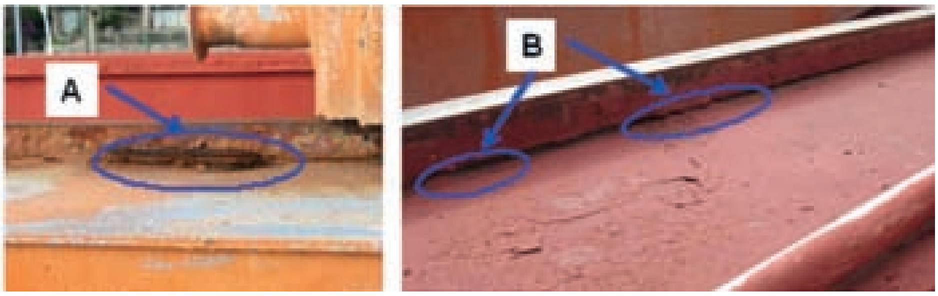

Fig. 4 – Corrosion damage in a bridge crane: crevice (A) and corrosion fatigue (B)

Fig. 4 – Danneggiamento per corrosione in un carroponte: crevice (A) e corrosione fatica (B).

corrosion developed in the interstitial at plates overlap, when enamel coating became damaged due to the combined effects of atmospheric agents.

The joint was mechanically cleaned and subjected to magnetic particle testing and thickness measurements by an ultrasonic thickness gauge.

The magnetic inspection showed no evidence of significant defects both in weld and heat affected zone. In particular, the few detected defects, mostly linear, are all less than 2 mm long.

The EN ISO 23278-2009 “Magnetic particle examination of welds” Standard sets the parameters recommended for the acceptable defect level in weld and in metal close to it. In this case, due to surface and weld conditions, a level of acceptance equal 2 was considered appropriate, which corresponds to a limit length $L \leq 3$ mm for linear indications and to a limit length $d \leq 3$ mm for non-linear indications [18].

Thickness measurements of plates showed a significant reduction (up to 50% of the original value) only in the crevice zone at the plates overlap: here corrosion damage was characterized by oxidation and plate swelling; far from this zone, plates underwent a thickness reduction of about 6% in areas where the lack of protective paint occurred. This thickness reduction was less than the limit (10%) prescribed by the standard Therefore a deep mechanical cleaning, followed by a passivating treatment with suitable products (rust converter) and by a subsequent coating with inorganic paint (enamel), are the only recommended treatments.

Case C – Corrosion fatigue in a shipyard bridge crane

The third case presented is a double girder bridge crane, which dates back to 1972, installed at a shipyard. This crane, used during boats hauling and launching, was installed on overhead rails near the water edge. This equipment was exposed for some decades to the daily aggressive action of direct solar radiation and sea salt, detrimental for protective coating. In this case both crevice and corrosion fatigue occurred in correspondence of welds between rails and sheets of the main girders, made of UNI EN 10025:1995 steel.

Figure 4 shows two images of the bridge crane, where corrosion damages of steel are visible at the interface between rail and upper surfaces of the girders sheets. These damages consist of flaking (A), due to crevice, and cracks, due to corrosion fatigue (B).

The carriage movement caused bending fatigue stress in rails: consequently a triaxial stress state occurred at the welding points between rail and horizontal sheet, exceeding locally the fatigue limit of steel that underwent an accelerated corrosion process.

Preliminarily the damaged areas in fig. 4 were cleaned first mechanically and then with lacquer thinner, in order to remove all traces of the enamel layers. Magnetic particle testing and thickness measurements by an ultrasonic thickness gauge were performed. The detected defects were within 2 mm long, with mutual distances of the same order of magnitude.

With reference to the EN ISO 23278-2009 Standard, for

the examined case a level of acceptance equal 2 was considered appropriate, corresponding to a limit length L ≤ 3 mm for linear indications and to a limit length d ≤ 3 mm for non-linear indications [18].
Thickness measurements of sheets showed a significant reduction (up to 20% of the original value) in the damaged zones, where the limit prescribed by the standard is equal to 10%.
On the basis of these results, a radical restoration was required: the addition of sheets of the same thickness and the realization of continuous welds between rails and sheets; then the application in the order of a primer, an epoxy paint and finally a rubber finishing, with the aim of isolating the steel surface from the external environment.

CONCLUSION

In this paper a specific case of hydrogen induced cracking in a pressure device and two cases of corrosion in lifting equipments, due to crevice and corrosion fatigue, were examined. The inspection procedures considered were referred to the current standards and regulations.
Concerning with pressure equipments, before their start up, thickness measurements must be performed in order to check for any deviations from project data. Then, after about 4-6 years (in the case of petrochemical industries, this period coincides with the plant shutdown for the scheduled maintenance), equipments must be visually inspected and thickness measured again. These tests are used to determine corrosion rate and evaluate residual life. If degradation is more than 30% of the corrosion allowance provided by the designer, it is fundamental to repeat, by the tenth year, thickness measurements. These investigations can be performed in advance to the time defined by the standards, that require a maximum time limit of 10 years for damage controls. It is worth considering that the Italian regulations devolve to manufacturers the definition of shorter period, when the utilized materials are subjected to an accelerated degradation, due to working and environmental conditions.
As regards lifting equipments verification, the main regulation is certainly the recent Legislative Decree No. 11/2011 that rules what provided by the Legislative Decree No 81/2008, paragraph 11 - Art. 71, implemented by the subsequent Legislative Decree No 106/2009. This regulation specifies the frequency of “periodic verifications” addressed to “assess the actual state of conservation and efficiency in order to assure safety”. In this regard, considerable relevance has the establishment of “additional investigations” aimed at “identifying possible faults, defects or anomalies, that are produced using equipments working for over 20 years”, and - particularly important - the determination of “residual life during which equipments can still operate safely with any new nominal loads”. Lifting equipments must be submitted to the controls listed in the ISO 9927-1 Standard [19].

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Danneggiamento per corrosione e ispezioni periodiche in apparecchiature in pressione ed attrezzature di sollevamento

Parole chiave: Corrosione - Collaudi e controlli - Pprove non distruttive - Ambiente e sicurezza - Igiene lavoro - Impianti e attrezzature

Le sollecitazioni di esercizio e le condizioni ambientali possono causare fenomeni corrosivi importanti nelle attrezzature di lavoro determinandone il degrado progressivo e generando situazioni di pericolo per persone e cose. Secondo la legislazione vigente sulla sicurezza dei luoghi di lavoro, i datori di lavoro devono sottoporre le attrezzature a verifiche periodiche, al fine di valutare le conseguenze del degrado in termini di ulteriore esercibilità. In linea generale, le attrezzature di sollevamento con portata superiore ai 2000 N ed i recipienti o le tubazioni con pressione superiore ai 0,5 bar devono essere sottoposti a verifiche periodiche. Il legislatore, al fine di garantire il mantenimento nel tempo dei requisiti di sicurezza, ha imposto sia controlli periodici interni all'azienda che attività di verifica a cura di soggetti abilitati, titolari del servizio per la conduzione della prima e delle successive verifiche, da condursi con cadenze periodiche in funzione del livello di rischio associato alla tipologia di attrezzatura.
Nel presente lavoro sono stati esaminati i requisiti di apparecchiature in pressione e di attrezzature di sollevamento, previsti dalle vigenti disposizioni legislative, in relazione ad alcuni fenomeni corrosivi, valutando le conseguenze sulla loro ulteriore esercibilità in condizione di sicurezza.
E' stato considerato il caso di cricche indotte da idrogeno nelle pareti di acciaio di un demister, un recipiente in pressione utilizzato per effettuare l'abbattimento di gocce di liquido all'interno di una corrente di vapore, effettuando misure ad ultrasuoni per valutare le dimensioni dei difetti e confrontarli con i valori limite imposti dalle norme.
Per quanto riguarda le attrezzature di sollevamento, sono stati esaminati due differenti casi di corrosione, valutando le dimensioni dei difetti e misurando lo spessore residuo delle lamiere interessate. Sono stati presi in esame i fenomeni di crevice negli interstizi presenti nelle zone di sovrapposizione delle piastre di acciaio, in un giunto saldato ed imbullonato facente parte di una gru a cavalletto, e, in ultimo, gli effetti del cervice e della corrosione - fatica nelle rotaie e nelle lamiere d'acciaio di una gru a ponte, installata in un cantiere navale ed esposta per alcuni decenni all'azione aggressiva della radiazione solare e della salsedine, dannosa per lo strato di verniciatura. Nei due casi esaminati sono state misurate le dimensioni dei difetti e gli spessori delle lamiere, al fine di indicare trattamenti e procedure di ripristino dei componenti danneggiati.