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IMPACT RESISTANCE OF API 5L STEEL IN AGGRESSIVE ENVIRONMENT WITH THE PRESENCE OF GREEN INHIBITORS

OTPORNOST NA UDAR API 5L ČELIKA U AGRESIVNOJ SREDINI U PRISUSTVU ZELENIH INHIBITORA

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- green inhibitor concentration
- API 5L steel

Ključne reči
- ispitivanje udarom
- koncentracija zelenog inhibitora
- API 5L čelik

Abstract

The effect of time and green inhibitor addition in 1 M HCl on API 5L steel X52 and X65 impact resistance is studied. The concentration of green inhibitor of 3, 5 and 10 % is produced by extract of compound for natural plant. Charpy V specimens are manufactured by special machine and covered by special resin. The immersed specimens are then subjected to high velocity impact with energy 150 J. The concentration of green inhibitor of 5 % resulted in optimum properties, with 42 % improvement in peak load and 32 % increase in elongation.

Izvod

Proučen je uticaj vremena i koncentracije dodataka u 1 M HCl na otpornost na udar API 5L čelika X52 i X65. Koncentracija zelenog inhibitora sa 3, 5 i 10 % je dobijena izdvajanjem komponente iz prirodne biljke. Šarpi V epruvete su napravljene specijalnom mašinom i pokrivene specijalnom smolom. Takve epruvete su ispitane udarom energije 150 J. Koncentracija zelenog inhibitora od 5 % dala je optimalna svojstva čelika, sa 42 % povećanja maksimalne sile i 32 % porasta izduženja.

INTRODUCTION

The demand for energy continues to grow and production sites are often far away from the centres of consumption and exploitation. For example, from 1970 to 2007 in Europe, the length of pipelines was multiplied by 4. On the other hand, the failure rate for the same period was divided by 6 /1/. To increase the profitability of this mode of transport, the industrialists increased the service pressure and pipe diameter. From 1910 to 2000, the diameter of the largest pipelines was multiplied by 4 and the transport pressure was multiplied by 60, /2/. All of this was made possible by the research work that improved mechanical characteristics of pipelines. Generally, over 90% of failures in pressure pipes are due to stress concentrations in the vicinity of a defect. Concern for the operation of pipelines is to ensure the maintenance of these networks to preserve the safety of population, as well as the impact that a major failure has on the environment, especially in the case of flammable or explosive gas. Recent studies, conducted by the European Gas Pipeline Incident Group /1/, confirm that out of 1060 cases of rupture in pipelines 49.6 % are caused by external aggression. Other causes of incidents are corrosion defects (15.3%), construction defects (16.5%), valve opening by mistake (4.6%), landslides (7.3%) and others (6.7%). A combination of the two phenomena: internal corrosion and internal aggression by crash, lead to catastrophic accidents in gas and oil transport pipelines, /3-5/.

Several studies have been oriented in order to understand the pipes' response in the presence of this double effect; in static, dynamic and crash tests, without presence of defects, generally focused on behaviour and standardisation. Few of them, tried to solve problems of the presence of defects, especially of internal corrosion, /6-12/. In this case, failure analysis of pipes is made by Charpy or crash test. The oldest method to protect and remedy internal defects is the injection of synthetic inhibitors, usually toxic and too expensive. A recent attempt is made to replace synthetic inhibitors with bios, extracting from medical plants. The results of the bios, or eco-friendly green inhibitors are very encouraging and promising in terms of price-efficiency. To evaluate the behaviour of pipelines under the strong acid environment and remedied by green inhibitors, the Drop Weight Test (DWT) is used. This test is one of the methods used to assess the impact properties of steels under service conditions. The specimen used for the test is commonly a flat plate, either specially moulded or cut from a larger component. It is supported at its edges and impacted centrally by a vertically falling dart. The incident energy of the dropped dart could be changed incrementally, either by varying the mass of the dart while keeping the drop height constant or keeping the mass constant and changing the drop height. A series of 60 specimens had to be tested to obtain the fracture energy, using incident impact energies near the fracture point. In the instrumented Drop Weight Impact (DWI) test, the falling dart is fitted with a force transducer to measure the force throughout the impact test. This basic force-time data is then processed to provide a wealth of information from each specimen tested, giving force, displacement and energy data throughout the test.

This paper describes the problem of external impact on oil/gas pipes under pressure during exploitation or on the pumping in the presence of water hammer phenomena. These external impacts are considered to be carried out at high deformation rate and led to rapid expansion of internal corrosion defects and then to eventual explosion. Internal corrosion defects are simulated as longitudinal cuts on the inner surface of pipes. The knowledge of the limit load with defect under service pressure with the presence of green corrosion inhibitor makes it possible to define the safety margin.

EXPERIMENTAL PROCEDURE

Materials

Specimens are prepared from steels X52 and X65 manufactured for Sonatrach Algeria. Specimens (55×10×9.2 mm) are prepared in mechanical laboratory at Chlef University, Figs. 1a and 1b, respectively. The following Table 1 presents mechanical properties of X52 and X65 steels. Figures 1a and 1b show that the microstructure is composed of fine grains of ferrite base and pearlite coloured in white and black, respectively. Mechanical properties of API 5L X52 are given in /13-15/, and API 5L X65 pipe steel is a widely used steel in the European pipe network (25%) with minimal yield strength of 448 MPa. Its chemical reference composition is given in Table 1. Mechanical properties of API 5L X65 steel, /14/, are reported in Table 2.

Table 1. Chemical composition of steels API5L X52 and X65.

Elements	C (max.)	Mn (max.)	P (max.)	S (max.)	Si	Other elements
X65	0.22	1.45	0.025	0.015	-	Nb+Ti+V < 0.15
X52	0.19	1.10	-	0.018	0.25	Nb+Ti < 0.052

Table 2. Mechanical properties of steels API5L X52 and X65, /14/.

Steel grade	Yield stress σ_y (MPa)	Ultimate strength σ_u (MPa)	Elongation %	Reduction of area %	Fracture toughness K_{Ic} (MPa√m)	Hardness HV
API X65	465	558	11	57	280	205
API X52	410	528	23	--	116.6	--

(a) (b)

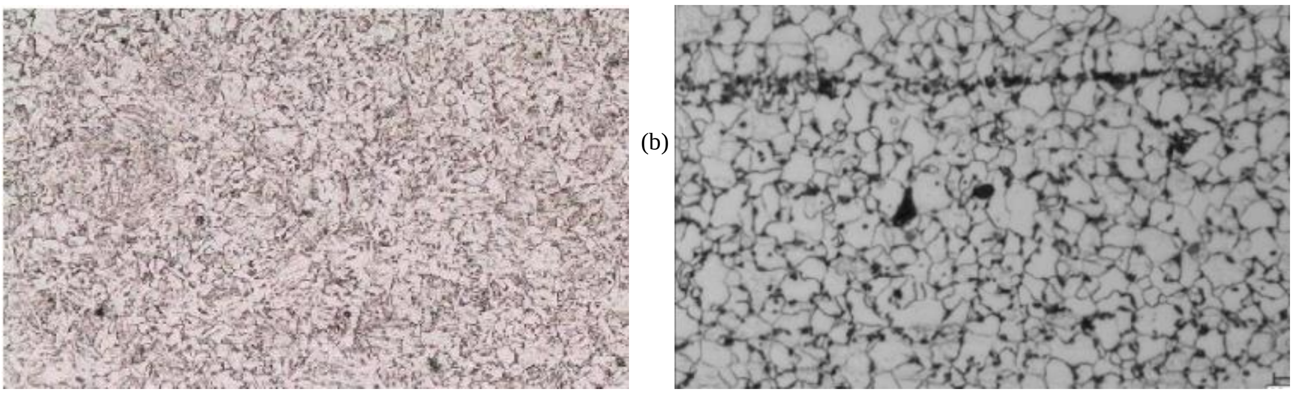


Figure 1. Pipe section showing a typical microstructure of: a) API X65, and b) X52.

Preparation of the green inhibitor

The corrosion inhibitor is prepared in the laboratory of department of Mechanical Engineering, King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia, from 10 g of plant flower *Ruta Chalpenis*, immersed in 1 M of HCl acid media until it decomposes completely. After that, the solution is filtered, and then different concentrations are prepared, as explained in more detail in previous work /15-17/. This concentrated solution is used to prepare solutions of different concentrations by dilution method. To obtain the mass of the plant extract, it was dried at 100 °C under vacuum in a vaporiser. From the weight of the vacuum dried liquid, plant extract is found to contain 50 mg/ml of plant compounds, /17/.

Drop-weight and impact test geometry

The main research interest is to assess the effect of green inhibitor using specimens of different concentrations in X52 and X65 pipe steels. The Charpy V specimen, calibrated load-cell and instrumentation are used, associated to a round nose impactor, as shown in Fig. 2. For each experiment, the load, energy and deflection traces are obtained from 8000 unfiltered load time data points. An impactor mass is 21 kg with velocity of 3.62 m/s.

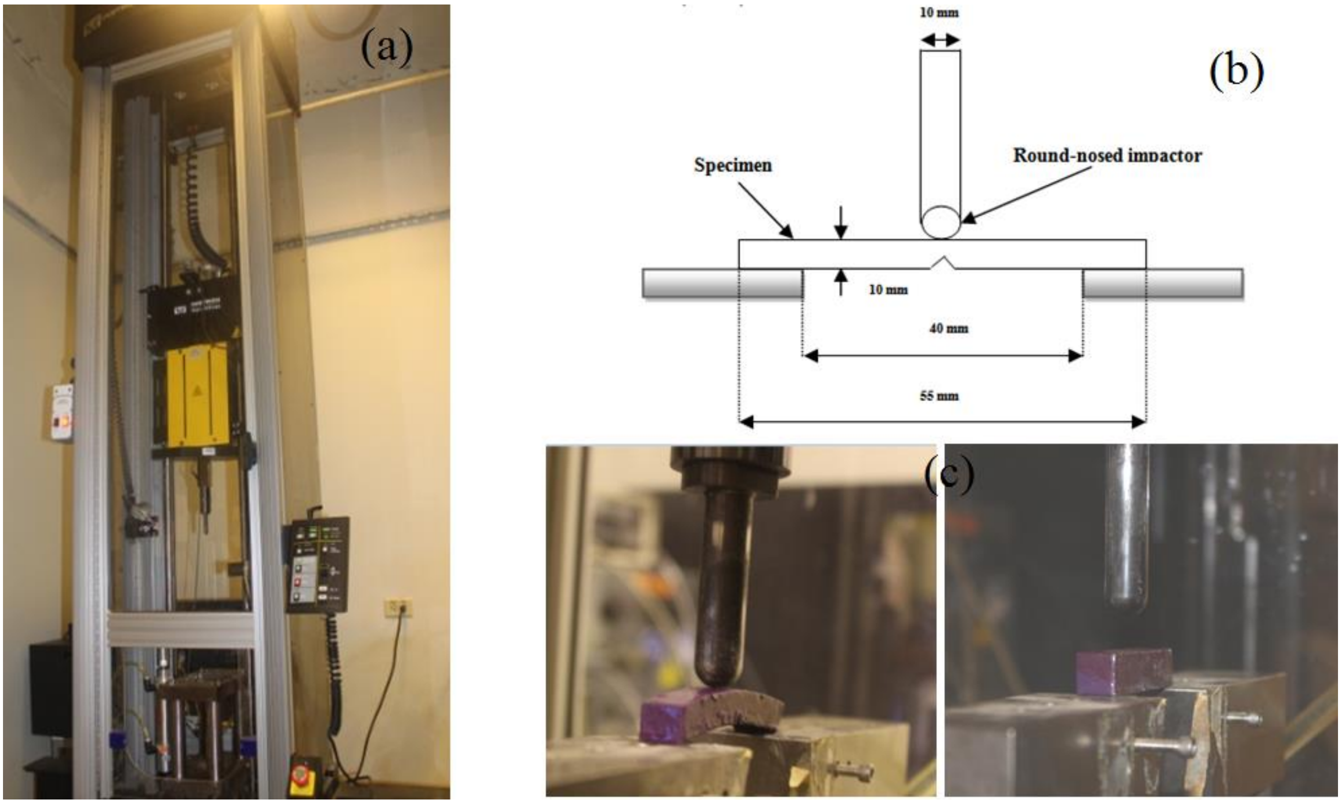


Figure 2. (a) Drop weight machine, and (b) specimen geometry of API X52 and API X65 steels. (c) Specimen geometry for drop-weight and servo-hydraulic impact experiments.

RESULTS AND DISCUSSIONS

Effect of concentration on load-time response

Force-deflection curves obtained from DWT had many different forms, depending on the type of steel, test temperature, type of any reinforcement included and processing conditions. All curves contain details of a complete impact event, including the type of fracture (brittle or ductile), fracture initiation and propagation. Figure 3a shows a typical force-deflection curve of X52 steel, which exhibits yielding with cup/cone formation (zero slope at maximum force), followed by splitting of the cup/cone (sudden drop in force) and stable tearing. The International Standard ISO 6603 recommends the routine characterisation of the test results as: (a) deflection at maximum force S_M, (b) energy to maximum force W_M, (c) maximum force F_M, (d) deflection S_p, (e) energy W_p.

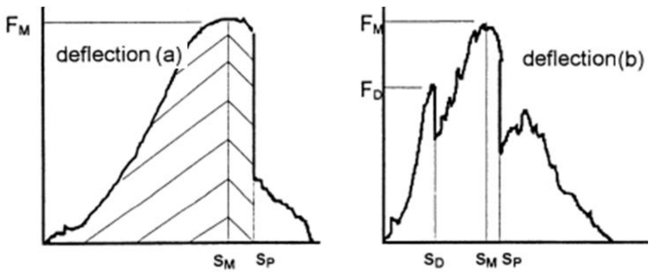


Figure 3. Scheme of force-deflection curves.

Force-deflection curves can show many more features than the 'idealised' behaviour of API X52 steel in the reference form (without HCl media). Figure 3b shows the curve from a test on API X52 steel in HCl and HCl with green inhibitor. The 'first damage' peak (at F_D-S_D) occurs before maximum force is reached. Such peaks are often associated with localised fracture, resulting in the load drop and change in specimen compliance. The local damage then stops growing, requiring increased force and energy for fracture to progress to F_M. Figure 3b also shows that considerable energy is required to progress the damage beyond S_p to produce total fracture of the specimen. Force-deflection curves thus, can contain much information about the initiation and propagation of fracture during the test. The interpretation of data obtained can be complex, but very informative on the effects of material or processing variables. Some force-deflection curves can contain many minor peaks besides the maximal force peak. The full interpretation of physical events associated with each peak normally requires the use of auxiliary equipment, such as short pulse photography, acoustic emission or high speed photography.

Effect of concentration on load-time response

Results obtained for load as a function of time for API-5L steels X-52 and X65, immersed in acid HCl for 3 days, with and without corrosion inhibitors, are shown in Fig. 4. Zones I and II correspond to the end of impact load event, which represents the damage of the specimen, /18-22/. The impact energy absorbed by specimen from X52 and X65 in Zone I is predominantly absorbed in the form of elastic and plastic deformation along with different concentration of green inhibitors.

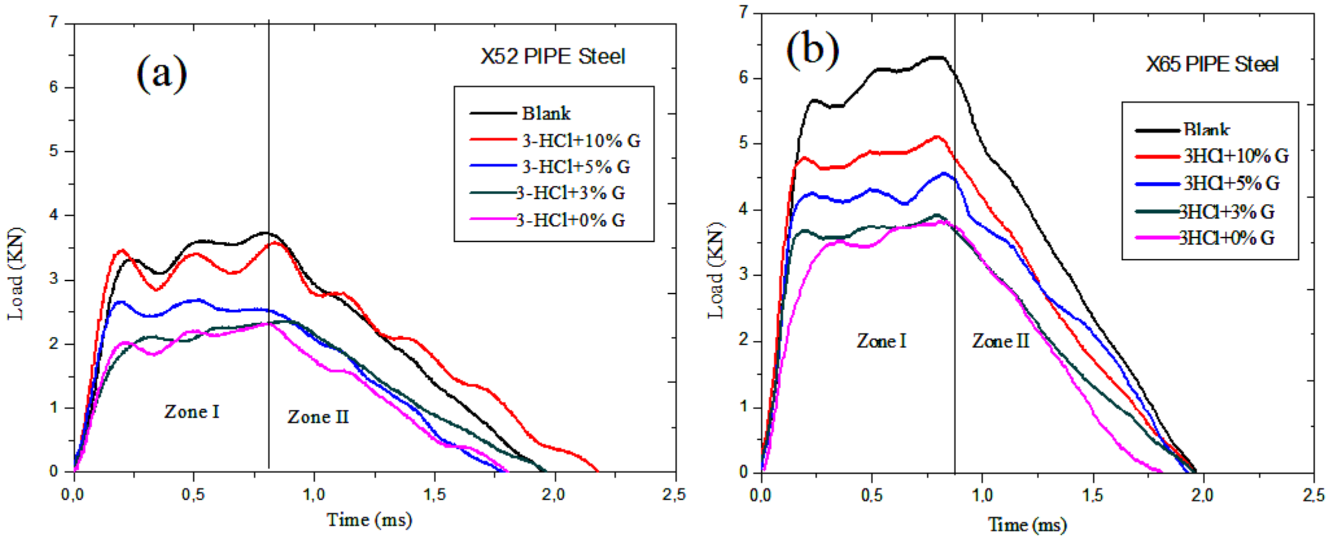
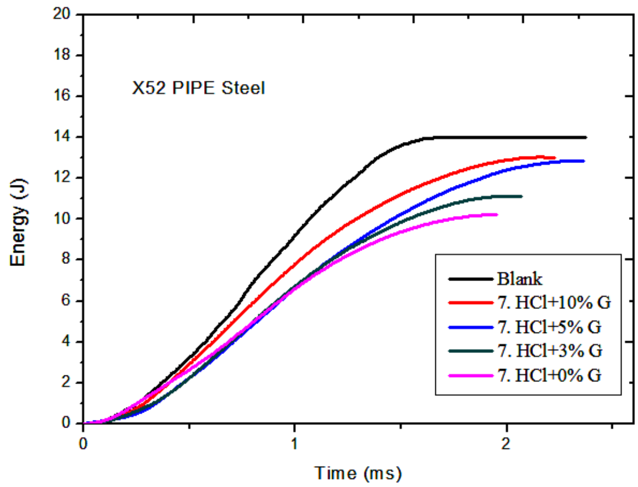


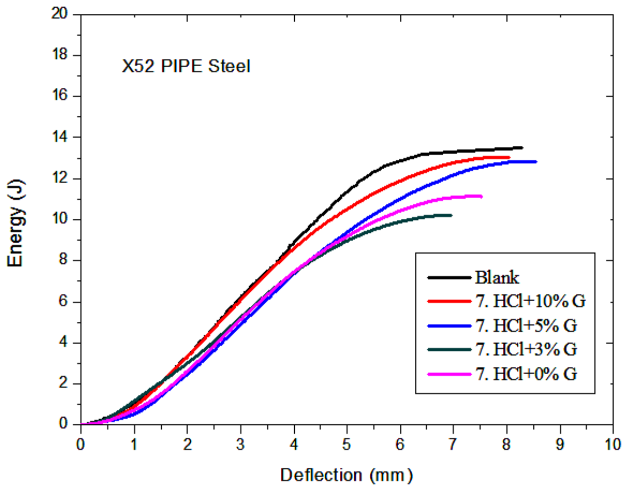
Figure 4. Load vs. time curves for specimens: (a) X52, (b) X65 API steels in HCl with various concentration of green inhibitors.

Time and deflection response

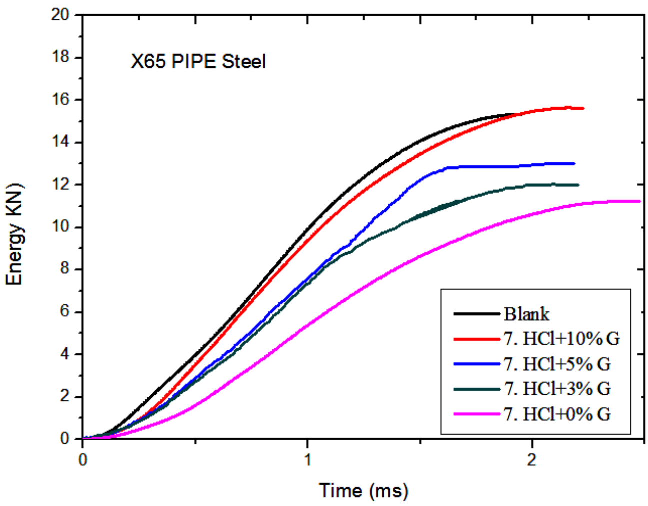
The effect of concentration on the mechanical properties of X52 and X65 steels is now presented by energy as a function of time and deflection, Fig. 5. Deflection at peak load is considered as an indicator of the stiffness of API steels X52 and X65 when immersed in HCl acid media with different concentration of green inhibitors, Figs. 5c and 5d. The higher the recorded deflection, the lower is the stiffness of steel before the fracture of specimen, /23-26/.



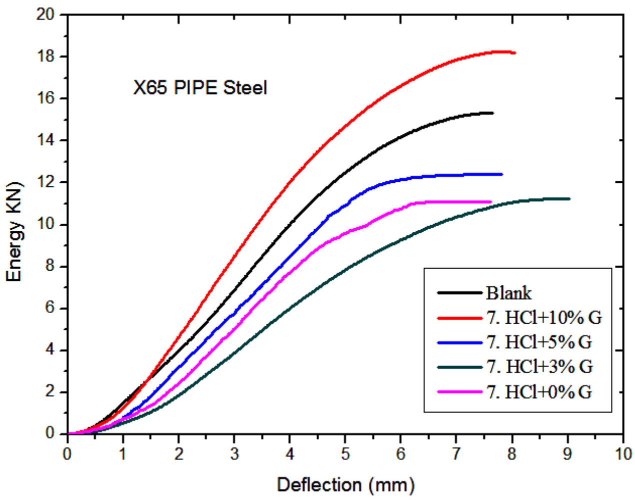
a) energy vs. time for X52 steel



b) energy vs. deflection for X52 steel



c) energy vs. time for X65 steel



d) energy vs. deflection for X65 steel

Figure 5. Energy for X52 and X65 steels immersed 7 days in HCl with different concentration of green inhibitors corrosion.

Deflection is seen to increase steadily until it reaches maximum, after which it is constant. The addition of 3, 5 and 10 % of green corrosion inhibitors seems to result in improvement of specimen internal resistance. The improvement in specimen internal resistance can also be related to the improvement of the percentage of green inhibitors corrosion changed the level of mechanical properties of X52 and X65 steel observed in different clay loadings, /18-22/.

Load vs. time and deflection response

Results from API X52 and X65 steel testing are also presented in the state after 7 days of immersion with a concentration of 1 M HCl acid at room temperature, as load versus time and deflection curves, Fig. 6, indicating different levels of peak load and the effect of green inhibitors concentration. One can notice small effect of 3% of green inhibitor, contrary to strong effect of 5 and 10 %, indicating the efficiency of green inhibitors in acid media.

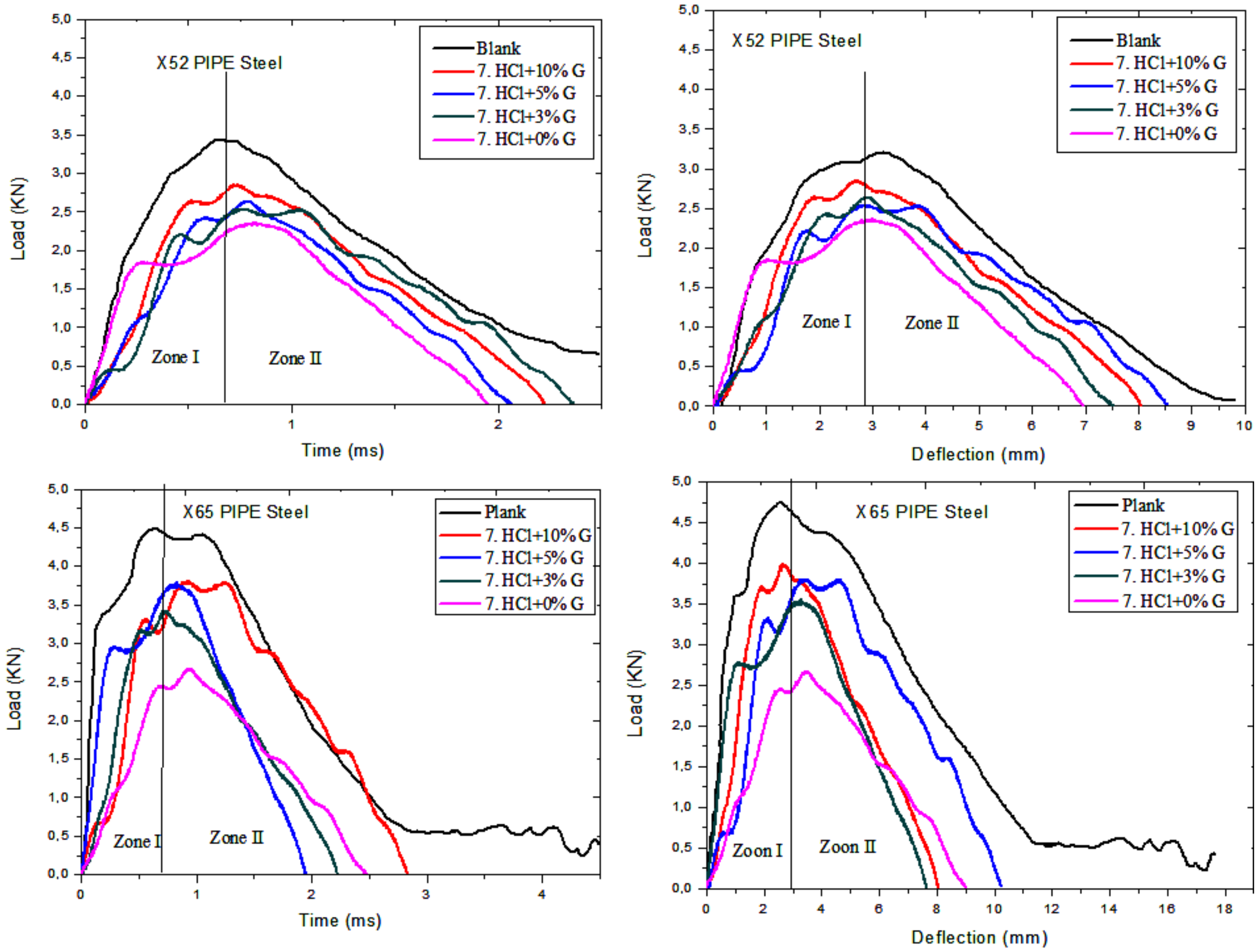


Figure 6. Evolution of load as function of time-deflection from specimens X52 (a, b) and X65 (c, d), immersed in HCl with different concentration of green inhibitors corrosion.

CONCLUSIONS

A new drop weight impact machine is successfully applied to investigate impact behaviour of X52 and X65 steels, with or without green inhibitors. Three days of immersion of X52 and X65 steels in 1 M acid media with different concentration of green inhibitors is relatively good for the stabilization of the corrosion reaction between metal and acidic environment. Changes in mechanical properties, with dynamic tests, are used to study the inhibitor effect on API X52 and X65 steels and the corrosion of mild steel in 1 M HCl solution. This compound exhibits excellent inhibition performance as a mixed-type inhibitor with different concentrations. The concentration of green inhibitor of 5% results in optimal properties, with 42% improvement in peak load and 32% increase in elongation.

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