v. 3, n. 3, 2023

Journal of
Engineering Research

DAMAGE EVALUATION OF ASTM A572 HSLA STEEL AFTER A REAL FIRE EXPOSITION IN SERVICE CONDITIONS

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Abstract: This metallurgical research determined the mechanical properties of steel ASTM A572 grade 60 that was subjected to fire incident. Mechanical properties were obtained by axial tension test and Rockwell hardness giving similar results than the typical ones observed in original material. A microstructural analysis was carried out obtaining micrographs using optical microscopy. The damaged steel was also analyzed by scanning electron microscopy to analyze the microstructure features after the fire exposition. These images were used to determine a percentage of phases employing the Image J free software. The results didn´t reveal damage at the bridge by fire because there is not microstructural damage due to the perlitic degradation or martensitic transformation as well as mechanical properties were not affected neither.

INTRODUCTION

Steel is the most important material used in the industry and construction as structural member of bridges due to numerous advantages that offers over others construction materials (Aziz 2015). This engineering material combines higher strength under tension and compression with great rigidity, ductility, stable mechanical behavior and ease of fabrication at relatively low price. The chemical composition, cooling speed, deformation, fabrication process and thermal treatment influence directly the mechanical properties which are necessary to know in order to make an adequate materials selection to the specific industrial application. In specific, the A572 structural steel (ASTM 572/A 572M, 2018) (Sajid and Kiran, 2018) is available in various grades (www.Ahmsa.com). This steel is currently the most widely used in the USA market although it is rapidly being replaced by other commercial ones such as A992 (ASTM A992/A992M, 2015) (Sajid and Kiran, 2018).

In recent years, there have been numerous bridge fires that sometimes result in the collapse of the steel girders (Kodur and Aziz, 2014) (Kodur and Naser, 2019). In major cases, structural parts retain most of their capacity after being exposed to fire, however, the recovery of resistance depends on the severity and duration of the fire (Aziz and Kodur, 2013). There are different approaches suggesting that the structural damage to the bridge impacts in different ways including whether the fire occurred on the bridge or under it (Aziz, 2015). In January 2018, a pipe overturned and exploded on a bridge near Tehuacán Mexico, this caused a fire that was controlled, neverless, the question of possible structural damage to the bridge's steel was raised, maybe weakening its resistance. Therefore, different samples of this damaged bridge were obtained to observe and analyze how it could have affected the mechanical properties and microstructural features of the material.

METHODOLOGY

METALLOGRAPHY

A plate was obteined by cutting at a high temperature using the oxyfuel technique. From the resulting plate, tension specimens test were machined using the water jet technique, obtaining that way a clean cut. The material near oxyfuel cut was discarded since its microstructure was damaged, at the same time, an area that was not affected by heat was obtained for which, the areas of the periphery of the plate were discarded, finally obtaining standardized size tensile specimens (ASTM E8M, 2013). Two more cuts were made, from which cubic shaped specimens were obtained by means of a disc cutter, having a very slow feed with constant lubrication to keep the material at low temperature for microstructure and hardness tests.

As early as the cubic specimens were acquired the metallographic process began. Abrasive papers of grade 80, 180, 220, 320, 320, 400, 600, 1000 and 1500 were used on a grinding machine, with each change of abrasive paper the direction of the specimen was changed by 90°. As a next step a rotary disc polisher was used with a microfiber cloth mounted on the disc and alumina was added as an abrasive agent. The process was carried out under the following conditions: 350 rpm with coarse alumina (1.0 µm), 300 rpm with medium alumina (0.3 µm) and 250 rpm with fine alumina (0.05 µm). This methodology was used until a specular surface finish was obtained in which the grinding lines were no longer visible to the naked eye. At the end of the polishing process, each specimen was cleaned with alcohol to avoid surface staining. Subsequently, a chemical attack was performed to reveal the microstructure of the steel under study. For this purpose, the material was immersed for 10 s in Nital at 2%. Thus, the material was polished a second time with medium and fine alumina at 250 rpm. The specimen was attacked again with the same reagent by 3 s, then immersed in alcohol to stop the reaction and finally the specimen was dried so that the microstructure could be observed by microscopy.

TENSION TEST

The tensile test is carried out in order to know the toughness, maximum stress, modulus of elasticity and ductility. A universal machine for mechanical tests brand Satec sistem inc was carried out, the specimens for the development of this test were machined with the water jet technique using the plate extracted from the bridge as material, taking the central specimens 3, 4 and 5 to avoid external specimens that could show damaged by cutting process, see Figure 1.

HARDNESS TEST

The hardness test is carried out on cubic specimens to determine its resistance by Rockwell B scale. In order to ensure the test was correctly implemented any kind of edge or deformation was avoided at surface plane parallel to the base. The test was carried out in a Mitutoyo brand Durometer with a 1/16" spherical indenter using a preload load of 10 and 150 kg_f, respecively.

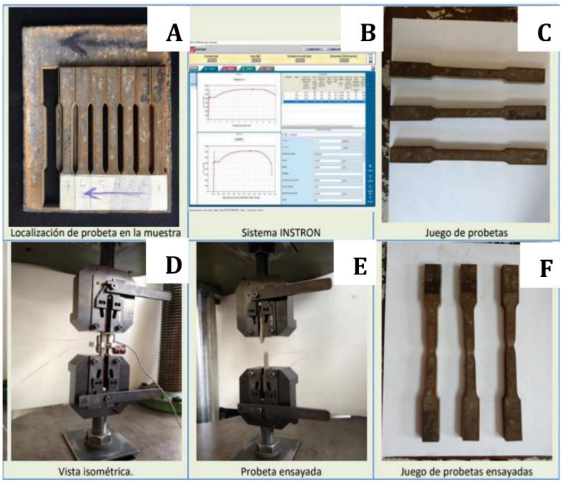

Figure 1. a) Plate obtained from the fired bridge and sectioned into specimens for tension testing, b) Instron software to obtain the results of the stress test, c) Specimens selected for the test, d) Assembly of the Satec sistem inc. universal machine, e) End of the tensile and fracture test of the specimen and f) Set of tested specimens, the fracture is observed in the thinnest area of the specimen.

RESULTS AND DISCUSSION

OPTICAL MICROSCOPY

Firstly, the microstructure was obtained using an Olympus Model PMG3 inverted optical microscope. Figure 2a) shows Steel A572 at 200 X, this was attacked with Nital for 4 s, having ferrite and perlite phases, figure 2b) shows the same microstructure modified with free software Image J (Rasband, 2015), the black color corresponds to pearlite phase, and white color is ferrite phase, this allows to get a quantitative analysis with percentage of each phase.

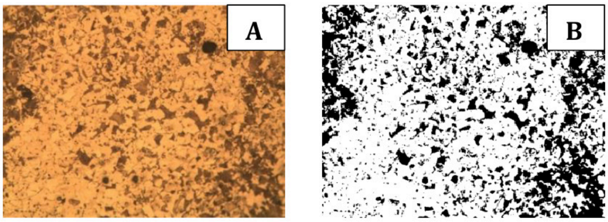

Figure 2. A572 steel at 200X: a) Attacked with Nital for 4 s, the ferrite and pearlite phases are observed in smaller amounts, and grain boundaries are more visible, and b) Modified with Image J software indicating shades of black (pearlite phase) and white (ferrite phase).

SCANNING ELECTRON MICROSCOPY (SEM)

The equipment used to obtain SEM images was a field emission microscope, Carl Zeiss brand, model SURPA 55pV. Figure 3a) shows the present phases of A572 steel, two phases can be seen, as observed at optical microscope, ferrite and pearlite, this last phase is presented in smaller proportion. Figure 3b) shows in better detail and at a higher magnification the phases grain boundaries. The figures 3c) and 3d) images shows a close-up of the perlite colonies, which allows us to appreciate the characteristic lamellae of the pearlitic phase.

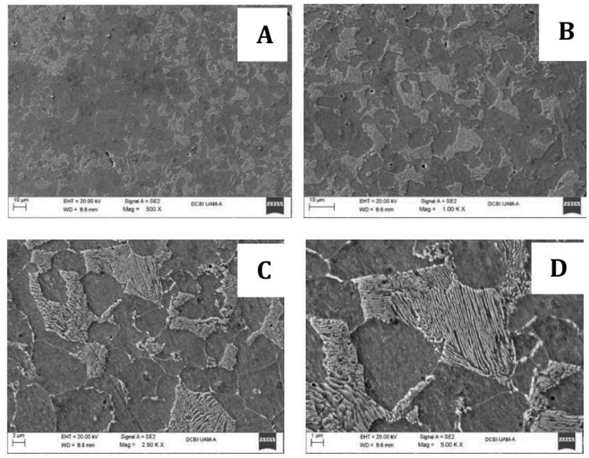

Figure 3. Micrographs obtained by SEM of A572 steel. a) Microstructure with two phases, ferrite which is the dark phase and lamellae of the pearlite phase in a light color, at 500 X both phases are observed, b) 1 KX the limits of both phases are appreciated in detail, c) 2.5 KX approach to the pearlitic phase, and d) 5 KX the characteristic lamellae of the pearlite phase are exhibited.

Moreover, the Figure 3b) was used to observe and quantify the phases with the Image J software mentioned above, resulting in Figure 4. In this particular case, the microstructure taken from SEM was at 1 KX, this magnification shows the separation of the phases and allows the accounting for the percentage present of the phases. Table 1 indicates the percentage of ferrite (Zone A) and pearlite (Zone B) phases.

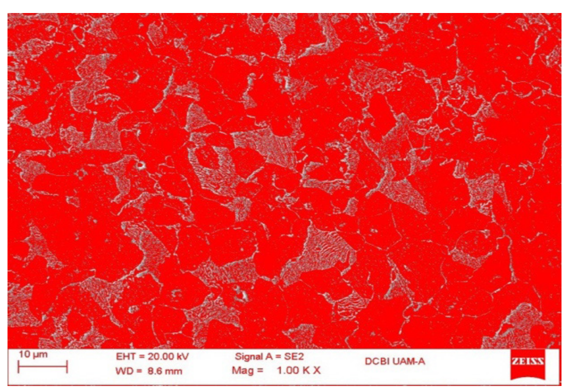

Figure 4. Image showing microstructure processing with Image J software, from Figure 3b) at 1 KX.

Measurement	Zone A ferrite (%)	Zone B perlite (%)
1	74.3	25.7
2	76.8	23.1
3	76.6	23.3
Average	**75.9**	**24.03**

Table 1. Percentage of phases by Image J software.

HARDNESS TESTS

The hardness measurement in transverse (T) and longitudinal (L) directions for cubic specimens in zone A and D are presented in Table 2. Where zone A indicates the external part of the plate, close to the oxyacetylene cut and zone D indicates the internal part of the plate. It is observed from the measurements that through the different zones similar hardness are obtained, so that the selected specimens are not affected by the heat induced in the cut process.

Measurement	Zone A-L	Zone D-L	Zone A-T	Zone D-T
1	82	81	80	80
2	81	80	79	81
3	81	81	79	79
Average	**81.33**	**80.66**	**79.33**	**80**

Table 2. HRB hardness measurements of the cubic specimens from both zones, in the longitudinal (L) and transversal (T) direction.

TENSION TESTS

The results of the tensile test were plotted in stress vs. strain curves of the specimens obtained from the incident plate, which are shown in Figure 5.

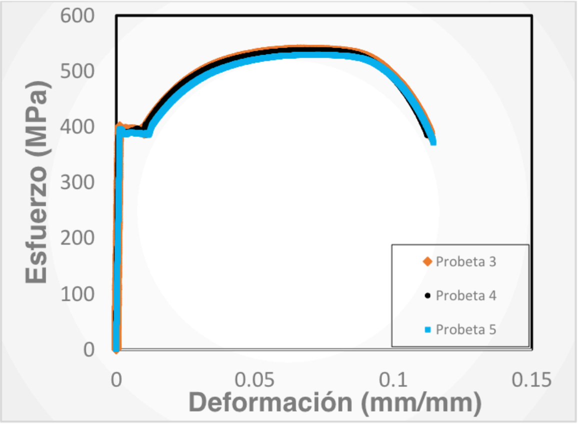

Figure 5. Stress vs. strain graph of specimens 3, 4 and 5 in Figure 1c) obtained from the incident plate.

CONCLUSIONS

From the microstructure evaluation obtained by SEM, the ferrite and pearlite (24 %) phases were observed, while there was not presence of hard martensite, therefore there was not microstructural damage as a consequence of the perlitic degradation or instantaneous martensitic transformation.

When comparing the mechanical properties obtained in this investigation with those described in the standard (ASTM 572/ A572M, 2004), it was observed that the yield stress, ultimate stress as well as the percentage of elongation were not reduced in comparison with the values of the aforementioned standard, resulting that the mechanical strength under tension and ductility were not affected by the fire incident in service. Considering the hardness assessment which showed minimal differences, it was guaranteed that the sampling was done correctly by taking different zones of the plate.

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