ppi 201502ZU4659
This scientific digital publication is continuance of the printed journal impresa p-ISSN 0254-0770/ e-ISSN 2477-9377 / Legal Deposit pp 197802ZU3

La Ciega Historical building. LUZ first headquarter

REVISTA TÉCNICA
DE LA FACULTAD DE INGENIERÍA

An international refereed Journal indexed by:

- SCOPUS
- SCIELO
- LATINDEX
- DOAJ
- MIAR
- REDIB
- AEROSPACE DATABASE
- CIVIL ENGINEERING ABTRACTS
- METADEX
- COMMUNICATION ABSTRACTS
- ZENTRALBLATT MATH, ZBMATH
- ACTUALIDAD IBEROAMERICANA
- BIBLAT
- PERIODICA
- REVENCYT

"Post nubila phoebus"
"After the clouds, the sun"

LUZ in its 130th anniversary
Established since 1891

REVISTA TÉCNICA
DE LA FACULTAD DE INGENIERÍA

UNIVERSIDAD DEL ZULIA

VOLUME 44 | MAY - AUGUST 2021 | NUMBER 2

Evaluation of 1.25Cr0.5Mo Steel Behaviour in Creep Conditions

R. Fernández-Fuentes[1*], A. Cruz-Crespo[1], A. Scotti[2], N. Guedes-De Alcãntara[3]

[1]Centro de Investigaciones de Soldadura, Facultad de Ingeniería Mecánica e Industrial, Universidad Central "Marta Abreu" de Las Villas, CP 54 830, Santa Clara, Cuba.
[2]Universidade Federal de Uberlândia - UFU, Uberlândia, Brasil.
[3]Universidade Federal de São Carlos - UFSCar, São Carlos, Brasil.
* Corresponding author: rfernandez@uclv.edu.cu
https://doi.org/10.22209/rt.v44n2a03
Received: 05 August 2020 | Accepted: 31 January 2021 | Available: 01 April 2021

Abstract

Studies about the influence of the post weld heat treatment on microstructures and mechanical behaviors of steam pipelines have focused on the weld region (fusion and heat-affected zones). However, this treatment has a thermal effect that surpasses this region, which has not been sufficiently studied. The aim of the present work consisted in evaluating the effect of the heat treatment on the microstructure and creep behavior in the region that is not affected by welding thermal cycle. The analyzed material was taken from a main steam pipe (1.25Cr0.5Mo steel, 20 years in-service aged at 480 ^oC). A piece of the pipeline was subjected to heat treatment, with parameters according to the ASME Boiler and Pressure Vessel Code. The creep rupture time and the microstructure were obtained from the in-service aged material, as well as from the heat-treated one. The heat treatment of in-service aged 1.25Cr0.5Mo steel increased the amount of the inside ferrite grain precipitates and reduced the creep resistance.

Keywords: 1.25Cr0.5Mo steel; posweld heat treatment; creep resistance.

Evaluación del Comportamiento del Acero 1,25Cr0,5Mo en Condiciones de Fluencia Lenta

Resumen

Los estudios sobre la influencia del tratamiento térmico pos soldadura en la microestructura y comportamiento mecánico de tuberías de vapor se han enfocado en la región de la soldadura (metal fundido y zona afectada por el calor). Sin embargo, dicho tratamiento tiene un efecto térmico que va más allá de esta región, el cual no ha sido suficientemente estudiado. El presente trabajo tuvo como objetivo evaluar el efecto del tratamiento térmico sobre la microsetructura y el comportamiento en fluencia lenta de la región que no es térmicamente afectada por la soldadura. El material analizado fue tomado de una tubería de vapor (acero 1,25Cr0,5Mo, 20 años envejecido en servicio a 480 ^oC). Una parte de la tubería fue sometida a tratamiento térmico, con parámetros de acuerdo con el código ASME de Calderas y Recipientes a Presión. Se obtuvo el tiempo de rotura en ensayo de fluencia lenta y la microestructura del material envejecido en servicio así como del tratado térmicamente. El tratamiento térmico del acero 1,25Cr0,5Mo envejecido en servicio aumentó el tamaño de los precipitados presentes en el interior de la ferrita y disminuyó la resistencia a la fluencia lenta.

Palabras clave: Acero 1,25Cr0,5Mo; tratamiento térmico pos soldadura; resistencia a la fluencia lenta.

Introduction

The creep phenomenon is evident in a group of industrial components subjected to working conditions which combines the action of mechanical load and temperature. As an example, can be mentioned steam generators and pipes intended for steam transportation. Cr-Mo low-alloy-ferritic steels, among others, have been developed to ensure safe and long service of such components under the aforementioned working conditions (Robertson 2014). In these steels, creep strength is achieved by action of solid solution and precipitation hardening mechanisms (Muránsky et al. 2020).

During design of the referred components an allowable stress is adopted for each type of steel, which guarantees safe service for at least 10^5 h at the working temperature. However, the applied safety factors allow in practice that components manufactured with Cr-Mo ferritic steels can exceed $2·10^5$ h of operation (Victoria and Felix 2007). Nevertheless, there are cases in which premature failures occur, associated with different degradation phenomena even before 10^5 h of operatation, (Victoria and Felix 2007, Furtado and Le-May 2004).

When such failures occur, in technically and economically justified cases, repair is carried out by removing the damaged area and welding a new material insert. The applied standars for this type of repair, among those are the ASME (American Society of Mechanical Engineers 2019) and JIS B8267 (Japanese Standards Association 2015), contemplate the technological requirements that guarantee the quality of the welded joint only in new materials. Signifying that the repair procedures become complex when they involve the in-service aged material, because, in most cases, its microstructure and mechanical behavior are unknown. This situation imposes the need to know the behavior of the material subjected to creep for long time.

This problem turns complicated in those cases in which the application of post weld heat treatment is required, being noticeable discrepancies in relation to whether it is favorable or not from the residual life point of view (Parker and Stratford 1995). In such sense, it is observed that the main focus of the corresponding studies has been centered on the effect of the heat treatment on the thermally affected zone (HAZ), despite the fact that it also exerts a significant thermal influence on a region that extends beyond the HAZ.

Based on the above statements, the purpose of the present work was to evaluate the behavior of the microstructure and creep resistance of in-service aged 1.25Cr0.5Mo steel subjected to heat treatment similar to that applied post-welding (PWHT).

Experimental

In order to accomplish the objective, material from a main steam pipe with 20 years in-service at 480 ^oC was used in this study. The chemical composition of the pipe material (Table 1) was determined by atomic absorption spectrometry, corresponding to that of steel type 1.25Cr0.5Mo, according to ASTM A387 (ASTM 2011a).

Table 1. Chemical composition of the pipe material (mass %).

C	Si	Mn	P	S	Cr	Mo	W	Ti	V	Fe
0.12	0.38	0.41	<0.03	<0.03	1.24	0.49	<0.01	<0.01	<0.01	base

A piece of the referred section was subjected to heat treatment in a muffle furnace, with a regime similar to that recommended by ASME code for post weld heat treatment (ASME 2019): heating rate of 200 ^oC/h and soaking time of 1.5 h at a temperature of 700 ^oC. Thus, two material conditions were evaluated:

a. In-service aged material (ISAM). It is associated with the material directly removed from the pipe.

b. In-service aged material and subjected to heat treatment (ISAM+HT).

From both conditions, creep tests at constant load were applied to cylindrical specimens (6-mm-diameter and 36 mm of useful length), according to ASTM E-139 (ASTM 2011d). Each tested condition resulted from the combination of stress and temperature values, according to Table 2.

Table 2. Combination of stress and temperature values for each material condition (ISAM and ISAM+HT).

Temperature °C	Stress, MPa		
	100	**125**	**150**
550	ISAM ISAM+HT	ISAM	ISAM ISAM+HT
575	ISAM ISAM+HT	ISAM	ISAM ISAM+HT
600	ISAM ISAM+HT	ISAM	ISAM ISAM+HT

ISAM = in-service aged material and ISAM+HT = in-service aged material and subjected to heat treatment.

From the creep test results, it was assessed:

a. The effect of in-service aging on the creep rupture time, for which the results from the ISAM condition were compared to values reported by Demirkol (1999). The referred author used a steel in the as-received condition, with microstructure compatible with those of the studied material.

b. The influence of heat treatment on the creep rupture time, for which the behaviors of ISAM and ISAM+HT conditions were compared at similar stress and temperature combinations.

The surface preparation of the specimens for the acquisition of microstructure images consisted of grinding with emery paper from grit P120 to P1000, followed by polishing with 3 and 1 μm alumina, according to recommendations of ASTM E-3 (ASTM 2011b). NITAL at 1 % was employed as chemical etchant (immersion for 10 s), according to ASTM E-407 (ASTM 2011c).

The observation of the microstructure was performed in a scanning electron microscope (Zeiss EVO MA10), with digital image acquisition of 3072 x 2304 pixels and resolution of 10 nm/pixel. Using the Image J software, digital image processing was performed, and the equivalent diameter of the precipitates was determined automatically, based on the area occupied by each section of the precipitates in the image.

A comparative analysis of the intra-granular precipitate size distribution of the studied conditions was carried out, so that, from the particle sizes, histograms of relative frequencies were made (using in all cases 15 classes of size equal to 40 nm) and the particle density in each class interval was determined (Smith and Jordan 1964).

The experimental values of particle density were fitted to a lognormal probability density function according to equation 1 and the parameters of the function (geometric mean and standard deviation) were obtained (Endo 2009). The values of the correlation coefficient and "F-test" were used as measure of the model lack of fit, (Sultan and Ahmad 2013, Krishnamoorthy and Mathew 2003, Martinez et al. 2015).

$$f(D_i) = \frac{1}{\sqrt{2\pi}\, D\,(\ln\sigma_g)} \exp\left[-\frac{1}{2}\left(\frac{\ln(D_i/D_g)}{\ln\sigma_g}\right)^2\right] \qquad (1)$$

Where:

Di: diameter (μm)
Dg: geometric mean of diameter (μm)
σg: geometric standard deviation

Results and Discussion

In the ISAM condition, a predominantly ferritic microstructure was observed, accompanied by lamellar pearlite (Figure 1a); intragranular (inside ferrite grains) and intergranular (at ferrite grain boundary) fine precipitates were observed (Figure 1b). Qualitatively, 1.25Cr0.5Mo steel shows this type of microstructure when it is in the annealed as-received condition, whereas bainite formed instead of pearlite in the normalized condition (Viswanathan 1995). Similar precipitation (intragranular and intergranular) was observed in 2.25Cr1Mo steel, both in the as-received and in-service conditions (Yang 1993). The formation of this type of precipitation has also been observed in samples of this steel family, subjected to the creep test (Afrouz et al. 1983).

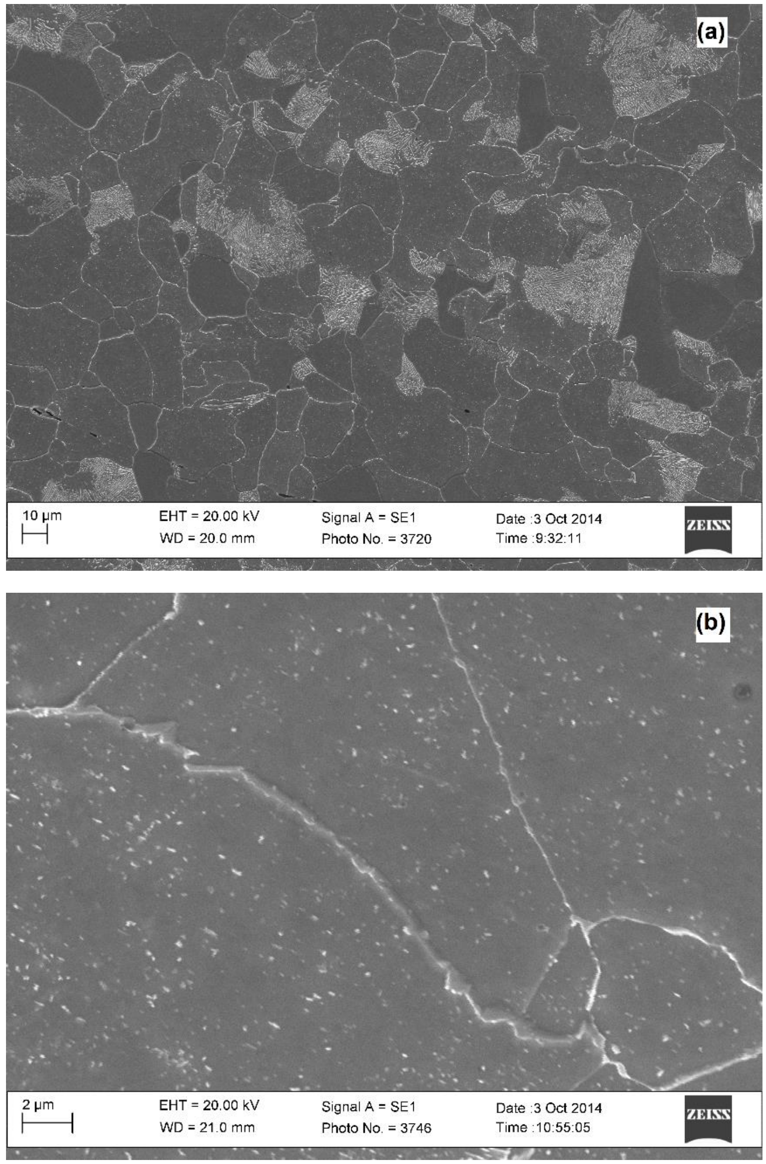

Figure 1. (a) Ferritic-perlitic microstructure of the in-service aged material (ISAM) condition; (b) Intragranular and intergranular precipitation in the in-service aged material (ISAM) condition.

The referred type of microstructure is preserved in the ISAM+HT condition, although, in this condition, larger precipitates were noticed inside ferrite grain (Figure 2), compared to those observed in the ISAM condition (Figure 1b). This difference was quantitatively evidenced in the relative frequency histograms of precipitate sizes and particle density curves (Figures 3 and 4, respectively).

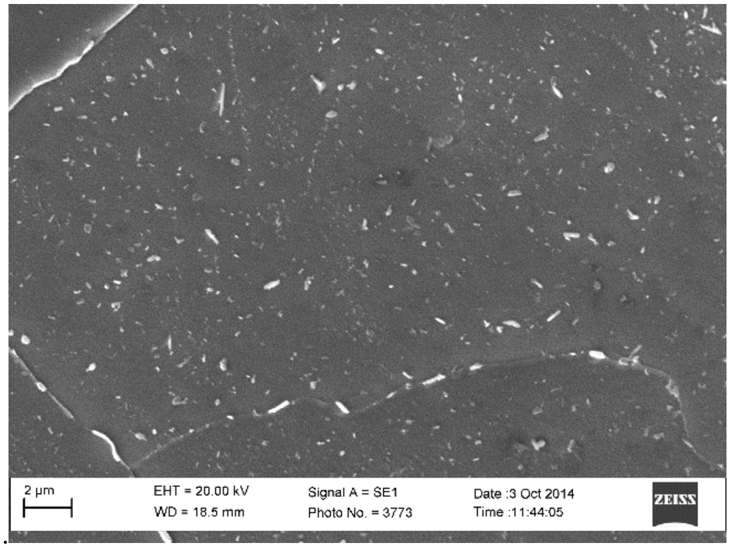

Figure 2. Microstructure of the in-service aged material with heat treatment condition (ISAM+HT)

According to Figure 3, with the heat treatment (ISAM+HT condition) the relative frequency of the 40-80 nm class decreased considerably, while it increases respectively in the rest of the classes (for sizes above 80 nm). Regarding particle density, an adequate fit to the lognormal model was obtained (correlation coefficient of 0.998 and probability $p<0.001$ for the ISAM condition, and 0.999 with $p<0.001$ for the ISAM+HT condition). In this case, it was noted that the heat treatment modified the fitted probability density curve (Figure 4), resulting in an increase of the mode (from 88 nm for the ISAM condition to 105 nm for the ISAM+HT condition) and of the geometric mean (from 101 to 117 nm, respectively).

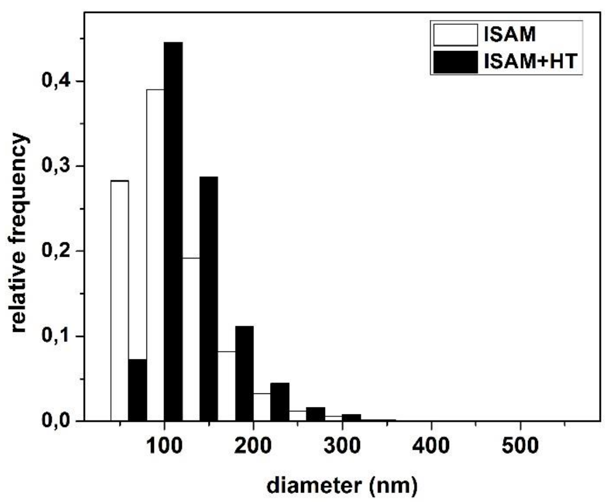

Figure 3. Relative frequency histograms of precipitate sizes for the ISAM (in-service aged material) and ISAM+HT (in-service aged material and subjected to heat treatment) conditions.

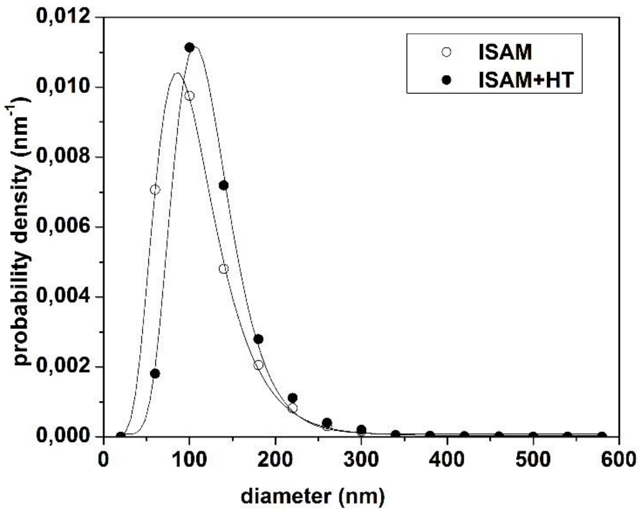

Figure 4. Experimental points and particle density curves of the ISAM (in-service aged material) and ISAM+HT (in-service aged material and subjected to heat treatment) conditions.

The noted effect of the post weld heat treatment on the precipitate size distribution is associated with the fact that the larger stable precipitates grow at the expense of the dissolution of the smaller ones, as a result of the process called competitive growth (Ouden 2015), reported for low alloy CrMo steels (Gustafson and Hattestrand 2002), whose driving force is the decrease of the free energy of the system caused by the decrease of the surface energy.

The graphical comparison of the creep test results for the ISAM and ISAM+HT conditions (Figure 5), indicates that, for the same experimental combinations of stress and temperature, the ISAM+HT condition presented lower rupture time compared to the ISAM condition. The reduction of the rupture time signify an unfavorable effect of the heat treatment on the creep strength. This result concur with a literature report for this steel family (Arnswald et al. 1986), although exist a report of a favorable effect (Lundin and Wang 1989).

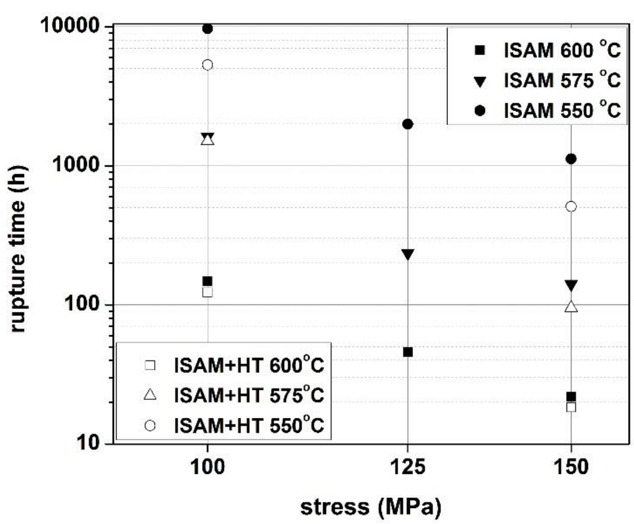

Figure 5. Creep rupture time of ISAM (in-service aged material) and ISAM+HT (in-service aged material and subjected to heat treatment) conditions, for different test combinations of stress and temperature.

Figure 6 shows the experimental values of the rupture time for the ISAM and ISAM+HT conditions (for stress 100 and 150 MPa and temperature 550 and 600 °C, respectively) and the trend lines for the 1.25Cr0.5Mo steel in the as-received condition, with chemical composition and microstructure similar to those determined in the samples under study in the present work (Demirkol 1999). In this case, the graphical comparison shows that both the ISAM and the ISAM+HT conditions presented lower rupture time compared to the material in the as-received condition (therefore, lower slow creep resistance).

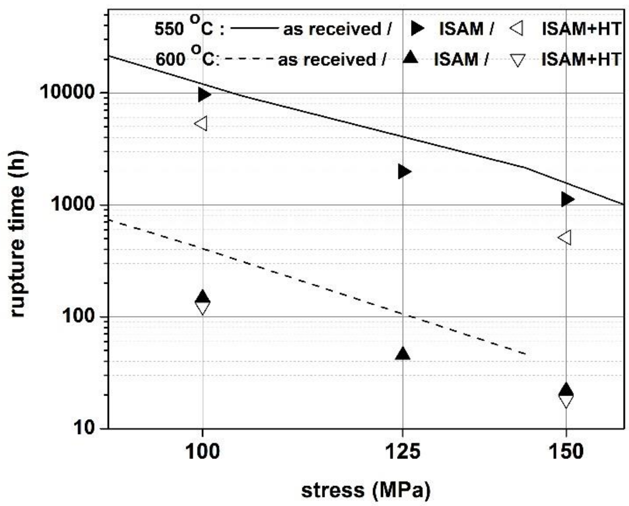

Figure 6. Creep rupture time from the experimental conditions ISAM (in-service aged material) and ISAM+HT (in-service aged material and subjected to heat treatment) and the as-received condition (Demirkol 1999).

The quantitative evaluation of the rupture time reduction in the different conditions was carried out on the basis of the statistical models (equations 2, 3 and 4, for the conditions ISAM, ISAM+HT and as-revived material, respectively) obtained by means of multiple regression analysis. For this analysis, the experimental values were fitted to different models recommended in literature for such purposes (Manson and Ensign 1979). For each condition, it was adopted that model in which the analysis of variance showed statistically significant values from the corresponding statistics ($p \leq 0.05$ for F and t-tests, respectively) and higher adjusted multiple correlation coefficient (adjusted R^2).

$$\log t_r = 13.96 - 19.3 \cdot \log(S) + 1.18 \cdot 10^4 (\log(S)/T) \quad (2)$$

$$\log t_r = 13.0 - 17.5 \cdot \log(S) + 1.06 \cdot 10^4 (\log(S)/T) \quad (3)$$

$$\log t_r = 8.5 - 15.9 \cdot \log(S) + 1.2 \cdot 10^4 (\log(S)/T) - 13.1(S/T) \quad (4)$$

Where:
t_r: rupture time, (h)
S: stress, (MPa)
T: temperature, (K)

Substituting in the models the values of the 1.25Cr0.5Mo steel allowable stress and the operating temperature, 94 MPa and 480 °C according to ASME code (ASME 2019), it was obtained that the rupture time of the ISAM+HT condition represents 32.2 % of that corresponding to the ISAM condition, while the rupture time of the ISAM condition represents 65 % of that corresponding to the material in the as-received condition. The rupture time of the ISAM+HT condition, in turn, represents 20.4 % of that corresponding to the material in the as-received condition. This result highlights the detrimental effect of the post-weld heat treatment on the creep strength of the in-service aged 1.25Cr0.5Mo steel, expressed in a reduction of the rupture time by 67.8 %. The observed mechanical behavior corresponds to the microstructural features, which shows that the heat treatment resulted in a decrease in the relative frequency of small precipitates, with an increase in the frequency of larger ones. It results in an increase in the distance between particles, with a detrimental effect on the increase in mechanical strength due to precipitation (Abbaschian et al. 2009).

Conclusions

The 1.25Cr0.5Mo steel qualitatively retains a microstructure of ferritic-perlitic type with grain boundary and inside ferrite precipitation after a prolonged period of operation in a steam pipeline, which is typical of the as-received condition.

The heat treatment, with a similar regime to that required after welding, does not modify this type of microstructure. However, because of the competitive growth phenomenon, it results in quantitative changes in the size distribution of the precipitates present inside ferrite grain, expressed by a decrease in the number of particles smaller than 80 nm and an increase in the number of particles larger than 80 nm.

For the 1.25Cr0.5Mo steel the density of particles inside ferrite grain obeys a lognormal distribution function in the as-received condition as well as in the subjected to heat treatment with a similar regime to that required after welding condition, showing an increase of 16% of the geometric mean of the equivalent diameter due to the effect of the heat treatment.

The creep rupture time fits adequately to a model of type $\log t_r = A + B \cdot \log(S) + C\,(\log(S)/T) + D(S/T)$, where: A, B, C and D are the model parameters, t_r the creep rupture time (h), S the stress (MPa) and T the temperature (K).

The heat treatment of in-service aged 1.25Cr0.5Mo steel, with parameters similar to those required post welding, reduces 67.8 % the creep rupture time, which is associated with a corresponding increase in the size of the precipitates inside the ferrite, leading to the detriment of the effect of increasing the mechanical strength by precipitation.

Acknowledgments

Thanks to the support provided by LAPROSOLDA and LDTAD of UFU (Brazil), DEMa - CCDM of UFSCar (Brazil) and CAPES-Brazil/MES-Cuba agreement.

References

Abbaschian, R., Abbaschian, L., Reed-Hill, R. (2009). *Physical Metallurgy Principles,* USA: Cengage Learning.

Afrouz, A., Collins, J., Pilkington, R. (1983). Microestructural examination of 1Cr0,5Mo steel during creep. *Metals Technology,* 10(12), 461-463.

ASTM. (2011a). ASTM A387/A387M-1: Standard specification for pressure vessel plates, alloy steel, chromium-molybdenum. American Society for Testing and Materials: West Conshohocken.

ASTM. (2011b). ASTM E3-11: Standard guide for preparation of metallographic specimens. American Society for Testing and Materials: West Conshohocken.

ASTM. (2011c). ASTM E407-11: Standard practice for microetching metals and alloys. American Society for Testing and Materials: West Conshohocken.

ASTM. (2011d). ASTM E-139: Standard practice for creep, creep-rupture, and stress-rupture tests of metallic materials. American Society for Testing and Materials: West Conshohocken.

ASME. (2019). Rules for construction of pressure vessels. Boiler and pressure vessel code. American Society of Mechanical Engineers: West Conshohocken.

Arnswald, W., Blum, R., Neubauer, B., Poulsen, K. (1986). Remaining life affected by repair welds, In: *International Conference on Creep,* JSME/IMechE/ASME/ASTM: Tokyo.

Demirkol, M. (1999). On the creep strength-rupture ductility behaviour of 1.25Cr-0.5Mo low alloy steel. *Journal of Engineering and Environmental Science,* (23), 389-401.

Endo, Y. (2009). Estimate of confidence intervals for geometric mean diameter and geometric standar deviation of lognormal size distribution. *Power Technology,* 193(2), 154-161.

Furtado, H., Le-May, I. (2004). High temperature degradation in power plants and refineries. *Materials research,* 7(1), 103-110.

Gustafson, A., Hattestrand, M. (2002). Coarsening of precipitates in an advanced creep resistant 9% chromium steel—quantitative microscopy and simulations. *Materials Science and Engineering,* 333(1), 279-286.

JSA. (2015). Construction of pressure vessel. JIS B8267. Japanese Standards Association: Tokyo.

Krishnamoorthy, K., Mathew, T. (2003). Inferences on the means of lognormal distributions using generalized p-values and generalized confidence intervals. *Journal of Statistical Planning and Inference,* 115, 103-121.

Lundin , C., Wang, Y. (1989). Repair welding of service exposed Cr-Mo steel weldments. *Welding Research Council*, 384, 1-39.

Manson, S., Ensign, C. (1979). A quarter century of progress in the development of correlation and extrapolation methos for creep rupture data. *Journal of Engineering and Materials Technology,* 101(10), 317-325.

Martínez, L., Linares, J., Martínez, R., Oliva, H. (2015). Regression models for prediction of properties of pvc compounds considering the effects of additives dosis. *Revista Técnica de la Facultad de Ingeniería. Universidad de Zulia,* 38(3), 266-274.

Muránsky, O., Zhu, H., Lim, L., Short, K., Cairney, J., Drew, M. (2020). On the evolution of mechanical properties and microstructure of ferritic-bainitic (FB) 2.25Cr-1Mo (Grade 22) steel during high-temperature creep. *Materialia,* (9), 1-14.

Ouden, D. (2015). Mathematical Modelling of nucleating and growing precipitates: distributions and interfaces. *Delft University of Technology*, Netherlands.

Parker, J. and Stratford, G. (1995). Effect of heat treatment on creep and fracture behavior of 1,25Cr0,5Mo steel. *Materials Science and Technology,* 11(12), 1267-1273.

Robertson, D. (2014). Traditional low alloy steels in power plantdesig, development and applications. In: *Coal Power Plant Materials and Life Assessment*. Ed. Shibli, A. Amsterdam, The Netherlands: Woodhead Publishing.

Smith, J., Jordan, M. (1964). Mathematical and graphical interpretation of the log-normal law for particle size distribution analysis. *Journal of Colloid Science*, 19(6), 549-559.

Sultan, R., Ahmad, S. (2013). Comparison of parameters of lognormal distribution based on the classical and posterior estimates. *Journal of Modern Applied Statistical,* 12(2), 304-313.

Victoria, H., Félix, S. (2007). Tendencias actuales para determinar la degradación de los materiales metálicos de componentes industriales. *Nucleus,* (42), 17-28.

Viswanathan, R. (1993). Damage mechanisms and life assessment of high-temperature components. Ohio: Carnes Publication Services.

Yang, R. (1993). Microestructural examination of 2.25Cr1Mo steel pipes after extended service. *Materials Characterization,* 30(2), 75-88.

UNIVERSIDAD DEL ZULIA

REVISTA TECNICA

OF THE FACULTY OF ENGINEERING
UNIVERSIDAD DEL ZULIA

Vol. 44. N°2, May - August, 2021

This Journal was edited and published in digital format on April 2021 ***by Serbiluz Editorial Foundation***

www.luz.edu.ve
www.serbi.luz.edu.ve
www.produccioncientificaluz.org