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Creep Life Assessment of IGT25 Gas Turbine Combustor for Offshore Applications

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Abstract
The Iranian gas turbine (IGT25) suffers from the sea salt when they are placed in offshore situations. The sea salt may deposit on the internal surface of the combustion chamber at high temperature. The comprised salt may create creep damage and decrease combustor lifetime. In the present study, creep life of IGT25 gas turbine was predicted based on the stress and strain results obtained from the numerical simulation. Creep life was estimated based on the damage recognized in combustion chamber by using Norton and Larson Miller methods. It was concluded that the strain rate may change at high temperatures. The creep life of the combustion chamber was decreased about 12.32%, where the strain rate has increased by 100%.
Keywords: Creep lifetime, Combustion chamber, IGT25, offshore

Introduction
The Ni-base superalloys are widely used in gas turbine engine components due to their high creep and oxidation resistance above 0.4 T_m [1, 2]. Since combustors work at elevated temperatures the reliability and durability of combustion chamber were important issues in IGT25. Creep phenomenon was often occurred due to high temperatures of combustor in working conditions. Hastelloy-X is a superalloy with Ni-base which have been employed in IGT25 combustor [3]. Long exposure to elevated temperature and pressure makes Hastelloy-X susceptible to the creep deformation and damage. Early failure could be occurred if creep is not considered in the schedule combustor design and maintenance. Hence, advanced wall cooling methods are required for thermal protection to the liners of the combustor to keep away them from the mechanical damages such as creep. These damages could be diminished by using angled effusion cooling technique [4] and thermal barrier coating by means of a composite with a ceramic base as it was presented by Sam-Daliri et al. [5]. It is proposed that increase in thermal barrier coating thickness contributes to the enhancement of cooling efficiency and life cycle of the combustion chamber [6]. Different temperatures of combustor chambers may influence on the strain rate significantly. Accordingly, the creep life of the combustion chamber can be influenced by the various temperatures. IGT25 sometimes operated in offshore environment where the atmosphere is often contaminated with tiny salt particles which lead to their premature failure. In offshore condition the salt contaminants of the intake air may deposit the salt on the combustion chamber. Mannava et al. [7] presented that oxidation/hot corrosion and creep phenomena has occurred in a Ni-base superalloy coated with sea salts mixture at elevated temperature. He et al. [8] presented that the comprised salt may increase the strain rate of the superalloy. This can be raised incredibly, especially at high temperatures. Several studies have been made on the creep rupture and some concepts have been offered to find the correlation between stress levels, temperature and time to rupture based on the laboratory test data [9,10]. However, there were no study which investigated the effect of the strain rate changes on the creep life of the combustor liner. Among the most important suggested approaches, Larson-Miller parameter is widely used for creep life prediction [10]. It assesses the creep lifetime of the combustor liner using the thermal stresses.
With these various topics of studies accomplished by other researchers, there is not creep damage work on the IGT25 combustor liner while sea salt deposited on the combustor liner. Therefore, this study taken into account the effect of strain rate induced from the sea salt on the damage propagation in the combustion chamber. This contributes to have an estimation of creep lifetime of combustion chamber which is worthwhile to schedule optimum inspection, maintenance and replacement intervals.

Numerical methodology
The geometry of the IGT25 combustion chamber is shown in Fig. 1. It includes of several components with different materials. This is one eighteens of the total geometry of the combustion chamber, as it had the cyclic symmetry which contributes to the lower number of elements and reduction in calculation time. One of the most important components of the combustor is liner. This part has been made of the Hastelloy-X which can tolerate the high temperature without deformation. Hastelloy-X alloy has exceptional forming and welding characteristics. The mechanical properties of Hastelloy-X at reference temperature (22°C) are listed in Table1. In addition, the mechanical properties of this alloy at higher

temperatures were according to Haynes international standard test [11], which were essential for creep analysis. The displacement is constrained in the longitudinal direction by an outer ring adjusted on the middle shell. A cubic mesh type was considered in the model. The number of elements and nodes were 184007 and 269471, respectively. Another boundary condition was thermal employed load which was obtained from CFD simulation. Since the salt amount in the offshore concentration was negligible, the thermal load was assumed to be same as that in typical onshore application, as it was presented by Soroudi et al. [12].

Table1. Mechanical properties of Hastelloy-X at reference temperature (22°C)

Density (Kg/m3)	Yield strength (MPa)	Ultimate tensile strength (MPa)
8220	2.5	4.6

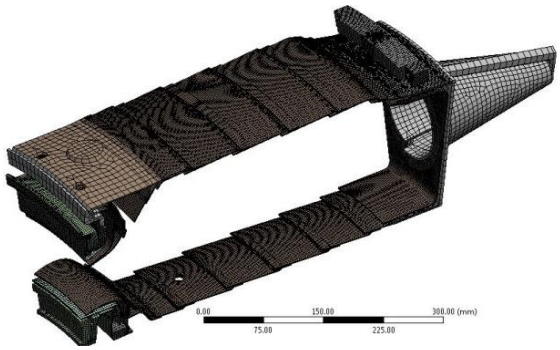

Fig. 1. the meshed combustor for creep analysis

Results and discussion

1. Characterization of stress function in Larson Miller model

In order to determine the creep lifetime of the combustion chamber, it is required to characterize the creep damage based on the obtained stress and strain from the numerical simulations. Creep damage theory as a failure analysis was presented by Rabinson in 1983 [13]. In the Rabinson model the creep damage is defined as eq. (1), where t_i is the current time, t_{Ri} is the creep rupture life in a constant stress and D_i is the creep damage in current time. The total creep damage is defined as the total of damage component during which the creep process takes places. In other words, creep damage for (i) stage will be defined as (eq. 2):

$$D_i = \frac{t_i}{t_{Ri}} \quad (1)$$

$$D = \sum_{i=1}^{n} \frac{t_i}{t_{Ri}} \quad (2)$$

material deformation rate in the presence of the stress and temperature can be described by the creep constitutive equations. The uniaxial creep behavior of the Hastelloy-X has been defined using the Norton creep law as eq. (3) [14]. In this formula, $\dot{\varepsilon}$ specifies the effective strain rate, T is the temperature, R is gas constant and Q is activation energy. The coefficients A and n are temperature dependent creep parameters which can be determined by the type of material. It is supposed that the temperature distribution is constant during the creep process of the combustor. Therefore, the strain rate is a function of equivalent stress (**σ**) [14, 15].

$$\dot{\varepsilon}_e = A\sigma^n \exp(-\frac{Q}{RT}) \quad (3)$$

The simplest way to find correlation between the stress, temperature and fracture time in creep process is the Larson-Miller parameter (LMP) (eq. 4) [10]. Where T and t_R are the test temperature in Kelvin and creep rupture time in hour. In addition, the constant C is obtained by fitting lines of 10 log (t_r) versus 1/T for constant stress. Therefore, Creep damage for (i+1) step can be calculated from the previous damage step (eq. 5). Fig. 2 shows the correlation between LMP and log**σ**. The obtained correlation formula in polynomial with order 4 (Fig. 2(b)) has more precision (R^2=0.9997) in comparison with the linear model (Fig. 2(a)) (R^2=0.9899). Therefore, the polynomial model was employed for creep life assessment of combustion chamber. The parameter C was considered equal to 19.6.

$$LMP(\sigma) = T[log(t_R) + C] \quad (4)$$

$$D(i+1) = D(i) + \frac{\Delta t}{t_R} \quad (5)$$

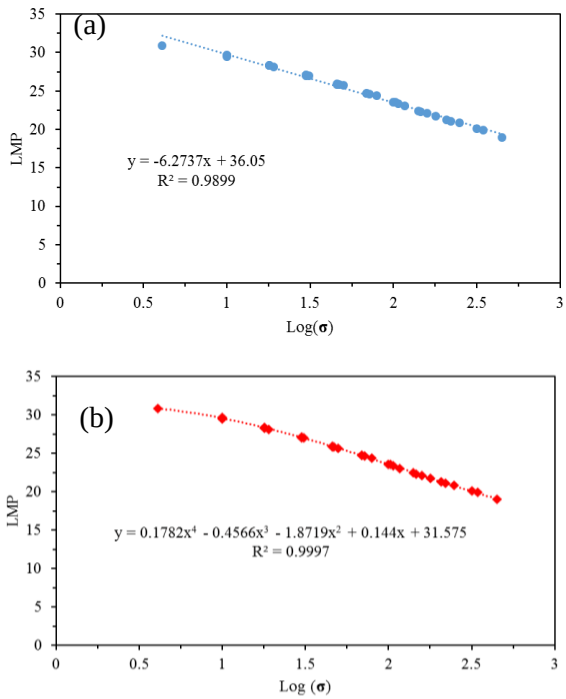

Fig. 2. LMP as function of stress with (a) linear and (b) polynomial model

2. Creep lifetime analysis

Two cases are considered for presenting the numerical results. In case I, equivalent stress, creep strain and damage were evaluated in combustor without change in strain rate (without salt). In case

II the same process was repeated with increasing of strain rate as many as 100%. The total time of simulation was 100 Kh. However, the combustor has recached to the failure damage in lower work time. Damage time was obtained 30.72Kh in the maximum damage. Combustor stress distribution in maximum and minimum damage time is shown in Fig. 3 (a) and (b) for cases without increase in strain rate and with increase by 100%, respectively. The maximum stress amount is associated to the combustor liner without salt which was characterized 53.723 MPa. The maximum stress was decreased 8.35% when strain rate increased by 100%. It was related to the stress relaxation as it was presented by Sam-Daliri et al. [16-17]. Creep strain and displacement in combustor can be measured by piezoresistive sensors which are able to maintain their strength at higher temperatures. Piezoresistive sensors was already used by Sam-Daliri et al. for structural heath monitoring [18-20]. The maximum creep strain was obtained for maximum change in strain rate. The distribution of the creep strain rate for case I and II are shown in Fig. 4(a) and (b), respectively. equivalent stress, obtained creep strain and creep lifetime amounts are presented in Table 2. The lifetime of the combustor characterized when the damage reaches one. In other words, the combustor liner could be failed in this situation or further damage will occur. It can be implied that the creep lifetime has decreased with increase in strain rate.

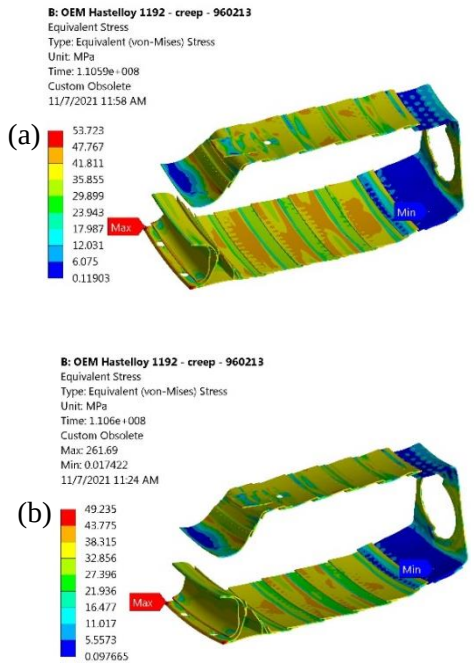

Fig. 3. (a) and (b) Equivalent stress distribution in combustion chamber with 0 and 100% increase in strain rate, respectively

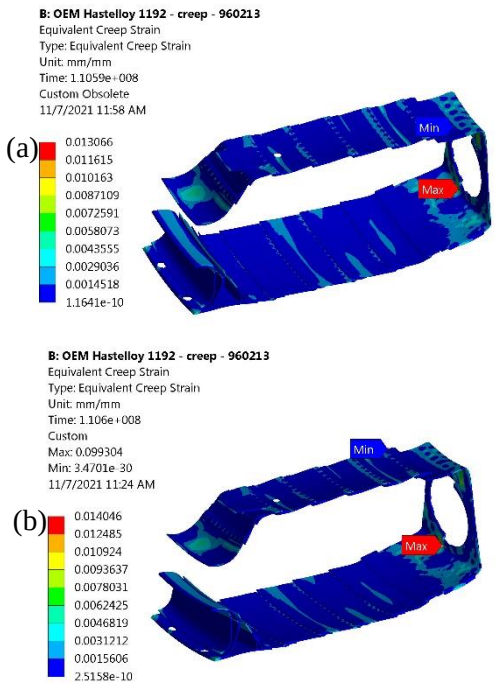

Fig. 4 (a) and (b) creep strain dissipation in combustion chamber with 0 and 100% increase in strain rate, respectively

Table 2. Creep results in different strain rate changes

Increase in strain rate (%)	0	100
Equivalent stress (MPa)	53.723	49.235
Creep strain (%)	1.3066	1.4046
Creep lifetime (Kh)	33.68	29.53

Conclusions

This study has evaluated the effect of the strain rate on the creep lifetime of the IGT25 combustion chamber. It is supposed that strain rate changes were made in the combustor due to comprised salt of offshore. Creep lifetime was obtained by LMP and Norton law. The accumulation of damages was calculated by Rabinson model. Different Norton constants were achieved based on the strain rate changes (0 and 100%). It was concluded that creep lifetime of the combustor decreased by 12.32%, when the change in strain rate has reached to 100%. The obtained results showed that the comprised salt on the combustor led to fundamental changes in strain rate and consequently reduction in combustor creep lifetime. Therefore, combustor creep lifetime should be improved by employing suitable thermal barrier coating on the internal surface of the combustor liner to prevent of salt penetration on the internal combustor surface.

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Symbols

D Total creep damage
T Temperature
i Stage number
T_m Melting Temperature
A Coefficient of creep strain rate parameter
Kh Kilo hour
n Exponent of creep strain rate parameter
t_i Current time
t_{Ri} Creep rupture life
Q Activation energy
C_1 Stress coefficient in creep strain rate equation
C_2 Stress exponent in creep strain rate equation
R Gas constant
σ Equivalent stress
ϵ Equivalent Strain
$\dot{\epsilon}$ Strain rate
Δt Time increment

References

[1] McLean, M., 1995, "*Nickel-base superalloys: current status and potential*", Philosophical Transactions of the Royal Society of London. Series A: Physical and Engineering Sciences, 351, 419-433.

[2] Pollock, T.M. and S. Tin, 2006, "*Nickel-based superalloys for advanced turbine engines: chemistry, microstructure and properties*", Journal of propulsion and power, 22, 361-374.

[3] Ding, Q., et al., 2021, "*Nano-twin-induced exceptionally superior cryogenic mechanical properties of a Ni-based GH3536 (Hastelloy X) superalloy*", Materials Today Nano, 14, 100110.

[4] Wang, J., et al., 2021, "*Numerical study of effusion cooling of a gas turbine combustor liner*", Fuel, 294, 120578.

[5] Daliri, O. S., Ghaderi, S. H., & Ghatee, M., 2013, "*Preparation and characterization of alumina/3YSZ nanocomposite doped with alumina-coated multi-wall carbon nanotubes*", International biennial conference on Ultrafine grained & Nanostructured materials, Tehran, Iran.

[6] Nagabandi, K., A.K. Pujari, and D.S. Iyer, 2020, "*Thermo-mechanical assessment of gas turbine combustor tile using locally varying thermal barrier coating thickness*" Applied Thermal Engineering, 179, 115657.

[7] Mannava, V., Sambasivarao, A., Paulose, N., Kamaraj, M., & Kottada, R. S., 2019, "*An investigation of oxidation/hot corrosion-creep interaction at 800° C in a Ni-base superalloy coated with salt mixture deposits of Na2SO4-NaCl-NaVO3*", Corrosion Science, 147, 283-298.

[8] He, J. and W. Xiong, 2017, "*Effect of high temperature hot corrosion on the compression creep behavior of 12Cr1MoV alloys*", High Temperature Materials and Processes, 36, 1011-1023.

[9] Bolton, J., 2013, "*A visual perspective of creep rupture extrapolation*", Materials at High Temperatures, 30, 87-98.

[10] Nobakhti, H. and N. Soltani, 2016, "*Evaluating small punch test as accelerated creep test using Larson–Miller parameter*", Experimental Techniques, 40, 645-650.

[11] Haynes-International., 1977," *Hastelloy X Alloy, High-Temperature Alloy*", 06002, 16.

[12] Soroudi M.A., Yazdani M., Abedini M., Bagheri Y., Sep. 2016, "*National Iranian gas turbine combustion system technology development and localization*", First international comprehensive competition conference on engineering sciences in Iran, Anzali, Gilan, Iran.

[13] Day, W.D., A.P. Gordon, 2013, "*A modified theta projection creep model for a nickel-based super-alloy. in Turbo Expo: Power for Land, Sea, and Air*", American Society of Mechanical Engineers.

[14] Kim, W.G., Yin, S.N., Ryu, W.S., Chang, J.H. and Kim, S.J., 2008. "*Tension and creep design stresses of the "Hastelloy-X*" alloy for high-temperature gas cooled reactors", Materials Science and Engineering: A, 483, 495-497.

[15] Daliri, O., Farahani, M., Farhang, M., 2019, "*A combined numerical and statistical analysis for prediction of critical buckling load of the cylindrical shell with rectangular cutout*" Engineering Solid Mechanics, 7, 35-46.

[16] Sam-Daliri, O. & Farahani, M., 2017, Characterization of stress concentration in thin cylindrical shells with rectangular cut-out under axial pressure, 10, 133-141.

[17] Farhang M., Sam Daliri, O., Farahani, M., Vatani A., 2021, "*Effect of friction stir welding parameters on the residual stress distribution of Al-2024-T6 alloy*", Journal of mechanical engineering and sciences, 15, 7684-7694.

[18] Stetco, C., Sam-Daliri, O., Faller, L. M., & Zangl, H. 2019, "*Piezocapacitive sensing for structural health monitoring in adhesive joints*" In 2019 IEEE International Instrumentation and Measurement Technology Conference (I2MTC), 1-5.

[19] Sam-Daliri, O., Farahani, M., Faller, L. M., & Zangl, H., 2020, "*Structural health monitoring of defective single lap adhesive joints using graphene nanoplatelets*", Journal of Manufacturing Processes, 55, 119-130.

[20] Sam-Daliri, O., Faller, L. M., Farahani, M., & Zangl, H., 2021, "*Structural health monitoring of adhesive joints under pure mode I loading using the electrical impedance measurement*", Engineering Fracture Mechanics, 245, 107585.