Evaluation on Creep Properties of Type 316SS Series

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Abstract. Evaluation on creep properties of type 316 stainless steel (SS) series has been done. Type of 316SS series is a candidate material for major structural components of high temperature reactor such as liquid metal reactor (LMR) because it has good mechanical property in high temperature, compatibility with the coolant sodium, and adequate welding ability. The objective of this research is to obtain and compare creep properties between type 316SS and type 316LN SS materials. The method used by conducted creep rupture tests in ranges temperature of 600°C, 700°C and 800°C and under a constant applied stress level of 200 MPa (393 N). Research result obtained that time to rupture of type 316SS less than that of type 316LN SS. The values of extension (mm), creep strain (mm/mm), creep strain rate (mm/mm/hrs), and rupture elongation (%) of type 316SS are higher than that of type 316LN SS for the same temperatures and applied constant stress level. It is concluded that type 316LN SS has a good creep resistance than that of type 316SS.

Keywords : Creep properties, type 316SS series, high temperature reactor

1. Introduction

Type of 316 stainless steel (SS) series is a candidate material for major structural components of high temperature reactor such as liquid metal reactor (LMR) because it has good mechanical properties in high temperature, compatibility with the coolant sodium, and adequate welding ability [1,2]. There are some types of 316SS series such as: 316SS, 316LN and 316FR. Since the LMR components are used for more than 30 years at a high temperature up to 600°C, one of the most important properties of the components is the creep behaviour [1,2]. It is essential to achieve reliable long-term test data beyond its design life to know a creep rupture of these components. However, it is difficult to actually obtain long-term creep data because of time consuming work and it is an expensive process. Therefore some designs of creep test have been carried out, one of them is called accelerated creep test means creep rupture test by increasing the test temperature or by increasing the test stress beyond its temperature design or stress design [3].

Research on creep properties of 316SS series for special purposes for example study on creep crack growth, analysis of stress effect on creep damage, predicting the creep life, creep fatigue life evaluation of nuclear component in ranging temperature of 550°C up to 950°C have been performed worldwide [1-5]. Research for a certain purpose to obtain and compare creep properties between type 316SS and type 316LN SS has never been done.
This paper presents creep properties obtained from the results of creep rupture tests of the type 316SS series such as type 316SS and type 316LN. Objective of this research is to obtain and compare creep properties such as: time to rupture, creep strain, creep strain rate, and rupture elongation between both of material. The method use by conducted creep rupture tests in ranges temperature of 600°C, 700°C and 800°C and under a constant applied stress level of 200 MPa (393 N).

2. Methodology

The methodology used by conducted creep-rupture test, such as a test in which progressive specimen deformation and the time for rupture are both measured. In general, deformation is much larger than that developed during a creep test [6]. The test temperatures in different condition such as 600°C, 700°C and 800°C and under a constant applied stress level of 200 MPa (393 N) for both of the materials.

Basic equation relating creep strain such as [7]:

\[
d\varepsilon/ dt = f(\sigma, \varepsilon, t, T)
\]

where \(\sigma\) is applied stress, \(\varepsilon\) is creep strain such as the time-dependent total strain (extension plus initial gage length) produced by applied stress during a creep test [8], \(t\) is time of creep test, and \(T\) is creep test temperature.

Creep rupture test were carried out using constant load machines with a 10/1 level ratio. The temperature is controlled by a thermocouple that is applied directly on the specimen and was maintained constant within 2°C maximum during the period of the test. The specimen is fitted with an LVDT (Linear Vertical Differential Transformer) for continuous of its elongation, if required. All specimens were held at the test temperature for about 1 hour minimum before starting the test. All creep data was automatically acquired through a data logger. Material used for this research are commercial materials such as type 316SS and type of 316LN SS. Creep specimens were a cylindrical form of a 25 mm gage length, and 5 mm diameter as shown in Figure 1, and chemical composition of the type 316SS and type 316LN SS is given in Table 1.

| Table 1. Chemical Composition of Type 316 SS and type 316 LN SS (% weight) |
|-----------------------------|---|---|---|---|---|---|---|---|---|---|---|
| Material    | C  | Si | Mn | P  | S  | Ni | Cr | N  | Fe  |       |
| 316SS       | 0.480 | 0.568 | 1.243 | 0.032 | 0.015 | 10.750 | 16.770 | 1.025 | Balance |
| 316LN SS    | 0.022 | 0.680 | 0.989 | 0.030 | 0.025 | 12.270 | 17.150 | 0.090 | Balance |

![Figure 1. Creep specimen [6,9]](image-url)
3. Results and Discussion

3.1. Creep rupture properties
To understand the creep properties such as: time to rupture, creep strain, strain rate, and rupture elongation of type 316SS and type 316LN SS, have been investigated through a series of creep rupture test at three difference test temperatures of 600°C, 700°C, and 800°C and under a constant applied stress level of 200 MPa (393 N). Long-term creep rupture data reached approximately 1,268 hours, 760 hours, and 384 hours for type 316SS at 600°C, 700°C, and 800°C respectively. For type 316LN SS at 600°C, 700°C, and 800°C reached approximately 3,880 hours, 2,350 hours, and 950 hours respectively.

The two creep curves such as extension (mm) vs. time to rupture (hours) and creep strain (mm/mm) vs. time to rupture (hours) obtained from three creep rupture tests data for each of both materials type 316SS and type 316LN SS are shown in Figure 2 up to Figure 5.

![Figure 2. The profile of extension base on time to rupture of type 316SS](image1)

![Figure 3. The profile of extension base on time to rupture of type 316LN SS](image2)
Figure 2 and Figure 3 shown curves of extension (mm) vs. time (hours) for type of 316SS and type of 316LN SS respectively. From these figures we obtained that time to rupture (hours) of type 316SS in three different temperatures of 600°C, 700°C, and 800°C and under applied stress constant of 200 MPa (393N) are less than that of time to rupture (hours) of type 316LN SS at the same temperatures and applied stress. These is indicated that type 316SS has creep-life less than that of type 316LN SS.

Figure 4 shows the curve of creep strain (mm/mm) vs. time (hours). From the figure 2 and 4, we can compared that the three values of extension (mm) and the three values of creep strain (mm/mm) obtained from the three values of extension (mm) divided by a 25 mm initial gage length of creep specimen of type 316SS are higher than that of the three values of extension (mm) and the three values of creep strain (mm/mm) of type 316LN SS for the same condition as shown on Figure 3 and Figure 5. Similar calculation of creep strain rate (mm/mm/hrs) obtained from creep strain (mm/mm) divided by time to rupture (hrs) for both of type materials obtained that creep strain rate (mm/mm/hrs) of type
316SS is higher than that of type 316LN SS for the same condition. In other hand, time to rupture of type 316SS for the three condition are less than that of type 316LN SS. It is means that type 316LN SS has a good creep resistance. This is has a good agreement with a theory as states in the reference [1].

3.2. Rupture elongation
Rupture elongation can be measured by fit the ends of the fractured specimen together carefully and measure the distance between gage marks or overall length to the nearest 0.2 mm at room temperature. When the gage length is marked on the reduced section of a specimen having a nominally uniform cross-sectional area, the elongation is equal to the gage length after fracture minus the original gage length, the difference expressed as a percentage of the original gage length. The method for calculating the rupture elongation shows in Figure 6.

\[ \% \text{Elongation} = \left( \frac{L_f - L_0}{L_0} \right) \times 100 \]

**Figure 6.** Method of calculating elongation when the gage length is marked on the reduce section of the specimen [6]

The value of time to rupture, creep strain, creep strain rate and rupture elongation have been calculated by formula (1). The summary of creep rupture test results is shown in Table 2 for both of type 316SS and type 316LN SS.

| Material | Test Temperature (°C) | Applied Stress (MPa) | Time to Rupture (hours) | Extension (mm) | Creep Strain (mm/mm) | Creep Strain Rate (mm/mm/hrs) | Rupture Elongation (%) |
|----------|----------------------|----------------------|-------------------------|----------------|----------------------|----------------------------|------------------------|
| Type     | 600                  | 200                  | 1.268                   | 1.965          | 0.0786               | 6.198E-05                  | 7.86                   |
| 316SS    | 700                  | 200                  | 760                     | 2.225          | 0.0890               | 1.171E-04                  | 8.90                   |
| 800      | 384                  | 2.260                | 2.350                   | 1.797          | 0.0904               | 2.354E-04                  | 7.35                   |
| Type     | 600                  | 200                  | 3,880                   | 1.435          | 0.0574               | 1.479E-05                  | 5.74                   |
| 316LN    | 700                  | 200                  | 2,350                   | 1.797          | 0.0719               | 3.059E-05                  | 7.19                   |
| SS       | 800                  | 950                  | 2.022                   | 0.0809         | 8.51E-05             | 8.09                       |

4. Conclusion
It is concluded that type 316LN SS used in this research has a good creep resistance than that of type 316SS. This is because type 316LN SS has a very low carbon (0.022% weight) and nitrogen (0.090% weight) contains. It is very well known that a material especially with very low carbon has a good creep resistance than that of a material with higher carbon contains. The requirement of type 316SS as a “LN” grade is shall be have carbon and nitrogen contains maximum are 0.03% and 0.1% weight respectively. Material with this specification is superior in creep resistance due to the “L” grade of low carbon. If it is compared in between both of these material, type 316SShas ten times higher in carbon contain than that of type 316LN SS.
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