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Simulation of Three Points Bending SS316 to Know Mechanical Stress with ABAQUS

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Abstract

The operating life of the Gen IV nuclear reactor, which is 60 years, will require material upgrades over a very long period of time. Stability, high reliability, adequate resources, and easy fabrication, as well as weldability, environmental impact, and aging, are other important aspects to consider during the material selection process. SS316 is currently in demand as a structural material for future Gen IV nuclear power plants operating at high temperatures. Although grade SS316 has been studied for current nuclear service conditions and other conventional applications, better data and models for long-term high-temperature properties are needed, especially with regard to primary to tertiary creep strain and creep-fatigue response. The three-point bending test on SS316 material can be modeled with ABAQUS simulation. The purpose of this study is to compare the distribution of the voltage profile for parameters at room temperature (25°C) and high temperature (650°C). In addition, simulations were conducted to compare the effects of load displacement (U2) variations, namely 25, 20 and 15 for each temperature. ABAQUS is an engineering simulation program based on finite element methods that can solve simple linear analysis problems to complex nonlinear simulations. ABAQUS comes with a comprehensive database of elements that can model almost any geometry. This simulation can describe the voltage profile that is spread over the geometry after the required parameters are entered. From the results obtained, the greater the displacement of U2, the smaller the maximum stress that can be resisted by the material. It also shows that at higher temperatures (650°C), materials tend to experience a decrease in strength or maximum stress compared to lower temperatures (25°C). So the material under test experiences a decrease in maximum strength or stress as the temperature increases and the U2 displacement.

Keywords: ABAQUS, bending test, nuclear reactor, 316SS

INTRODUCTION

Generation IV (Gen IV) nuclear reactors promise better features for energy resources that are already seen as reliable and exceptional resources that operate at high levels of fuel efficiency, safety, proliferation resistance, sustainability, and cost, and cost. Generation IV nuclear reactors have also found the performance and reliability of materials when exposed to higher neutron doses, higher neutron doses and highly corrosive high-temperature environments. This is because the main consideration for the successful development of generation IV nuclear reactors is the right structural material to be used, where the selection of materials in nuclear reactors must meet high safety standards, especially in terms of strength and durability of materials when exposed to high radiation [1]. The operating life of the Gen IV nuclear reactor, which is 60 years, will require material upgrades over a very long period of time. Stability, high reliability, adequate resources, and easy fabrication, as well as weldability, environmental impact, and aging, are other important aspects to consider during the material selection process [2].

SS316 is currently in demand as a structural material for future Gen IV nuclear power plants operating at high temperatures. Although grade SS316 has been studied for current nuclear service conditions and other conventional applications, better data and models for long-term high-temperature properties are needed, especially with regard to

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primary to tertiary creep strain and creep-fatigue response. Gen IV technology will require updates to predict safe life against strain and rupture in the temperature range of 500-750°C, and to facilitate FEA for complex product shapes. Modeling the stress dependence on creep strain and strain rate is particularly challenging due to the need for long-term extrapolation and limited data (public domain). Large variations in mechanical properties such as high temperature yield strength between the mold and the shape of the product also need to be addressed for design and age prediction.

SS316 is a steel material with excellent corrosion resistance in corrosive reactor environments such as LBE [3]. In addition, this material also has high tensile strength and good ductility, allowing SS316 to withstand deformation without cracking or rupture [4].

SS316 can be designed to operate in high-temperature environments, such as the one that occurs in hot part burner coatings. This material is resistant to cyclic strain generated thermally and mechanically, under this constant temperature and cyclic strain, isothermal and thermo-mechanical fatigue damage occurs which will lead to the initiation of cracking and subsequent cracking growth as occurs in *Advanced Gas-cooled Reactor* (AGR) [5]. In addition to *Low Cycle Fatigue* (LCF) due to *start-up/shut-down* cycles, high-temperature components are exposed to time-dependent creep damage due to their normal operation at high temperatures during service. For example, nuclear pressure vessels and heat exchangers, similar behavior is observed. As a result, for the materials used in these systems, the stress-strain behavior of the components under cyclic loading and both *creep-fatigue* damage need to be thoroughly understood when characterizing the mechanical behavior.

Bending testing is a test on an object to determine the resistance and strength of a material to elastic deformation. This test method is to press the material specimen. Materials used in contraction or components that receive a load on a material at one midpoint of the material are held on two platforms. Bending strength and hardness are carried out by applying a load to the material so that simultaneously tensile, compressive and shear stresses begin to form. The load will be maximum on the specimen surface, with a value of zero on the neutral axis [6]. The type of test piece material used as a test piece is very influential in *bending* testing. Because each type of material has different bending strength, which will later affect the results of the bending test itself [7].

The three-point bending test on SS316 material can be modeled with ABAQUS simulation. ABAQUS is an engineering simulation program based on finite element methods that can solve simple linear analysis problems to complex nonlinear simulations. ABAQUS comes with a comprehensive database of elements that can model almost any geometry [8]. This simulation can describe the voltage profile that is spread over the geometry after the required parameters are entered. ABAQUS also has a comprehensive list of material models and can simulate the attitude of almost any engineering material including metals, rubber, polymers, composites, concrete, *crushable* foams, *resilient* foams and geotechnical materials such as soil and rock [9]. Designed as a simulation tool that can meet the purpose, ABAQUS is able to simulate problems such as heat transfer, mass diffusion, acoustics, soil mechanics and mechanical stress [10-11]. ABAQUS was used in this study because of its various advantages, especially in determining the stress distribution profile and mechanical stress-strain. By simulating with ABAQUS, it is hoped that it can be known from the mechanical properties of things that cause creep failure in SS316.

EXPERIMENTAL METHOD
Materials and Instruments

SS316 is composed of a variety of elements, including chromium, nickel, molybdenum, carbon, manganese, silicon, phosphorus, and sulfur, each of which has a specific proportion [12-13]. The material composition of SS316 is shown in Table 1 (show the Appendix).

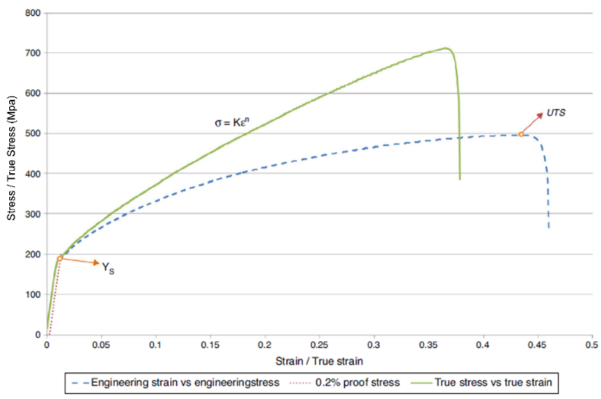


Figure 1. Mechanical properties of SS316L at 650°C temperature test [14]

The good temperature resistance of SS316 ensures that the material remains stable and does not deteriorate significantly at high temperatures. Another advantage of SS316 is its biocompatibility, which makes it safe to use in a variety of applications that require contact with biological materials. Figure

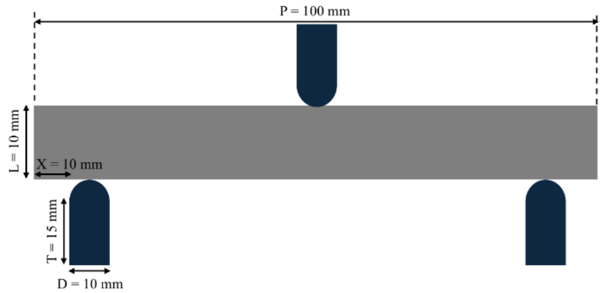
1 shows a graph of the strain and stress relationship in SS316L material which was tested at 650 °C.

Materials and Instruments

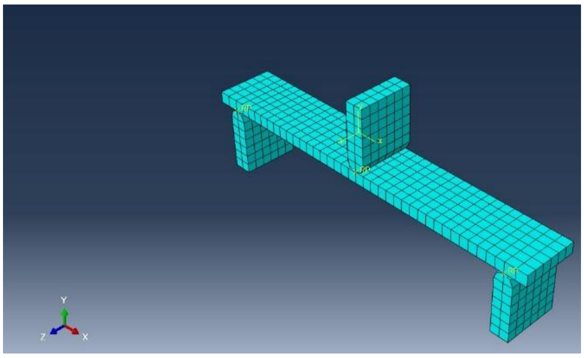
The ASTM B209 standard is used to configure three-point bending test samples in ABAQUS software [15]. In this study, the ABAQUS product used is ABAQUS CAE Learning Edition 2024. This product has limited access to 1000 nodes to create the desired geometry. The limited access of these nodes makes the mesh modeling results rough.

Model Geometry

The specimen model can be drawn directly in ABAQUS CAE. ABAQUS CAE, which is used as a place to enter data into files, plays an important role for designers who want to perform numerical analysis using software.



(a)



(b)

Figure 2. (a) Geometry of the three-point bending sample used for the simulation; (b) mesh model on ABAQUS CAE.

In Figure 2(a) the geometric size used in the simulation is shown. The length, width and height of the plate are 100 mm x 15 mm x 3 mm. As for the load, it uses a diamateur size and height, which is 10 mm x 20 mm, with a thickness of 3 mm. These measures were selected based on existing references and then modified according to the needs of the simulation carried out in this study. Then in Figure 2 (b) is the mesh model in ABAQUS CAE for the existing geometry, the sheet part for the plate is selected size 2.5 and produces 240 elements, while for the load size is selected size 3 and produces 104 elements. The total elements formed in the geometry of this study are 552 elements. Then in the simulation, load displacement (U2) variations were carried out to 25, 20 and 15.

Based on the tension-strain curve in Figure 1, the input value required for mechanical input at high temperature of 650 °C used in ABAQUS is obtained. Table 2 shows the input values for the three-point bending test (in the Appendix).

RESULTS AND DISCUSSION

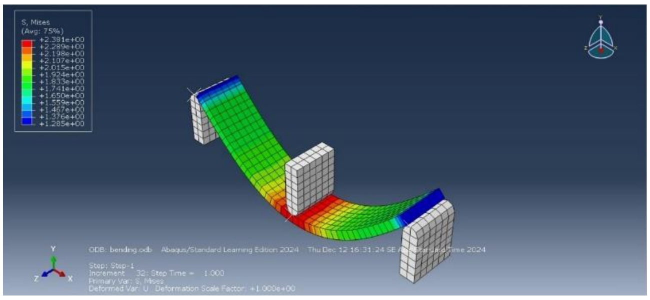


Figure 3. The stress profile at 25 °C with a displacement variation of U2 = 25.

In Figure 3, the simulation results are displayed in the form of a stress profile with a variation in displacement U2=25 at a temperature of 25 °C. It is seen that the tension is concentrated in the center area of the plate. The highest stress is inside the middle area and extends to the side area. The highest calculated srtess is about 2.381 MPa. The blue area is the area that is not too affected by the bending mechanism. Then the lowest stress calculated is around 1.285 MPa.

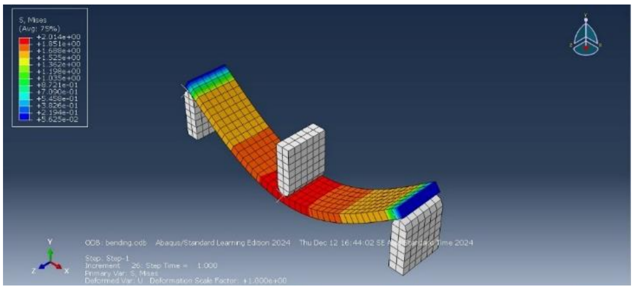


Figure 4. The stress profile at 25 °C with a displacement variation of U2 = 20.

Then in Figure 4, the simulation results are displayed in the form of a stress profile with a variation in displacement U2=20 at a temperature of 25 °C. In this condition, it can be seen that the tension is concentrated in the middle area of the plate.

However, unlike at the U2 = 25 displacement, the high stress does not extend too much to the side area. The maximum stress calculated is about 2.014 MPa. The blue area is the area that is not too affected by the bending mechanism. Then the minimum stress calculated is about 5.625 x10^{-2} MPa.

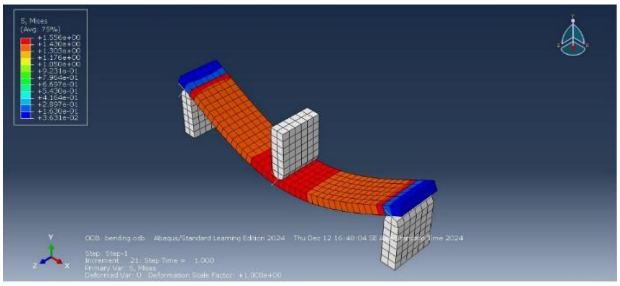


Figure 5. Stress profile at 25 °C with displacement variation U2 = 15.

The simulation results in the form of a stress profile with a variation in displacement U2=15 at a temperature of 25 °C shows in Figure 5. In this condition, a high stress spreads near the surface of the center plate. This mechanism is different compared to the previous two displacement conditions. This shows that the increase in displacement conditions greatly affects the voltage spread profile. However, unlike in U2=25 and U2=20 displacements, the high voltage does not extend too much to the side area. The maximum calculated stress is about 1.556 MPa. The blue area is the area that is not too affected by the bending mechanism. Then the minimum stress calculated is around 3.631 x10^{-2} MPa.

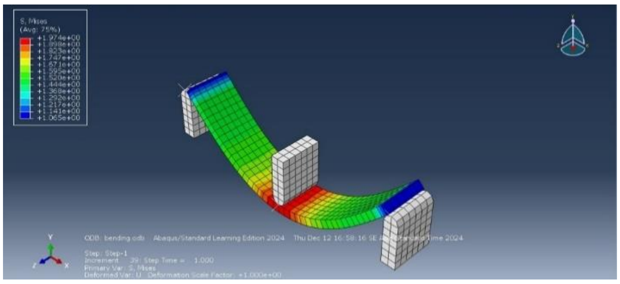


Figure 6. The stress profile at 650 °C with a displacement variation of U2 = 25.

In Figure 6, the simulation results are displayed in the form of a stress profile with a variation in displacement U2=25 at a temperature of 650 °C. It is seen that the tension is concentrated in the center area of the plate. The highest stress is inside the middle area and extends to the side area. The highest calculated stress is about 1.974 MPa. The blue area is the area that is not too affected by the bending mechanism. Then the lowest stress calculated is around 1.065 MPa.

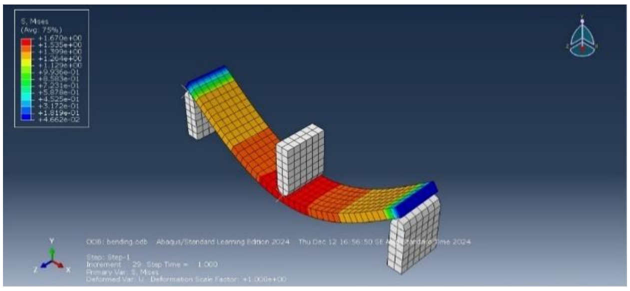


Figure 7. The stress profile at 650 °C with a displacement variation of U2 = 20.

In Figure 7, the simulation results are displayed in the form of a stress profile with a variation in displacement U2=20 at a temperature of 650 °C. In this condition, it can be seen that the tension is concentrated in the middle area of the plate. However, unlike at the U2 = 25 displacement, the high stress does not extend too much to the side area. The highest stress calculated is about 1.670 MPa. The blue area is the area that is not too affected by the bending mechanism. Then the lowest stress calculated is around 4.662 x10^{-2} MPa.

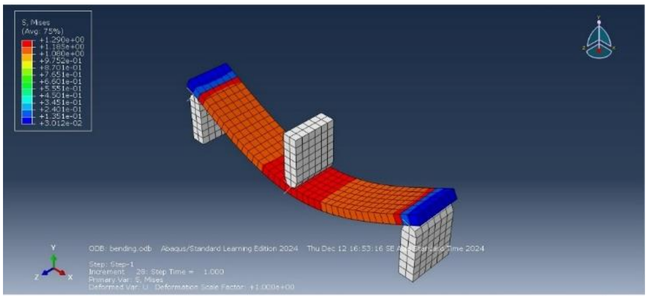


Figure 8. The voltage profile at 650 °C with a displacement variation of U2 = 15.

Figure 8. shows the simulation results in the form of a stress profile with a variation in displacement U2=15 at a temperature of 650 °C. In this condition, a high voltage spreads near the surface of the center plate. This mechanism is different compared to the previous two displacement conditions. This shows that the increase in displacement conditions greatly affects the stress spread profile. However, unlike in U2=25 and U2=20 displacements, the high stress does not extend too much to the side area. The maximum calculated stress is about 1.290 MPa. The blue area is the area that is not too affected by the bending mechanism. Then the minimum stress calculated is around 3.012 x10^{-2} MPa.

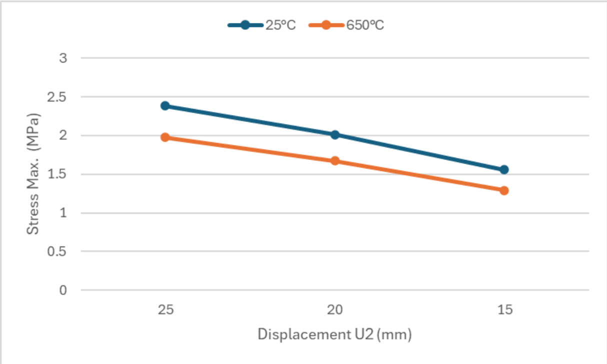


Figure 9. The maximum stress curve with respect to displacement under two different temperature conditions, namely 25°C and 650°C.

Figure 9 shows a comparison curve of the simulation results with different parameter conditions. The curve shows the inverse relationship between the displacement of U2 and the maximum stress. This means that the greater the displacement of U2, the smaller the maximum stress that the material can withstand. It also shows that at higher temperatures (650°C), materials tend to experience a decrease in strength or maximum stress compared to lower temperatures (25°C). So the material under test experiences a decrease in maximum strength or stress as the temperature increases and the U2 displacement.

CONCLUSION

Based on the research that has been carried out, it is concluded that the results of the three-point bending test simulation for the comparison of the distribution of the stress profile with parameters at room temperature (25°C) and high temperature (650°C) show that the stress value will further decrease in the material that has been tested at high temperature. In addition, the simulation results for the comparison of the influence of load displacement (U2) variations, namely 25, 20 and 15 for each temperature, show that the lower the value of U2, the smaller the voltage value read.

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Table 1. Material Composition of SS316 (wt.%) [13]

Element	Fe	Cr	Ni	Mn	Si	P	N	Cu	Mo
wt.%	69.04	16.84	10.12	1.28	0.47	0.02	0.0082	0.09	2.08

Table 2. Three-point bending test material properties for input data in ABAQUS

Materials and Conditions	Density	Elasticity		Plasticity		Stress fracture
		Modulus Young	Rasio Poisson	Yield Stress	Plastic Strain	
SS316 at room temperature (25°C)	7.87 x 10^{-9}	193000	0.3	425 505 615 1045	0 0.016 0.0299 0.85	0.2
SS316 at high temperature (650°C)	7.87 x 10^{-9}	160000	0.3	201 402 485 499	0 0.18 0.39 0.44	0.2