Creep behaviour of Super 304H Steel for Advanced Ultra Supercritical (AUSC) Boiler Applications

Somnath Nandi*, G. Jaipal Reddy, AHV Pavan, Dhirendra Kumar, M Swamy, Kulvir Singh
Metallurgy Department, Corporate R&D Division, BHEL, Hyderabad 500 093, India
**Email:* somnandi@bhel.in Phone: 040-23770692

Abstract

In the new era of 21st century, entire world especially India is facing a huge challenge of providing electricity to meet the needs of growing population in the strict environmental norms. Today, the foremost goal of coal based thermal power plant is to reduce the CO_2 emissions with improved thermal efficiency. To reduce CO_2 emissions, research and development on Advanced Ultra Super Critical (AUSC) power generation is in progress to enhance the efficiency of a coal fired power generation. Efficiency improvement is also a means for reducing the emission of carbon dioxide (CO_2) as well as a means to reduce fuel consumption. To meet the requirement of AUSC thermal plants, new materials are introduced in steam generator which can withstand high pressure and temperatures. Super 304H Steel is one of the new alloy steel chosen for AUSC steam generator applications. Creep is one of the major properties to be assessed for the material to be used in AUSC power plants. Creep rupture tests along with other mechanical tests were conducted on Super 304H steel at elevated temperatures to generate the data for design applications. In this paper, creep behaviour of Super 304H steel at various stress and temperatures and microstructures are correlated along with other mechanical properties.

Keywords: Super 304H steel, Creep, Microstructural behaviour, CO_2 emission, AUSC Power Plant

1.0 INTRODUCTION:

An enhanced ecological awareness in the industrialised countries prompted increased initiatives world over to reduce CO_2 emission levels in the power plants. Today, the coal based thermal power plant needs to reduce the CO_2 emissions by improving the thermal efficiency by using advanced steam parameters. Electricity production by fossil power plants prompted the development of Advanced Ultra-Supercritical (AUSC) fossil power plants that are capable of operations at much higher steam temperature/pressure conditions than those of the conventional plants operating worldwide [1]. Adaptation of the AUSC power plants with increased steam parameters significantly improves efficiency, which will reduce the consumption of fuel and the emissions of harmful gases (NOx, SOx) responsible for environmental damage [2]. The construction of steam generators with advance temperatures and pressures requires the development of new materials with high creep and mechanical properties with capability of handling the advance steam parameters for AUSC power plant applications. Studies show that the operating capability of the critical components like super-heater or re-heater tubes becomes the key for further increases in steam parameters in boiler. Hence, new cost effective materials with superior creep strength, good oxidation resistance, acceptable thermal fatigue resistance, good weld-ability as well as excellent fabricability are sought for selection of new material. Nickel base superalloys are chosen for the high temperature applications but in the intermediate temperature range of 600 to 650 Deg C,

austenitic stainless steels found to be superior for its application in AUSC boiler tubes with respect to its cost effectiveness. In addition, the high temperature properties mainly creep and tensile strength are comparable to nickel base superalloys at that temperature domain.
Out of various materials in the pipe line, Super 304H stainless steel is selected for the Indian AUSC boiler tube applications in the intermediate temperature zones. Creep is one of the major properties to be assessed for the material to be used in AUSC power plants. Studies on high temperature material properties are being carried out in every parts of the world for assessing its suitability to use in AUSC boiler tubes.

This study investigate the creep behaviour of Super 304H steel at high temperatures along with tensile properties at high temperatures along with the microstructural correlation of the alloy.

2.0 EXPERIMENTAL WORK:

2.1: Materials:

The material considered for this work is Super 304H steel which is compliant to ASME code case 2328-1[3]. Super 304H steel is procured from an Indian manufacturer of superalloys in plate form of thickness of 16 mm. The chemical composition details of the as-received plate with its respective nominal compositions were obtained by Optical Emission Spectroscopy technique using Spectro MAX X™ equipment and is reported in **Table1**. The microstructure of the as received alloy is shown in **Figure 1.**

Table 1: Chemical Composition of Super 304H Steel [4]

Elements	Ni	Cr	Nb	Mn	Al	C	Cu	Si	S	P	B	N	Fe
Super 304H Nominal	7.5-10.5	17.0-19.0	0.30-0.60	1.00 max	0.003-0.03	0.07-0.13	2.5-3.5	0.30 max	0.01 max	0.04 max	0.001-0.01	0.05-0.12	Bal
Super 304H Plate	9.25	17.50	0.57	0.78	0.008	0.08	2.90	0.20	<0.01	0.012	<0.001	0.12	Bal

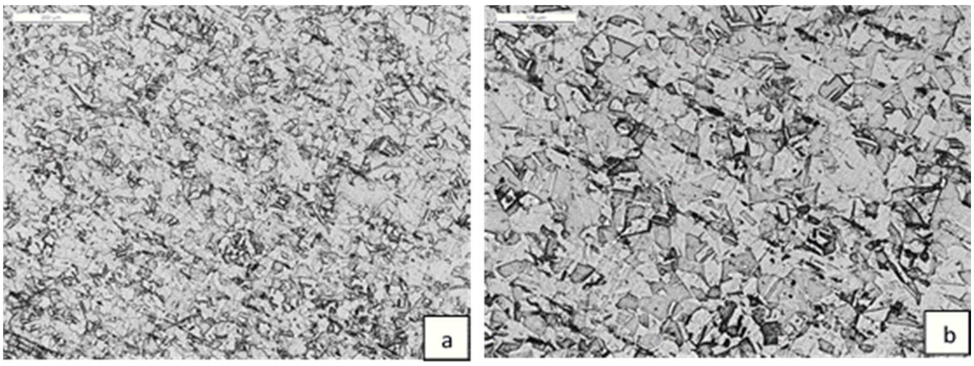

Figure 1: Microstructure of as received Super 304H Steel (a) 100 X (b) 200X respectively

2.2: Experimental procedure:

The rolled plate as received from M/s MIDHANI, Hyderabad as per the material data generation program for Indian Advance Ultra Supercritical (AUSC) technology development, was cut down from the centre location of the plate parallel to rolling direction into standard creep testing sample (M8) as per ASTM E139 [5]. The creep samples prepared and tested in a constant load Creep Testing machine (*M/s Star Testing Systems* make) under different stresses and temperatures. The temperature ranges from 650 to 750 degree Celsius whereas stresses are varied from 100 to 210 MPa. Apart from the creep testing, tensile tests as per ASTM E8M [6] were also carried out at different temperatures to study the mechanical behaviour of Super 304H steel for advance ultra-super critical power plant applications.

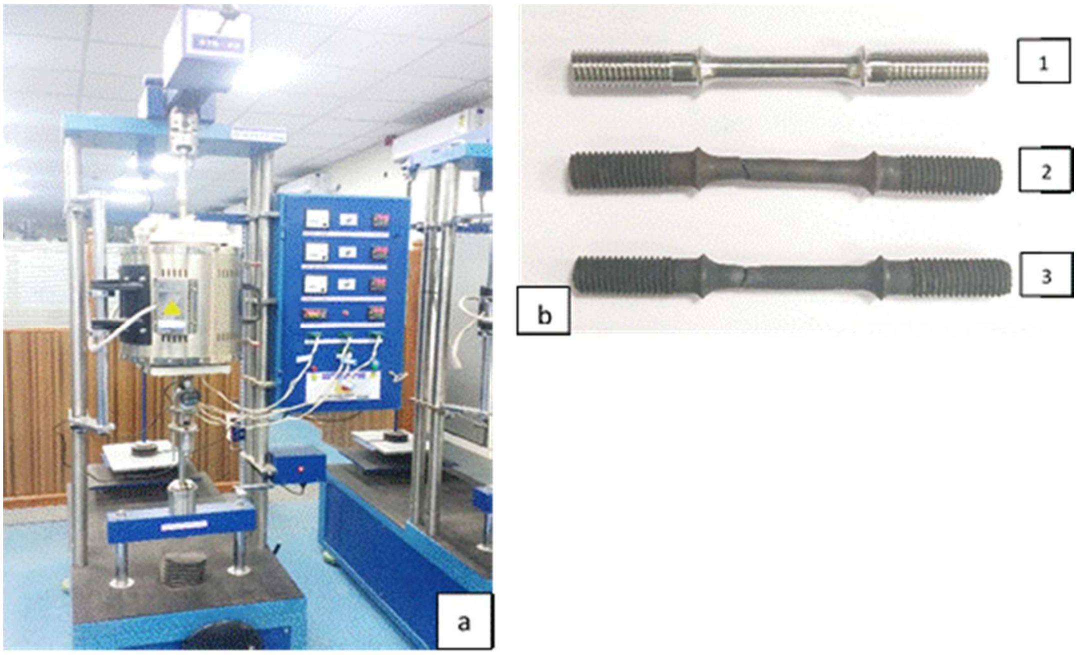

Figure 2: (a): Shows Single Lever Arm Creep Testing Machine (M/s Star Testing Systems, India), (b) Shows the standard M8 creep sample (1), ruptured samples of Super 304H steel tested at (2) 650 Deg C & (3) 700 Deg C respectively.

Microstructural analyses are also carried out on the tested samples to investigate and correlate the structural changes of the alloy with the mechanical properties of the alloy. Subsequently hardness measurements are done to study the changes in hardness of the alloy on effect of various stresses and temperatures applied on the alloy.

The study is basically the initial work started for the material development program taken for Indian Advance Ultra Super critical power plant technology.

3.0 RESULTS AND DISCUSSION:

3.1 Creep:

Creep plays a major role for high temperature applications, especially in fossil based power plants. For Indian AUSC power plant where the steam generators will be operating at temperature range of 720 Deg C, investigation of creep behaviour of alloys and its effect on microstructure due to creep at different stresses and temperatures is essential. The discussed alloy will be used in the temperature domain of 600 to 650 Deg C in the AUSC steam generator, hence creep testing were being carried out in the range of 650 to 750 Deg C with different stress condition ranging from 100 to 210 MPa. **Figure 3** shows the plot for stress applied against Larson Miller Parameter (LMP) obtained from the creep rupture testing of Super 304H steel at different stresses and temperatures. The majority of the creep tests are completed and compared with ASME code case 2328-1 data and shows the points obtained from their rupture values are above the average stress range as indicated in **Figure 3.**

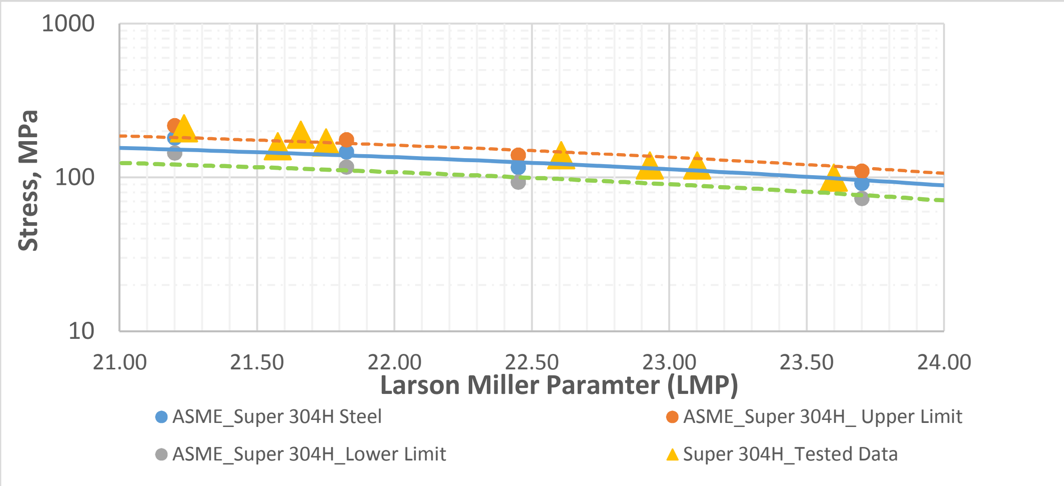

Figure 3: Stress with LMP Plot for Super 304H Steel

3.2 Effect of Creep on Microstructure:

Creep tests on Super 304H steel samples extracted from the rolled plate were carried out at two different temperatures of 650 and 700 degree Celsius at stress level of 190 and 140 MPa till rupture to see the effect of creep behaviour on the microstructures. In this paper, the microstructures of the ruptured samples tested with the above mentioned test conditions are discussed. In both the cases, the estimated creep life was 1000 hours and the results exceeds the expected life.

In the 1st test, at 650 Deg C with stress level of 190 MPa the creep life was 2920 hours where as in the 2nd test, at 700 Deg C with stress level of 140 MPa it was 1711 hours. Microstructural characterization was carried out using optical microscope (*M/s Leica DMI 5000M Inverted Microscope*) and Field Emission Scanning Electron Microscope (*M/s Carl Zeiss Make*) are reported in the paper. Microstructural studies using optical and Field Emission Scanning Electron (FESEM) microscopy reveals the precipitation of carbides in the form of $M_{23}C_6$ [7] and Nb carbides over the grain boundaries and fine precipitates were also observed inside the austenitic grains. **Figure 4** shows the microstructure of crept sample tested at 650 Deg C and **Figure 5** shows the microstructure of crept sample tested at 700 Deg C.

The precipitates in the grain interior are considered to be of Nb(C, N) and copper phases [8] and confirmed through EDAX analysis. Large precipitates were observed on the grain boundaries after 2920 hours of creep rupture life. The microstructure of the crept sample tested at 650 Deg C reveals coarser grains in comparison to the microstructure of the crept sample tested at 700 Deg C. Similarly, precipitates at 650 Deg C are found to be coarser as compared to the precipitates at 700 Deg C. Thinner precipitates at 700 Deg C may be the result of certain degree of dissolution. Annealing twins are visible in both the cases at 650 and 700 Deg C respectively. Though, Optical microscopy doesn't reveal much information about the microstructures of crept samples of Super 304H steel, FESEM was used for further characterization at higher magnification and precipitates were confirmed to be Cr and Nb carbides through EDAX analysis. Since, it's an initial study on Super 304H steel, a detailed correlation of the creep strength and other mechanical properties with the detailed microstructure are to be studied.

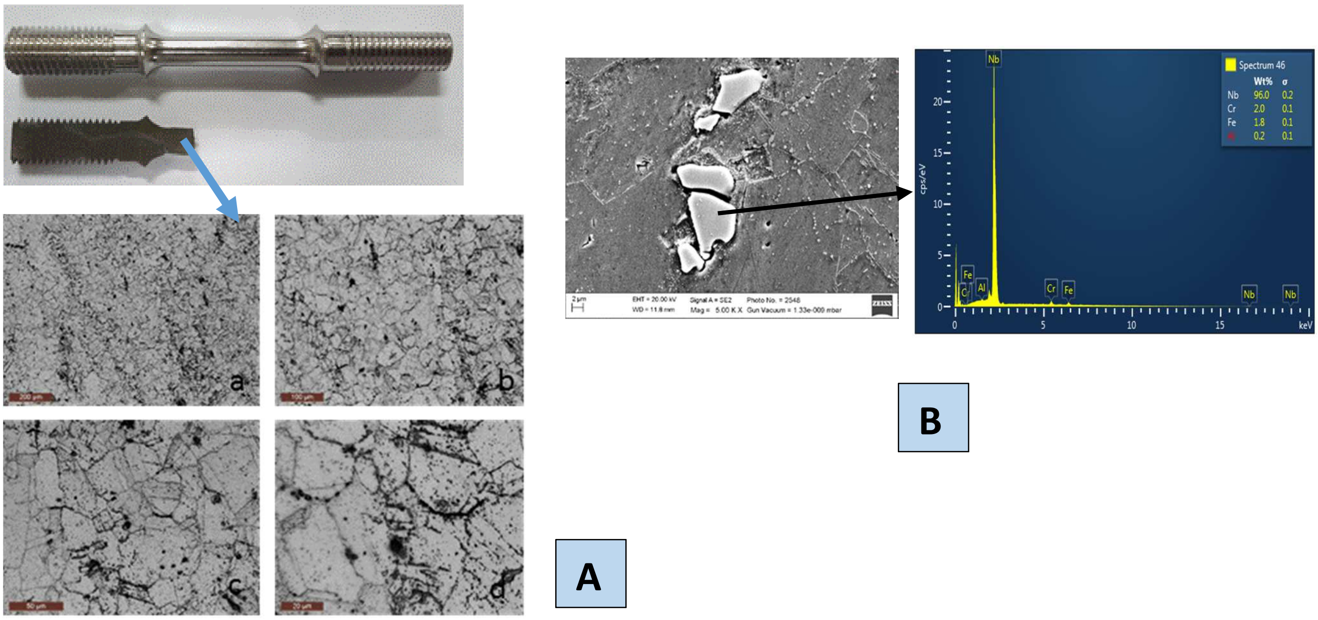

Figure 4: A: Optical Micrograph of Super 304H crept sample tested at 650 Deg C, 190 MPa at (a) 100X, (b) 200X and (c) 500X
B: SEM image at 5K X with EDAX Analysis

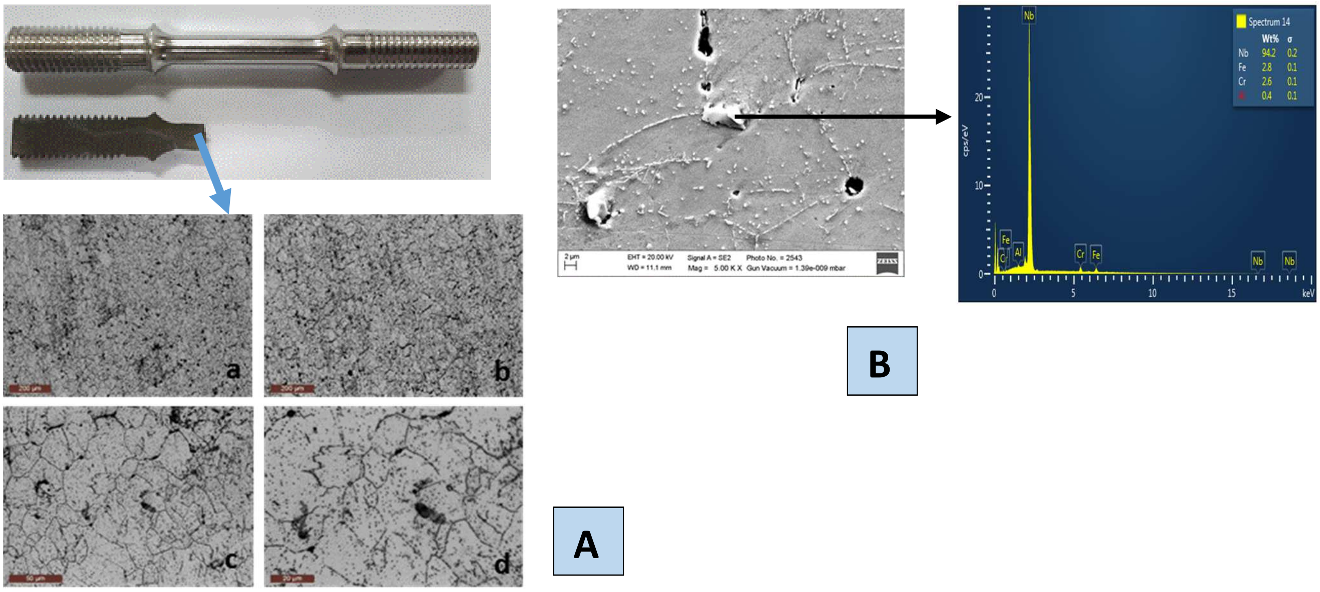

Figure 5: A: Optical Micrograph of Super 304H crept sample tested at 700 Deg C, 140 MPa at (a) 100X, (b) 200X and (c) 500X
B: SEM image at 5K X with EDAX Analysis

3.3 Mechanical Properties:

Apart from creep testing on Super 304H steel, mechanical properties assessment in terms of tensile testing has been carried out in room temperature as well as elevated temperatures. **Figures 6 (a) & (b)** show the plots of 0.2% Yield strength and Ultimate tensile strength data with temperature. The tested data (0.2% yield and UTS) are in line with the standard VdTUV material datasheet 550 [9] and it gives the confidence for applications of boiler tubes for AUSC power plant.

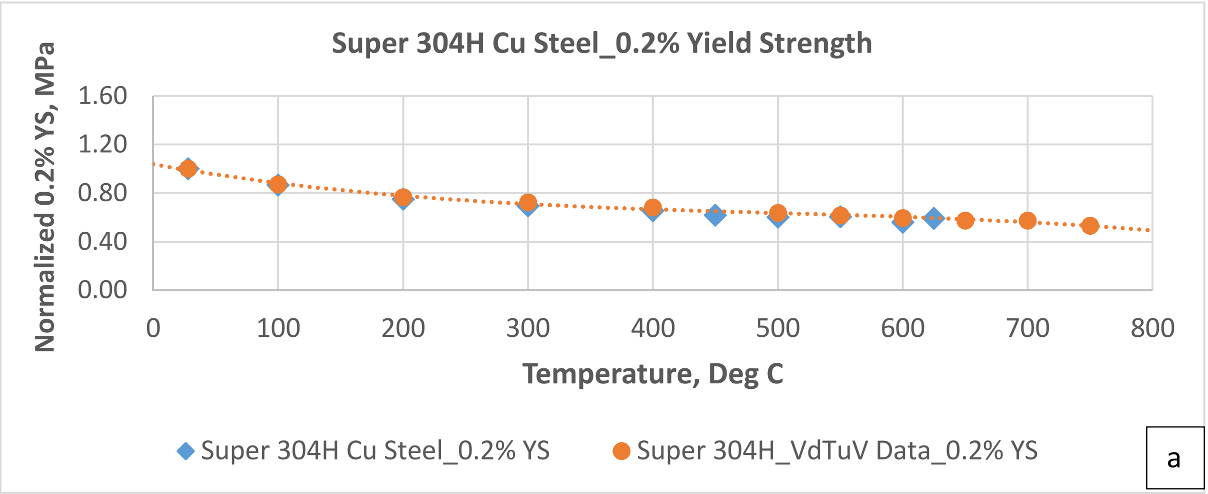

Figure 6: (a) 0.2% Yield strength data of Super 304H steel plotted against temperature

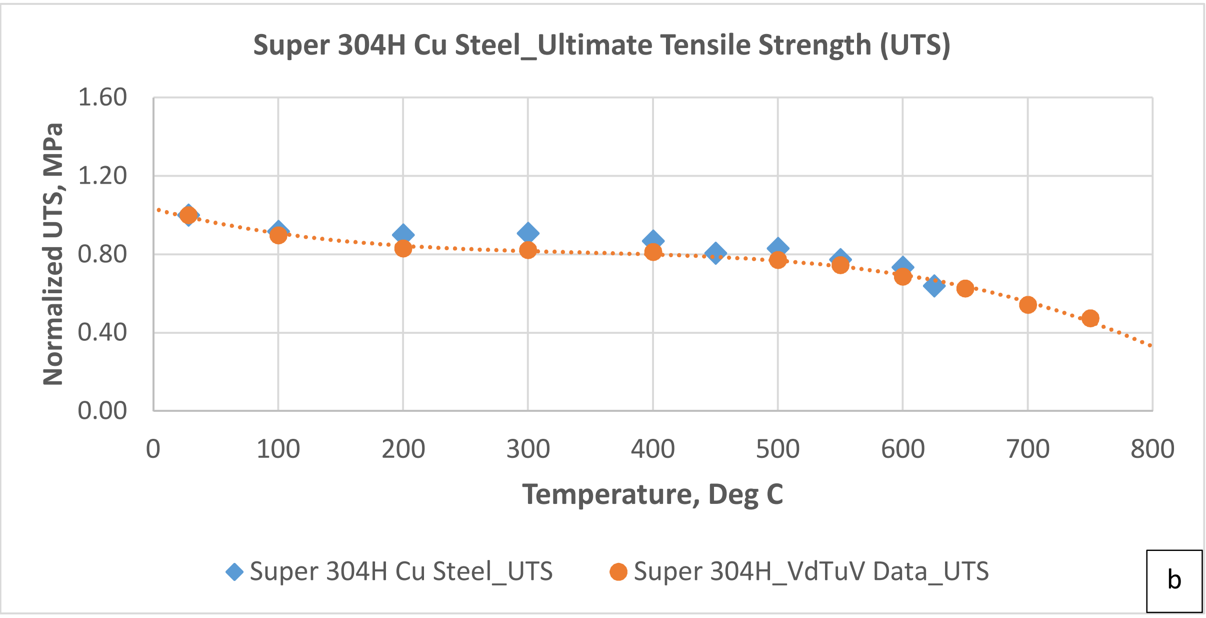

Figure 6: (b) Ultimate tensile strength (UTS) data of Super 304H steel plotted against temperature

4.0 CONCLUSIONS:

Based on the initial work carried out on Super 304H steel, the following conclusions can be drawn:

- The initial results on creep testing on Super 304H steel show that the material exhibits good creep strength in the temperature range of 600-650 Deg C for Advanced Ultra Supercritical (AUSC) boiler tube applications.

- Microstructural studies indicate the presence of carbides, especially the Cr-rich $Cr_{23}C_6$ type, Nb-rich & Cu precipitates in the grains and grain boundaries, which has strengthened the alloy for high temperature applications.

- Mechanical properties data (0.2% YS & UTS) of Super 304H steel shows good strength at elevated temperatures especially in the domain of 600-650^{o}C

- The study is basically an initial work for Super 304H steel for the material development program for Indian AUSC power plants, hence a detailed correlation of the creep strength and other mechanical properties with the microstructure are to be studied.

- Further, effect of thermal ageing on the creep behaviour of the alloy will be studied as a part of future work.

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