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Improving creep strength of 316L stainless steel by alloying with nitrogen

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ABSTRACT

The influence of nitrogen on the creep behaviour of 316L(N) SS has been studied at nitrogen levels of 0.07, 0.11, 0.14 and 0.22 wt.%. Creep tests were carried out at 923 K at stress levels of 140, 175, 200 and 225 MPa with rupture life up to 16,000 h. Creep rupture strength was found to increase substantially with increase in nitrogen content; rupture life increased almost 10 times by increasing nitrogen content from 0.07 wt.% to 0.22 wt.%. Steady state creep rate decreased significantly with increasing nitrogen content. The extent of internal creep damage and surface creep damage decreased remarkably with increasing nitrogen content, resulting in increased creep rupture strength. Solid solution strengthening, increase in Young's modulus, decrease in stacking fault energy and matrix precipitation of carbonitrides have contributed to the increase in creep strength with increasing nitrogen content.

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1. Introduction

For the high temperature structural components of sodium cooled fast reactors (SFRs), 316L stainless steel (SS) containing 0.02–0.03 wt.% carbon and 0.06–0.08 wt.% nitrogen designated as 316L(N) SS is one of the preferred materials [1]. The carbon content is kept low, so that the susceptibility of the steel to sensitization of the heat affected zone (HAZ) in welded components is minimized and thus the potential for stress corrosion cracking of HAZ in a corrosive environment is alleviated. Alloying with 0.06–0.08 wt.% nitrogen helps to increase the high temperature strength of 316L SS to levels comparable to that of 316 SS. In order to increase the economic competitiveness of SFRs, there is a strong desire to increase the design life from the current level of 40 years to at least 60 years in the future designs. As part of the efforts to develop structural materials suitable for very long design life, the influence of nitrogen at concentrations higher than 0.08 wt.% on the high temperature mechanical properties of type 316L SS is being studied extensively [2–5]. Nitrogen is a strong austenite stabilizer, solid solution strengthener, and it improves pitting corrosion resistance. Nitrogen is known to improve creep and fatigue strength at high temperatures and fracture toughness at cryogenic temperatures. Improvements in properties from alloying with nitrogen are reported in ferritic steels, austenitic steels, martensitic steels and duplex steels [6,7].

Four heats of 316L SS, containing 0.07, 0.11, 0.14 and 0.22 wt.% nitrogen referred hereafter as 316LN SS have been produced to study the effect of nitrogen on the tensile, creep, low cycle fatigue and creep-fatigue interaction properties of 316LN SS. The carbon content in these heats was maintained at 0.03 wt.% and the composition of all other elements was kept unchanged. This paper presents the results of extensive studies carried out on the influence of nitrogen on the creep properties of 316LN SS at 923 K. Although there have been several studies on the influence of nitrogen on mechanical properties of austenitic stainless steels [8,9], there have been no systematic studies on the influence of nitrogen over such a wide range of nitrogen levels in low carbon grade of 316L SS.

2. Experimental

Four heats of 316LN SS were produced through double melting process in a special steel making company. Primary melting of the steel was carried out by air induction melting. The charge consisted of pure raw materials in order to achieve good and consistent control on the chemical composition of the steel. During primary melting, nitrided ferrochrome was used to achieve the required amounts of nitrogen in the different heats. Other major and minor elements were controlled to the same level in all the heats. Secondary melting was carried out by electroslag refining (ESR) process in order to produce the steel with very low inclusion content. The ESR ingots were hot forged into slabs and subsequently hot rolled into plates of 22 mm thickness and finally given a solution annealing treatment above 1323 K. The four heats are designated as 7 N, 11 N, 14 N and 22 N. The chemical compositions of the four heats of 316LN SS and their grain sizes are given in Table 1. Constant

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Table 1
Chemical composition of 316LN SS (wt.%).

	Elements										Grain size µm	Vickers Hardness (HV)
	N	C	Mn	Cr	Mo	Ni	Si	S	P	Fe		
Specification	0.06–0.22	0.02 –0.03	1.6–2.0	17–18	2.30–2.50	12.0–12.5	0.50Max.	0.01Max.	0.03Max.	Bal.	<180	
7N	0.07	0.027	1.7	17.53	2.49	12.2	0.22	0.0055	0.013	Bal.	87 ± 9	155
11N	0.11	0.033	1.78	17.62	2.51	12.27	0.21	0.0055	0.015	Bal.	96 ± 8	160
14N	0.14	0.025	1.74	17.57	2.53	12.15	0.20	0.0041	0.017	Bal.	78 ± 8	166
22N	0.22	0.028	1.70	17.57	2.54	12.36	0.20	0.0055	0.018	Bal.	87 ± 11	192

load creep tests were conducted at 923 K at several stress levels in the range of 140–225 MPa using Star Testing System make creep machine with lever–arm ratio of 20:1. A linear variable differential transformer (LVDT) was used for monitoring the specimen elongation. Elongation and temperature were continuously recorded using an automatic data logging system, Eurotherm Model No. 5100 V. The creep rupture lives were in the range of 50–16,000 h. All the creep tests were conducted in accordance with ASTM standard recommended practice E-139 and the test temperature was controlled within ±2 K. Round specimens with 50 mm gauge length and 10 mm gauge diameter were used for the creep tests. Elastic modulus was determined in a Hung-Ta make (Model No. HT 2402) screw driven universal tensile testing machine having a high precision extensometer. Scanning Electron Microscope (SEM), Philips model PSEM 501 was used to study the fracture surfaces. For this purpose, the tip of fracture sample was cut and cleaned in acetone in

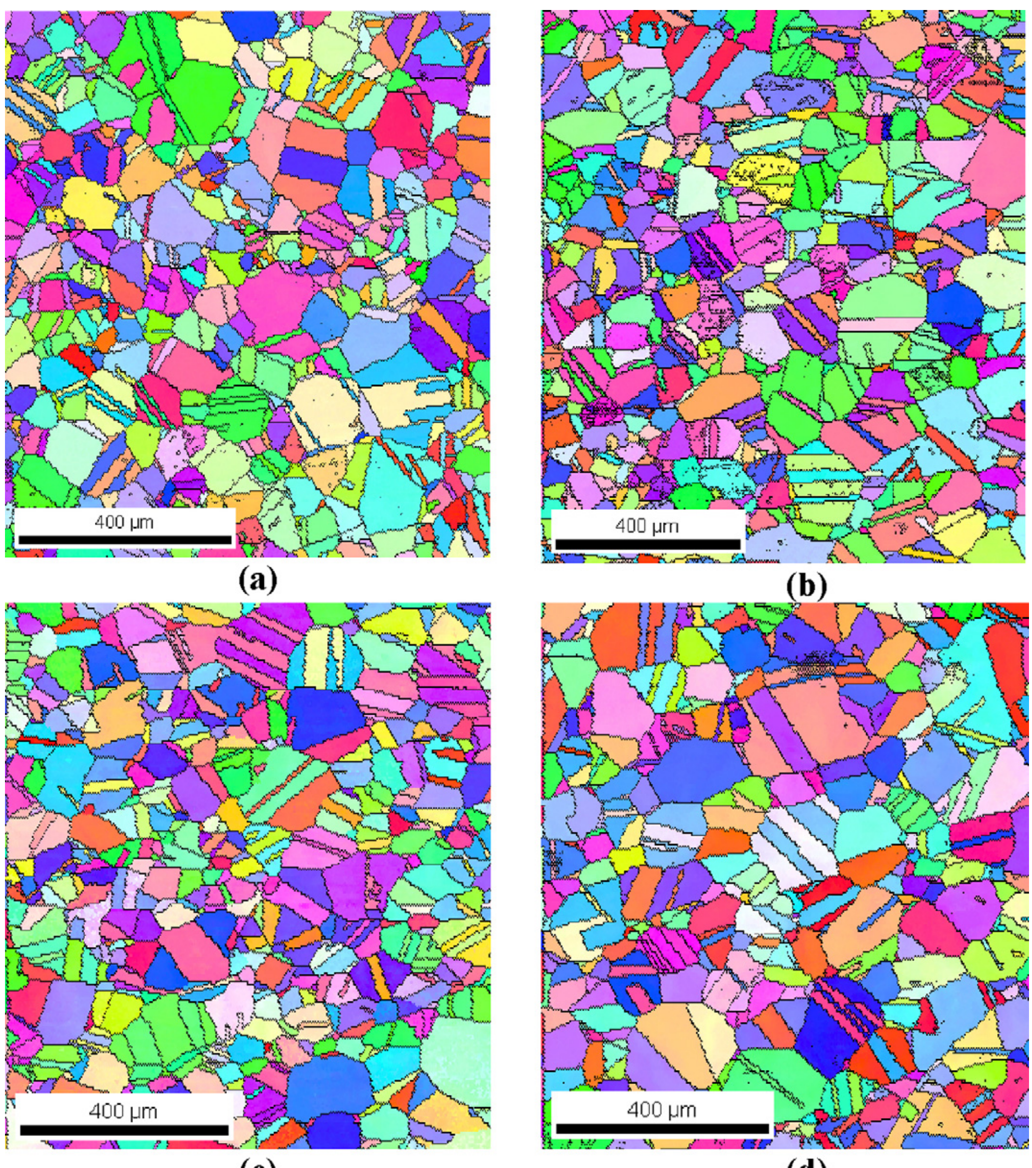

Fig. 1. Orientation imaging micrographs of solution annealed 316LN SS containing nitrogen (wt.%) of (a) 0.07, (b) 0.11, (c) 0.14 and (d) 0.22 N. Nearly equiaxed grains and annealing twins have been observed.

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