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Effect of Spinodal Decomposition Products on the Mechanical Properties of Super Duplex Stainless Steels

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Abstract: -- In this study effect of alpha prime (α') precipitate on the mechanical properties of thermally embrittled DSS has been investigated. Initially as received material was solutionized at 1070 ºC followed by water quenching in order to dissolve if any harmful precipitates were present. Then the samples were thermally embrittled by heating the samples at 475 ºC and water quenched for varying periods from 25 to 750 hours. Tensile and impact toughness tests were performed in order to evaluate the mechanical properties. Microstructure and fractured samples were examined by scanning electron microscope. Results showed that mechanical properties were significantly degraded when subjected to thermal ageing at 475 ºC which is one of the key limiting factor for the usage of Duplex stainless steels in power plants for long term applications. Mechanism behind475 embrittlement was also investigated in this study.

Keywords: Duplex stainless steel; ageing; embrittlement; tensile strength; ductility; impact toughness;

I. INTRODUCTION

Duplex stainless steels has been an attractive material in energy and environmental fields where both high mechanical strength and excellent corrosion resistance is required because of the unique microstructure which consists of almost equal amounts of austenite and ferrite. This austenite to ferrite ratio mainly depends upon chemical composition. Generally these alloys have replaced 300L austenitic stainless steels since it posses almost two to three times higher yield strength and exhibit greater corrosion resistance properties at a comparable cost.[1-3].

DSS are susceptible to thermal embrittlement when exposed to the temperature range of (250 ºC-500 ºC), and extensive researches have been performed to evaluate the degradation of properties. It is well known that thermal aging embrittlement of DSS would result in the increase in hardness and tensile strength, while decrease in ductility, impact strength, and fracture toughness. The primary mechanism of thermal aging embrittlement of DSS is the spinodal decomposition in the ferrite phase which is known to be a process of the nano-scale phase separation of the ferrite phase to the Cr-rich and Fe-rich phases [4]. For DSS this is very important problem because it limits their industrial applicability. Hence an attempt has been made to evaluate the mechanical properties of the embrittled DSS.

II. EXPERIMENTAL PROCEDURE

The material used in this investigation was wrought S2205 Duplex stainless steels rods with 20mm diameter. As received material were machined into tensile specimens with a gauge length of 30 mm and gauge diameter of 6 mm, in accordance with ASTM-E8M standard and subsequently subjected to solution annealing treatment at 1070°C for 70 minutes in order to ensure complete dissolution of any precipitates that may have formed during processing. The chemical composition of the specimen was determined by optical emission spectrometry and is shown in Table 1.

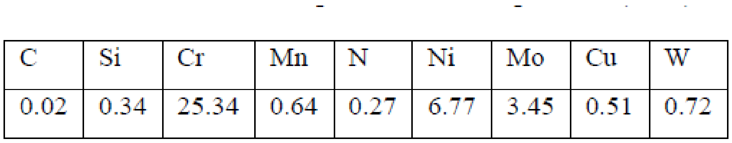
The specimens were aged at 475°C for 25, 50, 70, 80, 100, 250, 500 and 750 hours. Mechanical properties of the specimens were evaluated in both annealed and aged conditions.

Tensile strength, yield strength and ductility were determined at a strain rate 1mm/min using Shimadzu 100kN Universal Testing Machine according to ASTM E8M standards.

Charpy impact testing is performed according to ASTM A 370-13 using Charpy specimen with the dimension of 10x10x55mm3. A Charpy V notch inclusive angle of 45º a depth of 2mm and a root radius of 0.25mm is machined at the centre of the specimen.

Microstructural and fractography analysis were carried out using scanning electron microscope.

Table 1. Chemical Composition of The Specimen (wt%)



C	Si	Cr	Mn	N	Ni	Mo	Cu	W
0.02	0.34	25.34	0.64	0.27	6.77	3.45	0.51	0.72

III. RESULTS AND DISCUSSION

A. Annealing

Figure 1 shows the scanning electron micrograph of the specimen solution annealed at 1070°C for 70 mins and then metallographically polished before being etched with Beraha's Tint Etch (20 mL HCl, 1g K2S2O5, 100 mL water). The solutionised microstructure consists of FCC-austenitic islands in the BCC ferritic matrix. Solution heat treatment is generally used to dissolve harmful precipitates, eliminate the macro-segregation and to adjust the austenite and ferrite phase proportions [5]. Electro dispersive spectroscopic analysis was carried out by using SEM. Table 1 gives the EDS values of Austenite and Ferrite in annealed and aged condition.

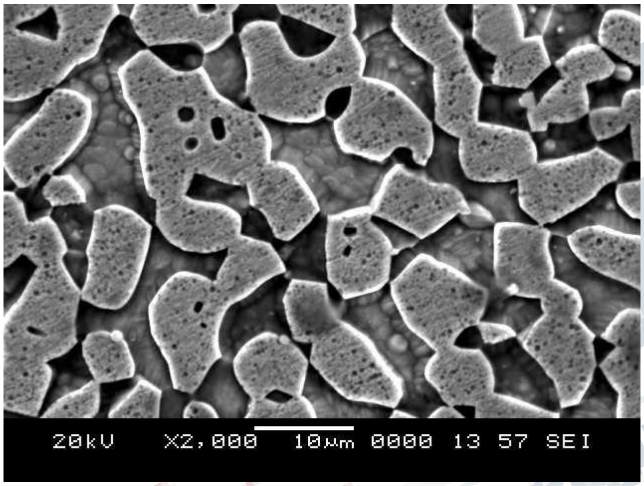


Fig 1. Scanning electron micrograph of annealed sample

B. Spinodal decomposition and its Effect on Mechanical Properties

Specimens were aged at 475ºC since embrittlement rate is highest at this temperature. Embrittlement is due to the formation of alpha prime(α') precipitate either through spinodal decomposition or through the mechanism of nucleation and growth because of the the existence of the miscibility gap present in the iron–chromium phase diagram in the temperature range of 280–500ºC[6].

Figure 2 shows the variation of room temperature impact values as a function of ageing time. Sigmoidal curve was obtained when change in impact values were plotted against ageing time. Impact values of 6joules were obtained for samples aged at 90, 100, 250,500 and 750 hours. Hence we can say that embrittlement reaches saturation at 100hours.

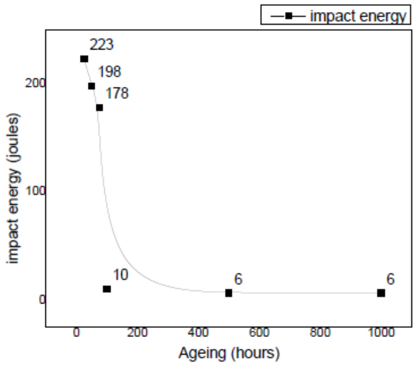


Fig 2. Impact value v/s Ageing time

Under impact loading in aged condition plastic deformation is severely constrained in the austenitic phase by the surrounding ferrite since plastic deformation hardly occurs in the ferrite phase. When the applied load reaches break strength of ferrite cracks initiates in ferrite and then quickly propagates through the ferrite grains, this propagation is hindered by austenite and ferrite phase boundaries which results in the stress concentration. When the loading is further increased, the shear stress on the crack exerts pressure on the austenite phase and tears them off.

The measured values of ultimate tensile strength and % elongation in solutionized and aged conditions are given in Table 3. The aged samples ultimate tensile strength was increased by 35% accompanied by a 57% loss in ductility. Tensile strength is increased because of the α' precipitate, which interferes the motion of dislocation. Whereas loss in ductility is due to the movement of interstial atoms which diffuse the dislocation obstacles in solid solution,

The fractographs of aged and annealed samples are shown in fig 3. In the solutionized condition (Fig. 3(a)), the fracture surface reveals a fully ductile fracture mode with dimples throughout. The fracture surface of the aged sample (Fig. 3(b)) revealed a predominantly brittle mode of fracture with cleavage facets in most regions as well as a few sheared regions. The cleavage facets are the embrittled ferrite grains while the sheared grains were those of austenite. The cleavage cracks are initiated at the α′ precipitates and then propagates across the ferrite network. The ductile fracture forms at weak phase boundaries and propagates through the austenite phase [7, 8].

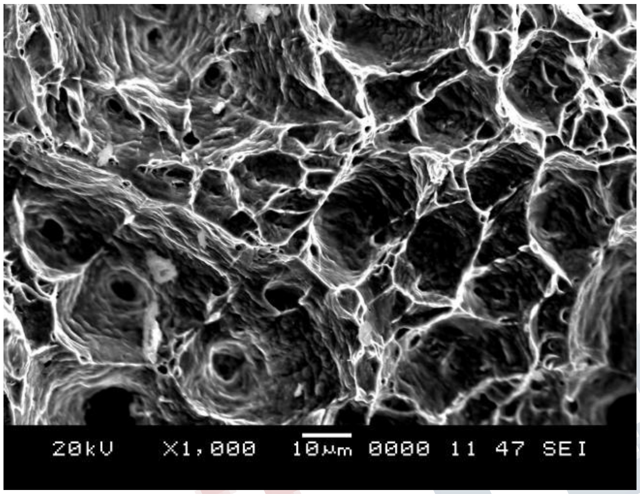


Fig 3a. Fracture surface of solutionized sample

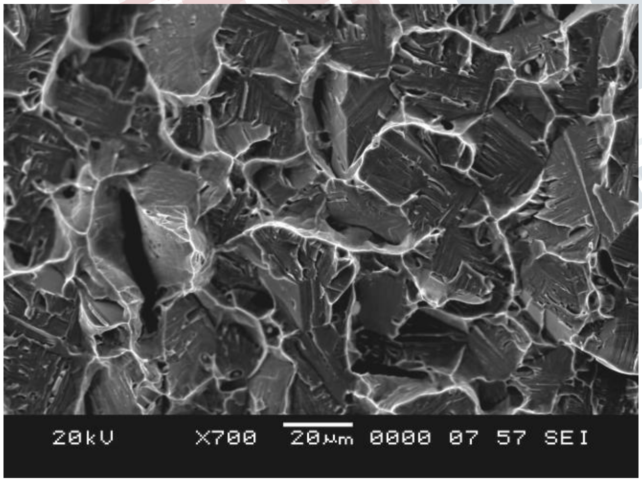
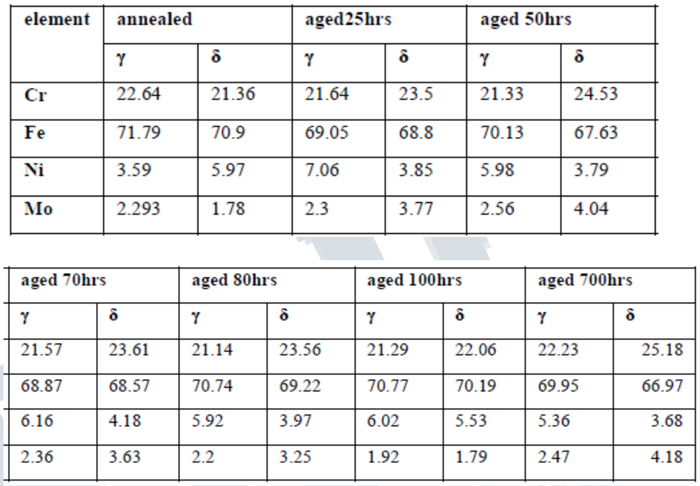


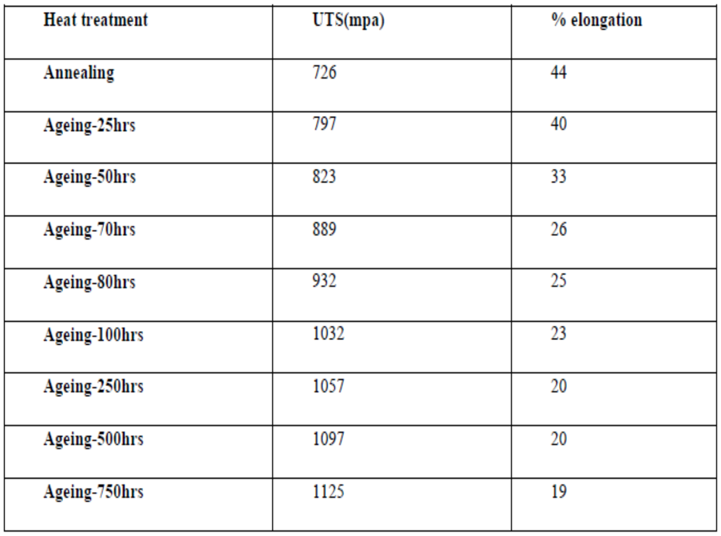
Fig 3b. Fracture surface of 750hrs aged sample

Table 2. Electro Dispersive Spectroscopic values of Austenite and Ferrite (wt%)



element	annealed		aged25hrs		aged 50hrs		aged 70hrs		aged 80hrs		aged 100hrs		aged 700hrs	
	γ	δ	γ	δ	γ	δ	γ	δ	γ	δ	γ	δ	γ	δ
Cr	22.64	21.36	21.64	23.5	21.33	24.53	21.57	23.61	21.14	23.56	21.29	22.06	22.23	25.18
Fe	71.79	70.9	69.05	68.8	70.13	67.63	68.87	68.57	70.74	69.22	70.77	70.19	69.95	66.97
Ni	3.59	5.97	7.06	3.85	5.98	3.79	6.16	4.18	5.92	3.97	6.02	5.53	5.36	3.68
Mo	2.293	1.78	2.3	3.77	2.56	4.04	2.36	3.63	2.2	3.25	1.92	1.79	2.47	4.18

Table 3. Tensile properties of S2205 DSS after different heat treatments



Heat treatment	UTS(mpa)	% elongation
Annealing	726	44
Ageing-25hrs	797	40
Ageing-50hrs	823	33
Ageing-70hrs	889	26
Ageing-80hrs	932	25
Ageing-100hrs	1032	23
Ageing-250hrs	1057	20
Ageing-500hrs	1097	20
Ageing-750hrs	1125	19

IV. CONCLUSION

An investigation of the effects of α' prime precipitate on the mechanical properties of S2205 duplex stainless steel reached the following conclusions:

- DSS in annealed condition have good mechanical properties which can be used in energy application.
- When DSS are aged at 475ºC α′ precipitates are formed either through spinodal decomposition or through the mechanism of nucleation and growth
- From impact test results we can conclude that ageing for 100hrs at 475ºC can cause necessary embrittlement of S2205duplex stainless steels.
- In aged condition the Cr rich α′ precipitates act as dislocation barriers and as a result the aged specimens show an increase in strength by 35%.
- Ductility is decreased by 57% with respect to annealed condition due to the stress triaxiality caused by dislocation pinning at the α′ precipitates

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