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RESISTIVITY OF LATTICE VACANCIES IN STAINLESS STEEL 316

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Abstract: Specimens of SS316 were solution treated for 60 min. at different temperatures i.e. 800 and 900°C, quenched in brine and aged at 70 and 450°C for various times. Cold worked specimens (75% cold rolled) were annealed at 40 and 70°C for different times. It is observed that resistivity first rises and then falls after subsequent annealing or aging at a constant temperature. The increase in resistivity after quenching and cold working is found to be due to creation of defects and imperfections such as vacancies and dislocations. The annealing can be attributed to recovery and recrystallization processes. The initial increase in resistivity during aging may be described by the formation of clusters/ precipitates at early stages of precipitation.

Keywords: Lattice vacancies, cold working, recovery, recrystallization, precipitation.

INTRODUCTION

Mechanical properties such as flow stress, hardness and ductility of metals and alloys recover monotonically towards the values characteristic of the fully annealed stage during the process. Obviously the cells, developed during deformation prior to the annealing process, grow in size during the recovery stage and presumably set the stage for eventual recrystallization events in metals and alloys [Tseng and Varma 1992, Bay *et al.* 1992]. So the kinetics of recovery in terms of sub-grain growth becomes a very critical area, which may need a better understanding in order to control the industrially important process of annealing.

Electrical resistivity data can be useful to understand various phenomena in metals and alloys. For example resistivity measurements provide an easy and inexpensive tool for the study of phase transitions with change of temperature in crystalline as well as amorphous metals and alloys [Shamim *et al.* 1988, Ansari *et al.* 1994, Rana and Ansari 1995, Shamim *et al.* 1998, Rana *et al.* 1999]. Similarly residual resistivity measurement is one of the most simple and sensitive method for studying impurities, defects and other structural changes [Rosenberg 1963].

Annealing of a material may affect either density of current carriers or their mobility. In metals and alloys the carrier density (free electron) remains unaltered by annealing. However, annealing increases mobility by relieving internal stresses and by decreasing disorder in the lattice

[Cahn and Haasan 1983, Raghavan 1992]. Therefore, the effect of annealing on metals and alloys is to decrease their resistivity. If the lattice were perfect, the electron waves would be transmitted through the lattice without scattering or with no resistance.

If a specimen is quenched after heating at a certain suitable temperature, its atoms freeze at their present positions producing defects and vacancies in it and if temperature is low enough, the equilibrium concentration of vacancies will be frozen in it [Thompson 1969]. Changes in a quenched material are so fast that it is in a state of strain that may cause surface or internal cracks. The strains set up in a quenching process can be relieved completely during annealing [White 1968].

In the present investigations, stainless steel SS316 was chosen to study the variation of electrical resistivity after quenching and aging at low and intermediate temperatures. Furthermore, the effect of low temperature annealing on electrical resistivity of 75% cold rolled SS316 was also studied.

MATERIALS AND METHODS

Samples of SS316 (American grade) in the form of thin sheets of uniform thickness (100μm) were obtained from KFA Juelich, Germany. Specimens having different dimensions (length, width and thickness) were used to measure electrical resistivity by well-known four-probe method [Ansari 1990, Rana *et al.* 1990, Ansari *et al.* 1994]. Specimens were quenched in brine after heating at 800°C for 60 minutes and then aged at 450°C for different times. The same specimen was reheated at 900°C for 60min., quenched in brine and isothermally aged at 70°C. Cold worked specimens (75% cold rolled, 25μm thick) were annealed at 40 and 70°C for various times.

RESULTS AND DISCUSSION

The effect of quenching on electrical resistivity of SS316 was observed experimentally. It was found that quenched sample shows higher resistivity at room temperature as compared to electrical resistivity before quenching due to the formation of vacancies and stress fields, which create more resistance to the flow of electrons during conduction [Anderson *et al.* 1974]. The percentage increase in resistivity due to quenching was ~25% (74.41-93.03μΩcm). On aging at 450°C for various times, Fig. 1 shows a sudden rise in resistivity followed by a slow increase with increasing time of aging. Increase in resistivity at the initial part of the curve indicates the formation of clusters/precipitates (carbides etc.) in the supersaturated matrix at early stages of aging [Ansari 1990, Ansari *et al.* 1994, Rana and Ansari 1995], which are extremely small and uniformly distributed. Carbide precipitation in SS316 is dependent on structure and energetics of the boundary on which carbide forms. Another source of increase in resistivity may be the formation of chromium carbide precipitates at both grain boundaries and grain matrix [Advani *et al.* 1992]. The same specimen was reheated at 900°C, quenched and re-aged at 70°C. Results are plotted in Fig. 2, which shows nearly same values of resistivity with increasing aging time due to very low temperature. It only shows the removal of stress fields and/or rearrangement and annihilation of few dislocations [Cahn and Haasan 1983] etc.

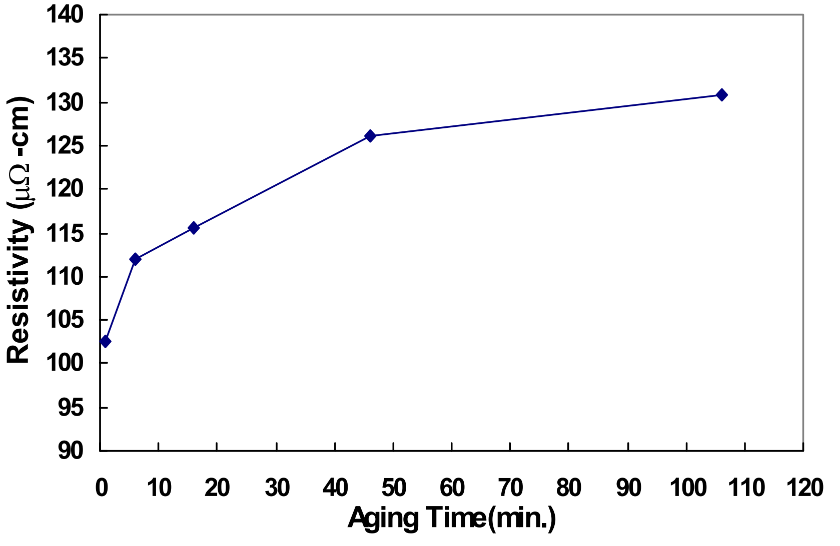

Fig. 1: Plot of electrical resistivity of SS316 as a function of ageing time when isothermally aged at 450°C.

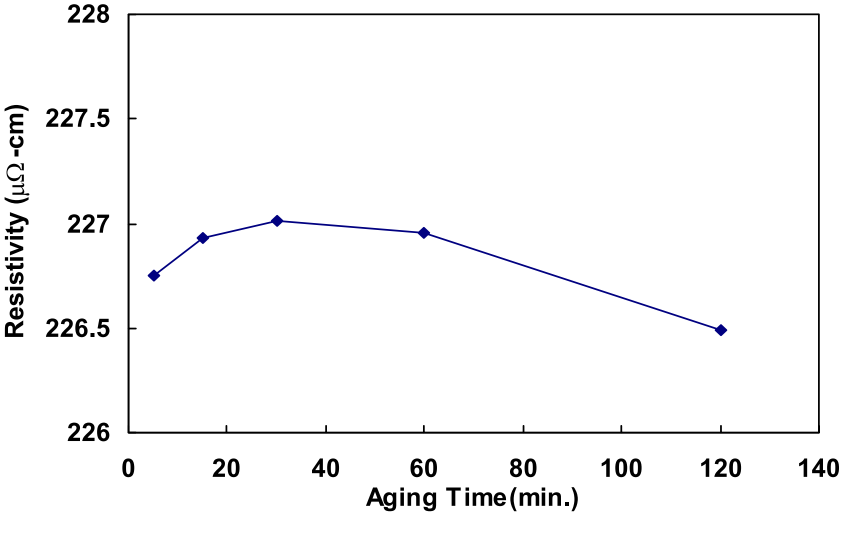

Fig. 2: Plot of electrical resistivity of SS316 as a function of ageing time when isothermally aged at 70°C.

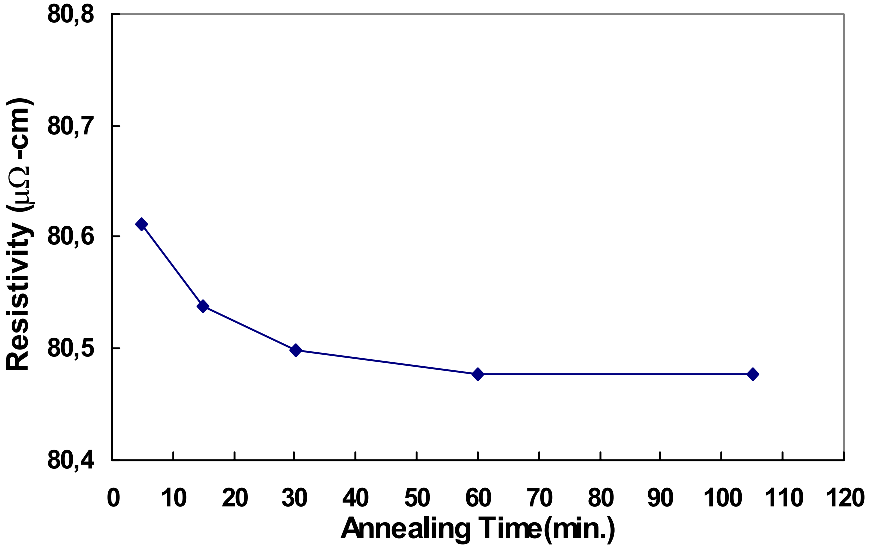

Fig. 3: Plot of Electrical Resistivity of cold rolled SS316 as a function of time during isothermal annealing at 70°C.

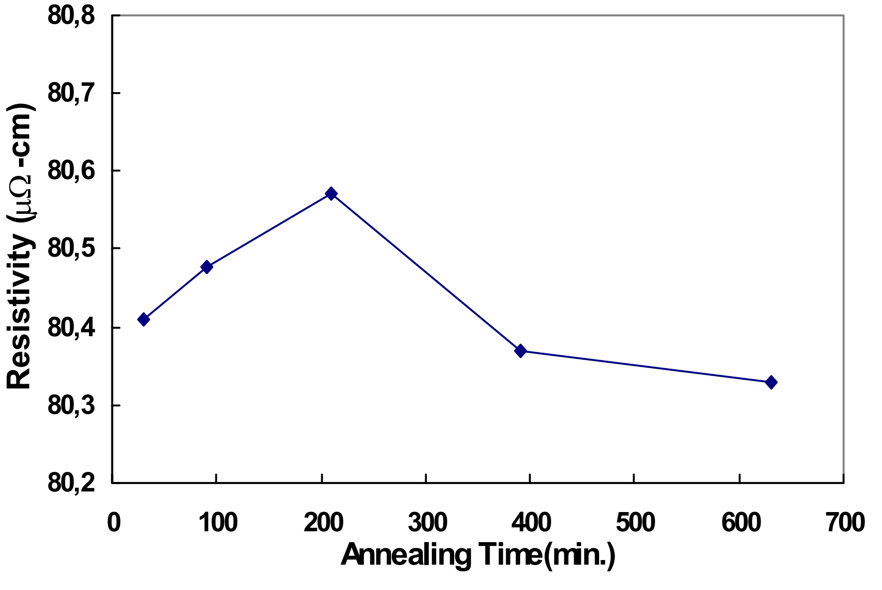

Fig. 4: Plot of Electrical Resistivity of cold rolled SS316 as a function of time during isothermal annealing at 40°C.

Due to cold rolling, room temperature electrical resistivity was found to increase from 74.41 to 80.49μΩcm (~ 8.17% increase). Since an ordered structure is known to have considerably lower resistivity than disordered structure [Theraja 1981]. The cause of increase in resistivity at room temperature of cold worked specimen can be attributed to formation of defects such as vacancies, dislocations and twins etc.[Broom 1954]. Cold worked specimen was annealed at 70°C for different times. Fig. 3 shows slight decrease of resistivity with annealing time. The stress fields and defects / dislocations setup by deformation process are seem to remove or rearrange themselves with increasing time of isothermal annealing [Carter 1979]. That is why resistivity of the specimen decreases due to long time annealing.

The plot of resistivity vs. annealing time (Fig. 4) shows that resistivity first increases slightly, attains a maximum and then decreases with annealing time. An important criterion for the application of this alloy is the behavior of precipitation. Two aspects have especially to be taken into account: the direct influence of precipitates and their influence on the formation and change in chemical composition [Avner 1974, Ehrlich 1981, Cahn and Haasan 1983], which accompany their formation. A large variety of intermetallic phases and carbide precipitates appear in different austenitic stainless steels. Therefore, resistivity increases at first stage and then from maximum, it falls down due to long annealing times, which is indicated in the second stage. The effect of impurities and defects at relatively low temperature may also cause an increase in resistivity initially. When these defects are removed due to long annealing time by starting recovery and recrystallization processes, specimen shows a behavior of decreasing electrical resistivity with increasing time of annealing [Cahn and Haasan 1983, Raghavan 1992].

CONCLUSIONS

Following conclusions may be drawn from the above discussion.

- Increase in resistivity at the initial stage of aging may indicate the formation of clusters/precipitates (carbides etc.) in the supersaturated matrix, which are extremely small and uniformly distributed.
- Electrical resistivity decreases on annealing with increase in annealing time due to the removal of stress fields and/or rearrangement and annihilation of dislocations.

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