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Determination of Heat Treatment Parameters of Cold Rolled AISI-304 Stainless Steel Plate by Electrical Resistance

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Abstract

Thermo-mechanical treatments have a great influence on the mechanical and corrosion properties of stainless steel, as with other steels. Stainless steel sheets are usually solution annealed after deformation in continuous heat treatment lines. Parameters determining the mechanical and corrosion properties of stainless steel; phase ratios, chemical composition, deformation rate, annealing temperature and annealing time. The element content of stainless and other steels of different grades is kept in relatively wide ranges, making it difficult to optimize thermo-mechanical parameters. Heat treatments and deformations that are not specific to the material increase the margin of error in the mechanical properties of the materials, reduce the corrosion resistance and increase the production cost, especially with unnecessary heat treatments. Crystal structure defects and Alpha-Martensite phase occur with deformation in AISI 304 quality stainless steel. These changes are proportional to the rate of deformation. The primary factor in electrical conduction is crystal structure perfection.

In this study, the electrical resistance of AISI 304 quality stainless steel after cold deformation was modeled numerically, depending on the increasing deformation rate..

Keywords: Stainless Steel, thermo-mechanical process, cold deformation, surface quality.

1. INTRODUCTION

With the developing industry, process optimization has become very important for all processes today. Now, a process that has not been optimized or made incompletely is considered as an incomplete process and necessarily causes many inefficiencies. These problems come in many forms; unnecessary energy use, loss of time in production, excessive use of resources, etc. which are the most important factors for a factory.

AISI - 304 quality stainless steels stand out with their high corrosion resistance, mechanical properties, compatibility with all standard welding techniques and appearance. Due to these features, it has a wide range of uses such as chemistry, petrochemistry, household appliances, industrial kitchens, medical industry, automotive industry and food industry.

In this study, the relationship between the heat treatment parameters of cold rolled AISI - 304 quality stainless steel and electrical conductivity was investigated based on the electrical resistance.

1.1. Electrical conductivity

A metal consists of a lattice of atoms, each with an outer shell of electrons that freely dissociate from their parent atoms and travel through the lattice. This is also known as a positive ionic lattice[1]. This 'sea' of dissociable electrons allows the metal to conduct electric current. When an electrical potential difference (a voltage) is applied across the metal, the resulting electric field causes electrons to drift towards the positive terminal. The actual drift velocity of electrons is typically small, on the order of magnitude of meters per hour. However, due to the sheer number of moving electrons, even a slow drift velocity results in a large current density[2].

When the electron wave passes through the lattice, the waves get mixed up, causing resistance. The tidier the cage, the less disturbance and therefore less resistance. The amount of resistance is therefore mainly due to

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two factors. The first is due to the temperature of the crystal lattice and hence the amount of vibration. Higher temperatures cause greater vibrations that act as irregularities in the cage. Second, the purity of the metal is important since a mixture of different ions is also a disorder[3][4].
The small decrease in conductivity upon melting of pure metals is due to the loss of long-range crystal order. The short-range order remains, and the strong correlation between the positions of the ions results in coherence between waves refracted by adjacent ions[5][6][7].

1.1.1. Stainless Steel Production and Electrical Resistance in the Product

While producing stainless steel, it is first cold rolled after casting and hot rolling stages. At this stage, the rate of deformation in the material increases. Parallel to this, dislocation density increases, martensite phase is formed and anisotropy increases. With the increase in the dislocation density, the movement of electrons in the material becomes difficult and the electrical resistance increases. When tetragonal volume-centered martensite phase is formed in austenite, which was previously in face-centered cubic structure, anisotropy increases and this results in an increase in resistance. Anisotropy causes the movement in the metal to be difficult and increases the resistance. As long as the alloying element content does not change, the parameter that affects the electrical conductivity of the material at a constant temperature is the properties and arrangement of the crystal structures.

In the production of stainless steel, there is a solution annealing phase after cold rolling. At this stage, the stainless steel plate first undergoes heat treatment, then the iron oxide layer formed during the heat treatment with acid solution is cleaned and a chromium oxide layer is formed. Thus, the stainless steel plate gains its passive layer on the surface and now it has the properties of stainless steel.

Stainless steel heat treatment; It is applied to obtain a homogeneous internal structure by reducing the high anisotropy that occurs in the material after cold deformation and to make the stainless steel plate suitable for the pickling stage of solution annealing.

With the increase of heat treatment power, dislocation density decreases, anisotropy decreases, grain boundaries become thinner and decrease, grains grow and coalesce. The martensite phase in the material turns into austenite phase.

1.1.2. Other Factors Affecting Electrical Resistance

Grain growth varies depending on composition, structure, degree of cold forming, and temperature, and parameters of this process have an important effect on the physical and mechanical properties of stainless steel. However, the effect of the alloying elements on electrical conductivity is much greater than that of grain boundary caused by grain growth and the change caused by plastic deformation[8].

According to Matthiessen's theory, electrical resistance, and its opposite electrical conductivity depend on many microstructural properties.

Thermal and electrical conductivity (or resistivity) values are affected by the microstructure of the solid sample which is, in turn, dependent upon the heat treatment and the cold work given to the alloy[9].

$$\rho = \rho 0 + \Delta\rho S + \Delta\rho P + \Delta\rho V + \Delta\rho D + \Delta\rho B \tag{1.1}$$

These are resistance of pure solvent metal (ρ0), electrical resistance of elements dissolved in solution (ΔρS), precipitates (ΔρP), voids (ΔρV), dislocations (ΔρD), and grain boundaries (ΔρB)[10].

2. EXPERIMENTAL METHOD

First of all, the electrical resistances of the samples taken from the plates to be used in the experiments were measured, depending on the deformation rates before deformation.

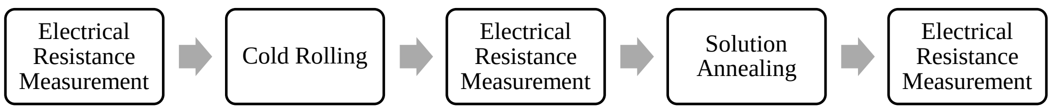

Fig. 1. Experimental Stages

Nickel equivalents, chromium equivalents and hardenability of stainless steel samples were calculated according to the element content varying according to their alloys.

$$Ni_{eq} = \%Ni + \%Co + 30(\%C) + 25(\%N) + 0.5(\%Mn) + 0.3(\%Cu) \quad (1.2)$$

$$Cr_{eq} = \%Cr + 2(\%Si) + 1.5(\%Mo) + 5(\%V) + 5.5(\%Al) + 1.75(\%Nb) + 1.5(\%Ti) + 0.75(\%W) \quad (1.3)$$

$$ß(\%) = 2.7(\%C) + 0.4(\%Si) + \%Mn + 0.45(\%Ni) + 0.8(\%Cr) + 2(\%Mo) \quad (1.4)$$

Then, electrical resistances, sample thicknesses, tensile strengths, yield strengths, percent elongation and hardness values were measured.

Vickers Hardness Measurement according to ASTM E384 Standard, tensile, yield and percent elongation tests were applied according to ASTM E8 Standard.

The determined samples were prepared as metallography samples in accordance with ASTM E3 Standard. Then, images at different scales were taken from the metallographed samples.

Cold rolling of the plates to be sampled was carried out. The cold rolled plates were re-sampled and the electrical resistance, thickness measurements, tensile strength, yield strength, percent elongation and hardness values were measured after deformation, and the amount of deformation was also obtained.

3. RESULTS AND DISCUSSION

When the electrical conductivity relationship was examined depending on the deformation rate, results that were in line with the literature were obtained. In particular, the increasing anisotropy due to the increasing deformation rate had a serious effect on the electrical resistance of the material. The measured electrical resistance was divided into thicknesses, and equivalent comparisons were made, since the materials were of different thicknesses and the electrical conductivity changed with the distance.

The graph below shows the change in the electrical resistance of the material with the increase in the deformation rate and the mathematical model of this change. The R^2 value obtained was found to be above 0.95.

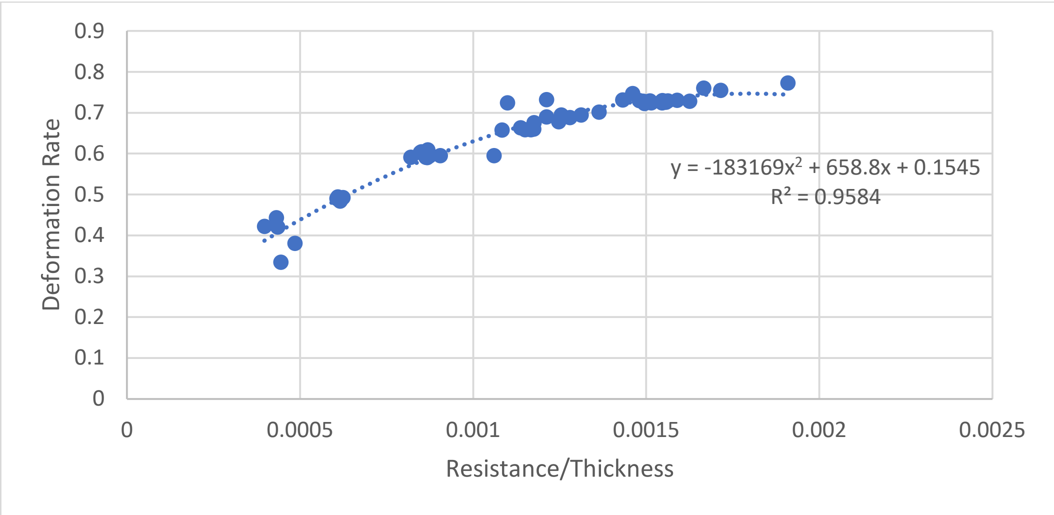

Fig. 2. Deformation Rate and Resistance/Thickness Graphic

With increasing deformation, the face-centered cubic austenite phase transformed into the tetragonal volume-centered martensite phase. Therefore, the hardness value has also increased.

The graph below shows the relationship between the measured HV1 hardness values and the electrical resistance per unit length. This correlation shows that the material also changes the electrical resistance due to the same reasons as the increase in hardness due to deformation. The mathematical model obtained is at a level that can predict the electrical conductivity and the hardness of the material with a success rate of over 88%.

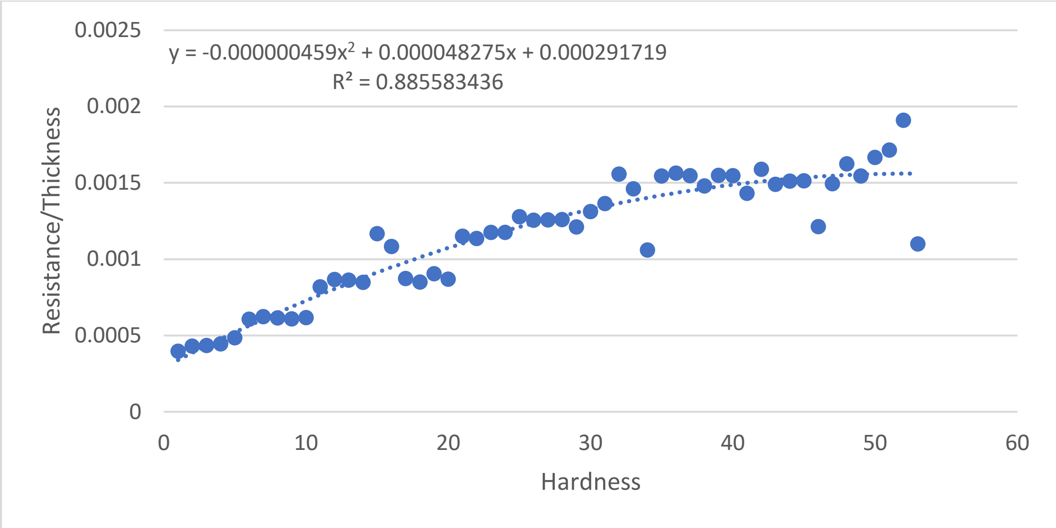

Fig. 3. Resistance/Thickness and Hardness Graphic

The hardenability of stainless steels is calculated as in Equation 1.3. One of the parameters that most affect the electrical resistance is the alloying elements. In the graphic below, the hardness value of AISI-304 quality stainless steel, which is of the same quality, and the alloy elements and resistance relationship are examined. It is clearly observed that the correlation obtained increases when alloying elements are taken into account. Samples with the same deformation amount in the previous graphs showed different electrical resistances. This situation is closely related to alloying elements. When the curing ability is examined with the resistance relationship, the R^2 value is above 0.89.

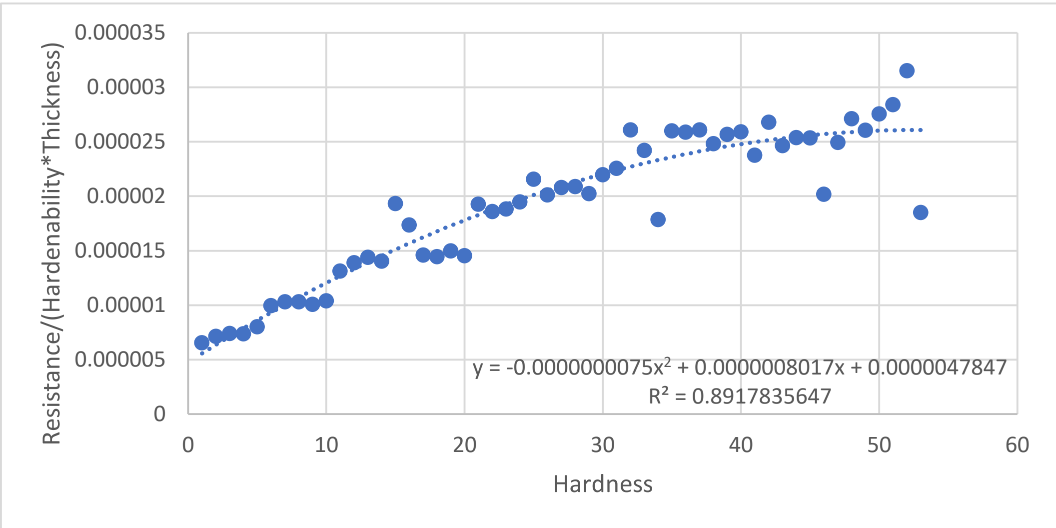

Fig. 4. Resistance/(Hardenability*Thickness) and Hardness Graphic

In addition, depending on the deformation rate, the relationship between the resistance/thickness ratio and the average resistance was also investigated and the following 92.53% accurate model was created.

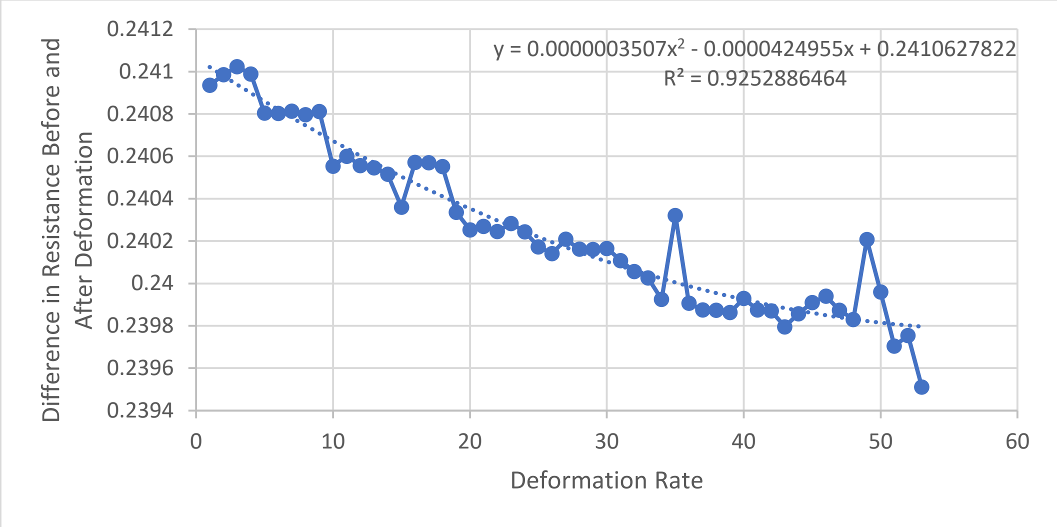

Fig. 5. Difference in Resistance Before and After Deformation and Deformation Rate Graphic

In addition, in order to examine the changes in the microstructure according to the deformation rates, metallography samples of the samples with different deformation rates were prepared and their microstructures were examined. As expected, it was observed that as the deformation rate increased, a finer grained, more anisotropic structure and even carbides were formed in the structure with the higher deformation rate.

Examined samples are; Sample with 33.4% deformation rate, sample with 59.5% deformation rate, sample with 72.5% deformation rate and sample with 87.9% deformation rate respectively.

Fig. 6 A. Microstructure of Sample With %33,4 Def. Rate

Fig. 6 B. Microstructure of Sample With %59,5 Def. Rate

Fig. 6 C. Microstructure of Sample With %72.5 Def. Rate

Fig. 6 D. Microstructure of Sample With %87.9 Def. Rate

4. CONCLUSIONS

As a result of the experiments, it has been determined that the same quality stainless steel plates with different deformation rates, show different mechanical properties and have a direct effect on the electrical conductivity.

As a result of the alloying of the same quality stainless steel plates at different rates, it has been observed that the element mixing ratios affect the mechanical properties of the material and directly affect the electrical conductivity.

It has been observed that it is possible to determine the heat treatment parameters by examining the alloy, thickness, thickness change, deformation rate and electrical conductivity datas of AISI-304 stainless steel.

Also;

- By making mathematical models on the electrical conductivity of AISI-304 quality stainless steel, its mechanical properties can be determined after heat treatment.
- In particular, the hardness after deformation can be determined by electrical resistance in the heat treatment of stainless steel.
- With the mathematical models obtained, the difference in electrical resistance after heat treatment and after plastic deformation and the deformation rate can be predicted.
- Especially in processes with continuous and long production processes such as continuous heat treatment lines, process optimizations can be made by associating electrical resistance and chemical structure of the material.
- Electrical conductivity decreases with increasing deformation rate.
- After solution annealing, the electrical conductivity changes depending on the alloying elements.

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