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Magnetism of Stainless Steel 304 Due to Cold Rolling

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ABSTRACT

304 austenitic stainless steel (SS 304) is widely used in the oil and gas industry to resist high pitting and stress corrosion. However, It's wear resistance to withstand the fine sand particles carried out from the oil well is very limited. Cold rolling is one of the mechanical methods used to increase the hardness of SS 304 steel. This method causes a crystalline structure deformation of ss 304 and transforms their phase from austenite to martensite. The phase transformation is followed by the change of magnetic properties of these materials.
The increasing percentage of structure deformation is followed by an increase of magnetic saturation value and a change of magnetic coercivity. A large population of martensite phase formed influenced the magnetic saturation value. While deforming of grain shape influenced the magnetic coercivity. The rise of its magnetic property will respond to an external magnetic field. Therefore, the observation of structural deformation of SS 304 can be identified by magnetic interaction.

Keywords: *stainless steel 304, deformation,cold rolling, magnetism.*

1. INTRODUCTION

304 austenitic stainless steel (SS 304) is widely used in oil and gas. The materials resist high pitting and stress corrosion. However, the application of SS 304 steel pipe in the oil and gas industry is still facing a problem. The wear resistance ability to withstand fine sand particles carried out by oil and gas causes wear, wear-corrosion, and micro-abrasion on the pipe from the well, which is limited [1,2].

SS 304 can apply various methods to enhance the wear-resistant. One of the methods is grain refinement which is widely used in industry. Among others, deformation through plastic deformation can produce nanostructured metal grains. This mechanical process can carry mechanical alloying, equal channel angular pressing, cold rolling, and surface mechanical friction treatment. This process refers to the Hall-Petch theory, which states that hardness and strength will increase linearly with decreasing grain size. Thus, the improvement in grain size will affect the increase in wear resistance [3].

Structural SS 304 stainless steel engineering through dynamic deformation and re-crystallizing process in range temperature of 773-1273 K could produce an ultrafine-grained austenitic phase. Microevolutionary kinetics influence the step made, which depends on dynamic recovery and increasing deformation temperature [4]. One of the deformation processes in SS 304 is the Cold rolling method [5]. In this process, the microstructure of SS 304 steel is transformed into a lamellar form or elongated structure. A shift followed this change in the SS 304 steel properties.

Byeon and Kwun (2003) found that the martensite phase was the most dominant phase affecting the magnetic properties of steel, especially after the water quenching method [6]. It caused microstructural abnormalities that will impact the increasing coercivity and remanence. Meanwhile, the magnetization saturation value of steel does not show a significant difference because the optimization of the magnetic properties tends to be influenced by grain size [7]. Mumtaz et al. (2004) found that cold rolling affects the magnetic properties of austenite steel. The greater the percentage of austenite phase deformation in steel, the magnetic saturation value of the steel will increase [8]. Ahmed et al. (1995) found that amount of martensite phase formed due to cold rolling will increase magnetic saturation value and coercivity (4).

The austenite phase is known to have paramagnetic properties. In contrast, the martensite phase is known to have ferromagnetic properties. The greater the martensite phase present in an alloy, the higher the magnetic saturation value [9].

The changes of magnetic properties in SS 304 steel raise concerns about its function and use and open up new discourses in the testing and identification process. The greater the magnetic properties formed on the steel, the greater the magnetic interaction. This behavior facilitates the identification process for indications of deformation of equipment made of SS 304 in the industrial environment.

In this study, the transformation of the structure of SS 304 on microstructural changes that cause changes in magnetic properties due to cold rolling deformation is studied.

2. EXPERIMENTAL

This research uses SS 304 steel which comes from a pipe with a diameter of 6 inches and a thickness of 11 mm. The composition of this pipe element was identified through the mill certificate, and the results of the identification using spectroscopy as shown in Table 1.

Table 1. Comparation elemental composition

No	Elemental composition [wt.%]	Source	
		Mill Certificate	AAS Spectrometer
1	Mn	1,08	1,49
2	Si	0,35	-
3	P	0,038	-
4	Fe	-	66,04
5	S	10^{-3}	-
6	C	0,05	-
7	Cr	18,65	21,20
8	Ni	8,50	10,6
9	HRB	86-87	-

The specimens were shaped into blocks with the sizes shown in Figure 1. Cold rolling mechanical treatment was applied to produce thickness deformations of 0%, 20%, 40%. The deformed specimens were then identified using X-ray diffraction (XRD) to see changes in their structure, using optics to see the morphology of the deformed grains and Scanning electron microscope (SEM), and PERMAGRAF to identify their magnetic properties.

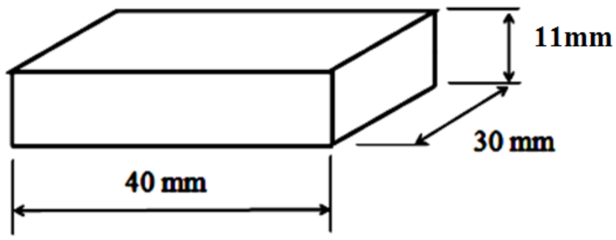


Figure 1. Specimen shape.

3. RESULTS

The cold rolling method is a mechanical stress treatment of the sample. Figure 2 shows the relationship between thickness deformation due to cold rolling mechanical treatment.

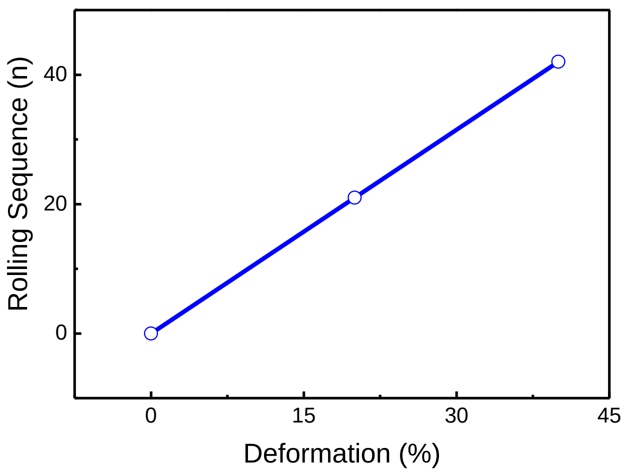


Figure 2. Deformation had a linear connection with the rolling sequence.

The decrease in thickness is consistent with the number of repetitions of the cold rolling mechanical process, from the initial thickness of 0% reduction to up to 40% reduction. SS 304 can achieve the repeatability of identical products in the specimen manufacturing process.

3.2 Microstruture transformation

The results of optical identification of the SS304 microstructure are shown in Figure 3. The grain size of the austenite phase before deformation is between 40–150 m (Fig. 3a).

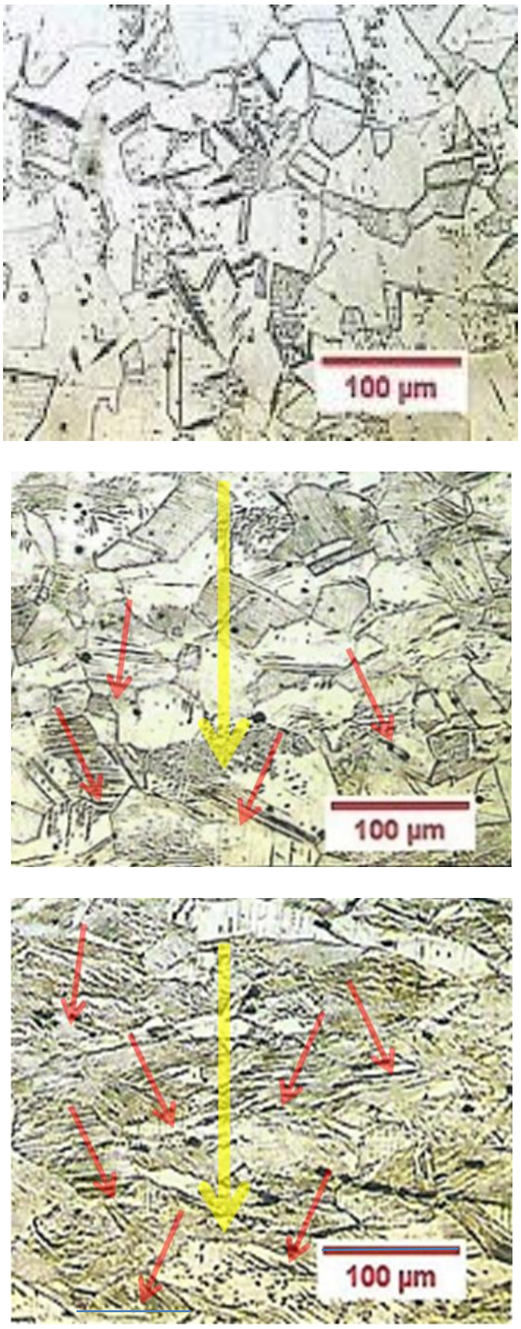
a)
b)
c)


Figure 3. Microstructure of 100x magnification at a) 0%, b) 20%, c) 40% deformation.

As a result of the 20% deformation, the grain size of the austenite phase is between 49-182 m. Compression occurs in the austenite grains in the direction indicated by the red arrow, while the movement of mechanical deformation is indicated by the yellow arrow (Fig. 3b) [10]. The compression of the grains forms parallel horizontal lines within the austenite grains. While the austenite phase still maintains its original shape.

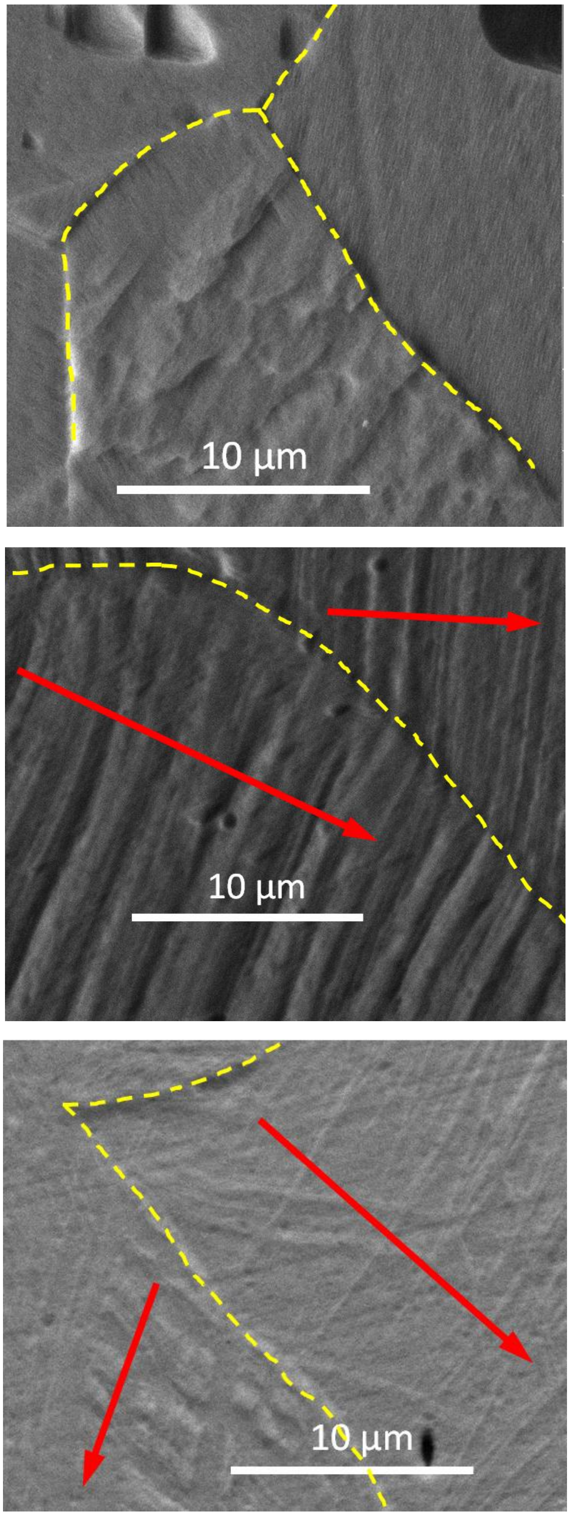
a)
b)
c)


Figure 4. SEM imaging of specimen at a) 0%, b) 20%, c) 40% deformation.

At 40% deformation, compression is formed evenly on the surface of the specimen. The grain shape also experienced significant flattening (Fig. 3c). The grain width of the austenite phase is between 63 -234 m.

Furthermore, the results of identifying these lines using SEM are shown in Figure 4. The grain boundaries are marked by a dotted yellow line, as seen in the initial shape of the austenite phase grains before undergoing mechanical treatment (Fig. 4a). After undergoing 20% deformation, the black lines on the optical photo are wrinkles on the grain surface due to compression. Maximum compression occurs in the center of the grain, while it is more challenging to wrinkle at grain boundaries [11–13]. The direction of the wrinkles on each grain is different. But the wrinkles are in the same direction as each grain. The cause is due to the different orientations of the crystal structure in each of these grains. In the 40% deformed condition, the figure shows that the wrinkles are getting closer. The grain boundaries appear to be wrinkled and sticking out to form the contours of the grain boundaries (dashed yellow lines) [14,15].

The formation of lines which is a wrinkle pattern in the austenite phase, forms a pattern as if the formation of the martensitic phase. The increase of structural deformation percentage creates more wrinkles in the grain surface. It seems to generate an increasing martensitic phase population within the phase grains [16,17].

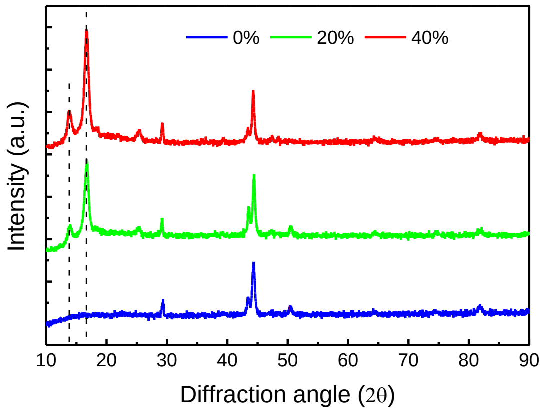


Figure 3. XRD pattern of the specimen at 0%, 20%, 40% deformed.

3.1 Crystallite Structure Deformation

The XRD profile of the 304 stainless steel deformation specimen is shown in Figure 3. The figure shows that under deformation conditions of 20% and 40%, deformation structure formed the 2θ diffraction peaks at angles of 14° and 17°. This peak is formed due to compression of the crystal structure of the austenite phase. These peaks also show the transformation from the austenite phase to the martensite phase due to mechanical treatment, cold rolled. The peaks at low angles ($2\theta<20°$) have shown that the atomic density of the unit cell enhances mechanically [18,19].

From the figure, the increasing peaks intensity at low angles is correlated with an increase in the population of the martensite phase.

3.3 Magnetic Saturation

Figure 4 shows the change in magnetic properties of the SS 304 specimen due to deformation. It appears that the cold rolling deformation treatment has affected the magnetic properties of the sample [8]. The increase in the deformation value from 0 – 40% shows an increase in magnetic saturation from 0T to 0.78T. The increasing magnetic saturation value is due to the formation of a martensite phase. The phase formation is derived from the mechanically transformed austenite phase [6,7].

The Austenite and martensite phase have different magnetic properties, which is paramagnetic and ferromagnetic. Both of them have other characteristics of hysteresis curves. The martensite will have a higher magnetization saturation (Ms) than the austenite [9]. The shift in atomic positions in the crystal structure causes a magnetic moment to form based on the ferromagnetic properties that appear [20]. Lowering the magnetic coercivities value from 20% to 40% deformation indicates that the grain size is getting smaller [8].

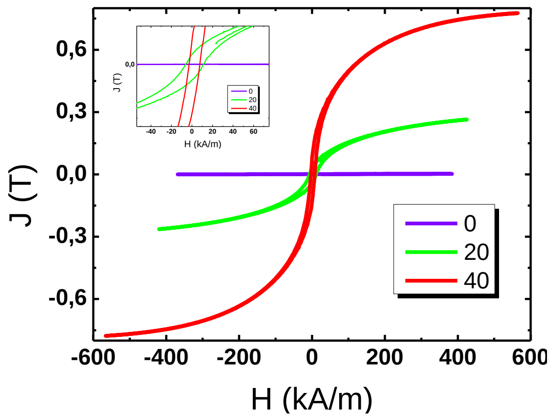


Figure 4. Magnetic properties of the specimen at 0%, 20%, 40% deformed.

A cold rolling method has changed the microstructure and crystalline structure of the compressed austenite phase to martensite. At deformation between 0 – 20%, the magnetic saturation value is not too high, but the phase can maintain its magnetic state based on its magnetic coercivity value. Meanwhile, at 40% deformation, the resulting magnetic saturation is high. The magnetic properties show that the ss 304 specimen responds strongly to the external magnetic field. When the specimen is brought close to a magnetic object, the two of them will attract each other. This phenomenon can be used to identify the deformation events in existing pipes by observing the interaction between SS 304 steel and external magnetic field materials brought near.

4. CONCLUSION

Cold rolling is one of the methods used to increase the hardness of SS 304 steel mechanically. The method deforms the crystalline structure and transforms the austenite phase within the grain into martensite. The phase change is followed by the generating of magnetic properties.

The increase of deformation percentage is followed by an increase in the magnetic saturation value and a change in the magnetic coercivity. The rise of Magnetic saturation value is influenced by the large population of martensite phase formed in grain. While the decreasing of magnetic coercivity value is caused by the changing grain shape. This magnetic property will respond to an external magnetic field. So magnetic properties can identify the deformation by observing the interaction of the SS 304 material with a magnetic object brought near.

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