# Effect of Grain Misorientation and Martensitic Transformation on Surface Roughening Behavior in Thin Austenitic Stainless Steel Foils

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# Effect of Grain Misorientation and Martensitic Transformation on Surface Roughening Behavior in Thin Austenitic Stainless Steel Foils

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## Abstract

Correlation of surface roughening, martensitic phase transformation (MPT) and grain misorientation (GM) of SUS 304 and 316 thin metal foils were studied through a uniaxial tensile stress state, repeated five times in 1,5 % strain level, and an Scanning Electron Microscope-Electron Backscatterred Diffraction (SEM-EBSD) analysis. The results showed that surface roughening increases proportional in coarse grain with grain size (Dg) of 9.0 µm both in SUS 304 and SUS 316 thin foil. Surface roughening increased proportionally in fine grain of Dg 1.5 µm lower than coarse grain of SUS 304 and 316 thin metal foils. The grain strength in SUS 304 is more inhomogeneous compared to SUS 316 that shown by SEM-EBSD results and as a result, increasing ratio of the surface roughness (Ra) is higher in coarse grain SUS 304 compared to SUS 316.

Keywords : Martensitic Phase Transformation (MPT); Grain Misorientation (GM); Grain Size (Dg).

## 1. Introduction

Stainless steel has wide application used in electronic, electrical power, biomedical, food and nuclear industry. Stainless steel easier to process, has excellent corrosion resistance, excellent mechanical properties. Stainless steel has received much attention in the recent decades as the consequence of the high demand for microparts. Martensitic – induced transformation occurs in stainless steel, because of plastic deformation applied to stainless steel. When plastic deformation applied to stainless steel, the martensite phase volume fraction (Mf) increase proportional [Engel et al.,2002; Xue et al.,2020]. Found that the strength increase and the roughness decrease after MPT occurred in stainless steel [Milad et al.,2008;Jah et al.,2008]. [Xue et al.,2020; Qin et al.,2020] found that the Mf in stainless steel strip occur after plastic deformation [Tomita et al.,1995] found that shear band intersection become the place of MPT nucleation. [Zhang,L et al.,2017] Studied evolution of surface roughness in face centered cubic (FCC), this it need to study evolution of surface roughness beside the materials with FCC structure. [Yoshida et al.,2014] Found that surface roughness affected mainly by Dg. Surface roughness increase in proportion with the increasing Dg. The increasing Dg affect to the decreasing ratio of surface roughness to Thickness (Ng). [Shimizu et al.,2001] concluded that surface roughness behavior affected by grain deformation. Furthermore, the surface roughness in sheet metal increases, because of different single grain deformation. [Furushima et al.,2013] Concluded weak grain deformation affect to surface roughening phenomena. [Aziz et al.,2020] Concluded that surface roughness increase proportional in coarse grain (Dg = 9 µm) and increase not proportional in the fine grain ( Dg 3µm and Dg 1,5µm). The MPT in coarse grain of SUS 304 thin foils is lower than fine grain. [Shuro et al.,2010] found that annealing treatment enhance the strength of

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stainless steel. It is very important to study on surface roughness behavior in SUS 304 thin metal foils with grain size 1,5 µm and 9,0 µm and compare each other in the same Dg with SUS 316 thin foil. In this study, we attempt to clarify the surface roughness mechanism in SUS 304 and SUS 316 thin metal foils with Dg below 10µm and the correlation of the MPT and grain misorientation to surface roughness behavior.

## 2. Methods

Thin metal foils of SUS 304 and SUS 316 rolled into a 0.1 mm thickness in grain sizes of Dg 9.0 and Dg 1,5 µm were used as the specimen since SUS 304 thin metal foils consist of more complicated phases in their microstructure than SUS 316 thin metal foils and the microstructure affects the MPT formation and the occurrence of surface roughening. The thin metal foils were provided by Komatsu Seiki Koshakuso Co. Ltd., Suwa City, Nagano, Japan. The materials were heat-treated in a condition of annealed at 400°C for one hour in order to make samples more relax for investigating how the MPT and GM affect to surface roughening of SUS 304 and SUS 316 thin metal foils with various grain size.

Before thin metal foils subjected with uniaxial tensile stress state at 1,5% strain level for each step, the thin metal foils are cleaned using ethanol combined with ultrasonic vibration for 30 minutes to increase the cleaning of the surface. The surface roughening behavior of SUS 304 and SUS 316 with various sizes of Dg were investigated. The samples are subjected to the uniaxial tensile stress state for five steps using commercial tensile test machine, Shimadzu Tensile Machine, with generic name AGX-50KNVD, capacity used is 5 KN, produced by Shimadzu Corp., Japan, with constant strain level. After the samples are subjected to the uniaxial tensile stress state, the surface roughness is measured using a confocal laser microscope (OLS-5000, produced by Olympus, Co., Japan). The microstructure of the materials after tensile test are analyzed by SEM-EBSD. The microstrucute behavior investigated using the SEM SU-70, produced by the Hitachi High Technology, Japan. The acceleration voltage was 5 kV, the emission current 16µA, and the working distance 10 mm. The phase transformation was investigated using EBSD Digi View (EDAX) in field-free mode, with an acceleration voltage 15 KV, emission current 16 µA, and working distance of 20 mm. The sample was observed in 30 µm x 50 µm area. The resolution of the EBSD machine 0,1 µm and the pixel binning is 8 x8.

## 3. Results and Discussion

The resultant stress-strain curves by the tensile test are shown in Fig.1. The tensile strength and ductility of SUS 304 is higher than SUS 316 thin foils for case of same grain size. For some kind of materials, the tensile strengths for fine grain are higher than that for coarse grain. Fig.2 and 3 show increase of the surface roughness for both materials in different Dg. Surface roughness Ra increases proportionally in coarse grain both in SUS 316 and SUS 304 thin metal foil with the same strain level. The increase ratio of Ra for SUS 304 is higher than that for SUS 316 as shown in Fig.2. Furthermore, the increase ratio for coarse grain is higher than that for fine grain for both materials by comparing Fig.2 and 3.

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The MPT and GM analysed by the SEM–EBSD are shown in Fig. 4 and 5, respectively. Fig.4 is the phase mapping that consists of MPT and austenite phase. The green one is MPT and the red one is austenite. Fig.5 is the kernel average misorientation (KAM) mapping that consists of GM indicated by the green color, red color and no GM by the blue color. Misorientation indicated by green color equals to 2$^{o}$. GM indicated by red color equals to 5$^{o}$ GM. The KAM map is obtained from the calculation of the misorientation between the centre point and all the surrounding points in the kernel are calculated and averaged (12). In SUS 304 both in coarse and fine grain, MPT and GM occur as shown in Fig.4 and 5 while MPT not occurs in SUS 316 both in coarse and fine grain and GM occurs in both in low and coarse grain as shown in figure 4 and 5.

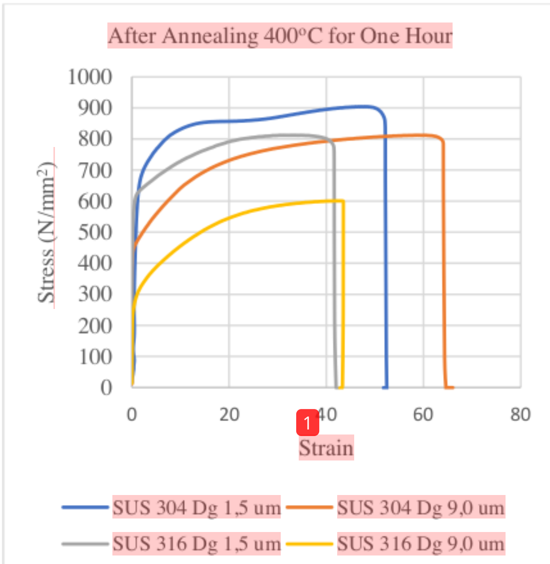


Figure 1. Material Deformation Behavior

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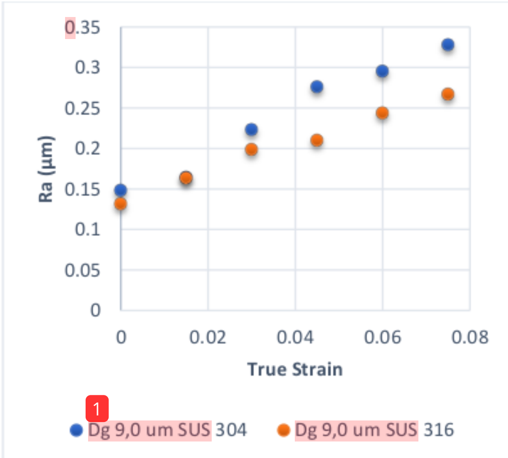


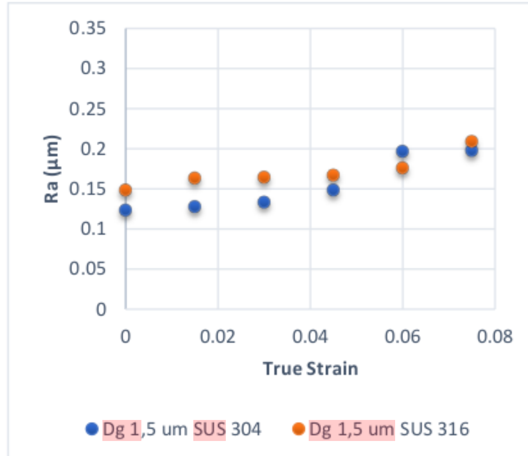
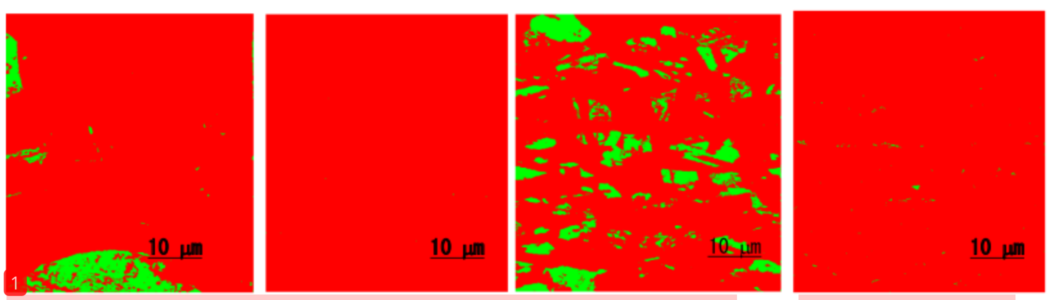




Figure 2. Surface Roughness in Dg 9,0µm    Figure 3. Surface Roughness in Dg.1,5um

Surface roughness increase proportional both in coarse grain and fine grain as shown in fig.2 for coarse grain and as shown in fig.3 fine grain as shown in fig.3. Surface roughness increase higher in coarse grain than fine grain, because of higher ductility in coarse grain than fine grain as shown in figure 1. Since thin metal foils have higher ductility, it means the grain strength in coarse grain is lower than fine grain.




SUS 304 Dg 9,0µm    SUS 316 Dg 9,0µm    SUS 304 Dg 1,5µm    SUS 316 Dg 1,5µm

• = MPT

• = Austenite Phase

Figure 4. EBSD Phase Mapping at 7,5% in accumulation

MPT occur higher in fine grain SUS 304 thin foil than coarse grain after uniaxial tensile test. MPT occur uniform in fine grain of SUS 304 thin metal foil after uniaxial tensile stress state that affect to homogeneous grain strength. MPT not occur in SUS 316 thin metal foils both in fine grain and coarse grain. MPT occur not uniformly in SUS 304 coarse grain that affect to inhomogeneous grain strength as shown in fig.4.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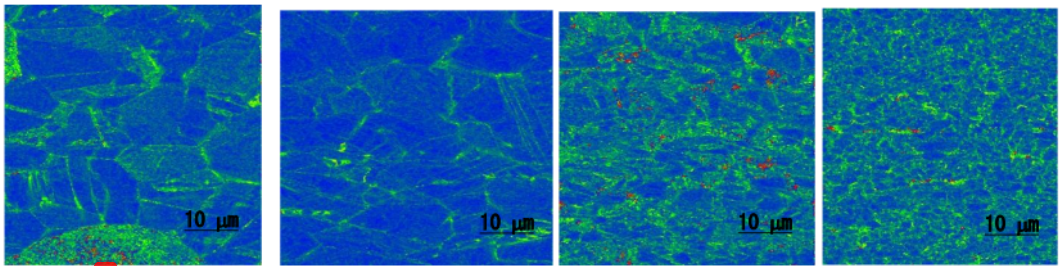


GMSUS 304 Dg 9,0 µm GM SUS 316 Dg 9,0 µm GM SUS 304 Dg 1,5 µm GM SUS 316 Dg 1,5 µm

• = 2° Misorientation
• = 5° Misorientation
• = No Misorientation

Figure 5. EBSD KAM Mapping at 7,5% in accumulation

MPT and GM in SUS 304 is higher than SUS 316 thin metal foil that affect to higher grain strength in SUS 304 thin foil compared to SUS 316 thin metal foil. The higher grain strength affects to more difficult in grain deformation. Non uniformity of grain strength in SUS 304 thin foil affects to more inhomogeneous grain. More inhomogeneous SUS 304 grain strength could affect to higher surface roughness in SUS 304 thin metal foil compared to SUS 316 thin metal foil with coarse grain. The SUS 316 coarse grain consists of homogeneity phase mapping as shown in Fig.4 and inhomogeneity GM mapping in Fig.5, but Ra in SUS 304 is higher than SUS 316 coarse grain. It means that inhomogeneity of grain affected by MPT is stronger than that affected by GM.

On the other hand, GM in SUS 304 fine grain is the same with SUS 316 that affect to the strength and ductility of SUS 304 and 316 thin foils. GM spread homogenous both in SUS 304 and 316 thin foils. GM spreads homogenous both in SUS 304 and 316 thin foils. The strength of SUS 304 affected by the high MPT and high GM. The strength of SUS 316 affected only by high GM. The existing of MPT and GM in SUS 304 affect to higher strength compared to SUS 316.The lower ductility in SUS 316 compared to SUS 304 caused by the existing of α' phase in SUS 316 and SUS 304 after annealing in 400°C for one hour. The lower ductility in SUS 316 compared to SUS 304 thin foils also caused by lower toughness of SUS 316 thin foil compared to SUS 304 thin foil (12,13). Even grain strength of SUS 304 is higher compared to grain strength of SUS 316 fine grain, but they have similar Ra. The reason is the grain deformation mechanism in which each grain rotates with the same angle from the normal direction (10).

The findings in this research are MPT and GM give different effect to Ra for different Dg. The inhomogeneous grain deformation affect to Ra. The quantity of GM, MPT and Dg give effect to the inhomogeneous grain deformation. The MPT, GM and and Dg are an important kinds on clariying Ra mechanism during tensile test in SUS 304 and SUS 316 thin metal foils.

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The coarse grain will affect to higher Ra compared to fine grain, because the coarse grain has more inhomogeneous grain strength compared to fine grain.

## 4. Conclusions

The effect of MPT to Ra is higher than Effect of GM to Ra in coarse grain. The increase of Ra in SUS 304 coarse grain is higher than fine grain, because of lower slip band intersection that affect to lower MPT in coarse grain compared to fine grain.

In SUS 316 coarse grain has more inhomogeneous grain strength compared to fine grain that affect to higher increase of Ra in coarse grain compared to fine grain. The higher inhomogeneous grain strength in coarse grain of SUS 316 thin foil affected by the lower GM in coarse grain compared to fine grain.

In fine grain of SUS 304 and SUS 316 have similar Ra behavior because of the similar homogeneous grin strength. The Ra behavior in SUS 304 coarse grain is higher than SUS 316 thin foil both in coarse grain and fine grain.

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