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Effect of Phase Transformation on Surface Roughening Behavior in Austenitic Thin Metal Foils

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Abstract. Stainless steels have wide application in the field of micro manufacturing industry. The demand of austenitic stainless steel foils increase unabated every year. The size effect occur in thin metal foils because of low number of grain. Martensitic phase transformation (MPT) occur after plastic deformation subjected to stainless steel thin metal foils. Beside that, free surface roughening occur in thin metal foils after plastic deformation. The surface roughening mechanism in stainless steel thin metal foils after plastic deformation such as uniaxial tensile test not yet clarified well. The aim of these research are to clarify effect of MPT and grain misorientation (GMO) to surface roughening behavior in austenitic stainless steel foils. MPT and GMO have huge effect to surface roughening behavior in stainless steel thin metal foils. The effect of GMO and MPT to surface roughening in SUS 316 and 304 thin metal foils were studied through uniaxial tensile stress state, repeated five times in 6% strain level for one time strain and 30% strain for the total of strain level. After that, an Scanning Electron Microcope- Electron Backscatter Diffraction (SEM-EBSD) analysis applied to 304 and 316 thin metal foils. The result showed that in stainless steel thin metal foil, surface roughening increase proportional both in fine gain (grain size 1,5 μm) and in coarse grain (grain size 9,0μm). The surface roughening in coarse grain, increased higher than in fine grain. 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 fine grain and coarse grain of SUS 304 compared to SUS 316. The inhomogeneity of the grain strength in SUS 304 thin metal foil is higher than SUS 316 thin metal foil as shown by SEM-EBSD result. Furthermore, the increased surface roughness in stainless steel 304 is higher than stainless steel 316 thin metal foil both in fine grain and coarse grain.

Introduction

The wide useful of stainless steel such as for biomedical, electronic, electrical power, nuclear and food industry attract high demand of micro forming industry product in the recent decades. When uniaxial tensile test applied to stainless steel, over the yield point, martensitic phase transformation (MPT) occurred. After plastic deformation to stainless steel, not only MPT increase, but also martensitic volume fraction (Mf) increase [1–3]. MPT increase the strength of stainless steel thin foil but decrease the toughness[4,5]. Xue et al. [1] and Qin et al. [6] found that the uniaxial tensile test affect to Mf in stainless steel strip. Tomita et al. [7] found that Plastic deformation to stainless steel affect to shear band intersection and nucleation of MPT.

Zhang,L et al [8] Used face center cubic (FCC) materials on clarifying the surface roughness evolution. It need to study surface roughening beside FCC structure. Kengo Yoshida et al. [9] found that grain size (Dg) is an important factor that affect to surface roughening. It need to investigate surface roughness with Dg below 10 μm in thin metal foils. Shimizu et al. [10] concluded that surface roughness affected by grain deformation. grain plastic deformation affect to surface roughness behavior. beside that, the increase of surface roughness in sheet metal depend on single grain deformation. The different plastic deformation in a unit grain increases the surface roughness. Furushima et al, [11] Weak grain deformation affect to surface roughening.

Aziz et al [12] concluded that the surface roughness behavior in SUS 316 and SUS 304 thin foils depend on the existence of MPT in various Dg below 10μm. When the MPT is lower, the surface roughness increase higher. Surface roughness increase proportional in coarse grain (Dg = 9μm) and not proportionally in fine grain (Dg =1,5μm) of SUS 304 thin metal foils. Surface roughness affected by grain misorientation in fine grain with Dg 1,5 μm of SUS 316 thin metal foil. Shuro et al [13] concluded that annealing in austenitic stainless steel increase α' phase in grain boundary of stainless steel that increase the strength of stainless steel. The increase in strength of stainless steel depend on the existence of α' phase in grain boundary that produced by annealing treatment in materials. The increase of α' affect to an increasing strength of material. It need experiment of surface roughness behavior in SUS 316 thin foils with grain size below 10 μm. It need study in surface roughening behavior deeply in stainless steel thin metal foils.

In this study, we attempt to clarify the surface roughness mechanism in stainless steel with Dg below 10μm and the correlation of the MPT and grain misorientation (GMO) to surface roughness behavior. In order to achieve that, a uniaxial tensile test applied, surface roughness measured and analyzed for every step of tensile test until five steps. Then, thin metal foils analyzed using SEM-EBSD.

Research Method

Stainless steel thin foil of SUS 316 and SUS 304 with Dg 9,0 μm and 1,5 μm was deformed with rolling technique into 0,1mm in thickness. The reason on using these metal foils that SUS 304 has more complicated phase than SUS 316 thin metal foil. The microstructure in SUS 304 and SUS 316 thin foil affect to the occurrent of the MPT and grain misorientation (GMO). MPT and GMO may have great effect to surface roughness behavior of SUS 316 and SUS 304 thin metal foil. The material sample were provided by Komatsu Seiki Koshakuso Co. Ltd., Suwa City, Nagano, Japan. In order to remove residual stress, thin foil materials of SUS 304 and SUS 316 were annealed at 400°C for one hour. Then, initial surface roughness behavior measured, after that uniaxial tensile test conducted to thin metal foils at first step of tensile test with 6,0% strain level, after that surface roughness measured and analyzed. The uniaxial tensile test and surface roughness measurement repeated five times with constant strain level. The value of the surface roughness is average of three kind experiment using three samples. Before uniaxial tensile test, thin metal foils were cleaned using electric vibration for 30 minutes.

The investigation in surface roughening behavior of material samples with various grain size (Dg) were verified using uniaxial tensile test 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 that, the surface roughness behavior investigated using Confocal Laser Microscope (OLS-5000, produced by Olympus, Co., Japan). The microstructure of the materials after tensile test are analyzed by SEM-EBSD. SEM SU-70 used produced by the Hitachi High Technology corporation, Japan was used to investigate the microstructure behavior. The 5 kV voltage acceleration was used. Beside that, the emission current of 16μA and working distance 20 mm were used. The area of observation was 30 μm x 50 μm area. The EBSD step machine resolution is 0,1 mm and the pixel binning is 8x8.

Result and Discussion

Uniaxial tensile test subjected to thin metal foils until thin metal foils fractured. After that, we obtain stress strain curve as shown in Fig. 1. The materilas with fine Dg has higher tensile strength and lower ductility. SUS 304 thin metal foils has higer ductility and higher tensile strength than SUS 316 thin metal foil as shown in Fig.1. The increase of surface roughness with different materials and the same Dg shown in Fig.2 and 3. Surface roughness increase proportional both in fine Dg and coarrse Dg of SUS 316 and SUS 304 thin metal foils. Surface roughness increase higher in coarse Dg than fine Dg both in SUS 316 and SUS 304 thin metal foils. Surface roughness in SUS 304 increase higher than SUS 316 in the same Dg as shown in Fig.2 and Fig.3, because SUS 304 more ductile than SUS 316 as shown in Fig.1.

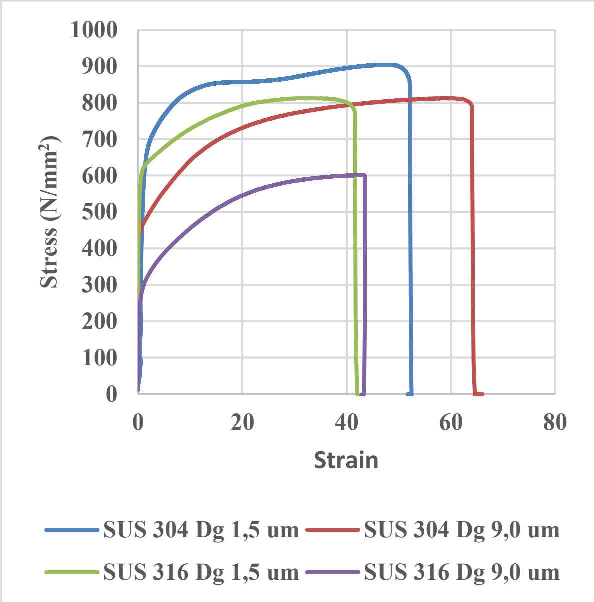
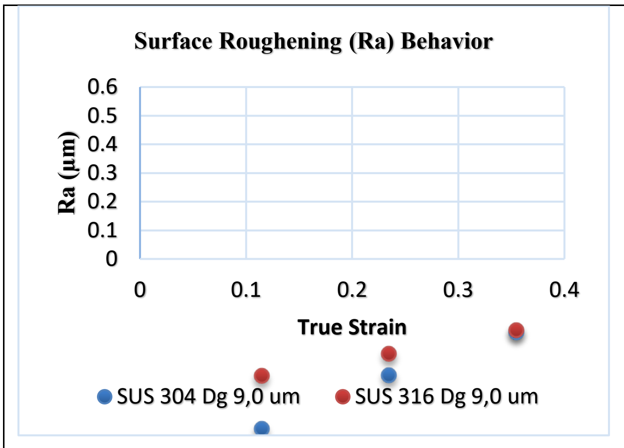


Figure 1. Material deformation behavior

The GMO and MPT analysed by the SEM–EBSD are shown in Fig. 4 and 5, respectively. Fig.4 is the analysis of phase mapping that consists of MPT and austenite phase. The red one of the picture is austenite and the green one of the picture is martensite. Kernel average misorientation (KAM) mapping that consists no GMO by the blue color, GMO indicated by the green color, red color as shown in Fig.5. GMO showed by red color equals to 5°. GMO showed by green color equals to 2° . GMO showed by blue color equal to 0°. The KAM map is obtained from the calculation of the misorientation between the centre point and all the surrounding in the kernel are calculated and averaged (12). In the SUS 304 thin foil both in coarse and fine grain, The occurent of MPT and GMO are shown in Fig.4 and Fig 5. In SUS 316 thin metal foil, MPT not occur both in coarse and fine grain as shown in Fig.4. in SUS 316 thin metal foil, GMO occurs both in low and coarse grain as shown in Fig 5.



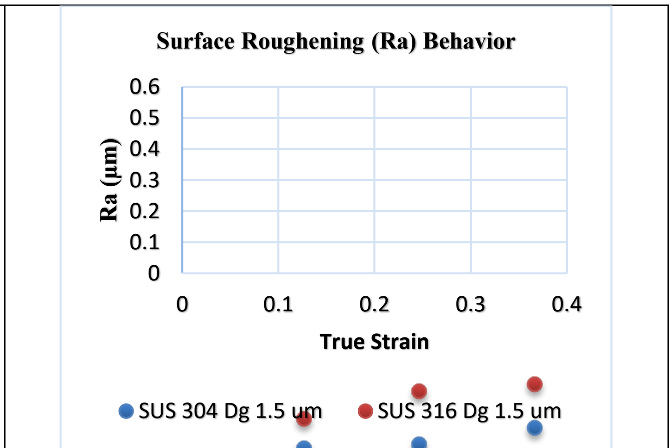
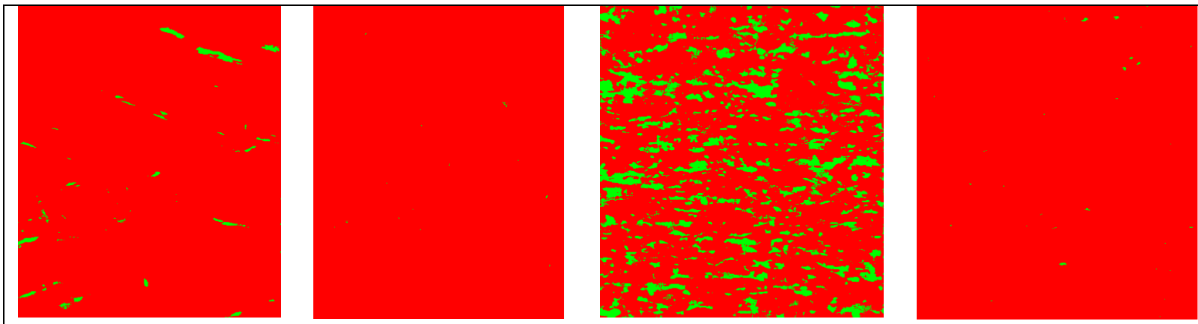


Figure 2. Surface roughness in Dg 9,0 µm	**Figure 3.** Surface roughness in Dg 1,5 µm

The strain level increase higher in higher Dg than fine Dg. The strength and ductility of SUS 304 is higher than SUS 316 in the same Dg. This phenomena may affect to surface roughening (Ra) behavior. The strength and ductility in fine Dg of SUS 304 thin metal foil is highest than the whole samples as shown in fig.1.

Surface roughening (Ra) behavior increase proportional both in SUS 304 and SUS 316 as shown in fig 2 and fig 3. Surface roughness increase higher in coarse Dg than fine Dg. The increase of surface roughness has the correlation with the strength and ductility as shown in fig 1. The higher ductility of the thin metal foils of SUS 304 and SUS 316 have the higher surface roughness compared to lower ductility of the thin metal foils.

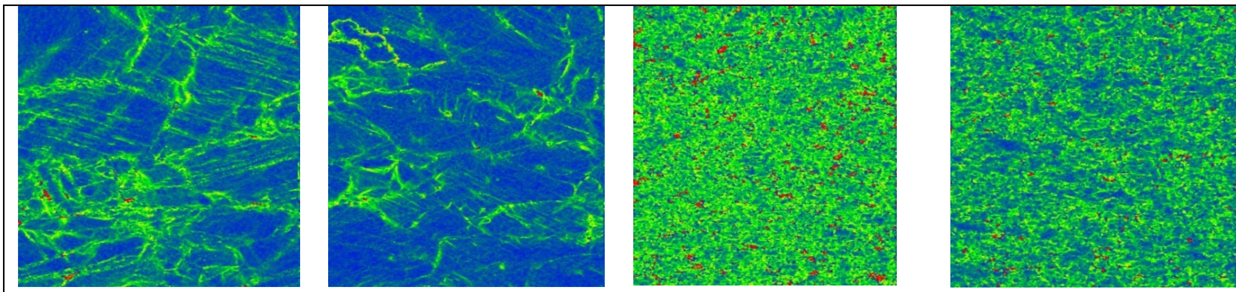


a. SUS 304 Dg 9,0µm | b. SUS 316 Dg 9,0µm | c. SUS 304 Dg 1,5µm | d. SUS 316 Dg 1,5µm

• = MPT
• = Austenite

Figure 4. EBSD phase mapping at 30%

Fig. 4 A is phase mapping after tensile test for five steps in Dg 9,0 µm after tensile test in SUS 304. The MPT is spread not uniform and grain become inhomogeneous. Fig. 4B is phase mapping after tensile test for five steps in Dg 9,0 µm after tensile test in SUS 316. There are no MPT after tensile test for five steps. Fig. 4 C is phase mapping after tensile test for five steps in Dg 1,5 µm SUS 304. The MPT spread uniform and grain become homogeneous. Fig.4D is phase mapping after tensile test for five steps in Dg 1,5 µm SUS 316. The grain become homogeneous.



a. SUS 304 Dg 9,0µm | b. SUS 316 Dg 9,0µm | c. SUS 304 Dg 1,5µm | d. SUS 316 Dg 1,5µm

• = 2° Green Misorientation
• = 0° Green Misorientation

Figure 5. EBSD KAM mapping at 30%

Fig. 5A is GMO in Dg 9,0 µm after tensile test in SUS 304. The GMO spread not uniform and the grain become inhomogeneous. Fig. 5B is GMO in Dg 9,0 µm after tensile test in SUS 316. The GMO spread not uniform and the grain become nonhomogeneous. Fig.5C is GMO in Dg 1,5µm SUS 304. The GMO spread uniform and the grain become homogeneous. Fig.5D is GMO in Dg 1,5 µm SUS 316 that spread uniform and the grain become homogeneous.

The higher grain strength in SUS 304 than SUS 316 thin metal foil caused by higher MPT and GMO in SUS 304 in comparison with SUS 316 thin metal foils. The GMO in SUS 304 is nearly equal with SUS 316 thin metal foils. But, the MPT in SUS 304 much higher than SUS 316 thin foil. Grain deformation become more difficult since grain strength become higher and more uniform. Non uniformity of grain strength in SUS 304 thin foil affects to more inhomogeneous grain. Non uniformity of grain strength is similar with inhomogeneous grain strength. MPT is the dominant factor that affect to the grain strength in SUS 304 thin foil. The inhomogeneous grain strength in coarse grain is higher than fine grain in SUS 304 thin metal foil. The more inhomogeneous of grain strength affect to higher surface roughness in thin foil of SUS 304 and SUS 316 after plastic deformation with the same strain level. In coarse grain of SUS 316, the grain strength only affected by low volume of GMO. In fine grain of SUS 316, the grain strength affected by high volume of GMO and No MPT occured. The SUS 316 thin metal foil consist of no MPT both in coarse and fine grain. the surface roughness in SUS 304 is higher than SUS 316, because the inhomogeneous grain strength in SUS 316 is lower than SUS 304. The SUS 316 inhomogeneity phase mapping is shown in Fig.4 and inhomogeneity GMO mapping in SUS 316 is shown in Fig.5, but surface roughness in SUS 304 is higher than SUS 316 coarse grain. It means that inhomogeneity of grain strength affected by MPT is stronger than inhomogeneity of grain strength affected by GMO.

On the other hand, GMO 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. GMO spread homogenous both in SUS 304 and 316 thin foils. The strength of SUS 304 affected by the high MPT and high GMO. The strength of SUS 316 affected only by high GMO. The existing of MPT and GMO 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^{o}C for one hour (13). The lower ductility in SUS 316 compared to SUS 304 thin foils also caused by lower inhomogeneous grain strength in SUS 316 thin foil compared to SUS 304 thin foil (11-13). Even grain strength of SUS 304 is higher compared to grain strength of SUS 316 fine grain, but they have surface roughness of SUS 304 is higher than SUS 316. The reason is the grain deformation mechanism in which each grain rotates with the higher angle of SUS 304 than SUS 316 thin metal foils from the normal direction (10).

It is found that the effect of MPT and GMO on surface roughness (Ra) are different for different Dg. Ra affected by inhomogeneous grain deformation. The inhomogeneous grain deformation affected by the quantity of MPT, GMO and Dg. Three kinds of influential factors have an important role on clarifying the Ra mechanism in this research. The inhomogeneous grain in the higher Dg will affect to higher Ra. The homogeneous grain in the lower Dg will affect to lower Ra.

Conclusion

In SUS 304 thin metal foil, the Ra increases higher for coarse grain than fine grain, because of the lower slip band intersection in coarse grain that affect to lower MPT in coarse grain, compared to fine grain.

In SUS 316 thin metal foil, the Ra increase higher for coarse grain compared to fine grain, because of GMO lower in coarse grain compared to fine grain that affect to more inhomogeneous grain strength in coarse grain compared to fine grain.

Surface roughness in SUS 304 thin metal foil increase higher than SUS 316 thin metal foil in the same Dg both in fine grain and coarse grain. The effect of MPT to Ra is higher than GMO in stainless steel.

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