Effect of Martensitic Transformation and Grain Misorientation on Surface Roughening Behavior in Thin Stainless Steel Foils During Tensile Test

Abdul Aziz (1), Ming Yang (1), Tetsuhide Shimizu (1), Tsuyoshi Furushima (2)

1. Tokyo Metropolitan University, Hino Campus, 6-6-Asahigaoka, Hinoshi, Tokyo Japan, 191-0065
2. Institute of Industrial Science, The University of Tokyo, 4-6-1, Meguro City, Tokyo Japan, 153-8505

Abstract

Surface roughening, martensitic phase transformation (MPT) and grain misorientation (GM) of SUS 304 and 316 thin metal foils were studied through two experiment : a uniaxial tensile stress state, repeated five times in 1% strain level, after that , an Scanning Electron Microscope-Electron Backscatterr Diffraction (SEM-EBSD) investigation. The correlation between MPT, GM and surface roughening were evaluated after five times tensile test. The result showed that surface roughening increases proportional in coarse grain with grain size (Dg) 9µm both in SUS 304 and SUS 316 thin foil. Surface roughening increased not proportional in fine grain Dg 3µm and Dg 1,5 µm both in SUS 304 and 316 thin foils. Surface roughness (Ra) increased higher in coarse grain SUS 304 after 5% strain level compared to SUS 316 after 5% strain level, because grain strength in SUS 304 is more inhomogeneous compared to SUS 316 that shown by SEM-EBSD result.

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

1.Introduction

Stainless steel has excellent corrosion resistance, easier to process, and has been widely used in electronic, biomedical, electrical power, food and nuclear industry. Besides that, the high demand for microparts has received much attention in the recent decades. When a plastic deformation is applied to the stainless steel, martensitic-induced transformation occurs in stainless steel. The martensitic phase volume fraction (Mf) increases in proportion to the increase in plastic deformation [1–3]. Martensitic phase transformation (MPT) decreases the toughness but increases the strength of stainless steel [4,5]. Xue et al. [1] and Qin et al. [6] found that the deformation in a stainless steel strip affects the Mf. Tomita et al. [7] found that MPT nucleation occurs because of the shear band object of their recent study on the evolution of surface roughness. Besides the FCC structure, it is very important to study surface roughening. Kengo Yoshida et al. [8] found that surface roughness is mainly affected by Dg. When the Dg increases, the surface roughness to thickness (Ng) ratio decreases. The effect of surface roughness in metal foils with a Dg lower than 10 µm needs to be investigated. Shimizu et al. [9] concluded that grain deformation affects surface roughness behavior. Furthermore, a different single grain deformation increases the surface roughness in sheet metal. Furushima et al. [10] Concluded that surface-roughening phenomena occur because of a weak grain deformation. Aziz et all [11] concluded that the MPT affect to surface roughness behavior in thin metal foils of SUS 304 with various Dg lower than 10 µm. When the MPT is lower, the surface roughness increase higher. Surface roughness increase proportional in coarse grain (Dg = 9µm) and increase not proportional in fine grain (Dg 3µm and Dg 1,5µm) 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 all (12) concluded that annealing in austenitic stainless steel increase α' phase in grain boundary of stainless steel that increase the strength of stainless steel. It need experiment of surface roughness behavior in SUS 316 thin metal foils with grain size over than 1,5 µm. In this study, we attempt to clarify the surface roughness mechanism in austenitic stainless steel with Dg below 10µm and the correlation of the MPT and grain misorientation to surface roughness behavior.

2.Materials and Methode

Thin metal foils SUS 304 and SUS 316 were heat treated and rolled into a 0.1 mm thickness. The thin metal foils were obtained from Komatsu Seiki Koshakuso Co. Ltd., Suwa City, Nagano, Japan. This study investigates how the austenitic stabilizer affects the MPT induced by plastic deformation. Furthermore, based on the chemical composition, SUS 304 thin metal foils consist of more complicated phases in their microstructure than SUS 316 thin metal foils. The microstructure affects the MPT formation and the occurrence of surface roughening.

the materials are subjected to the uniaxial tensile stress state, they are cleaned using ethanol and combined with ultrasonic vibration for 30 min to increase the cleaning of the surface.

The samples are subjected to the uniaxial tensile stress state for five steps, with constant strain. After the samples are subjected to the uniaxial tensile stress state, the surface roughness is measured using a confocal laser microscope, the Keyence Confocal Laser Microscope (VE 8800, Keyence Co., Japan). The uniaxial tensile test was conducted using a commercial tensile test machine, Autograph AG-IS 50 kN, produced by Shimadzu Corp., Japan, with capacity of 50 kN. The surface roughening behavior of SUS 304 and SUS 316 with various sizes of Dg were investigated using a uniaxial tensile test.

3.Result and Discussion

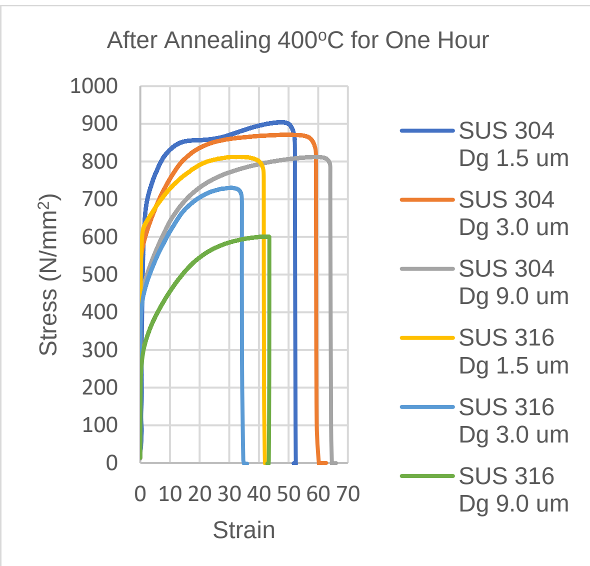

Figure 1. Material Deformation Behavior

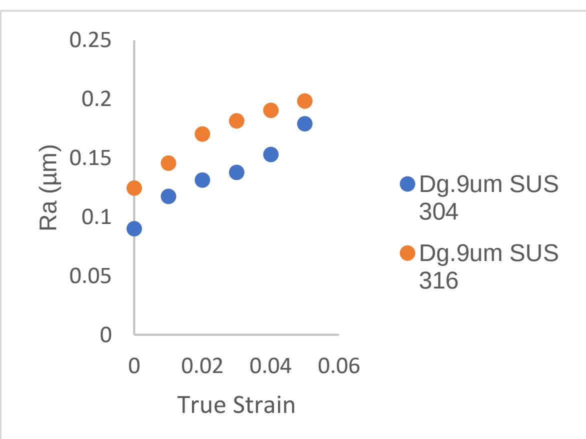

Figure 2. Surface Roughness in Dg

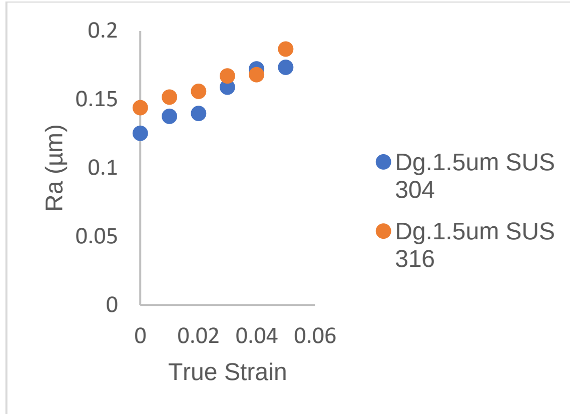

Figure 3. Surface Roughness in Dg.1.5um

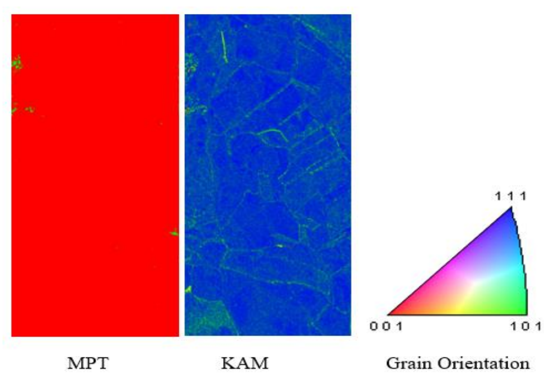

Figure 4. EBSD of SUS 316 Dg 9 um at 5%

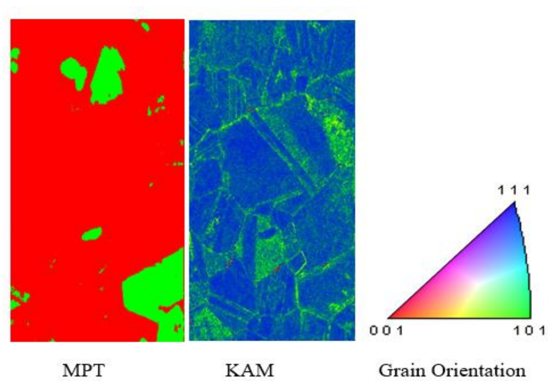

Figure 5. EBSD of SUS 304 Dg.9 um at 5%

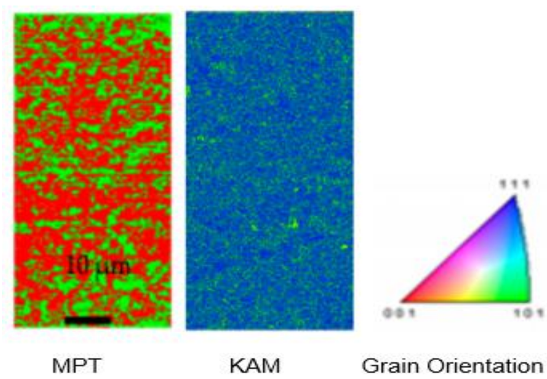

Figure 6. EBSD of SUS 304 Dg 1,5 um at 5%

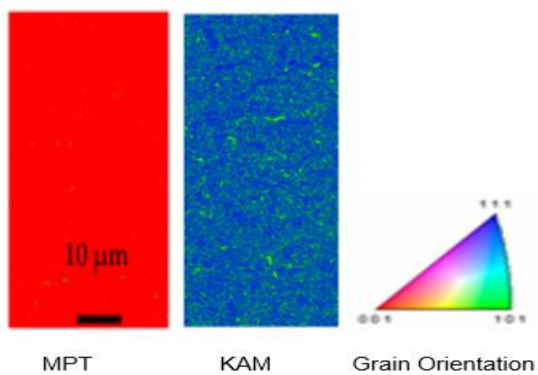

Figure 7. EBSD of SUS 316 Dg.1,5 um at 5%

The tensile strength and ductility of SUS 304 higher than SUS 316 thin foils, as shown in figure 1. In coarse grain, Ra increase higher than fine grain as shown in figure 2 and 3. In SUS 304 both in coarse and fine grain, MPT and GM occur as shown in figure 5 and 6. MPT not occur in SUS 316 both in coarse and fine grain, GM occur in SUS 316 thin foil both in low and coarse grain as shown in figure 4 and 7.

Ra increase proportional in coarse grain (Dg = 9um) both in SUS 316 and SUS 304 thin metal foils with the same strain level as shown in figure 2. Ra increase higher in coarse grain compared to fine grain as shown in figure 2 and 3. MPT and grain misorientation 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 affect to more difficult of grain deformation. Non uniformity of grain strength in SUS 304 thin foil affect to more inhomogenous grain. More nonhomogenous SUS 304 grain strength affect to higher surface roughness in SUS 304 thin metal foil compared to SUS 316 thin metal foil with coarse grain. Small MPT and grain misorientation occurs at SUS 304 which is higher than thin foil SUS 316. Small MPT increase the strength of the inhomogenous grains in SUS 304. MPT occur because of slip band intersection during plastic deformation. The slip band intersection will become place of martensitic embryo and martensitic nucleation until become MPT. This condition make the strength of inhomogeneous grain in SUS 304 higher than SUS 316, thus the roughness in SUS 316 coarse grain become lower compared to SUS 304 coarse grain. The difference of increasing surface roughness in SUS 304 compared to SUS 316 coarse grain is low. The roughness increase in SUS 304 thin foil higher is than SUS 316 thin foil in coarse grain with the same strain level. It means the inhomogeneous grain in SUS 304 is higher compared to SUS 316 thin metal foil that affect to higher surface roughness in SUS 304 thin foil compared to SUS 316 thin metal foil. Based on material deformation behavior shown that SUS 304 thin foil in coarse grain has higher strength and higher ductility compared to SUS 316 thin foil. it means in SUS 304 thin foil is more difficult to deform than SUS 316 thin foil, but SUS 304 has more ductility than SUS 316. In other word that SUS 304 after annealing for one hour is more tough than SUS 316 thin foil. the higher toughness in SUS 304 coarse grain affected by the existing of MPT and GM fraction volume are higher than SUS 316 as shown in SEM-EBSD result. MPT and GM in crease the strength of materials. The nonhomogenous existing of MPT and GM affect to increase the ductility of SUS 304 compared to SUS 316 thin foils in coarse grain.

Ra increase smaller in fine grain than coarse grain as shown in figure 2 and 3 with the same strain level, because of lower inhomogeneous grain deformation in fine grain compared to coarse grain with the same strain level. According to the Hall-Petch equation, the finer grain, the higher strength of the grain or material. The GM in SUS 316 with fine grain is higher compared to SUS 316 with coarse grain. It means the inhomogenous grain in SUS 316 fine grain is lower compared to SUS 316 coarse grain. This condition affect to the more difficult to deform in SUS 316 thin metal foil with fine grain compared to SUS 316 thin metal foil with coarse grain. MPT and GM in SUS 304 with fine grain is higher than SUS 304 with coarse grain. It means the SUS 304 thin foil with fine grain is more difficult to deform compared to SUS 304 with coarse grain. Based on material deformation behavior as shown in figure 1, the strength and ductility of SUS 304 is higher than SUS 316 thin foils both in fine and coarse grain. This occurrent phenomena caused by the MPT in SUS 304 is higher than SUS 316 that affect to the higher strength of SUS 304 compared to SUS 316 fine grain. The GM in SUS 304 similiarly the same with SUS 316 that affect to the strength of and ductility of SUS 304 and 316 thin foils. GM spread in homogenous both in SUS 304 and 316 thin foils. The strength of SUS 304 affected by the high MPT and GM. The strength of SUS 316 affected only by GM. The existing of MPT and GM in SUS 304 affect to higher strength compared to SUS 316. The lower ductility of SUS 316 than SUS 304 thin foils affected by the grain strength homogeneity in SUS 316 is higher than SUS 304. The lower ductility in SUS 316 compared to SUS

304 also caused by the existing of α' phase in SUS 316 higher than SUS 304 after annealing in 400ºC for one hour.

Based on SEM - EBSD analysis for SUS 304 and SUS 316, the GM in KAM map in SUS 304 is higher than SUS 316 as shown in figure 4,5,6 and 7. It means SUS 304 is more inhomogenous than SUS 316 both in fine and coarse grain. Beside that, there are MPT in SUS 304, even in small volume fraction that affect to the increasing grain strength together with grain misorientation. Thus the grain in SUS 304 is more inhomogenous compared to a grain in SUS 316 with coarse grain. This condition affect to higher surface roughness in SUS 304 compared to SUS 316 thin metal foils with coarse grain in the same strain level. In fine grain, the grain strength of SUS 304 affected by the very high MPT and high GM. In fine grain, the grain strength of SUS 316 only affected by high GM. From this phenomena, concluded that the grain strength in SUS 304 fine grain is higher than SUS 316 thin foils. The inhomogenous grain strength in SUS 316 and 304 similiarly the same as shown in SEM – EBSD result that affect to similarity of the Ra increase with the same strain level.

4.Conclusion

- In SUS 304 thin foil, the Ra increases higher for coarse grain than fine grain, because of the lower slip band intersection, which affect to lower MPT in coarse grain, compared to fine grain. The slip band intersection increases more in fine grain, compared to coarse grain. As result, the MPT increases more in fine grains than in coarse grains. Beside that, GM in fine grain higher than coarse grain, that affect to more inhomogeneous grain strength in coarse grain compared to fine grain.
- In SUS 316 thin foil, the Ra increase higher for coarse grain compared to fine grain, because of GM lower in coarse grain compared to fine grain that affect to more inhomogeneous grain strength in coarse grain compared to fine grain.
- In fine grain, SUS 316 and SUS 304 thin metal foil have the similar Ra with the same strain level, because they have the same inhomogeneous grain strength. In coarse grain, SUS 304 thin foil has higher Ra than SUS 316 thin foil, because SUS 304 thin foil has higher inhomogeneous grain strength than SUS 316 thin foil.

5.References

1) Xue, Z.Y.; Zhou, S.; Wei, X.C. Influence of pre-transformed martensite on work-hardening behavior of SUS 304 metastable austenitic stainless steel. J. Iron Steel Res. Int. 2010, 17, 51–55.
2) Engel, U.; Eckstein, R. Microforming—From basic research to its realization. J. Mater. Process. Technol. 2002, 125–126, 35–44.
3) Furushima, T.; Manabe, K. Experimental and Numerical Study on Deformation Behavior in Dieless Drawing Process of Superplastic Microtubes. J. Mater. Process. Technol. 2007, 191, 59–63.
4) Milad, M.; Zreiba, N.; Elhalouani, F.; Baradai, C. The effect of Cold Work on Structure and Properties of AISI 304 Stainless Steel. J. Mater. Process. Technol. 2008, 203, 80–85.
5) Jha, A.K.; Sivakumar, D.; Sreekumar, K.; Mittal, M.C. Role of Transformed Martensite in the Cracking of Stainless Steel Plumbing Lines. Eng. Fail. Anal. 2008, 15, 1042–1051.
6) Qin, Z.; Xia, Y. Role of strain–induced martensitic phase transformation in mechanical response of 304L steel at different strain–rates and temperatures. J. Mater. Process. Technol. 2020, 280, 116613.
7) Tomita, Y.; Iwamoto, T. Constitutive modeling of TRIP steel and its application to the improvement of mechanical properties. Int. J. Mech. Sci. 1995, 37, 1295–1305.
8) Zhang,L;Xu,W;Liu,C;Ma,X;Long,J. Quantitative Analysis of Surface Roughness Evolution in FCC Polycrystalline Metal during Uniaxial Tension. Comput, Mater.Sci.2017,132,19-29.
9) Yoshida, K. Effect of Grain Scale Heterogeneity on Surface Roughness and Sheet Metal Necking. Int. J. Mech. Sci. 2014, 83, 48–56.
10) Shimizu, I.; Okuda, T.; Abe, T.; Tani, H. Surface Roughening and Deformation of Grains during Uniaxial Tension of Polycrystalline Iron. JSME Int. J. Ser. A 2001, 44, 499–506.
11) Aziz, Abdul; Yang, Ming. Effect of Martensitic Transformation and Grain Size on The Surface Roughening Behavior in SUS 304 and SUS 316 Thin Metal Foils. A.Eng.MDPI. October 2020.
12) Innocent, Shuro; Umemoto Minoru; Todaka, Yoshikazu; Yokoyama, Seiji; Phase Transformation and Annealing behavior of SUS 304 Austenitic Stainless Steel Deformed by High Pressure Torsion. Material Science Forum.Vols.654-656 (2010) pp334-337.