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Microstructure and Evaluation of Wire-brushed Mg Sheets

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Abstract

Wire-brushing was applied to surfaces of AZ31B Mg alloy sheets, and the microstructure, mechanical properties and corrosion resistance were investigated. A nanocrystalline surface layer, which consists of equiaxed nano-crystals, can be obtained by the wire-brushing. The mean grain size in the nanocrystalline layer depends on the condition, and the smallest mean grain size was 68.2nm. The grain size depends on the feed speed rather than pressing load. The proof stress and tensile strength slightly increased after the wire-brushing. Corrosion resistance of the Mg sheet significantly increased after the wire-brushing.

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Keywords: AZ31B alloy; wire-brushing; nano crystal; tensile test; surface roughness; corrosion resistance

1. Introduction

Ultragrain refinement of metallic materials by the severe plastic deformation (SPD) process has been much studied because they show high mechanical properties. The SPD process, which mechanically induces large strain into materials, can fabricate bulk ultrafine grained (UFG) materials consisting of the ultrafine grain smaller than 1μm. The UFG materials exhibit high mechanical properties superior to conventional materials with coarse grains [1-3]. In the SPD process, increasing deformation temperature can be not avoided, although all of the grains in the sample can be refined to smaller than 1μm. Therefore, the smallest grain size obtained by the SPD process is limited, and it is usually around 100nm [1,3]. On

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the other hand, in the shot peening [4], shot materials, such as round metallic or ceramic particles, impact to the sample surface by high speed air or jet gas. Shot peening can produce a compressive residual stress layer and modify mechanical properties of metals. In addition, a nanocrystalline surface layer consisting of nanocrystals smaller than 100nm can be formed by the shot peening. Although the nanocrystals can be obtained, the special apparatus and the high energy (or cost) are required for the shot peening.

The wire-brushing has been suggested as a simple process to obtain nanocrystals near surface [5]. The wire-brushing is basically used to polish surfaces or remove the rust (or oxide layer) on the surfaces. In the wire-brushing process, a brush consisting of steel wires was revolved at high speed with a commercial angle grinder. The angle grinder was gripped, and the revolved wire brush is pressed to the surface of the sheet materials. As a result, nanocrystals can be obtained near surface in various kinds of metallic materials: Al, Al alloy, Cu, Cu alloy, steel, etc. [5]. Although the wire-brushing is certainly a simple process to obtain the nanocrystals, the process conditions, such as pressing load and feed speed, depend on a worker. Therefore, instrumentation of the wire-brushing process is required. In addition, the effects of the nanocrystal layer on mechanical and functional properties of the wire-brushed sheet were not investigated. In this study, wire-brushing was instrumented, and the instrumented process was applied to the AZ31B Mg alloy sheets. The microstructures, mechanical and functional properties of the wire-brushed Mg alloy sheets were investigated.

2. Experimental Procedure

2.1. Wire-brushing

AZ31B alloy sheets with 1mm thick were used in this study. The wire-brushing was carried out with a commercial angle grinder and a milling machine. A milling machine was used for the instrumentation of the wire-brushing process. Pressing load was measured with a load cell. Revolution speed of the wire brush was 2120 rpm, and two kinds of feed speeds were used in the wire-brushing with the milling machine. The conditions of the wire-brushing with an angle grinder (A.G.) and a milling machine were summarized in Table1.

Table 1 Conditions of the wire-brushing

sample	tool	pressing load [kgf]	revolution speed [rpm]	feed speed [mm/min.]
A.G.	angle grinder	~1	9000	not measured
1-H	milling machine	1	2120	248 (High speed)
3-H		3		
1-L		1		35 (Low speed)
3-L		3		

2.2. Evaluation of the wire-brushed Mg alloy

Microstructures of the wire-brushed Mg sheets were observed by TEM. Thin foils for TEM were prepared by the FIB (focused ion beam) process. Electron diffraction pattern was obtained from the selected area of 1μm in a diameter. The surface of the wire-brushed sheets was also observed with a confocal microscope, and the surface roughness (Rz: ten-point mean roughness) were analyzed. Mechanical properties of the wire-brushed sheets were evaluated by the tensile tests and the Vickers hardness tests. In the tensile tests, both sides of the specimen were wire-brushed, and the surface treatment for tensile test was not carried out. The initial strain rate of the tensile test was 8.4×10^{-4}. Corrosion resistance of the wire-brushed sheets were evaluated by the salt spray test according to JISZ2371. The test conditions were pH6.5~7.2 and $35^{o}C\times24h$. The thickness of the oxide layer (i.e., MgO) was measured with a SEM/EDX after the salt spray test.

3. Results and Discussion

3.1. Microstructure

Starting sheet of the Mg alloy had equiaxed grains, and the mean grain size was 7.3μm. Figure 1 shows the TEM image of the cross section of the wire-brushed Mg sheet with an angle grinder. Symbols and circles in the TEM image indicate the selected area positions whose diameter is 1μm, and they correspond to the diffraction pattern images. A boundary between deformed area and un-deformed area was clearly observed in shot peeing [4]. However, the boundary was not clearly observed in this study. From wire-bushed surface to 4μm depth, corresponding diffraction patterns show the ring-like patterns. This shows that many grains whose size was smaller than 1μm exist until 4μm depth. The enlargement image of the microstructure positioned between 2 and 3μm depth is shown in Fig.2. Equiaxed nano-crystals and ultrafine grains with high dislocation density were clearly observed in Fig.2. It was worth noting that the grain shows equiaxed morphology in spite of as-deformed-structure. This suggests that recrystallization occurs in local area under or after wire-brushing and the temperature is smaller than recrystallization temperature. The mean grain size was 93 nm, and the nanocrystals in the Mg sheet can be obtained by wire-brushing with the angle grinder. The thickness of nanocrystalline surface layer was determined from mean grain sizes and selected area diffraction patterns. As a result, the nanocrystal layer was until about 4μm depth from the wire-brushed surface. Figure 3 shows the TEM images of the cross section of the wire-brushed Mg sheet with the milling machine. The observed position was 1μm depth from the surface. Nanocrystals also can be obtained by the wire-brushing with the milling machine. The mean grain size and the thickness of nanocrystalline layer were shown in Table 2. Mean grain size was measured from the nanocrystalline layer between surface and 3 μm depth. In the same feed speed, the grain size was about the same (1-H and 3-H, 1-L and 3-L). The same pressing load condition were compared (1-H and 1-L, 3-H and 3-L), the mean grain size decreased with decreasing pressing load. In this study, the mean grain size depends on

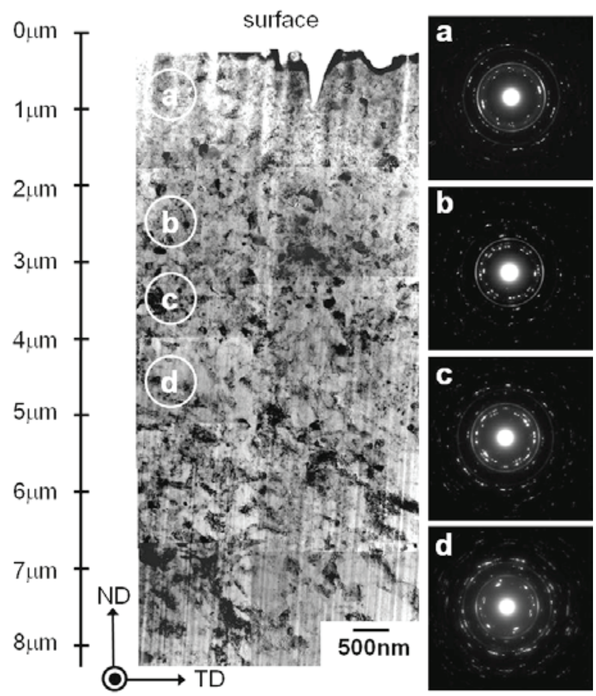

Fig.1 TEM image of the cross section of the wire-brushed Mg sheet with an angle grinder. Symbols in the TEM image indicate the selected position for the diffraction patterns. Observed from the parallel to the wire-brushing direction.

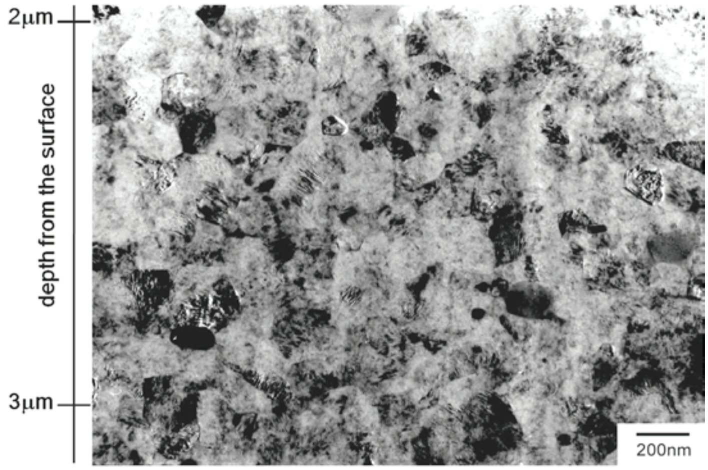

Fig.2 TEM image of the wire-brushed Mg sheet with an angle grinder. This image is enlargement of the area positioned at 2~3μm depth from the surface in Fig.1.

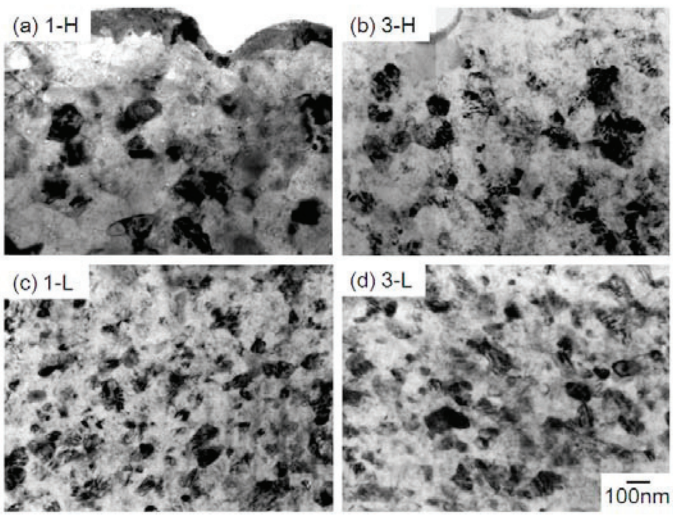

Fig.3 TEM images of the cross section of the wire-brushed Mg sheets. (a)1-H,(b)3-H,(c)1-L and (d)3-L.

Table 2 Mean grain sizes and thicknesses of the nanocrystalline layer in the wire-brushed Mg sheets

	A.G.	1-H	3-H	1-L	3-L
mean grain size (until 3μm depth) [nm]	92.9	86.4	87.9	68.2	72.2
thickness of the nanocrystalline layer [μm]	4	5	3	3	5

the feed speed rather than pressing load. On the other hand, the thickness of the nanocrystalline layer did not depend on the conditions, and it ranges from 3 to 5μm. Figure 4 shows the surface roughness (Rz) of the starting sheet and wire-brushed sheets. The roughness of the starting sheet and A.G. were about the same. The roughness depends on the wire-brushing condition, and increased in the following order: A.G., 1-H, 3-H, 1-L, 3-L. However, the thickness of the nanocrystalline layer was about the same as shown in Table 2. This suggests that nanocrystalline layer was formed and removed during the wire-brushing in the same time.

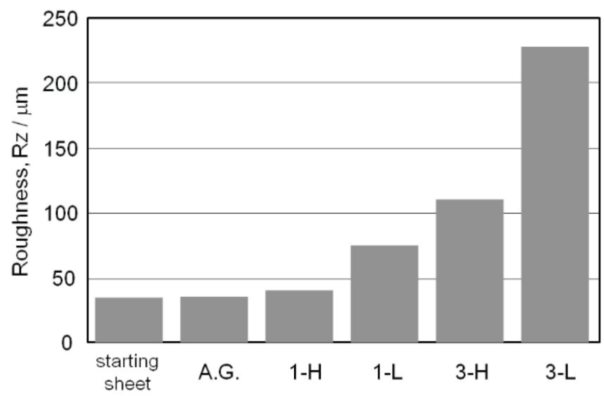

Fig.4 Surface roughness (Rz) of the starting sheet and the wire-brushed Mg sheets.

3.2. Evaluation of the wire-brushed Mg sheet

Figure 5 shows the stress-strain curves of the starting and wire-brushed sheets. Although the elongation decreased, the 0.2% proof stress ($\sigma_{0.2}$) and tensile strength slightly increased after the wire-brushing except for the 3-L. The thickness of the nanocrystalline layer ranges from 3 to 5 μm as shown in Table 2. This shows that the thin nanocrystalline layer affects the mechanical properties of the 1mm thick sheet. It is also expect that the compressive residual stress affects the strength. The compressive residual stress depends on the thickness of the sheet. The wire-brushing was applied to the 0.5mm and 1mm thick sheet, and the hardness of the wire-brushed surface were compared. As a result, the hardness was about the same. The compressive residual stress would be hardly on the wire-brushed surface. Therefore, the increasing strength would results from nanocrystalline layer. The tensile stress and elongation of the 3-L was lower than that of the starting sheet. The 3-L has rough surface as shown in Fig.4. Therefore, the stress concentration occurs from the rough surface under the tensile test, and both tensile stress and elongation would decrease in the 3-L condition.

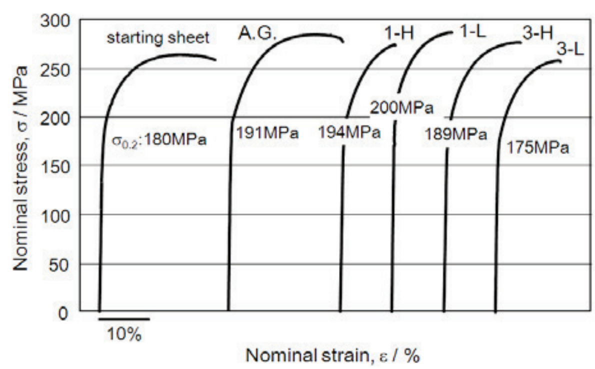

Fig.5 Norminal stress-strain curves of the starting sheet and wire-brushed Mg sheets.

The salt spray test of the wire-brushed Mg was carried out as an evaluation of a functional property. The starting sheet and 1-H were applied to the salt spray test, because the surface roughness was about the same. Figure 6 shows the SEM and SEM/EDX images of the cross section of the starting sheet and the 1-H. The corrosion rate of the starting sheet and the 1-H were 5.67 and 0.85 mm/year, respectively. The corrosion rate of the 1-H was about 7 times slower than that of the starting sheet. Mg alloy generally shows transgranular corrosion in the salt spray test. The wire-brushed Mg alloy has many grain boundaries, and the corrosion resistance increased for the salt spray. The simple wire-brushing can improve the mechanical properties and corrosion resistance for the salt spray in the AZ31Mg sheet.

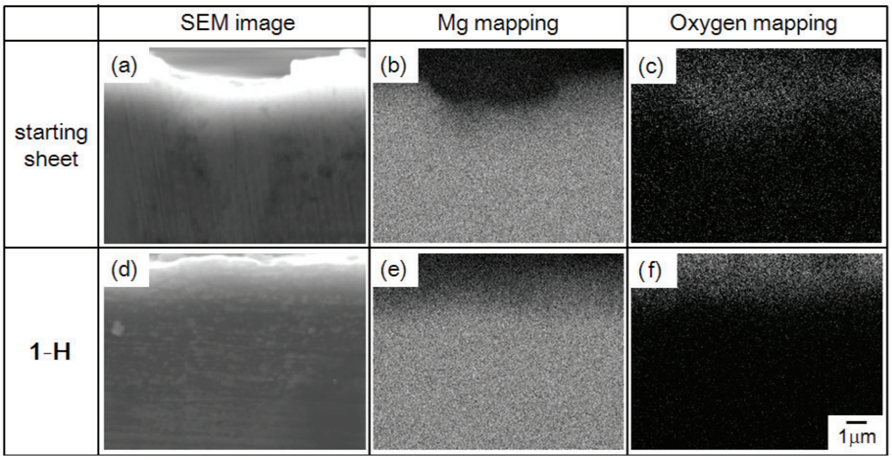

Fig.6 SEM and SEM/EDX images of the cross section of the starting sheet ((a),(b) and (c)) and 1-H((d),(e) and (f)).

4. Conclusion

Wire-brushing was applied to the AZ31B Mg alloy sheets, and the microstructure, mechanical properties and corrosion resistance were investigated. Equiaxed nanocrystals and ultrafine grains can be obtained, and the mean grain size ranges from 68.2 to 92.9nm near surface. The mean grain size depends on the feed speed than pressing load in the wire-brushing. The thickness of the nanocrystalline layer does not depend on the condition, because the nanocrystalline layer was formed and removed by the wire-brushing in the same time. The 0.2% proof stress and tensile strength slightly increased after the wire-brushing. The wire-brushed sheet shows high corrosion resistance for the salt spray test, and it was 7 times higher than that of the starting sheet. The simple wire-brushing can improve the mechanical properties and corrosion resistance for the salt spray in the AZ31Mg sheet.

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