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Solid State Recycling of 5083 Al Alloy by Hot Extrusion

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The machined chips of 5083 Al alloy were recycled by hot extrusion at 723 K with an extrusion ratio of 44:1 in air. Corrosion and mechanical properties of the recycled specimens have been compared with those of a virgin extrusion which was processed from the ingot block. As a result of salt immersion tests, mass loss of the recycled specimen was not less than twice of that of the virgin extrusion. The deterioration in corrosion properties for the recycled specimen was attributed to the excessive contamination of Fe which promoted galvanic corrosion. As a result of tensile tests, the recycled specimen exhibited a good combination of high strength and high elongation to failure at room temperature. The excellent mechanical properties for the recycled specimen were attributed to the refined microstructure. However, the elongation to failure of the recycled specimen at elevated temperatures more than 573 K was lower than that of the virgin extrusion. The contamination of oxide particles is likely to be responsible for the lower elongation in the solid recycled specimen.
Key words: Al alloy, solid state recycling, hot extrusion, mechanical properties, corrosion properties

1. INTRODUCTION

Now, Al alloy ranks the second in consumption in the world among metals [1] and recycling of it is one of important technologies for materials circulation. A large energy of about 2.6×10^5 J/t is needed when an Al virgin ingot is smelted from bauxite. However, the energy for recycling by remelting of Al scraps is about 1.0×10^4 J/t, which is only 4% of the smelting energy from bauxite. Hence, Al scraps should be recycled to reduce the environmental loads. Actually, recycling of Al scraps is being done by the some recycling processes on the basis of remelting [2,3]. However, it is metallurgically difficult to refine Al scraps by the remelting processes. Hence, most of the current recycling processes are *downgrade* recycling [4].

The desirable recycling is recycling from scraps to high performance materials with low energy consumption. Solid state recycling [5-8] is one of solutions for such low energy recycling. In the solid state recycling, metal scraps are directly recycled by plastic deformation process such as hot extrusion. In the previous works [5,6], the solid recycled Mg alloy showed high strength due to microstructural control by hot extrusion. Thus, the solid state recycling leads not only to a reduction in recycling energy consumption, but also to improvement of mechanical properties of recycled materials.

The aim of the present research is to apply the solid state recycling using hot extrusion to 5083 Al alloy. In the present paper, machined chips of 5083 Al alloy are recycled by solid state recycling using hot extrusion and mechanical and corrosion properties of the recycled 5083 Al alloy have been investigated.

2. EXPERIMENTAL PROCEDURE

Chips were prepared as Al alloy scraps by machining an as-received 5083 Al alloy [9] in a lathe without lubricants. The average length, width and thickness of the machined chips were 9.3, 1.8 and 0.3 mm, respectively. The machined chips were filled into a container with a diameter of 40 mm and extruded at 723 K with an extrusion ratio of 44:1 in air. For comparison, extrusions were processed from an as-received 5083 Al alloy ingot block under the same conditions as the extrusions from machined chips. In the present study, the extrusion specimen from machined chips is called the solid recycled specimen and the one from the as-received block is called the virgin extruded specimen.

The corrosion properties of the solid recycled specimen and the virgin extruded specimen were evaluated by the salt immersion test in which the mass loss of the specimens after 12 and 24 hour in 3 mass% NaCl aqueous solution was measured. The dimensions of specimen for the salt immersion test were 30 x 12 x 3 mm.

Tensile tests were carried out at a strain rate of 1.7×10^{-3} s^{-1} to investigate mechanical properties at from room temperature to 673 K. The tested specimens had a gauge length of 10 mm and a gauge diameter of 2.5 mm. The tensile axis was parallel to the direction of extrusion. Cavities were investigated by scanning electron microscopy. Cavity size distributions were examined based on quantitative metallographic measurements, assuming a spherical shape.

3. RESULTS AND DISCUSSION

3.1 Microstructures

Microstructure of the as-received specimen is shown in Fig.1 (a) and that of the solid recycled specimen in the transverse section to the extrusion direction is shown in Fig.1 (b), respectively. In the as-received specimen, coarse grains of about 390 μm were observed by OM

(Optical Microscopy) observation. However, in the solid recycled specimen, a small equiaxed grain with grain size of 6.2 μm was observed by TEM (Transmission Electron Microscopy) observation. Dynamic recrystallization occurs during hot extrusion for Al-Mg Al alloys [10]. It is suggested that a fine-grained microstructure in the solid recycled specimen is attributed to dynamic recrystallization during hot extrusion. Microstructure of the virgin extruded specimen was almost the same as that of the solid recycled specimen. The grain size of the virgin extruded specimen was 4.7μm.

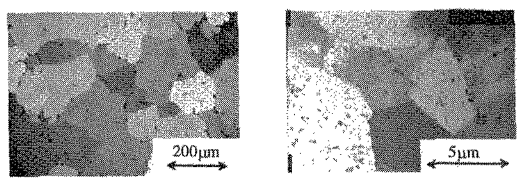

Fig.1 Microstructures of the 5083 Al alloy specimens: (a) the as-received specimen observed by OM, (b) the solid recycled specimen in the transverse section observed by TEM.

3.2 Corrosion properties

The salt immersion tests for the solid recycled specimen and the virgin extruded specimen were carried out using 3mass% NaCl aqueous solution at 293K. Figure 2 shows mass loss of the specimens after 12, 24 hour in the aqueous solution. The mass loss of the solid recycled specimen after 24 hour was not less than twice of that of the virgin extruded specimen. Figure 3 shows Fe particles observed by SEM (Scanning Electron Microscopy) (a) and the corresponding Fe and O images by EPMA (Electron Probe Microanalyzer) (b) and (c), respectively, for the solid recycled specimen. An oxygen rich region is observed in Fe rich region. The region would be a sintered interface of the machined chips. It is suggested that Fe particles shown in Fig.3 are contaminants introduced by the recycling. It is known that contamination of Fe in Al alloy promotes galvanic corrosion due to the formation of local cell [11]. Therefore, it is suggested that excessive contamination of Fe caused the deterioration of corrosion properties for the solid recycled specimen. Anyway, when the solid state recycling is applied as recycling of fine scraps such as machined scraps without laundering process, contamination is inevitable. Further researches are needed to develop the laundering process and to deepen understanding of the contamination tolerance for the solid state recycling.

3.3 Mechanical properties

Mechanical properties of the as-received specimen, the solid recycled specimen and the virgin extruded specimen at room temperature are summarized in Table I, respectively. The solid recycled specimen showed a good combination of high ultimate tensile strength of 329 MPa, 0.2 % proof stress of 179 MPa and elongation to failure of 16 %. It is suggested that the excellent mechanical properties for the solid recycled specimen are mainly attributed to the refined microstructure by hot

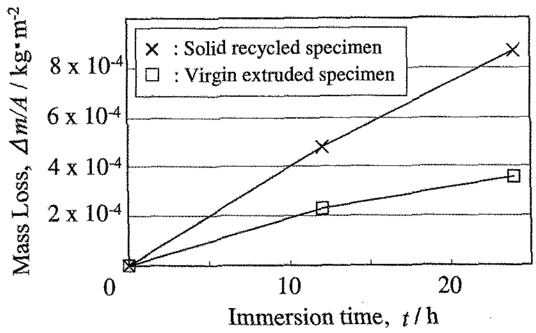

Fig.2 The variation in mass loss of the 5083 Al alloy specimens in 3mass% NaCl immersion tests as a function of immersion time.

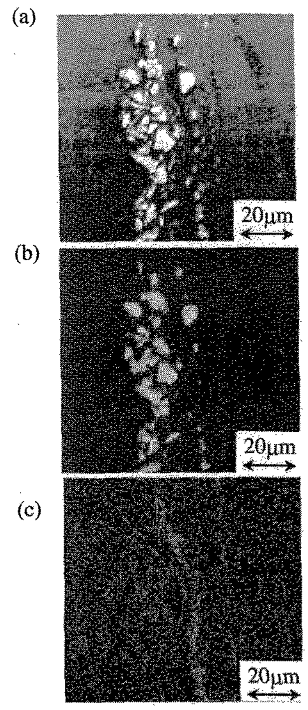

Fig.3 Fe particles in the solid recycled specimen observed by SEM (a) and the corresponding Fe and O images by EPMA (b) and (c), respectively.

Table I Tensile properties at room temperature of the 5083 Al alloy specimens.

Alloy	Ultimate tensile strength (MPa)	0.2% Proof stress (MPa)	Elongation to failure (%)
As-received specimen	277	131	13
Solid recycled specimen	329	179	16
Virgin extruded specimen	345	187	17

The variation in ultimate tensile strength and elongation to failure as a function of testing temperature for the solid recycled specimen and the virgin extruded specimen is shown in Fig.4. The tensile strength of the solid recycled specimen was almost the same as that of the virgin extruded specimen. However, the elongation to failure of the solid recycled specimen at the testing temperatures more than 573 K was lower than that of the virgin extruded specimen. As a result of SEM analysis, bumpy surface, indicating grain boundary sliding, was observed for the side surfaces of the solid recycled specimen and the virgin extruded specimen deformed to fracture at 673 K, respectively. Also, the grain size of the solid recycled specimen after the tensile test at 673K (= 10 μm) was almost the same as that of the virgin extruded specimen (= 13 μm). Thus, there was no difference in deformation and grain growth behavior between the solid recycled specimen and the virgin extruded specimen.

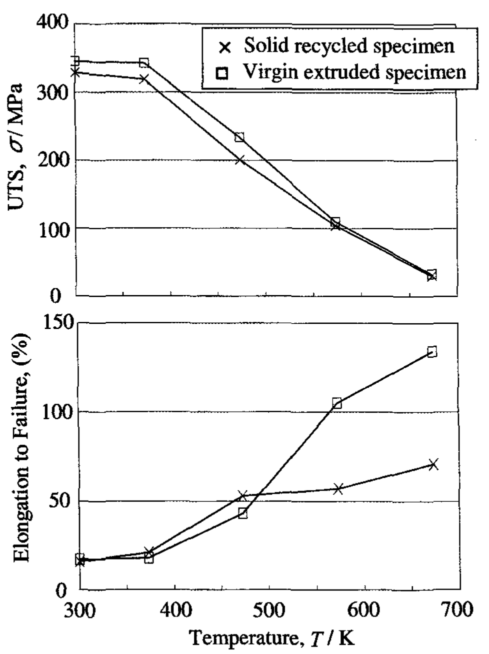

Fig.4 The variation in ultimate tensile strength (top figure) and elongation to failure (bottom figure) as a function of testing temperature in 5083 Al alloy.

Cavitation is often observed in a wide range of superplastic materials whose dominant deformation process is grain boundary sliding [12,13]. Cavities often grow during grain boundary sliding, resulting in premature fracture. The cavity diameter distributions in unit area (= 1 mm^2) for the both specimens are shown in Fig.5, where the specimens were deformed to the true strain of 0.6 at 1.7 x 10^{-3} s^{-1} and 673 K. The total number of cavities for the solid recycled specimen was 2,624 which was larger than that of the virgin extruded specimen (= 989). Furthermore, the average cavity size for the solid recycled specimen of 2.5 μm was larger than that of the virgin extruded specimen (= 1.7 μm).

Mahoney and Ghosh [14] suggested that large size reinforcements play the role as barrier of grain boundary sliding in the Al alloy matrix composites and also promote cavitation during superplastic flow, resulting in premature fracture. The inhomogeneous distribution of the oxide particles shown in Fig.3 (c) would promote excessive cavity formation in the solid recycled specimen. It is suggested that the low elongation at elevated temperatures for the solid recycled specimen is attributed to cavitation stimulated by the oxide contamination introduced during hot extrusion. It has been reported that large elongation is obtained in Al alloys containing fine and homogeneously dispersed particles [15,16]. Hence, further investigations are needed to investigate the process conditions for homogeneous dispersion and refinement of the oxide particles in the solid recycled Al alloy.

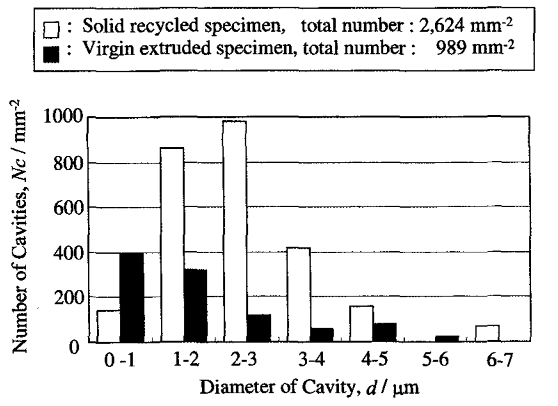

Fig.5 Cavity size distributions for the 5083 Al alloy specimens deformed to $\varepsilon = 0.6$ at 1.7×10^{-3} s^{-1} and 673 K.

4. CONCLUSIONS

Solid State Recycling of 5083 Al Alloy by Hot Extrusion has been carried out by model experiments. The results are summarized as follows.

(1) As a result of the salt immersion tests, the mass loss of the solid recycled specimen was not less than twice of that of the virgin extruded specimen. The deterioration in corrosion properties for the solid recycled specimen was attributed to the excessive contamination of Fe which promoted galvanic corrosion.

(2) The solid recycled specimens exhibited a good combination of high strength and high elongation to failure at room temperature. The excellent mechanical properties for the solid recycled specimen were attributed to the refined microstructure.

(3) The elongation to failure of the solid recycled specimen was lower than that of the virgin extruded specimen at the testing temperatures more than 573 K. The contamination of oxide particles would be responsible for the lower elongation in the solid recycled specimen.

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