Compressive Properties of Lotus-Type Porous Stainless Steel

TANE Masakazu and NAKAJIMA Hideo

(Institute of Scientific and Industrial Research)

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Lotus-type porous stainless steel (Fig. 1), possessing cylindrical pores aligned in one direction, was fabricated by a continuous zone melting technique in a pressurized mixture gas of hydrogen and helium. Compression tests were carried out on the lotus stainless steel not only in the directions parallel and perpendicular to the elongated-pore direction but also in other directions to reveal its anisotropic compressive behavior. The macroscopic deformation modes depend on the porosity and the angle θ between the elongated-pore direction and compression direction, which is a unique characteristic resulting from its anisotropic porous structure. The yield stress in the pore direction, $\sigma_{y\parallel}$, decreases almost linearly with increasing porosity, while that in the perpendicular direction, $\sigma_{y\perp}$, decreases more rapidly (Fig. 2). The yield stress in the direction of θ from the elongated-pore direction, $\sigma_{y\theta}$, decreases monotonically with increase in θ (Fig. 3). The yield behavior of lotus stainless steel was described using micromechanical mean-field theory based on Eshelby’s inclusion theory and Mori-Tanaka mean-field theory.

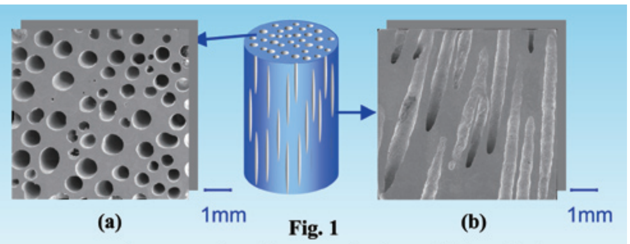

Fig. 1

Pore structures of cross sections (a) perpendicular and (b) parallel to elongated-pore direction of lotus stainless steel.

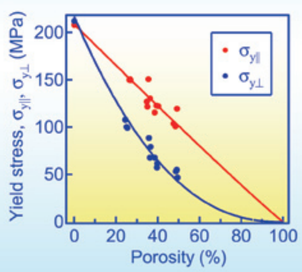

Fig. 2

Porosity dependence of yield stress in the directions parallel and perpendicular to elongated pore direction, $\sigma_{y||}$ and $\sigma_{y\perp}$.

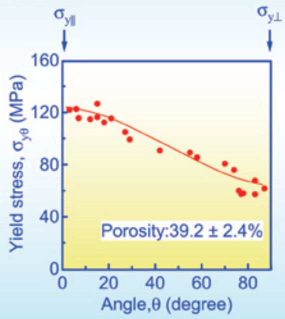

Fig. 3

Yield stress in the direction of θ which is an angle between elongated-pore direction and compression direction.

Quantification of Annealed Microstructures in ARB Processed Aluminum

KAMIKAWA Naoya and TSUJI Nobuhiro

(Graduate School of Engineering)

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When metallic materials are plastically deformed up to ultrahigh strain, ultrafine grained (UFG) structures with mean grain size around 100 nm or nanocrystalline structures with grain size of 10 nm are formed. The UFG metals are expected as future structural materials because of their excellent mechanical properties. For example, the UFG metals show strength 2-4 times higher than conventionally coarse grained ones with the same chemical compositions, so that aluminum can be as strong as steel. Furthermore, the UFG metals sometimes perform surprising properties which have not yet been known in conventional metallic materials. One of such peculiar properties the present authors have found is “*hardening by annealing, and softening by deformation*” behavior, which is totally opposite to the commonsense of previous knowledge in materials science *(Science, 312, 249-251 (2006))*.

In the present paper, the microstructure and crystallography of the UFG Al fabricated by the ARB (accumulative roll bonding) process, that is a kind of ultrahigh straining process originally developed in Osaka University in 1998, were quantified by advanced electron microscopy techniques (TEM/Kikuchi-line and FE-SEM/EBSDS analyses) in details. The main results are summarized in Fig.1. Firstly, it was found that the as-ARB processed Al had an unique microstructure: the ultrafine grains certainly have large misorientation to each other, and at the same time the structure involves high density of low-angle boundaries as well as dislocations. That is, the UFG structure fabricated by ultrahigh strain has characteristics of “grains” as well as “deformed metals”. The ARB Al was annealed at various temperatures for various periods, and then the microstructures were again observed in details. Recovery and grain growth happened during annealing. Microstructure coarsening was quantitatively determined by the present investigations. It was found that the fraction of low-angle boundaries greatly decreased by low temperature annealing. It was suggested that such a structural change is responsible for the occurrence of the unique mechanical property in the UFG metals, *hardening by annealing, and softening by deformation*.

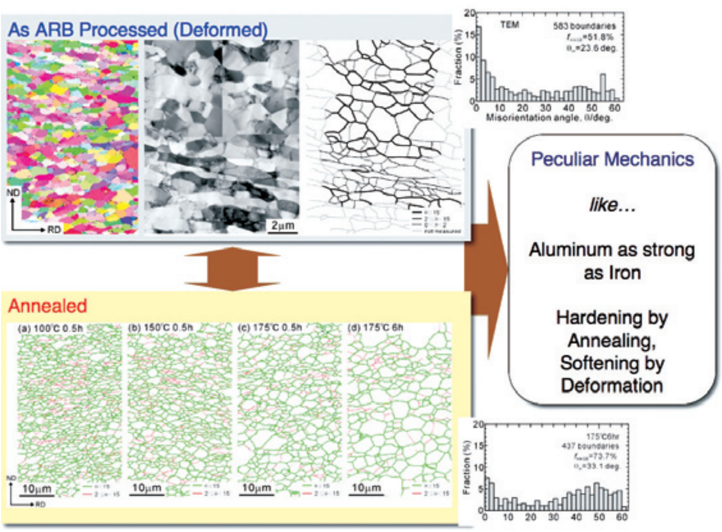

Fig. 1 Change in ultrafine grained microstructures and statistical crystallography of the aluminum highly deformed by the accumulative roll bonding process and then annealed.