Extra Strengthening of Age-Hardenable Aluminum Alloys through Combination of Severe Plastic Deformation and Subsequent Aging

モハメド, インタン ファデリナ ビンティ

（様式２）

氏　　名　：インタン　ファデリナ　ビンティ　モハメド

論 文 名　：Extra Strengthening of Age-Hardenable Aluminum Alloys through Combination of Severe Plastic Deformation and Subsequent Aging
(巨大ひずみ加工と時効処理を融合した高強度アルミニウム合金の超強度化に関する研究)

区　　分　：甲

論　文　内　容　の　要　旨

In this thesis, the possibility of simultaneous strengthening by grain refinement and precipitation hardening is studied in the aluminum alloys with different systems. The mechanical properties, evolution of microstructures and aging behavior are investigated to evaluate quantitative contribution of solid solution strengthening, grain boundary strengthening, dislocation strengthening and precipitation strengthening to the total strengthening of the alloys.

In Chapter 1, a brief description of the strengthening mechanisms is given first and severe plastic deformation (SPD) processes such as high-pressure torsion (HPT) and high-pressure sliding (HPS) are described as important tools for grain refinement.

In Chapter 2, the microstructures, mechanical properties and formation of precipitates are investigated in an Al-Cu alloy after HPT processing and after post-HPT aging at 353 K. The contribution of different hardening mechanisms (solid solution hardening, grain boundary hardening, dislocation hardening, and precipitation hardening) are quantitatively evaluated for different processing conditions. Hardness increases with strain and saturates to a steady-state level as 205 HV after HPT processing, while the grain size is reduced to ~210 nm at the steady state. Age hardening occurs after aging of the HPT-processed sample at room temperature and 353 K and Al_2Cu particles precipitate. The HPT-processed Al-Cu alloy exhibits weak thermal stability. The material exhibits a softening behavior within a few days after storage at room temperature and within a few minutes after aging at 353 K. Dislocation recovery occurs after aging for short time while grain growth occurs by prolong aging for a few days although the grain size is kept well within the submicrometer range. The strengthening by grain boundaries and precipitates are the dominant strengthening mechanism, while the contribution of strengthening by solid solution and dislocations accumulation is less than 10%.

In Chapter 3, a commercial AA2024 alloy is processed by HPT and it is shown that the hardness increases rapidly at an early stage of straining and finally reaches a saturation level (a steady-state level) with further straining as in the Al-Cu alloy. The grain size is refined to ~240 ± 80 nm and Vickers microhardness is significantly increased through application of HPT processing. The hardness values after 0.75, 1 and 5 turns fell well on a single curve when they are plotted against the equivalent strain. The hardness increases with straining by HPT and saturates to a constant level at 260 HV after the HPT

processing for 5 turns. Simultaneous strengthening due to grain refinement and fine precipitation is achieved when the HPT-processed samples through 5 turns are aged at 423 K. Three hardening mechanisms as grain refinement hardening, dislocation hardening and precipitation hardening contribute significantly to the total hardening, while the effect of grain boundary strengthening is the highest by comparison with solution strengthening which is small.

In Chapter 4, a commercial AA6061 alloy is subjected to grain refinement by HPT processing and found that the grain size is effectively reduced to the nanometer scale after a few turns. The Vickers microhardness data after HPT processing for 0.75, 1 and 5 turns lie well on a single curve when they are plotted against equivalent strain. The hardness increases with straining and saturates to a constant level of 163 HV at large strains. TEM observation reveals that the grain size is refined to ~200 nm at the saturation. The saturation hardness remains almost unchanged during aging at 373 K but gradually decreases by aging at 423 K, suggesting that the aging temperature of 423 K is too high. Simultaneous strengthening by fine precipitation and grain refinement occurs when the sample processed at relatively low strains is aged at low temperatures as 373 K. The tensile test shows that the strength significantly increases to more than 400 MPa with some ductility reserved after HPT or after post-HPT aging. The hardening mechanisms as grain refinement hardening, dislocation hardening and precipitation hardening contribute significantly to the total hardening, while the effect of solution hardening is minimal.

In Chapter 5, an AA7075 alloy is subjected to aging after HPS processing. It is possible to achieve simultaneous strengthening due to grain refinement and fine dispersion of precipitates. Grain refinement is achieved to average grain sizes of ~280 nm, ~ 240 nm and ~ 250 nm in the samples processed by HPS at R.T., 373K and 423 K, respectively. The values of 0.2% yield strength (YS), ultimate tensile stress (UTS) and elongation (EL) to failure are measured as 550 MPa, 620 MPa 7.5% and 600 MPa, 650 MPa, 7% after HPS processing at R.T. and 373K, respectively. The values of YS and UTS are further increased by aging treatment to 640 MPa and 745 MPa for the sample processed by HPS at R.T. and to 550 MPa and 690 MPa for the sample processed by HPS at 373K, while the values of EL are well retained as 4% and 10%, respectively. It is possible to achieve simultaneous strengthening due to grain refinement and fine dispersion of precipitates by HPS processing and by subsequent aging.