EXPERIMENTAL AND NUMERICAL STUDIES ON SUPERHIGH STRENGTHENING SINTERED LOW ALLOY STEELS FABRICATED BY METAL INJECTION MOLDING

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論　文　内　容　の　要　旨

Metal injection molding (MIM) process is an advanced powder processing technique because of net shaping with shape complexity at low processing energy and 100 % material utilization. This study has been performed to clarify and to optimize the relationship between the mechanical properties and the microstructures for the superhigh strengthening sintered low alloy steels (Fe-Ni system) by using MIM process. The influence of nickel particle sizes, nickel content, and sintering conditions on the microstructure and mechanical properties of superhigh strengthened Fe-Ni steel compacts have been systematically investigated. As starting materials, the mixed elemental carbonyl iron and water-atomized nickel powders were utilized. Tempered compact added 6 mass% fine nickel powder and sintered at 1250 ºC for 1 hour showed superhigh strength of 2040 MPa with elongation of 8.1 %, which was the best properties among reported data in P/M low alloy steels so far. These excellent mechanical properties are due to the fine heterogeneous microstructure consisted of nickel rich phase surrounded by a network of tempered martensitic structures. The mechanical properties of MIM compacts are highly dependent on two major factors; the porosity and the microstructural morphology in the matrix. Both factors were cautiously considered in the present work. The studies on effect of porosity was carried out on high strength sintered steel (SUS 440C) with homogeneous microstructure. Subsequently, the superhigh strengthened Fe-Ni steel compacts which was a primary material in this study was employed for the studies on effect of microstructure. Not only experimental work but also numerical simulation by finite element method was engaged to understand how those factors work. According to the numerical simulation, the model demonstrated that the tensile properties was enhanced at reduced pores and depreciated when the porosity was increased. Also, when the mechanical properties of the compacts with similar porosity level is compared, the difference of pore factor such as size and number can be disregarded due to their minimum influences. After the pore factor was successfully tested and evaluated, the effect of heterogeneous microstructure was introduced in order to evaluate superhigh strengthened Fe-Ni steel compacts. Sintered density of all Fe-Ni steel compacts obtained in this study was 95-96 %, which means the porosity levels were about similar. Therefore, the effect of pore factor has been simply omitted in this work. The microstructure of all superhigh strengthened Fe-Ni steel compacts have been consistently structured by heterogeneous condition. The microstructural heterogeneity aspects of the compact were changed by the characteristics of Ni powder, such as particle size and content, which play important roles in the behavior of microstructural morphology. A complex network of higher Ni region which firmly bounded by the lower Ni region (matrix region) has been comprehensively observed. The high ductility and high strength offered by the superhigh strengthened Fe-Ni steel compacts were also due to the mechanically induced martensitic transformation that took place during deformation. The Ni rich phase was initially metastable retained austenite which was relatively ductile phase, and the ductility was enhanced by the martensitic transformation-induced plasticity (TRIP) phenomenon. The high strength was due to the transformation of the soft austenite phase to the hard martensitic phase during the deformation as experimentally observed. In order to understand how the heterogeneous microstructure effects on the mechanical properties, finite element modeling based on the spatial distribution obtained experimentally was developed. Some parameters were prepared to control the heterogeneity in the representative volume element. The simulated results were compared to experimentally obtained behavior, and which showed good agreements. These successful simulations by FEM suggest the possibility to identify and design an optimum microstructure for superhigh strengthening sintered alloy steel compacts.

論文審査の結果の要旨

本論文は，金属粉末射出成形（MIM）プロセスによって作製されたFe-Ni系焼結低合金鋼の機械的特性と組織の関係を明らかにし，それらの最適化に向けて，数値計算による検討も加えたもので，最終的にNiリッチなマルテンサイトをネット構造的に焼戻しマルテンサイトが取り囲むメゾヘテロ組織とすることで，引張強度2040 MPa，伸び8.1 %の超強靭な特性を得ることができた．これは，これまでの粉末冶金による焼結低合金鋼を凌駕するものであり，焼結金属材料の高性能化に対して，機械工学上寄与するところが大きい．よって博士（工学）の学位論文に値するものと認める．