World Academy of Science, Engineering and Technology
International Journal of Materials and Metallurgical Engineering
Vol:19, No:02, 2025

Structural Characterization and Hot Deformation Behaviour of Al3Ni2/Al3Ni in-situ Core-shell intermetallic in Al-4Cu-Ni Composite

Authors : Ganesh V., Asit Kumar Khanra

Abstract : An in-situ powder metallurgy technique was employed to create Ni-Al3Ni/Al3Ni2 core-shell-shaped aluminum-based intermetallic reinforced composites. The impact of Ni addition on the phase composition, microstructure, and mechanical characteristics of the Al-4Cu-xNi (x = 0, 2, 4, 6, 8, 10 wt.%) in relation to various sintering temperatures was investigated. Microstructure evolution was extensively examined using X-ray diffraction (XRD), scanning electron microscopy with energy-dispersive X-ray spectroscopy (SEM-EDX), and transmission electron microscopy (TEM) techniques. Initially, under sintering conditions, the formation of "Single Core-Shell" structures was observed, consisting of Ni as the core with Al3Ni2 intermetallic, whereas samples sintered at 620°C exhibited both "Single Core-Shell" and "Double Core-Shell" structures containing Al3Ni2 and Al3Ni intermetallics formed between the Al matrix and Ni reinforcements. The composite achieved a high compressive yield strength of 198.13 MPa and ultimate strength of 410.68 MPa, with 24% total elongation for the sample containing 10 wt.% Ni. Additionally, there was a substantial increase in hardness, reaching 124.21 HV, which is 2.4 times higher than that of the base aluminum. Nanoindentation studies showed hardness values of 1.54, 4.65, 21.01, 13.16, 5.52, 6.27, and 8.39GPa corresponding to α-Al matrix, Ni, Al3Ni2, Ni and Al3Ni2 interface, Al3Ni, and their respective interfaces. Even at 200°C, it retained 54% of its room temperature strength (90.51 MPa). To investigate the deformation behavior of the composite material, experiments were conducted at deformation temperatures ranging from 300°C to 500°C, with strain rates varying from 0.0001s-1 to 0.1s-1. A sine-hyperbolic constitutive equation was developed to characterize the flow stress of the composite, which exhibited a significantly higher hot deformation activation energy of 231.44 kJ/mol compared to the self-diffusion of pure aluminum. The formation of Al2Cu intermetallics at grain boundaries and Al3Ni2/Al3Ni within the matrix hindered dislocation movement, leading to an increase in activation energy, which might have an adverse effect on high-temperature applications. Two models, the Strain-compensated Arrhenius model and the Artificial Neural Network (ANN) model, were developed to predict the composite's flow behavior. The ANN model outperformed the Strain-compensated Arrhenius model with a lower average absolute relative error of 2.266%, a smaller root means square error of 1.2488 MPa, and a higher correlation coefficient of 0.9997. Processing maps revealed that the optimal hot working conditions for the composite were in the temperature range of 420-500°C and strain rates between 0.0001s-1 and 0.001s-1. The changes in the composite microstructure were successfully correlated with the theory of processing maps, considering temperature and strain rate conditions. The uneven distribution in the shape and size of Core-shell/Al3Ni intermetallic compounds influenced the flow stress curves, leading to Dynamic Recrystallization (DRX), followed by partial Dynamic Recovery (DRV), and ultimately strain hardening. This composite material shows promise for applications in the automobile and aerospace industries.

Keywords : core-shell structure, hot deformation, intermetallic compounds, powder metallurgy
Conference Title : ICCM 2025 : International Conference on Composite Materials
Conference Location : Tokyo, Japan
Conference Dates : February 24-25, 2025