Electron microscopy investigation of ceramic-metal interfaces in alumina/Al-Fe composite synthesized by reactive metal penetration

Solomon, C.V.[1], Moro, M.[2], Yurcho, A.M.[3] and Wagner, T.R.[1]

[1] Youngstown State University, United States, [2] The Goodyear Tire & Rubber Company, United States, [3] Sharon Tube Company, United States

Alumina/Al-Fe composites have been synthesized by immersion of vitreous silica preforms into molten Al-7.5 wt% Fe alloy. Following the reaction between silica and molten metal the part's microstructure transforms into a mixture of Al_2O_3 and Al-based metallic phases, while the preform shape is preserved. This process is called reactive melt penetration (RMP). The mechanical, physical and chemical properties of the ceramic-metal composite are completely different than those of the staring materials. In the case of Al_2O_3/Al-Fe-based material the ceramic phase provides high stiffness, high strength and low density to the composite, while the continuous metal network provides the composite with high thermal and electrical conductivity, and high fracture toughness. The purpose of this research was to identify the metallic phases formed as the result of RMP process and to investigate the ceramic-metal interfaces using analytical electron microscopy techniques. Samples for SEM/EDS investigations have been prepared using metallographic techniques, while electron transparent lamellas for TEM investigation were processed by FIB from selected volumes containing ceramic-metal interfaces. Two JEOL instruments, a JIB-4500 Multi Beam FIB/SEM and a JEM 2100 S/TEM equipped with EDAX EDS systems, have been used for the investigation.

SEM/EDS investigations showed that the part's microstructure consists of three dimensional interpenetrating networks of Al_2O_3 and Al-based metallic phases, and revealed the existence of manufacturing defects such as voids and interfaces formed as the result of interaction between different reaction fronts propagating along converging directions. Analysis of EDS results indicate the presence of elemental Al, two Al-based intermetallic phases, and a limited amount of elemental Si throughout the composite microstructure, in addition to the Al_2O_3 phase. Using electron diffraction in the TEM, the intermetallic phases were identified as $Al_{13}Fe_4$ (monoclinic; *C2/m*; a = 1.549 nm; b = 0.808 nm; c = 1.248 nm; β = 107.72°) and $Al_4Fe_{1.7}Si$ (hexagonal; $P6_3/mmc$; a = 0.7509 nm; c = 0.7594 nm). Stalking faults observed in Si grains might be formed as the result of different thermal expansion behavior of Si, Al_2O_3, and Al-based phases during material cooling at the end of the RMP process. The orientation relationship between Al_2O_3 and Al was determined as $[-100]_{Al2O3}//[310]_{Al}$, $(006)_{Al2O3}//(002)_{Al}$. STEM imaging and HRTEM investigations revealed that $Al_4Fe_{1.7}Si$ acts as a buffer nano-scale layer at the $Al_2O_3/Al_{13}Fe_4$ interface, in order to accommodate the crystallographic mismatch between the two phases.