

Abstract

The influences of the SiC nanoparticles (SiC_{np}) dispersion on the microstructural modification, tensile, compression, creep, and corrosion behavior of the squeeze-cast Mg-5.0Al-2.0Ca-0.3Mn (AXM520) (wt.%) alloy have been investigated. The concentrations of the SiC_{np} are varied from 0.5 to 3.0 (wt.%), and the squeeze-cast nanocomposites (NCs) are abbreviated as NC0.5SiC, NC1.0SiC, NC2.0SiC and NC3.0SiC. A detailed microstructural characterization of the AXM520 alloy and NCs has been carried out. The as-cast microstructures of the AXM520 alloy and NCs consist of a primary solid solution (α -Mg), a eutectic of α -Mg and $(\text{Mg,Al})_2\text{Ca}$ (C36) phases, and an Al_8Mn_5 phase. Additionally, the SiC phase is also present in the NCs. The continuous network of the C36 phase is fragmented and becomes discontinuous as the content of the SiC_{np} increases in the NCs.

The ambient temperature tensile and compressive properties of the AXM520 alloy and NCs have been evaluated. All the NCs exhibit superior tensile and compressive properties to the AXM520 alloy. The NC2.0SiC exhibits the best tensile properties among the NCs employed. The YS of the NCs improves with the increase in the SiC_{np} content up to 3.0 (wt.%). The UTS and %El of the NCs increase up to 2.0 SiC_{np} (wt.%), and beyond that, the same declines owing to the agglomeration of the nanoparticles. The discontinuous network of the C36 phase in the NCs inhibits crack propagation, leading to their improved %El. All the NCs exhibit a higher strain-hardening exponent (n) and strain-hardening rate (SHR) compared to the AXM520 alloy. The superior ' n ' and SHR exhibited by the NCs are attributed to the grain refinement and dislocations generation. The strengthening from CTE mismatch contributes the most to the overall strengthening of the NCs. The 'Zhang and Chen' model is modified by introducing an agglomeration factor, and the predicted YS of the NCs matches pretty well with the experimentally obtained values.

The creep behavior of the AXM520 alloy and NCs has been examined using impression creep tests in the temperature range from 448 K to 523 K and stress range from 390 to 490 MPa. All the NCs reveal improved creep performance compared to the AXM520 alloy. The creep rate of the NCs decreases with the increase in the SiC_{np} content. The NC2.0SiC exhibits an improvement in creep resistance by 73.2% compared to the alloy. However, the creep resistance deteriorates since the amount of the nanoparticles is further increased in the

NC3.0SiC, leading to agglomeration. The stress exponents vary from 5.0 to 6.7, and activation energies vary from 89.8 to 101.8 kJ/mol, implying that the creep in the materials is controlled by the climb of dislocation assisted by the pipe diffusion. The pile-ups of dislocations take place around the C36 phase and near the SiC_{np}. The additional strengthening owing to the presence of the SiC_{np} in the NCs is responsible for their improved creep performance compared to the AXM520 alloy.

The corrosion behavior of the AXM520 alloy and NCs has been investigated in a 3.5 (wt.%) NaCl solution at a pH of 7.0. The corrosion resistance of the NCs measured in the hydrogen evolution test is superior to the AXM520 alloy, and the improvement is 91.1% in the NC3.0SiC. The polarization resistance determined from the EIS increases with the increase in the SiC_{np} content in the NCs. The potentiodynamic polarization scans further confirm the superior corrosion resistance of the NCs to the AXM520 alloy. Among the fabricated NCs, NC3.0SiC exhibits the highest corrosion resistance, and it is 91.3% lower in comparison to the AXM520 alloy. The corrosion products predominantly consist of Mg(OH)₂. The addition of SiC_{np} reduces the formation of Mg(OH)₂ and increases the content of the Al(OH)₃ in the NCs, leading to the higher stability of the corroded film formed on them. The α -Mg phase is severely damaged owing to the galvanic corrosion between the α -Mg and C36 phases. However, the same is reduced due to a decrease in the volta potential between α -Mg and C36 phases in the NCs, resulting in their superior corrosion resistance.

The squeeze-cast AXM520 alloy and NCs are further subjected to age-hardening. The alloy and NCs are homogenized at 773 K and artificially aged at 523 K. The aged alloy is designated as AXM520HT, and the nanocomposites containing 1.0 and 2.0 (wt.%) of SiC_{np} are designated as NC1.0SiCHT and NC2.0SiCHT, respectively. The microstructural evolution and creep characteristics of the squeeze-cast age-hardened alloy and NCs have been investigated. The age-hardened alloy and NCs contain primary α -Mg grains, (Mg, Al)₂Ca (C36), Al₂Ca (C15), and Al₈Mn₅ phases. The SiC phase is additionally identified in the NCs. The NCs reveal superior creep resistance compared to AXM520HT, and it is the best in the NC2.0SiCHT. The creep resistance of the NC2.0SiCHT surpasses AXM520HT by 76%. Dislocation climb, facilitated by pipe diffusion, emerges as the mechanism governing creep deformation in the alloy and NCs. The creep deformation mechanism maps for the Mg-Al-Ca-based alloys and NCs are successfully constructed. The microstructural observation of the creep-tested specimens under the indenter concludes that the C36 phase is utterly broken in the

AXM520HT, whereas the same remains intact in the NC2.0SiC_{HT}. The percentage of twins in the creep-tested specimen of NC2.0SiC_{HT} is lower than in the AXM520HT alloy. Two different types of twins, i.e., extension twin $\{10\bar{1}2\}\langle 10\bar{1}1\rangle$, and double twin $\{10\bar{1}1\}-\{10\bar{1}2\}$ are observed in the NCs. The density of the $\langle c \rangle$ type dislocations is much higher than that of the $\langle a \rangle$ type dislocations in the NCs. The presence of SiC nanoparticles impedes the dislocation motion. The significant improvement in creep resistance of all the NCs over the AXM520HT alloy is attributed to the age-hardening as well as dispersion strengthening from the presence of the SiC nanoparticles.

To conclude, the tensile, compression, creep, and corrosion behavior of the squeeze-cast NC0.5SiC, NC1.0SiC, NC2.0SiC, and NC3.0SiC are superior to that of the AXM520 alloy. Thus, the use of NCs is beneficial over the AXM520 alloy. Among the as-cast NCs, NC2.0SiC is the best, considering the mechanical properties and corrosion behavior. In addition, the creep behavior of the age-hardened NC1.0SiC_{HT} and NC2.0SiC_{HT} is superior to that of the AXM520HT alloy. Among the aged alloy and NCs, the NC2.0SiC_{HT} is the best considering the creep behavior.

Keywords: Magnesium alloy; Nanocomposite; Squeeze-cast; Microstructure; Creep; Corrosion