Magnesium alloys are being developed as an advanced material for structural applications where reduced weight is a primary motivator. Alloying can enhance the properties of magnesium without significantly affecting its density. Essential to alloy development, inclusive of processing parameters, is knowledge of thermodynamic, kinetic, and mechanical behavior of the alloy and its constituents. Appreciable progress has been made through conventional development processes, but to accelerate development of suitable wrought Mg alloys, an integrated Materials Genomic approach must be taken where thermodynamics and diffusion kinetic parameters form the basis of alloy design, process development, and properties-driven applications.

The objective of this research effort is twofold: first, to codify the relationship between diffusion behavior, crystal structure, and mechanical properties; second, to provide fundamental data for the purpose of wrought Mg alloy development. Together, the principle deliverable of this work is an advanced understanding of Mg systems. To that end, the objective is accomplished through an aggregate of studies. The solid-to-solid diffusion bonding technique is used to fabricate combinatorial samples of Mg-Al-Zn ternary and Mg-Al, Mg-Zn, Mg-Y, Mg-Gd, and Mg-Nd binary systems. The combinatorial samples are subjected to structural and compositional characterization via Scanning Electron Microscopy with X-ray Energy Dispersive Spectroscopy, Electron Probe Microanalysis, and analytical Transmission Electron Microscopy. Interdiffusion in binary Mg systems is determined by Sauer-Freise and Boltzmann-Matano methods. Kirkaldy’s extension of the Boltzmann-Matano method, on the basis of Onsager’s formulism, is employed to quantify the main and cross-interdiffusion coefficients in ternary Mg solid solutions. Impurity diffusion coefficients are determined by way of the Hall method. The intermetallic compounds and solid solutions formed during diffusion bonding of the combinatorial samples are subjected to nanoindentation tests, and the nominal and compositionally dependent mechanical properties are extracted by the Oliver-Pharr method.

In addition to bolstering the scanty available experimental data and first-principles computations, this work delivers several original contributions to the state of Mg alloy knowledge. The influence of Zn concentration on Al impurity diffusion in binary Mg(Zn) solid solution is quantified to impact both the pre-exponential factor and energy of activation. The main and cross-interdiffusion coefficients in the ternary Mg solid solution of Mg-Al-Zn are reported wherein the interdiffusion of Zn is shown to strongly influence the interdiffusion of Mg and Al. A critical examination of rare earth element additions to Mg is reported, and a new phase in thermodynamic equilibrium with Mg-solid solution is identified in the Mg-Gd binary system. It is also demonstrated that Mg atoms move faster than Y atoms. For the first time the mechanical properties of intermetallic compounds in several binary Mg systems are quantified, and the influence of solute concentration on solid solution strengthening in binary Mg alloys is reported. The most significant and efficient solid solution strengthening is achieved by alloying Mg with Gd. The Mg-Nd and Mg-Gd intermetallic compounds exhibited better room temperature creep resistance than intermetallic compounds of Mg-Al. The correlation between the concentration dependence of mechanical properties and atomic diffusion is deliberated in terms of electronic nature of the atomic structure.

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