Project 39: Solute and Precipitate Effects on Magnesium Recrystallization

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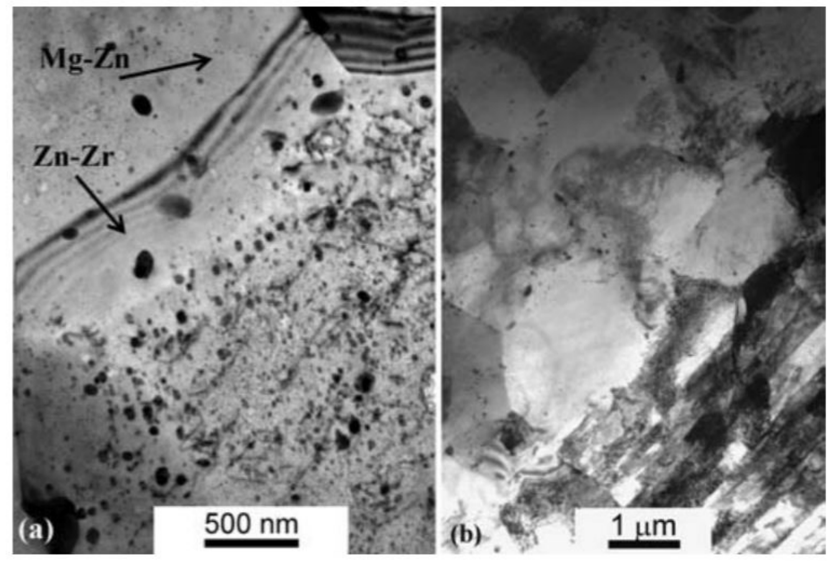
Center for Advanced Non-Ferrous Structural Alloys
An Industry/University Cooperative Research Center

Background:

Problem: Current recrystallization studies focus on texture modification and grain size reduction mechanisms that are not industrially viable.

Objective: Study the effects of varying precipitate and solute content on recrystallization kinetics. Determine effects of kinetics on hot working parameters and material properties. (Proposed alloy: modified ZK60).

Benefit: Common alloys may be studied using standard processing parameters modified for industrial benefit.



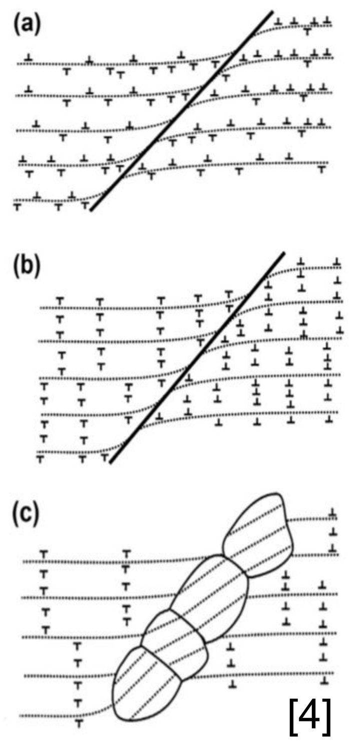
[1]

Constant strain rate dynamic recrystallization kinetics define industry processing parameters for ZK60

ZK60 is a commercial alloy with insoluble Zr particles that influence grain size and recrystallization [2] and undergoes age hardening [3]

Replacing Zr with rare earth elements (e.g., Ce or La) improves strength and creep resistance [4]

Recrystallization driving force (T, ε) needs to be determined for industrial processing

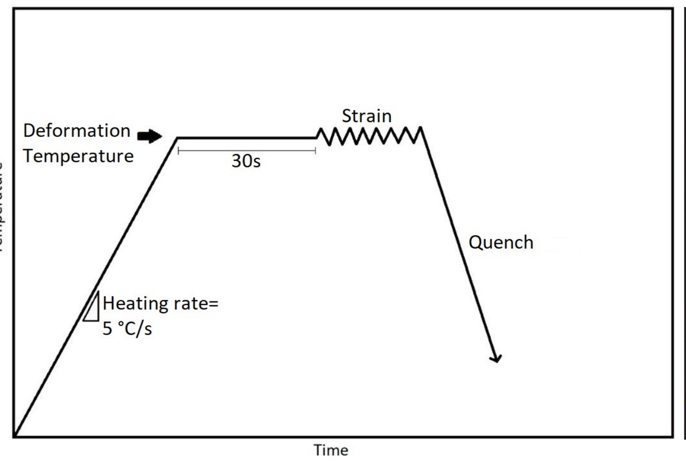


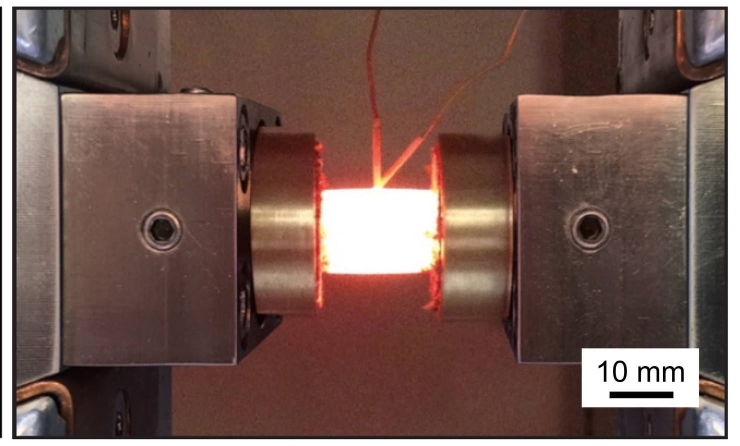
[4]

Methods:

	Complete Solid Solution	1% pinning phase	3% pinning phase
Low solute (~1%Zn)	-	**Alloy LZ-0.4Ce** Mg-1.40Zn-0.38Ce	-
Med solute (~2.5%Zn)	-	**Alloy MZ-0.4Ce** Mg-3.52Zn-0.38Ce	-
High solute (~4%Zn)	**Alloy HZ-0Ce** Mg-4.21Zn	**Alloy HZ-0.1Ce** Mg-5.26Zn-0.12Ce	**Alloy HZ-0.3Ce** Mg-6.78Zn-0.31Ce

- Homogenized and extruded 12.7 x 22.2 mm cross section bars of five compositions were supplied by Mag Specialties.
- ***Static annealing/recrystallization trials*** were performed on material cold-rolled to ~15% reduction and held at 350 or 400°C for times from 6 to 60hrs.
- ***Dynamic recrystallization tests*** were performed on as-extruded samples in compression at displacement-controlled strain rates of 0.001 to 0.1s^{-1} at either 350 or 400°C to 0.8 true strain.

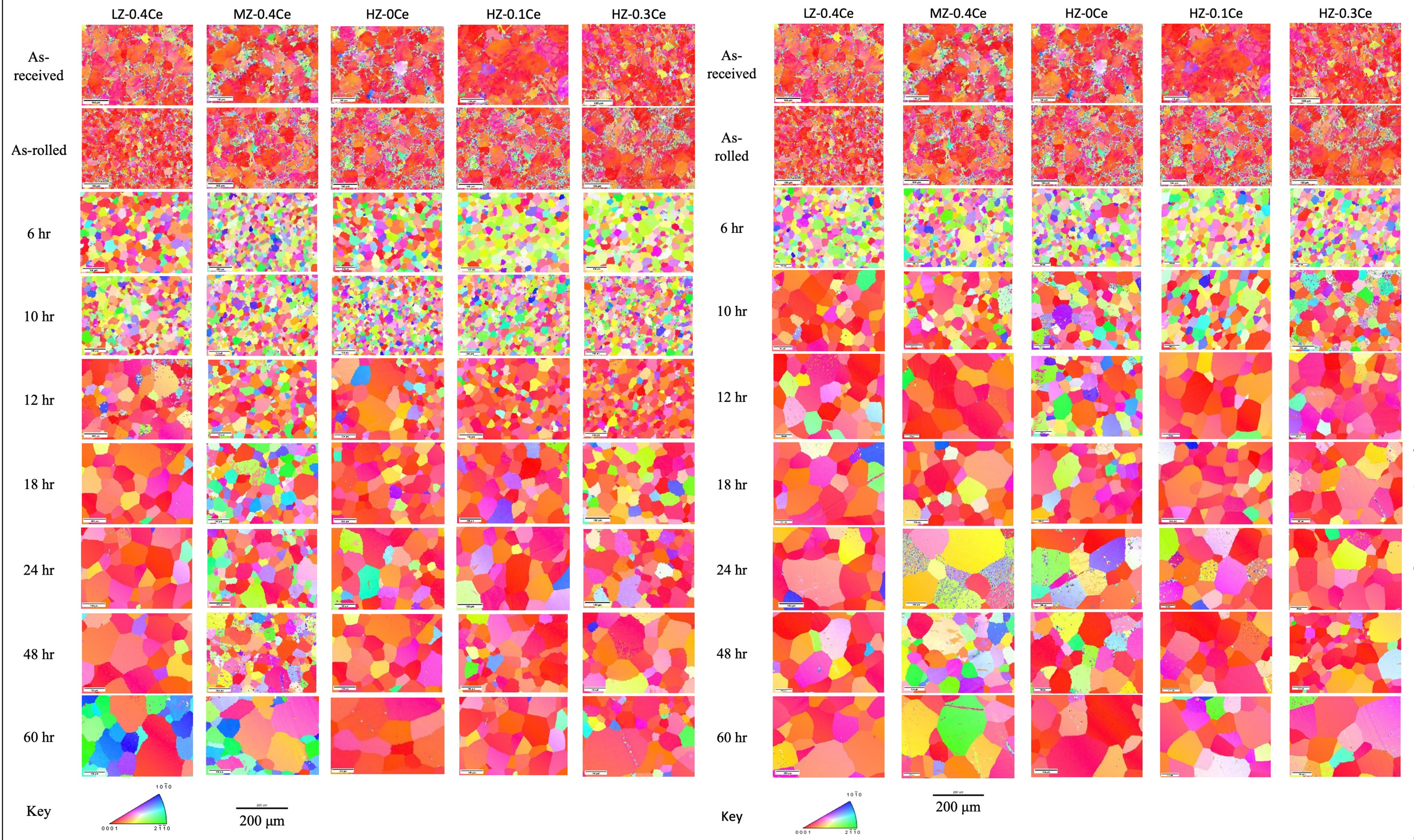




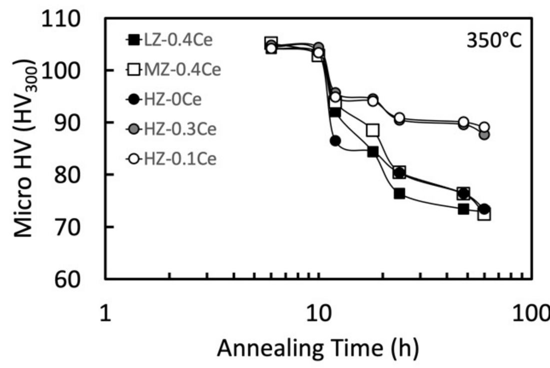
A Gleeble™ thermomechanical simulator was used to perform dynamic recrystallization compression tests with controlled thermal and displacement cycles.

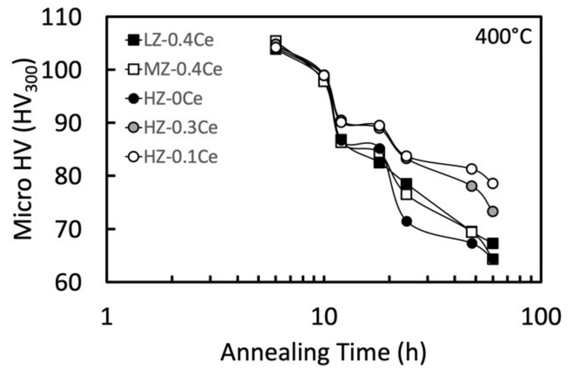
Results:

Static Recrystallization and Grain Growth



Electron Backscattered Diffraction (EBSD) maps showing recrystallization and grain growth as a function of time for thermal treatments at 350°C (left) and 400°C (right)





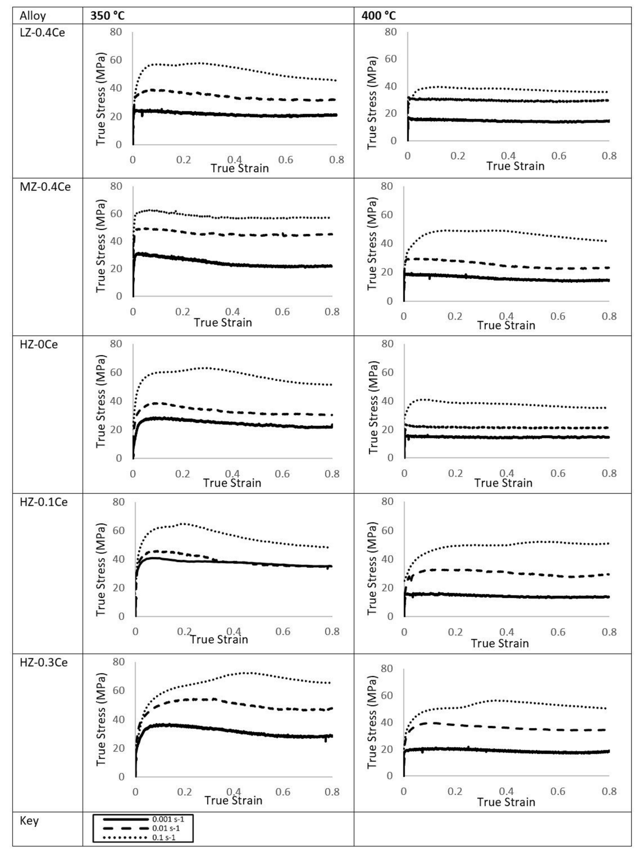
Vickers 300 g hardness measurements for each condition, showing Ce+Zn compositions maintaining higher hardness at longer times.

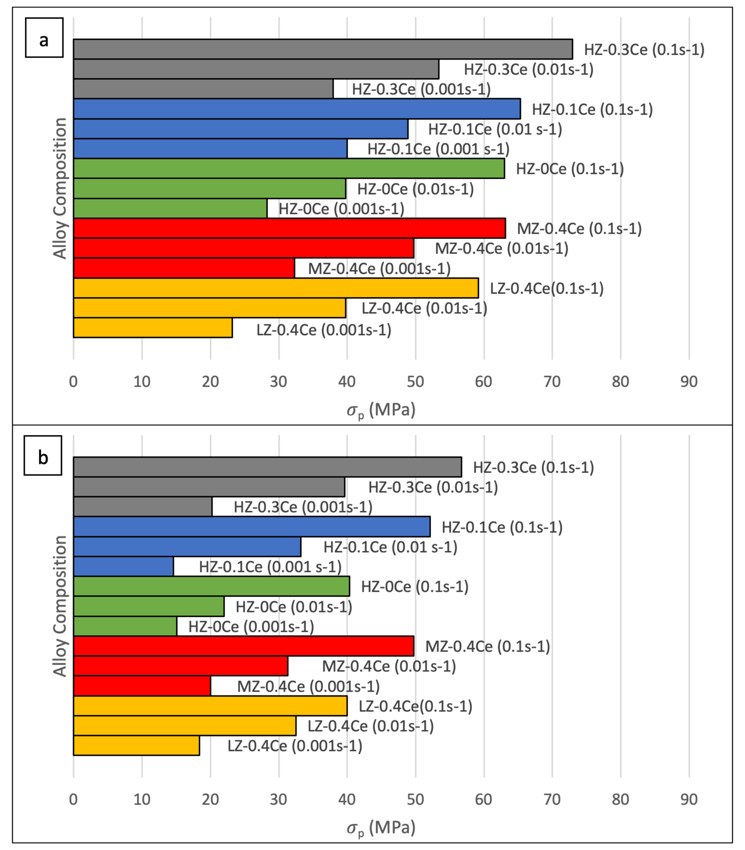
Dynamic Recrystallization

(Left) Hot compression testing results for all conditions.

(Right) Peak stress for each alloy and strain rate combination (a) at 350°C, and (b) at 400°C.

(Below) Zener-Hollomon parameter values for experimental alloys





Alloy	lnZ-ln(sinh($\alpha\sigma_p$))
LZ-0.4Ce	lnZ = 2.8711ln(sinh($\alpha\sigma_p$)) - 0.2696
MZ-0.4Ce	lnZ = 6.0024ln(sinh($\alpha\sigma_p$)) + 3.6255
HZ-0Ce	lnZ = 9.6003ln(sinh($\alpha\sigma_p$)) + 28.687
HZ-0.1Ce	lnZ = 12.766ln(sinh($\alpha\sigma_p$)) + 9.4806
HZ-0.3Ce	lnZ = 2.6505ln(sinh($\alpha\sigma_p$)) + 4.4968

Conclusions:

Static recrystallization and grain growth:

- Increasing Zn content in ZK60 variation Mg-Zn-Ce alloys increases precipitate volume fractions and solute levels present in the matrix, increasing Zener pinning and solute drag and correspondingly decreasing grain growth kinetics. Increases in Ce content cause a more significant decrease of grain growth kinetics, apparently due to greater Mg-Zn-Ce precipitate formation and strengthening.
- Grain growth modeling based on Burke and Turnbull's equation is a useful way to model grain growth kinetics and the utilization of the Arrhenius equation provides reasonable values for Q, k and k_0 to compare relative grain growth kinetics between alloys.
- Texture weakening and texture randomization occurs during SRX due to Ce and Zn additions. Basal oriented grains grow preferentially during grain growth, yet rare-earth texture develops at the initiation of SRX within shear bands and grain boundaries.

Dynamic recrystallization;

- Cerium additions are more effective at impeding recrystallization kinetics than zinc when normalize by composition (wt. pct.). Cerium increases precipitate fraction to increase Zener pinning, while zinc primarily increases solute drag. Combinations of Ce and Zn additions are most effective.
- The determined constitutive equations for the DRX process reflect the activation energy and effective Zener-pinning effect expressed in each alloy and can be used to determine industrially relevant processing parameters, given different processing conditions.
- Texture weakening and randomization is prevalent in the microstructure after DRX. A less homogenous basal texture is observed with increases in Zn, higher strain rates and lower temperatures.

Future Work:

A static recrystallization and grain growth manuscript has been submitted to the Journal of Materials Performance. A dynamic recrystallization manuscript is ready for submission to Metallurgical and Materials Transactions A.

Acknowledgments:

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References:

[1] Shahzad, M., Janecek, M., Wagner, L., International Journal of Materials Research, 2009

[2] T. Bhattacharjee, T. Sasaki, B. Suh, Role of Zr in the Microstructure Evolution in Mg-Zn-Zr Based Wrought Alloys, Magnesium Technology, (2015) 1-16.

[3] E. I. Poliak, J.J.Jonas, Initiation of Dynamic Recrystallization in Constant Strain Rate Hot Deformation, ISIJ International. 43 (2003) 684-691.

[4] S. Wang, S. Kang, Effects of hot compression and annealing on microstructure evolution of ZK60 magnesium alloys, Journal of Materials Science, (2009) 5475-5484.

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