Grain Boundary Pinning by YH_2 Particles in Magnesium Processed by Cryomilling and Spark Plasma Sintering

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MOTIVATION

- Magnesium has a high specific strength and is biocompatible making it attractive in light-weighting applications and medical implants.
- However, magnesium has a poor overall strength
- Metals can be strengthened by grain refinement → increasing the number of barriers to block defect motion.
- But, magnesium grains tend to grow at low homologous temperatures.

METHODS

- Mg and YH_2 powders are cryomilled to mix, and refine grain structure and particle size.
- Spark plasma sintering (SPS) is used to sinter quickly.

RESULTS

- Grain size is compared at various sintering conditions
- Grains grew from ~1µm at 350ºC to ~4µm at 425ºC.
- In contrast, pure magnesium grains grew to ~27µm at 425ºC.
- XRD analysis shows no contamination from cryomilling or SPS processing.
- TEM images show YH_2 particles at grain boundaries with the boundaries bowing around them.

DISCUSSION

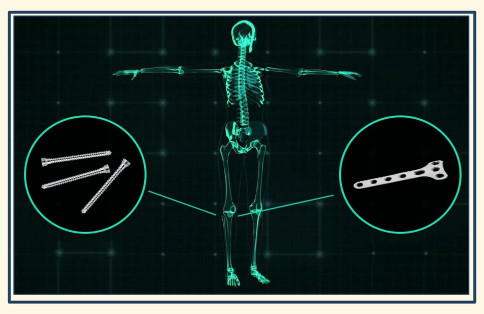
- Keeping grain refinement (achieved in earlier processing steps) during sintering is difficult as grain growth in magnesium is prevalent even at room temperature, and has a recrystallization temperature ~420ºC.
- The YH_2 particles exert a Zener pinning force on the grain boundaries as additional barriers for grain boundaries to bow around for continued growth.

FUTURE WORK

- Refining the YH_2 particle size and increasing the volume fraction to exert a higher Zener pinning force in order to maintain nanostructured magnesium.
- Analyze the plasticity mechanisms present in nanocrystalline magnesium.

MOTIVATION FOR THIS WORK

High Specific Strength



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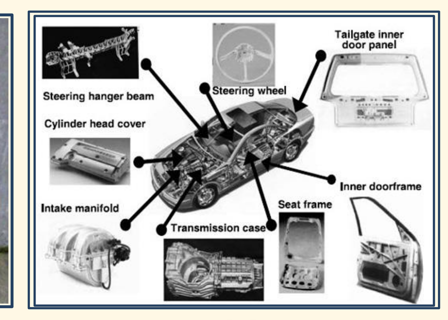

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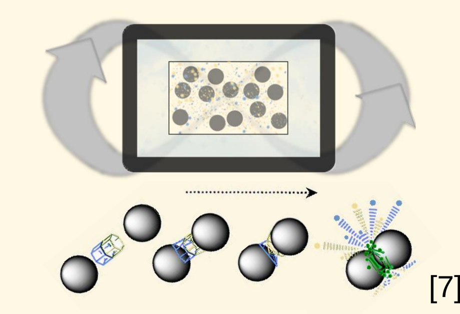
Material	Tensile Strength (Mpa) [4]	Density (g/cm^3) [4]	Specific Strength (kN-m/kg)	Commodity Price/lb [5]	Abundancy (Crust / Ocean) [6]
SS 304	505	8.00	63.1	$0.04 (Iron Ore)	Fe Crust: 4th/Ocean: 27th
Titanium	344	4.51	76	$4.13	Ti Crust: 9th/Ocean: 32nd
6061-T6 Al Alloy	310	2.70	115	$1.15	Al Crust: 3rd/Ocean: 24th
Mg Alloys	275	1.74	158	$2.15	Mg Crust: 6th/Ocean: 5th

Poor Strength

Grain Growth at Low Homologous Temperatures

METHODS

Cryomilling



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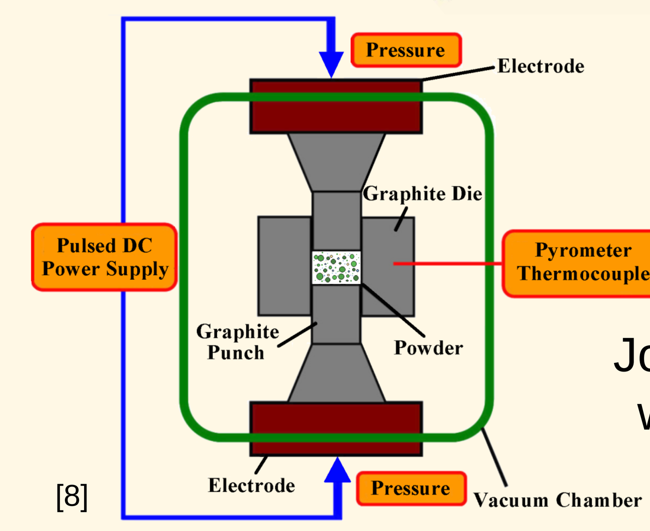
Refined Powders

Particle size of 63µm -125µm, and grain sizes on order of 100's of nanometers.



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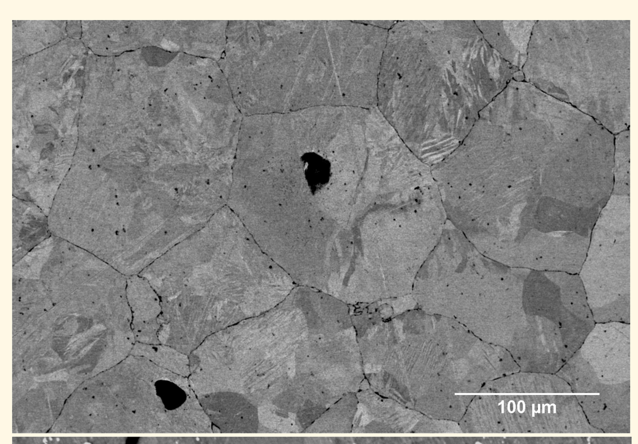
Densification

Fast Sintering

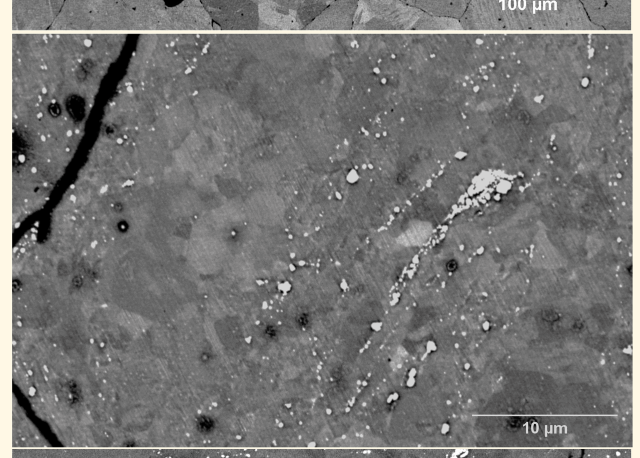
Joule heating to sinter quickly, with a peak temperature hold time of only 5 minutes.

RESULTS

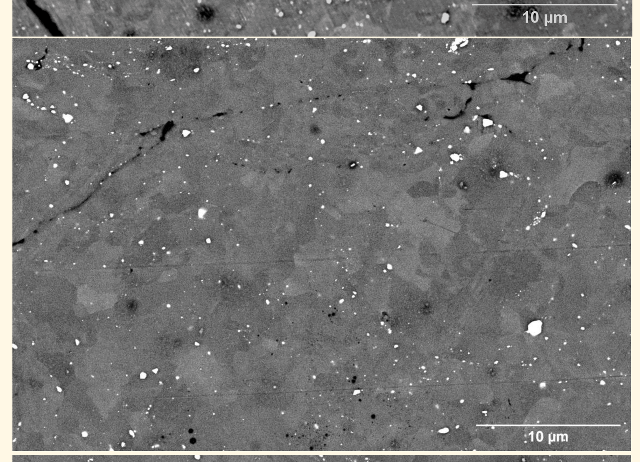
Pure Mg Sintered at 425ºC



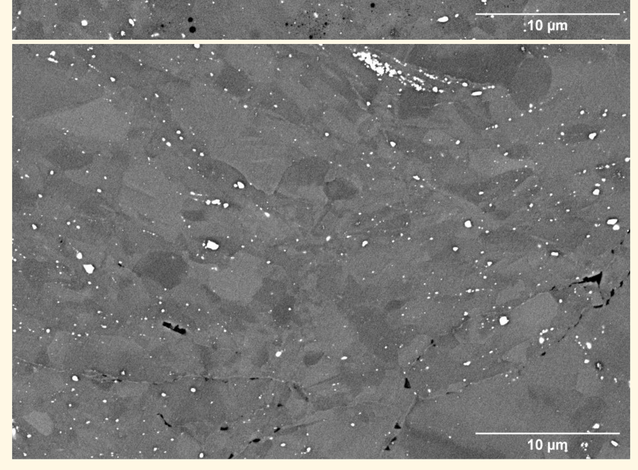
Mg-1YH_2 Sintered at 350ºC



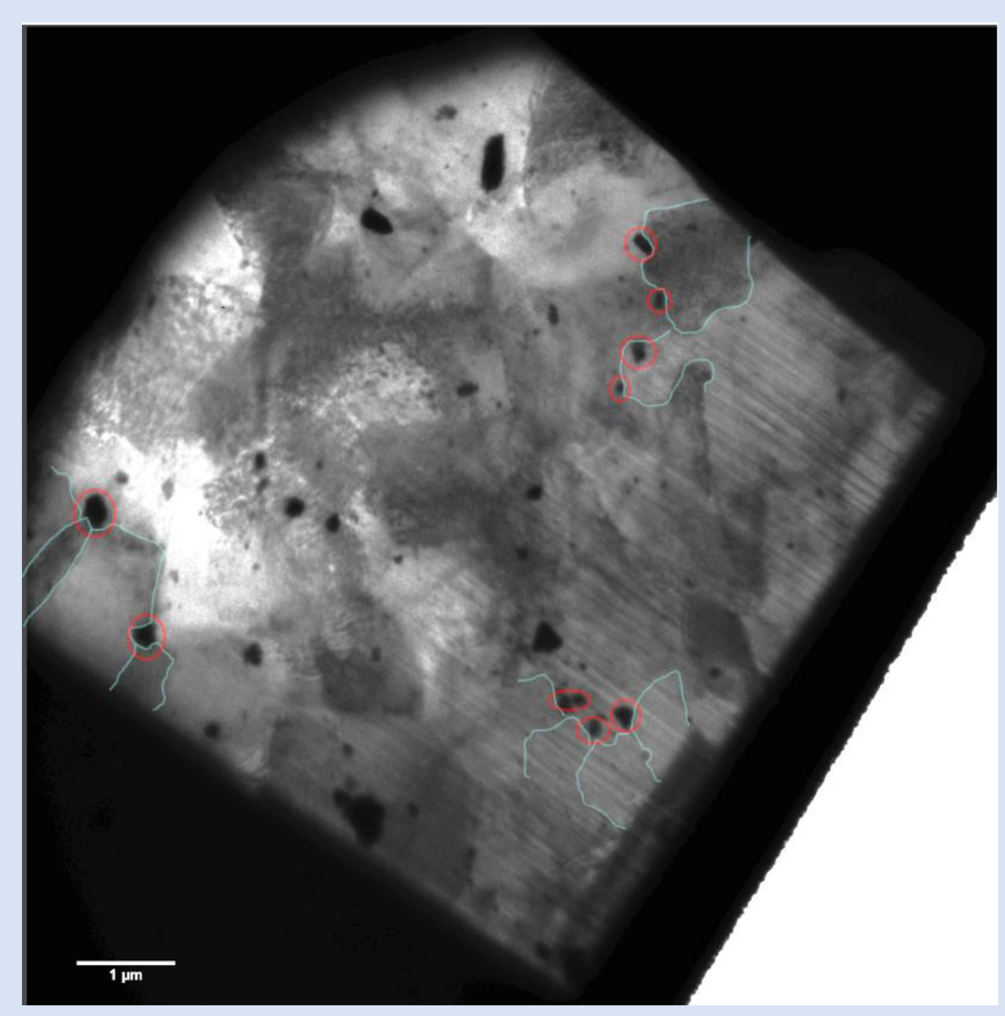
Mg-1YH_2 Sintered at 375ºC



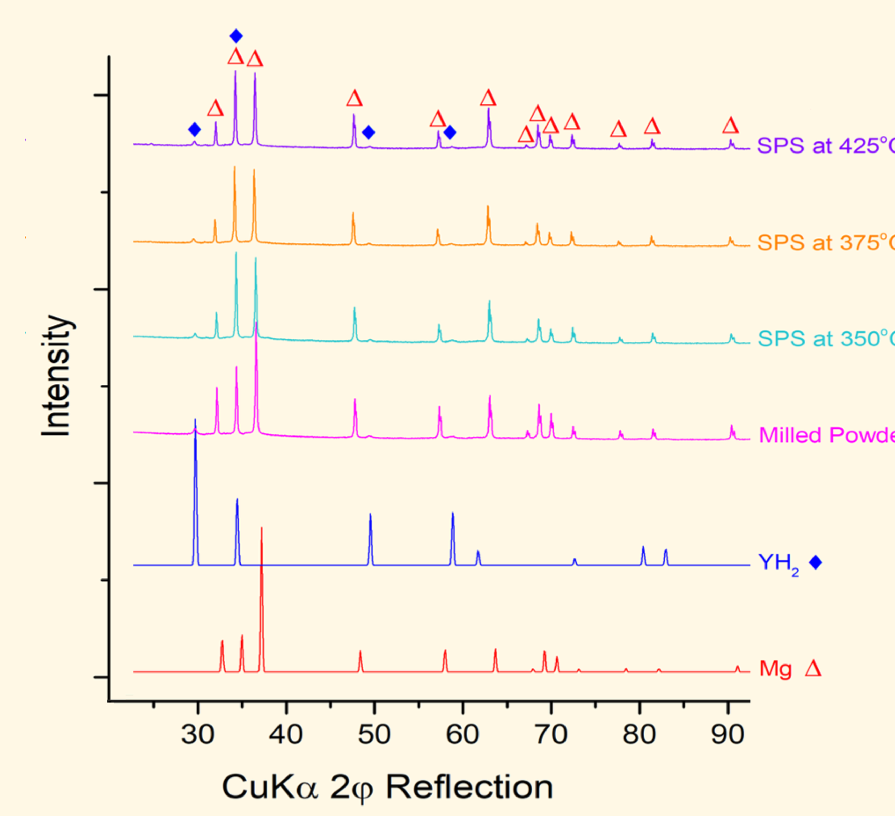
Mg-1YH_2 Sintered at 425ºC

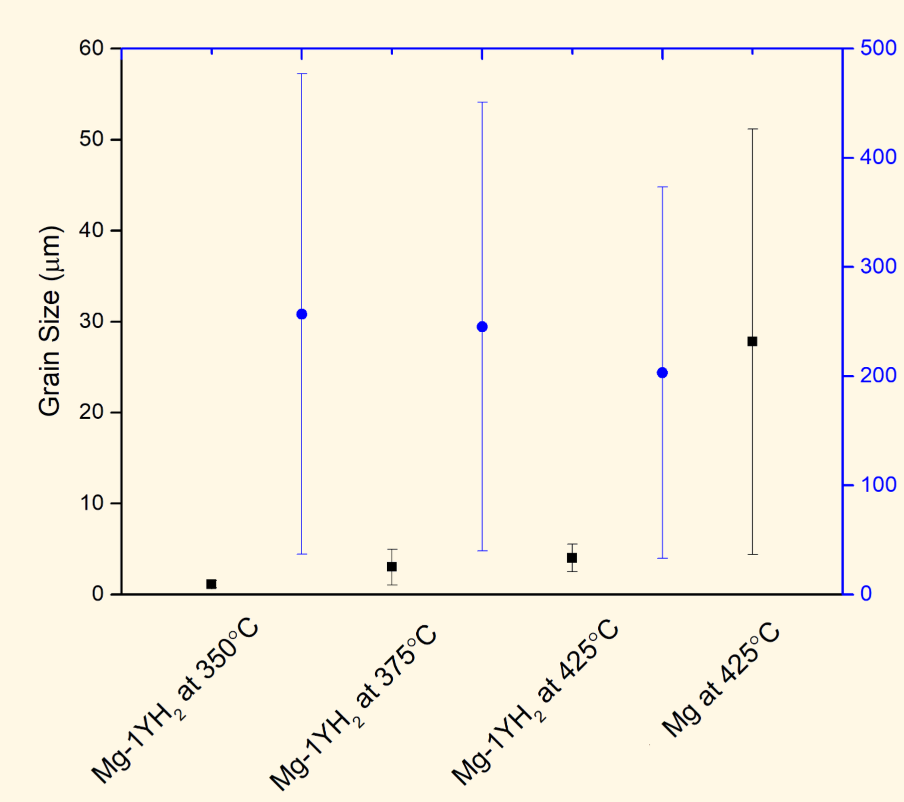


Grain Boundary Pinning

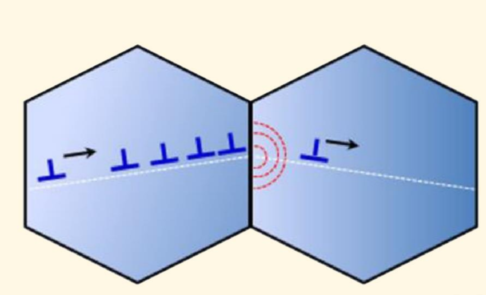


TEM-BF image showing YH_2 particles pinning grain boundaries, slowing grain growth





DISCUSSION



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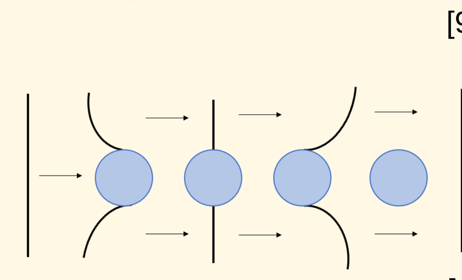
Grain size grows from ~1µm to ~3µm to ~4µm at sintering temperatures of 350ºC, 375ºC and 425ºC respectively.



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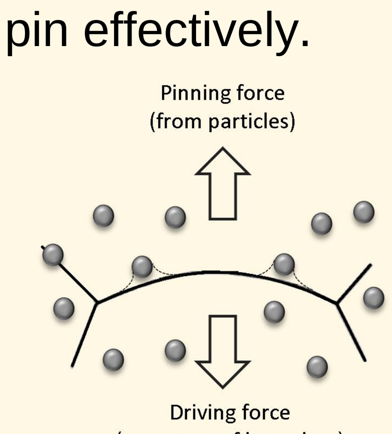
When comparing to pure magnesium sintered at 425ºC which exhibits a grain size of ~28µm, the YH_2 particles pin effectively.



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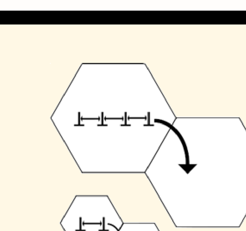
XRD doesn't show evidence of any contaminants from the processing conditions, and confirms that there is little to no solid solutionizing of yttrium.

TEM images show grain boundaries bending around YH_2 particles which is indicative of the Zener pinning effect.

FUTURE WORK



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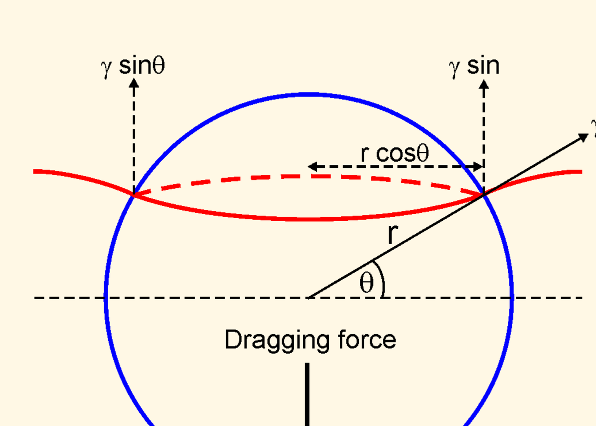

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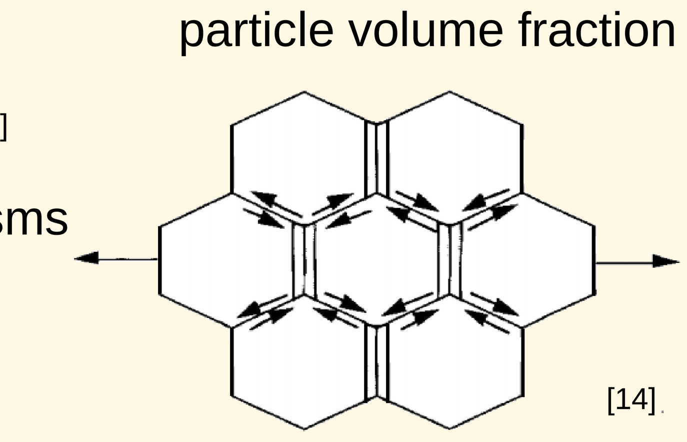
Increase the Zener pinning force to achieve nanostructured magnesium.

- Smaller pinning particles
- Increased pinning particle volume fraction

Study plasticity mechanisms in stable, nanostructured magnesium.



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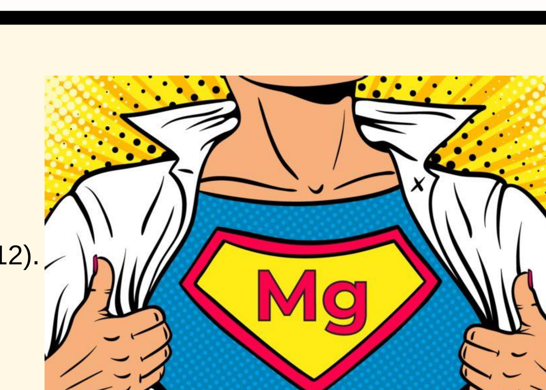
REFERENCES

[1] http://www.e-ande.com
[2] www.totalmateria.com
[3] https://investingnews.com/daily/resource-investing/critical-metals-investing/magnesium-investing/magnesium-the-other-bike-frame-metal/
[4] http://asm.matweb.com/
[5] https://www.usgs.gov/centers/nmic
[6] https://periodictable.com
[7] J. Huot, Viktor Balema, "Mechanochemical effect of severe plastic deformations; metal alloys, hydrides and molecular solids", *Material Matters* (2012).
[8] A. Chang et al., "Spark Plasma Sintering of Negative Temperature Coefficient Thermistor Ceramics", Sintering Techniques of Materials (2015).
[9] H. Yu et al., "Hall-Petch relationship in Mg alloys: A review", *Journal of Materials Science & Technology* (2018).
[11] ASM Handbook vol. 6A (2011)
[12] https://en.wikipedia.org/wiki/Grain_boundary_strengthening
[13] https://en.wikipedia.org/wiki/Zener_pinning
[14] RF Cook, GM Pharr, "Indentation load-displacement behavior during conventional hardness testing", *Journal of Hard Materials* (1994).



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