The Effect of Rare Earth Elements, Temperature and Rolling Speed on the Microstructure Evolution of Magnesium

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Introduction

•The improvement of magnesium alloys is studied extensively due to its many advantages:

- Lowest structural density for a metal: 1.74 g/cm³
  - 2/3 the weight of Aluminum
- Abundance: 8th most abundant element in Earth's crust (2% by mass)

•These properties can serve as a promising replacement for steel in the automotive industry which can lead to:

- Decreased weight and fuel consumption

•These advantages are limited by:

- Magnesium's ability to deform plastically at low temperatures

•Rare earth elements are the current focus of study due to:

- Ability to weaken the rolling texture of magnesium alloys

•Some effective parameters on the deformability and strength of metals are

- Precipitation: Precipitates can increase the yield strength by impeding the movements of dislocations and change the deformation mechanism
- Recrystallization: the nucleation and growth of new undeformed grains over original grains; this phenomenon is usually accompanied with increased ductility and decreased strength and hardness

•Goal: to study the effect of different rolling conditions and, alloy composition and precipitates on the recrystallization and grain growth of some magnesium alloys and compared with AZ31 as a reference alloy.

Experimental Procedure and Methodology

Different cerium and neodymium additive samples were acquired then subsequently rolled at different temperatures (300°C and 450°C) and rolling speeds (15 m/min and 1000 m/min). These samples were then annealed for 0, 60, 250 or 900 s at 450C followed by quenching. These samples were then analyzed after standard metallography. The hardness of these samples were tested by a Macro-Vickers Indentation Hardness Tester. The same preparation method was used for the SEM and X-ray bulk texture analysis.

Grind
- Mount and grind the rolled samples with 200, 500 and 1200 grit sandpapers

Polish
- Polish with 3 µm and 1 µm diamond paste
- Polish with 0.02 µm colloidal silica for 1-2 min

Etch
- Etch with acetic picral solution (4.2 g picric acid, 10 ml acetic acid, 10 ml acetic acid and 70 ml ethanol)

Optical microscopy
- Take pictures at 100X, 200X and 500X with a Clemex optical microscope
- Determine average grain sizes manually using a linear intercept method

Results

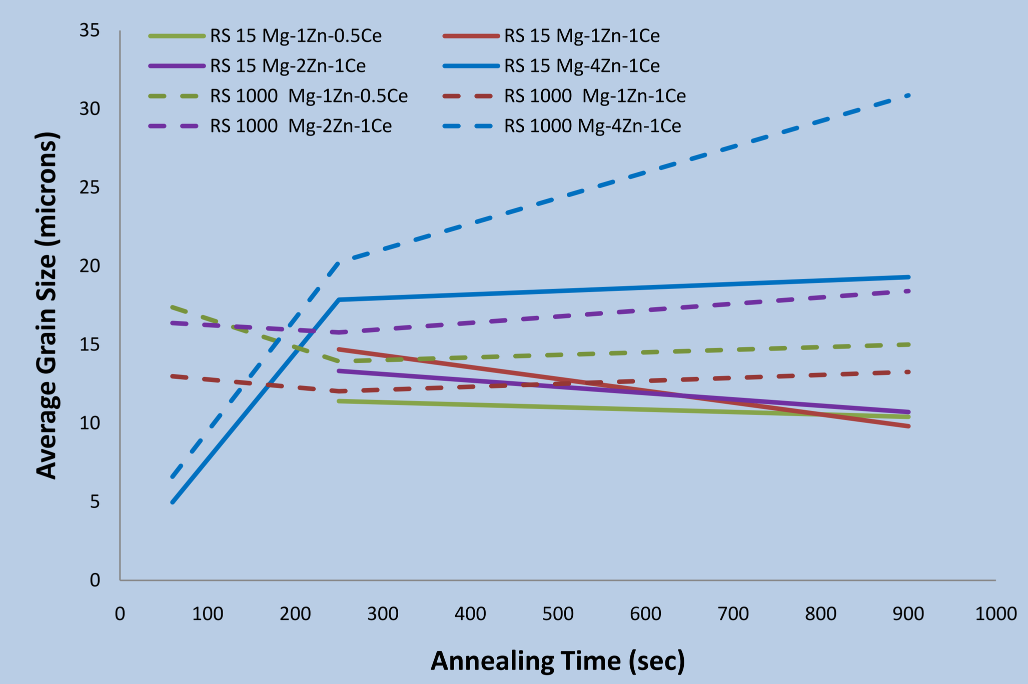

Fig. 1. Average grain size vs Annealing time (450°C and different rolling speeds of Mg-Zn-Ce alloys.)

As expected of a recrystallization type metal, these samples made at 450°C have increased grain size with increased annealing time. It can also be noted that the high rolling speed samples have a slightly higher average grain size. It seems that the effect on the grain growth of Mg-4Zn-1Ce of is more prominent although the initial grain size is smaller.

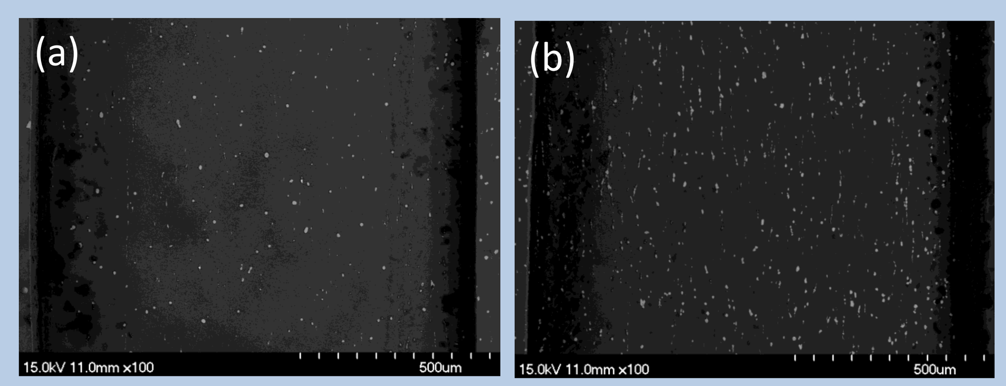

Fig. 2. (a) SEM of precipitate of Mg-1Zn-0.5Ce and (b) Mg-4Zn-1Ce

To study the amount of precipitate in these alloys, the back scatter image were taken from the alloys using SEM. The amount of precipitates calculated using image processing were about 2.01 and 7.30 percent.

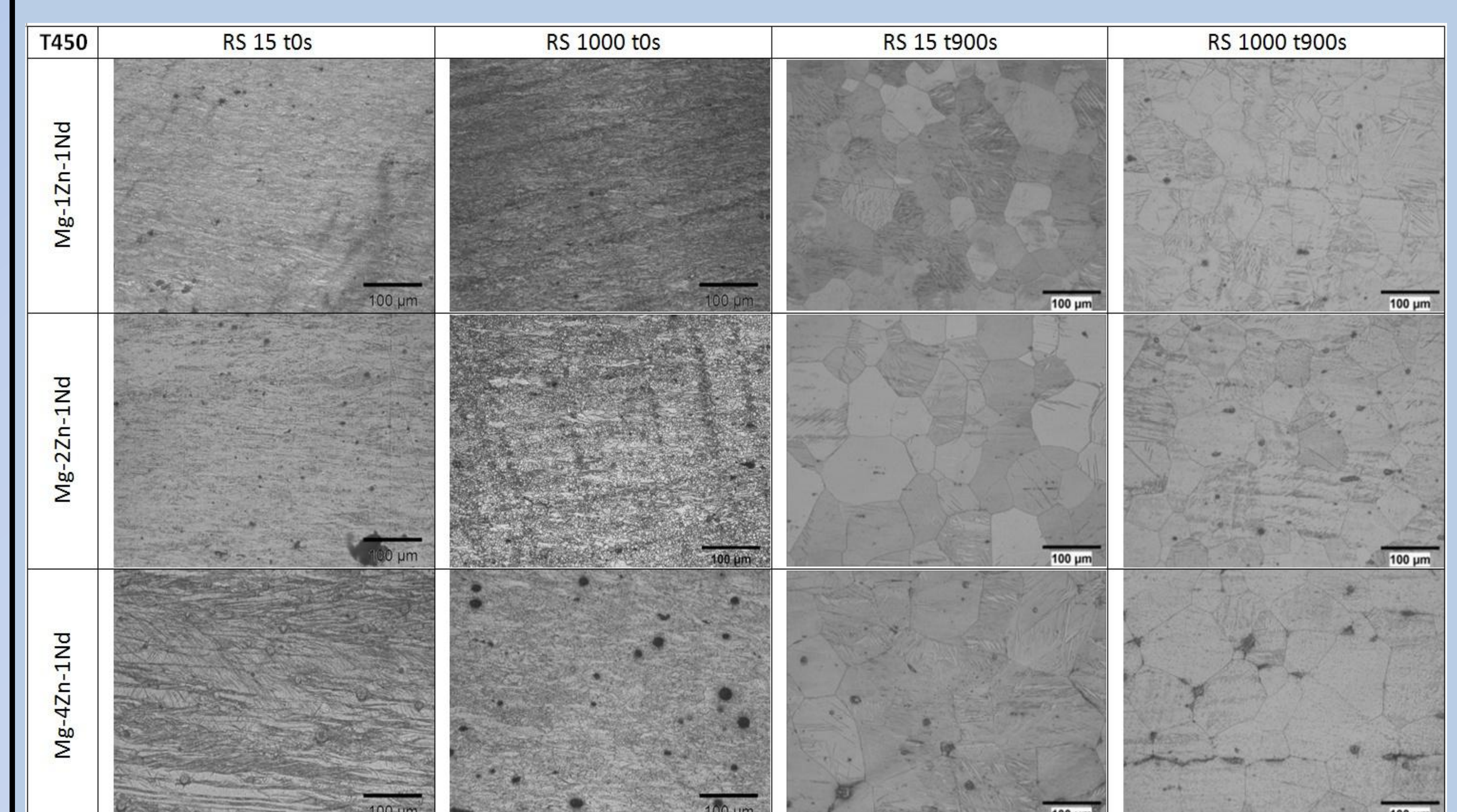

Fig. 3. Microstructure comparison for various neodymium samples

The effect of rolling speed, temperature and annealing time were investigated in Mg-Zn-Nd system in the same manner as the Mg-Zn-Ce. In general, increasing the rolling speed will increase the volume fraction of recrystallized material. At rolling speed of 15 m/min and specially for the Mg-4Zn-1Nd alloy some twinning can be detected in the not fully recrystallized sheet. After being annealed for 900 seconds, the grain size for this set of samples have grown rapidly to an average grain size of about 70 microns.

Results

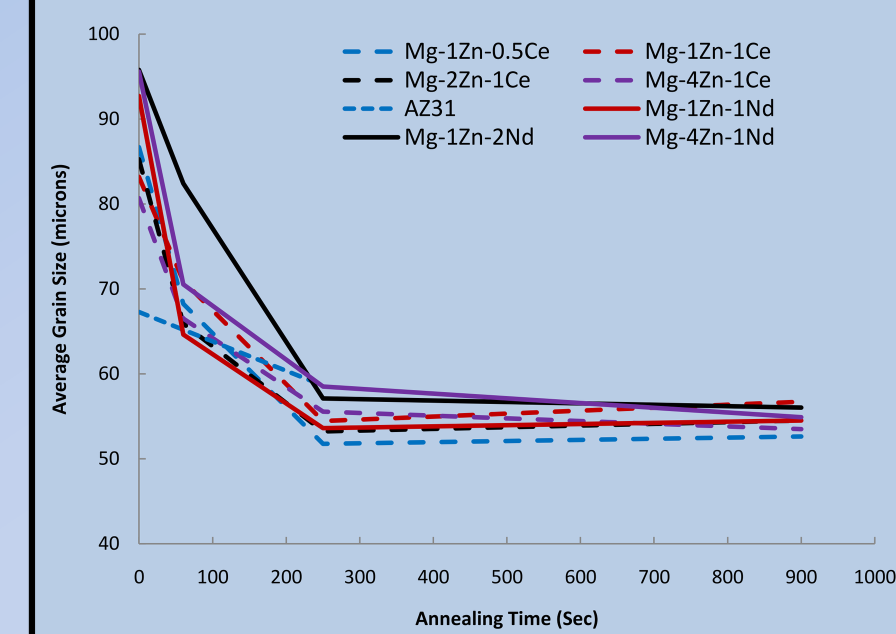

Fig. 4. Annealing Time vs Hardness Value (300°C and 1000 m/s rolling speed)

As can be seen in Fig. 4 all the samples examined have similar hardness between 0 and 900 seconds of annealing. Although the neodymium samples have a slightly higher hardness value.

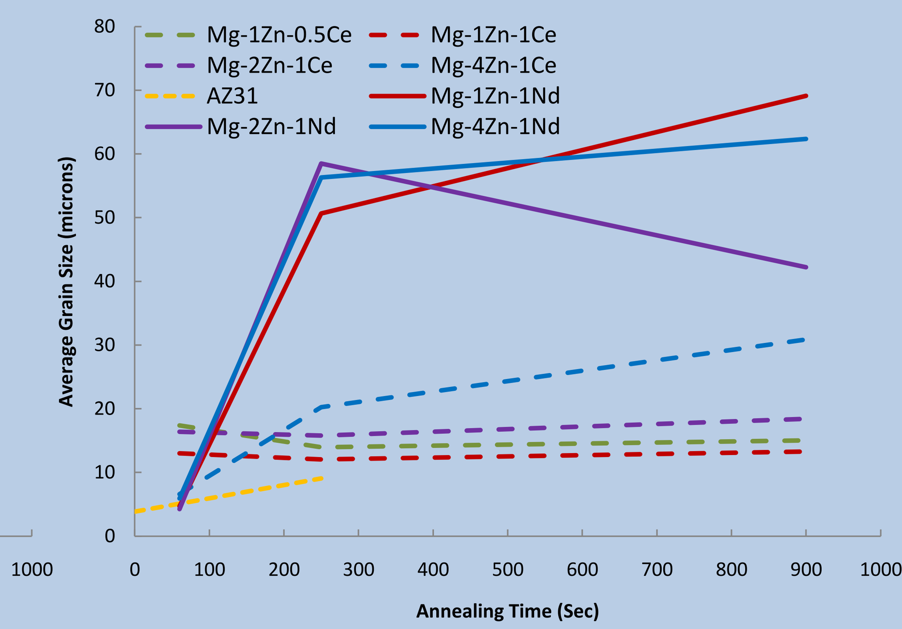

Fig. 5. Annealing Time vs Average Grain Size (300°C and 1000 m/s rolling speed)

Fig. 5 shows that by 250 seconds of annealing, both cerium and neodymium samples have completed grain growth although the neodymium samples have much larger grains. The average grain size is much higher than the AZ31 reference alloys.

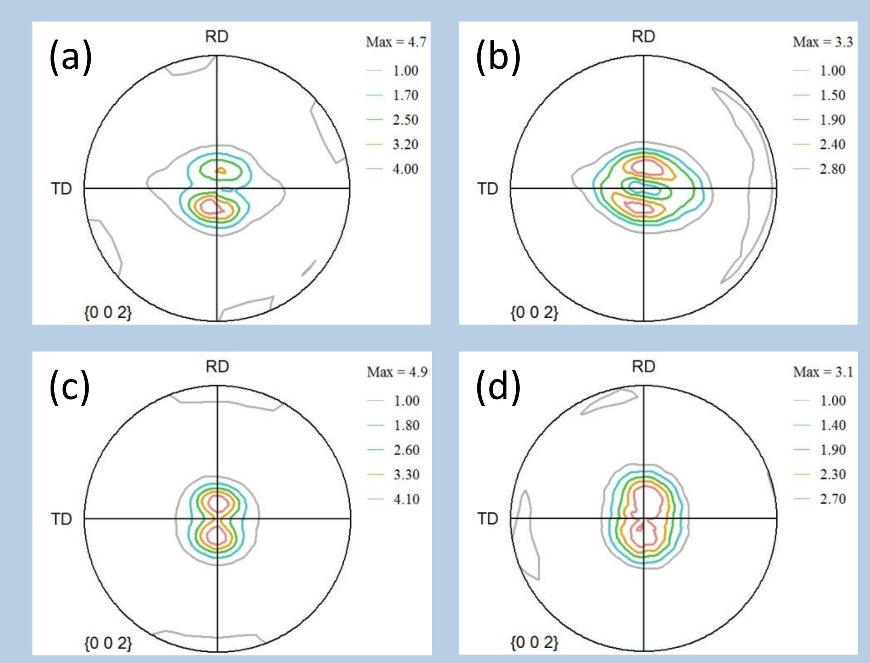

Fig. 6. Texture of Mg-1Zn-0.5Ce as rolled at 450°C (a) 15 m/min (b) 1000 m/min and AZ31 as rolled at 450°C (c) 15 m/min (d) 1000 m/min

It is known that if the intensity of the texture is decreased or the texture has more random distribution, the formability of the Mg alloy sheet increases. As shown in Fig.6, by increasing the rolling speed, the intensity of the pole figure decreased in both AZ31 and Mg-1Zn-0.5 Ce; in addition, the Mg-1Zn-0.5Ce basal poles are tilted toward the rolling direction.

Conclusion

•The higher amount of precipitates in Mg-4Ce-1Zn may have retarded the dynamic recrystallization which explains the smaller initial grain size but the faster grain growth might be caused by a change in the type and morphology of the precipitate which led to a less pinning effect.

•The neodymium samples have longer grain growth period than their cerium counterpart and have up to 70 micron grain sizes

•Higher rolling speeds yield an insignificant increase in grain size after annealing due to higher amount of stored energy but yields a significant decrease in hardness

•The hardness for all neodymium and cerium samples plateau after approximately 250 seconds of annealing with approximately 50 HV

References

Beer, A. G. "Microstructure Evolution in Hot Worked and Annealed Magnesium Alloy AZ31." *Material Science and Engineering* (2007): 318-24. Print.