Mechanical Properties and Microstructures of $Mg_{97}Zn_1MM_2$ Alloys

Asian Forum on Light Metals

ALMA Forum 2014 ,

November 14, 2014, Shinagawa, Japan

Jian-Yih Wang (王建義)
Department of Materials Science and Technology,
National Dong Hwa University (NDHU;国立東華大学),
Taiwan

Research purpose

- The rapid solidified Mg alloy ($Mg_{97}Zn_1Y_2$; Kumadai alloy) with long-period stacking ordered (LPSO) phase possesses good combination of mechanical properties and corrosion resistance. It is attracted considerable attention.
- However, the expense of Y addition and inconvenience of rapid solidification process restricts the application of this alloy.
- Low priced misch metals were used to replace the Y, and alloys were cast by conventional VIM method.
- The room temperature and elevated temperature mechanical properties of $Mg_{97}Zn_1MM_2$(La, Ce-rich misch metal) alloys were investigated.
- The $Mg_{97}Zn_1Y_2$ alloy is also investigated for a comparison with $Mg_{97}Zn_1MM_2$ alloys in mechanical properties and microstructure.

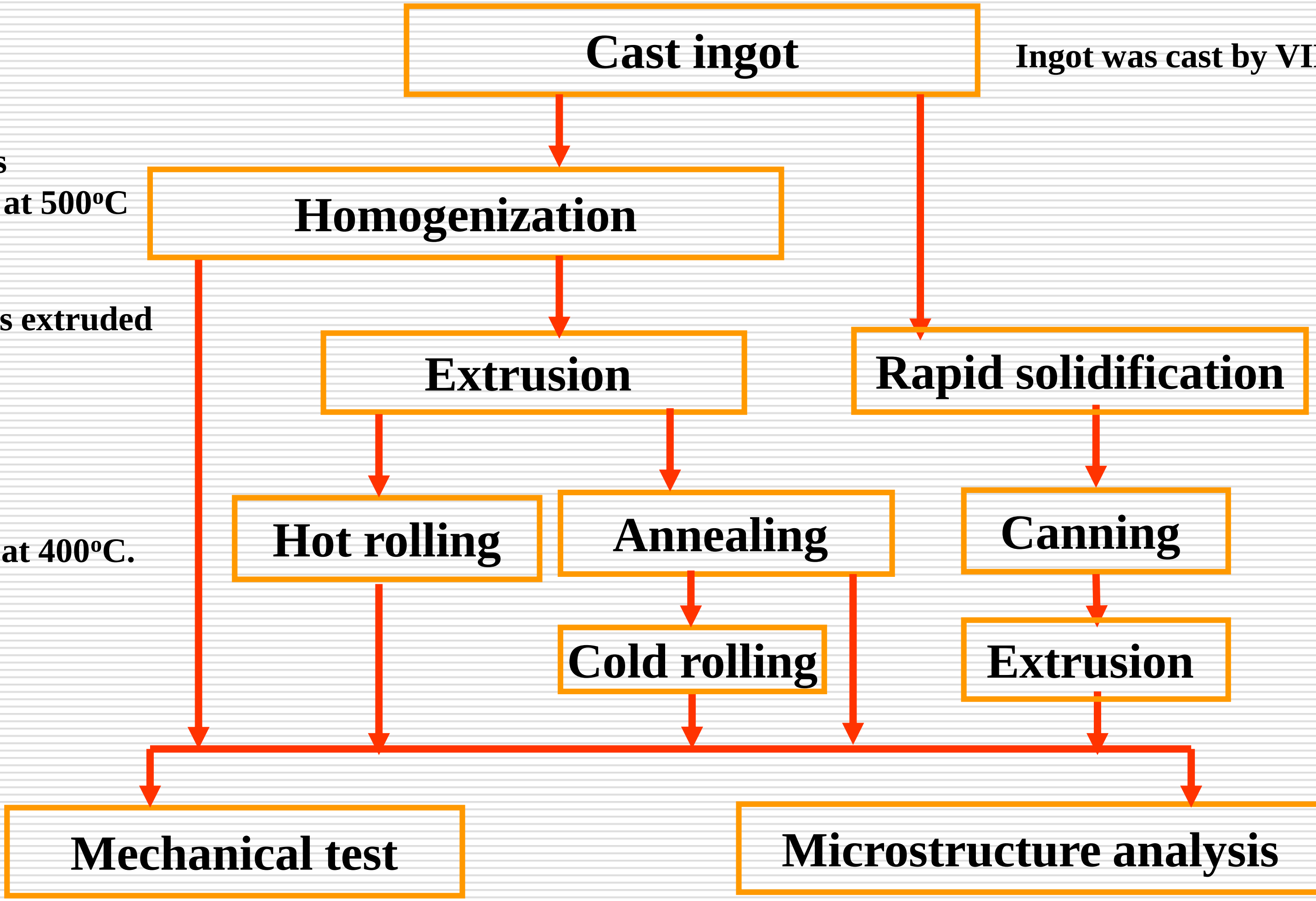
Experimental procedures

Ingot was cast by VIM method.

The ingot was homogenized at 500^{o}C for 10h.

The ingot was extruded at 400^{o}C.

Hot rolling at 400^{o}C.



Tensile, compressive test and microhardness measurement

FE-SEM, XRD, EDS and OM, image analysis

The chemical compositions of alloys

The chemical composition of the alloys were measured by ICP-OES and listed below.

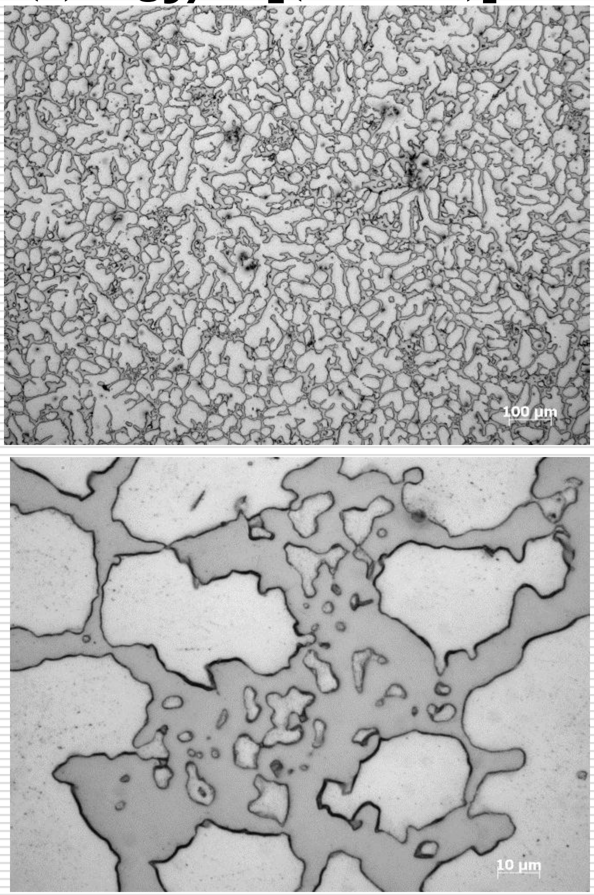
Alloys (wt.%)	Mg	Zn	Y	La	Ce	Al	Si
$Mg_{97}Zn_1Y_2$	85.8	2.49	6.42	0.186	0.077	0.030	0.047
$Mg_{97}Zn_1(MM\text{-}La)_2$	75.4	2.59	<0.009	6.80	2.83	0.067	0.062
$Mg_{97}Zn_1(MM\text{-}Ce)_2$	68.9	2.13	<0.009	2.98	5.08	0.034	0.032

Two different kinds of misch metals (La-rich and Ce-rich) were added in the $Mg_{97}Zn_1MM_2$ alloys, respectively.
The ratios of lanthanum and cerium in the $Mg_{97}Zn_1MM_2$ alloys are different, but other added elements are almost the same.

Both misch metals contain some minor elements of Nd and Pr.
The total amounts of minor elements below 1wt.%.

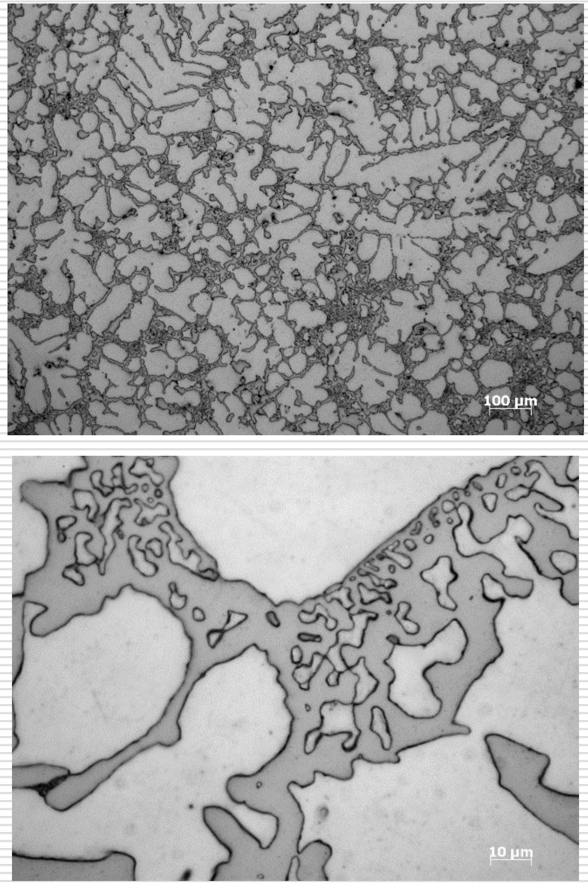
OM images of as-cast alloys

(a) $Mg_{97}Zn_1(MM\text{-}La)_2$



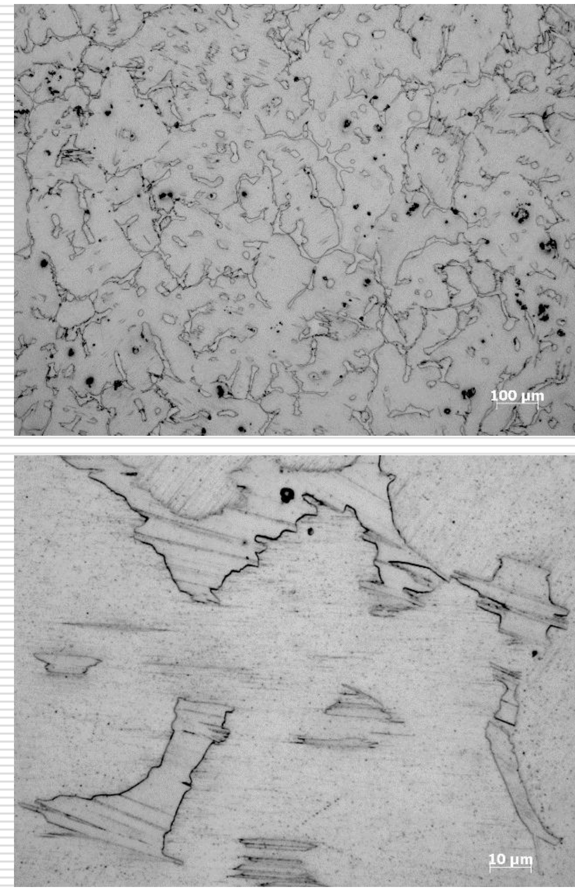
Mg grain: 142.3µm

(b) $Mg_{97}Zn_1(MM\text{-}Ce)_2$



Mg grain: 196.6µm

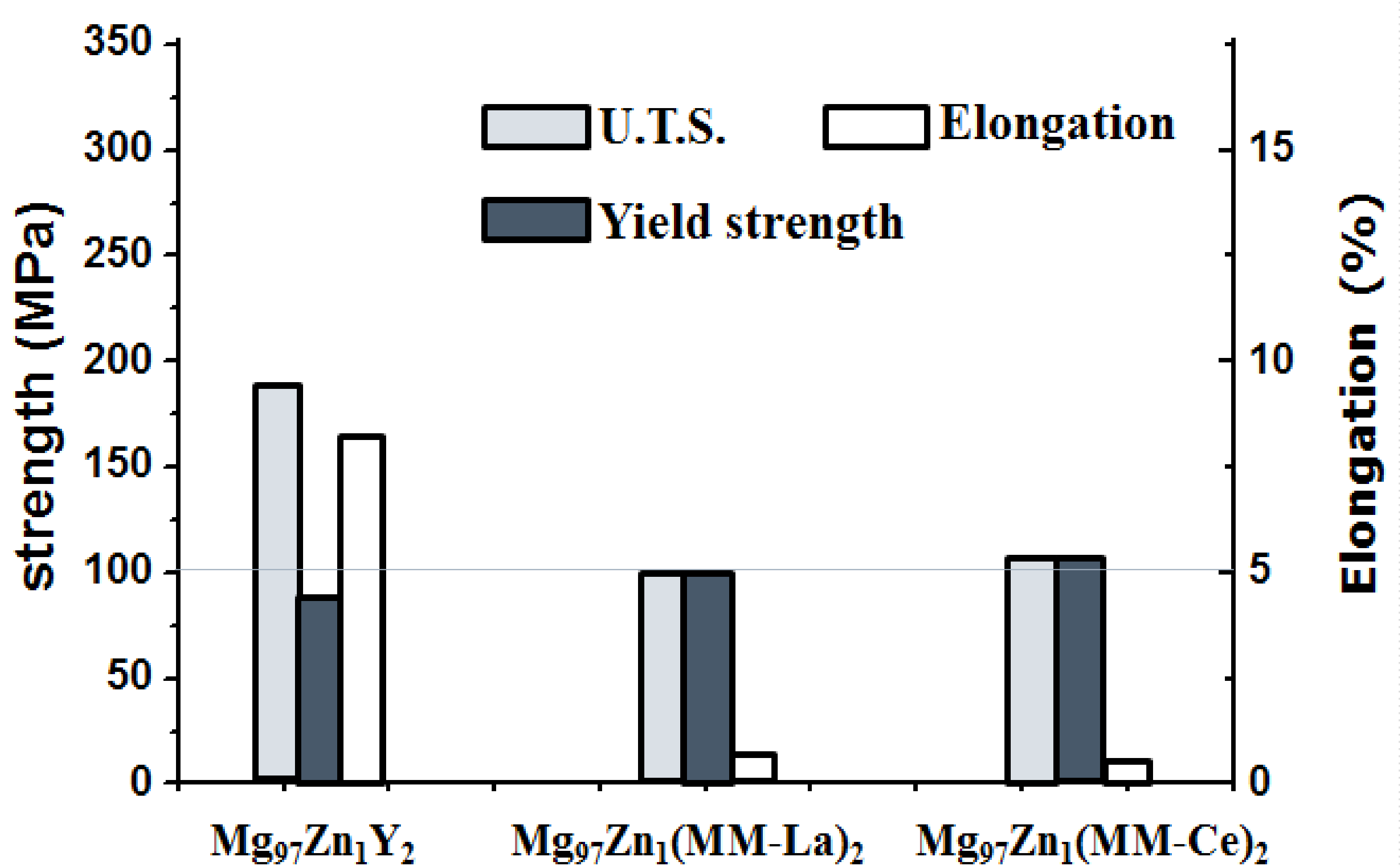
(c) $Mg_{97}Zn_1Y_2$



Mg grain: 257.6µm

All of the alloys demonstrate a dendrite structure with large grain sizes as well as second phase particles.

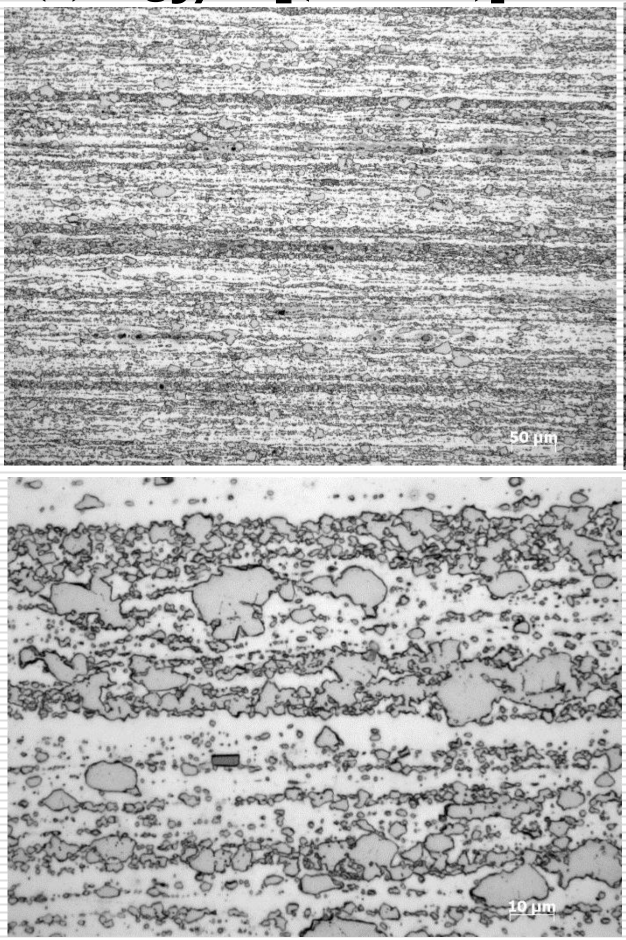
Mechanical properties of as-cast alloys



The yield strengths of both $Mg_{97}Zn_1MM_2$ alloys are higher than that of $MgZnY_2$ alloy.

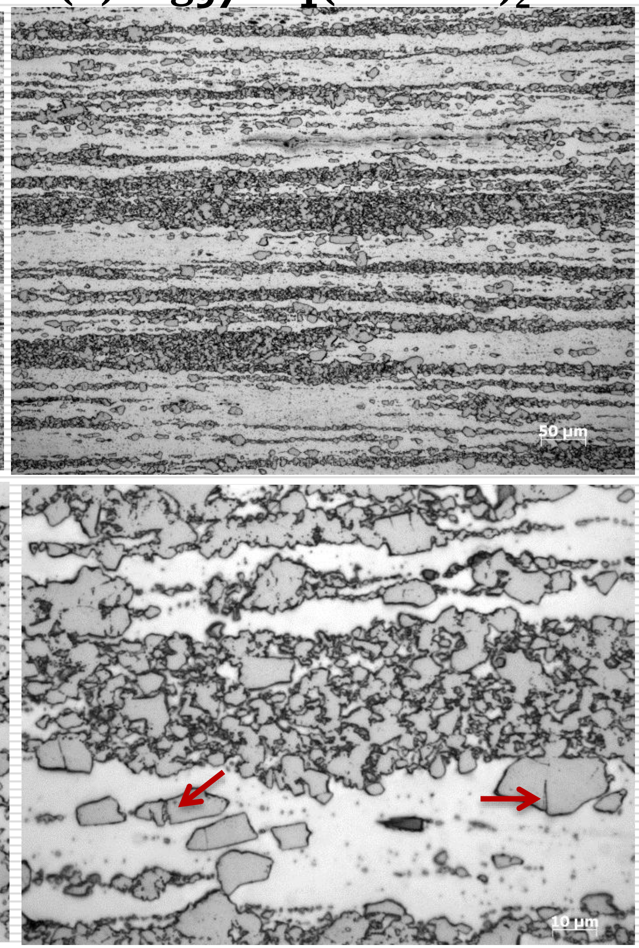
OM images of extruded alloys

(a) $Mg_{97}Zn_1(MM\text{-}La)_2$



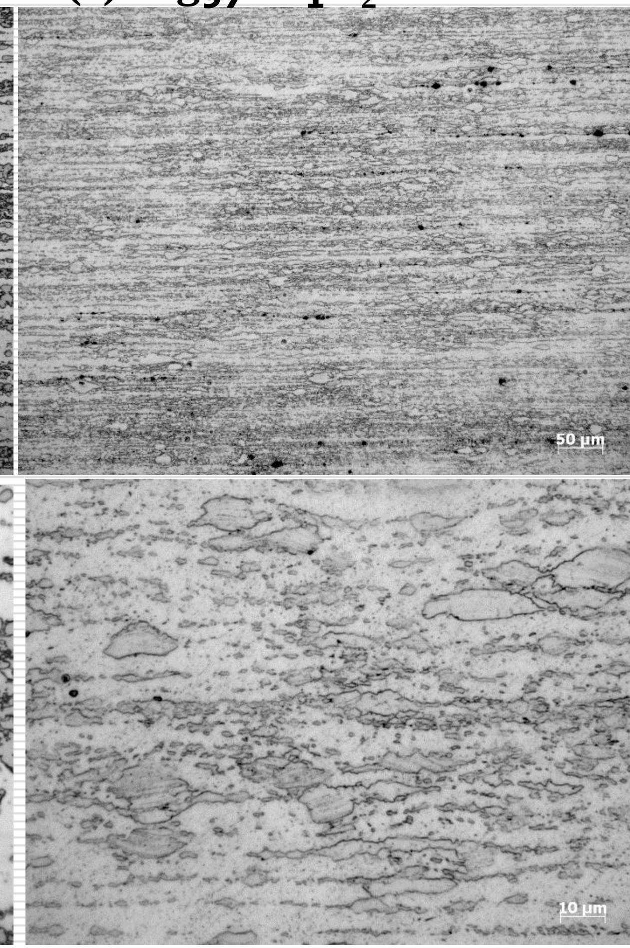
Mg grain: 10.2µm

(b) $Mg_{97}Zn_1(MM\text{-}Ce)_2$



Mg grain: 11.5µm

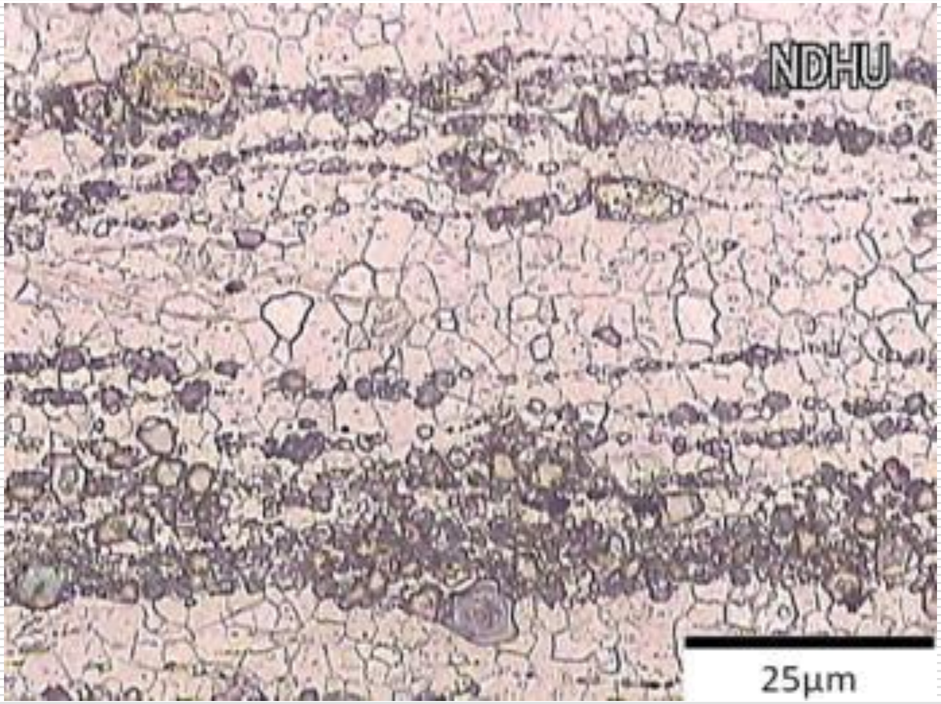
(c) $Mg_{97}Zn_1Y_2$



Mg grain: 16.8µm

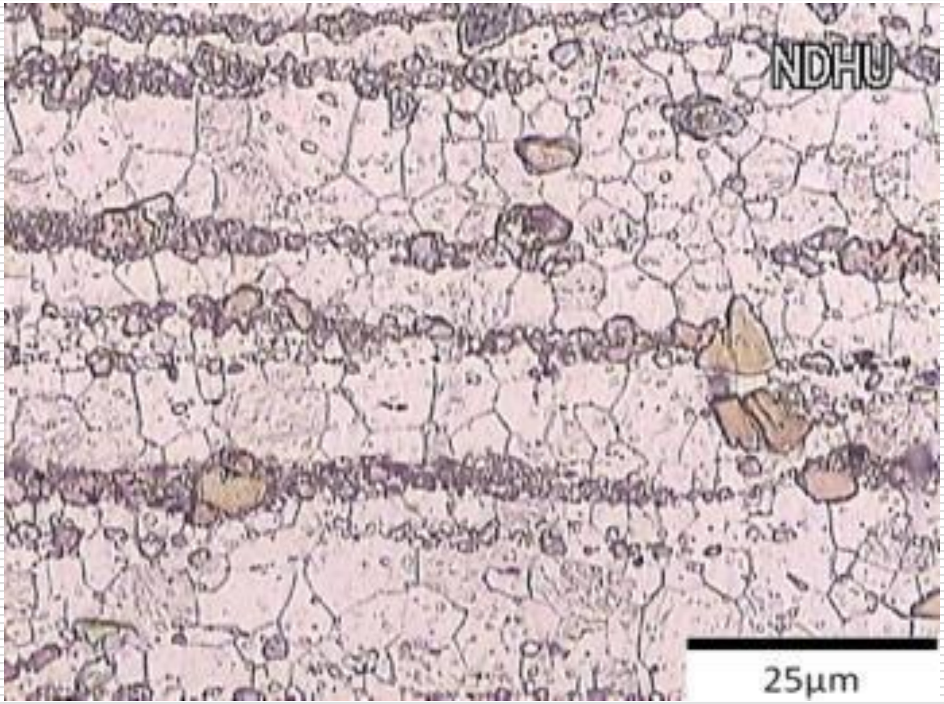
The grain size of Mg matrix as well as second phase particles can be refined by extrusion remarkably. However, the shape of second phase particles is irregular and they are distributed unevenly.

OM images of as-extruded $Mg_{97}Zn_1MM_2$ alloys



(a) $Mg_{97}Zn_1(MM\text{-}La)_2$

Mg grain: 10.2μm

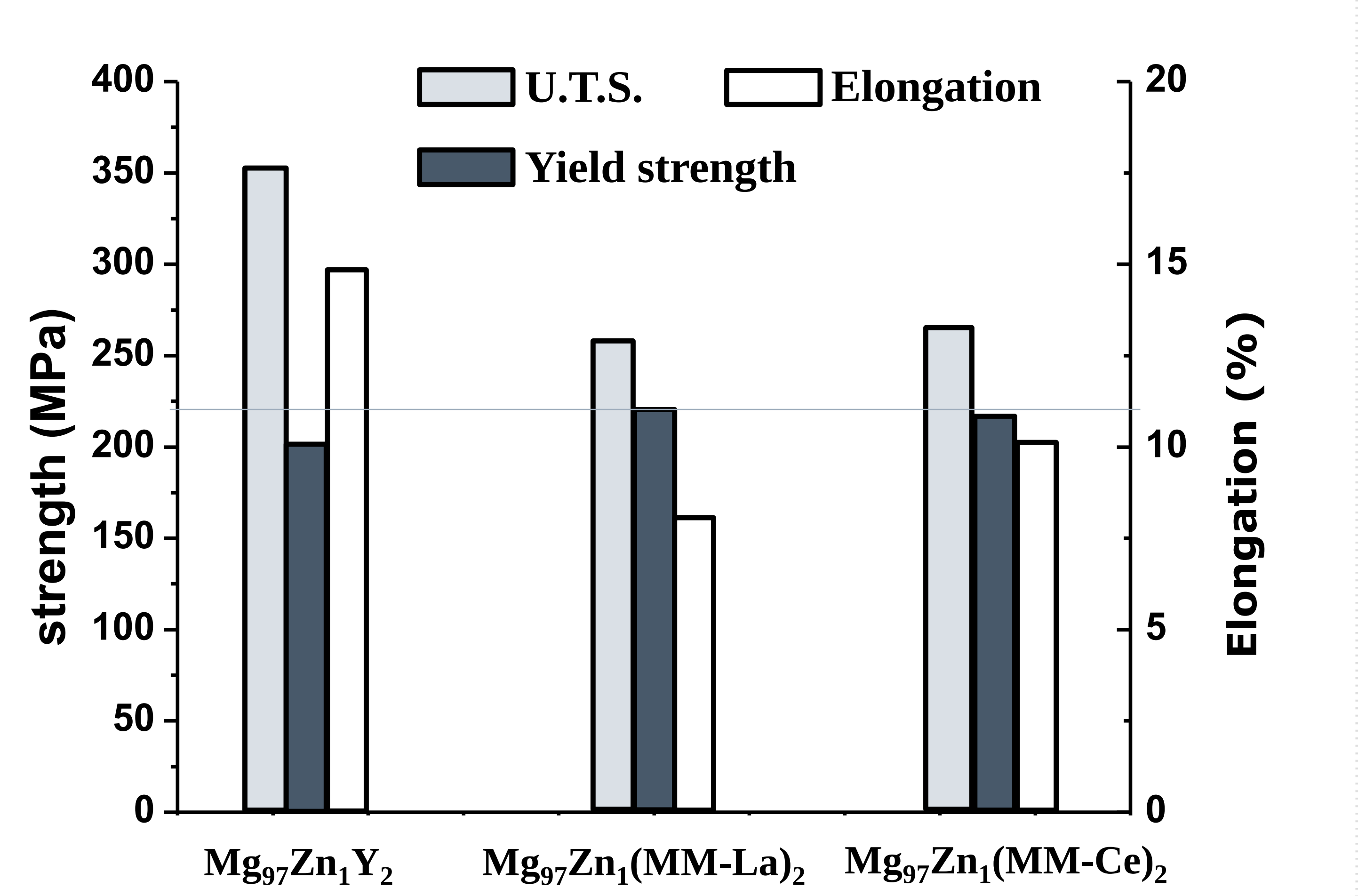


(b) $Mg_{97}Zn_1(MM\text{-}Ce)$

Mg grain: 11.5μm

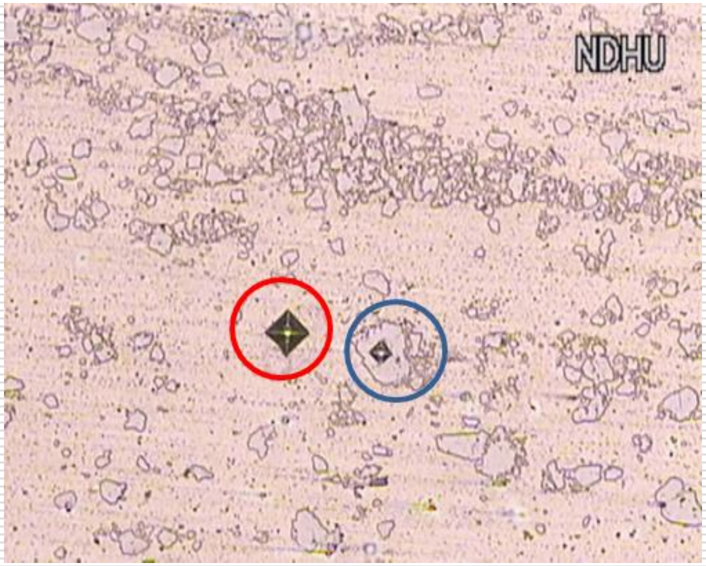
The volume fractions of second phase particles in $Mg_{97}Zn_1(MM\text{-}La)_2$ and $Mg_{97}Zn_1(MM\text{-}Ce)_2$ alloys are 24.9% and 23.1%, respectively.

Mechanical properties of extruded alloys



The yield strengths of all alloys are improved due to the contribution of fine structure. And strengths are increasing by almost two times comparing with as-cast ones.

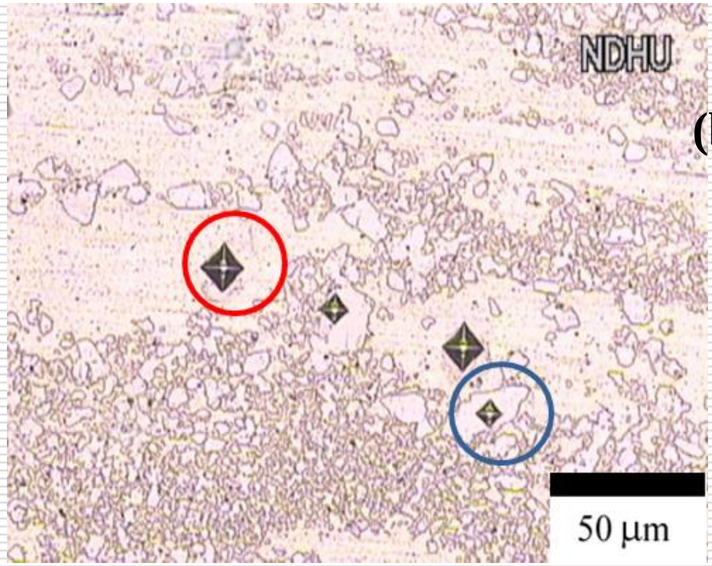
Microharnesses of extruded alloys



(a) $Mg_{97}Zn_1(MM\text{-}La)_2$

2nd phase: 146.2Hv

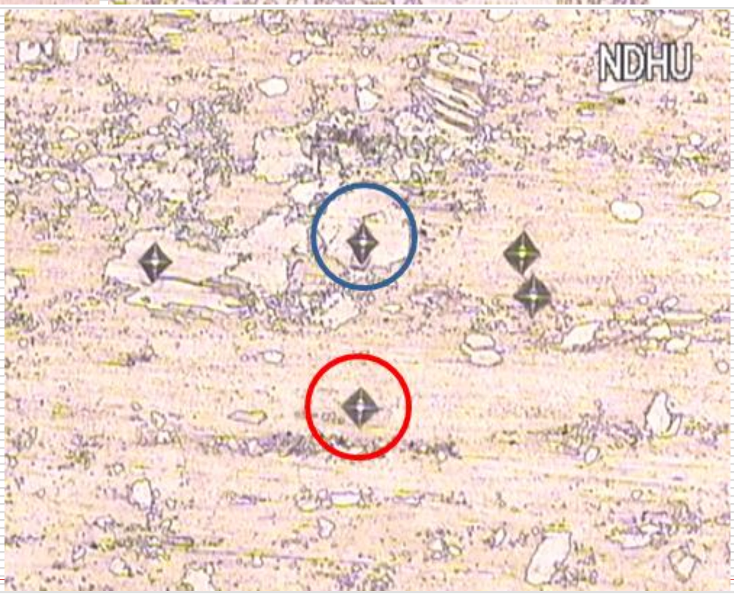
Mg : 52.8Hv



(b) $Mg_{97}Zn_1(MM\text{-}Ce)_2$

2nd phase: 135.5Hv

Mg: 60.3Hv



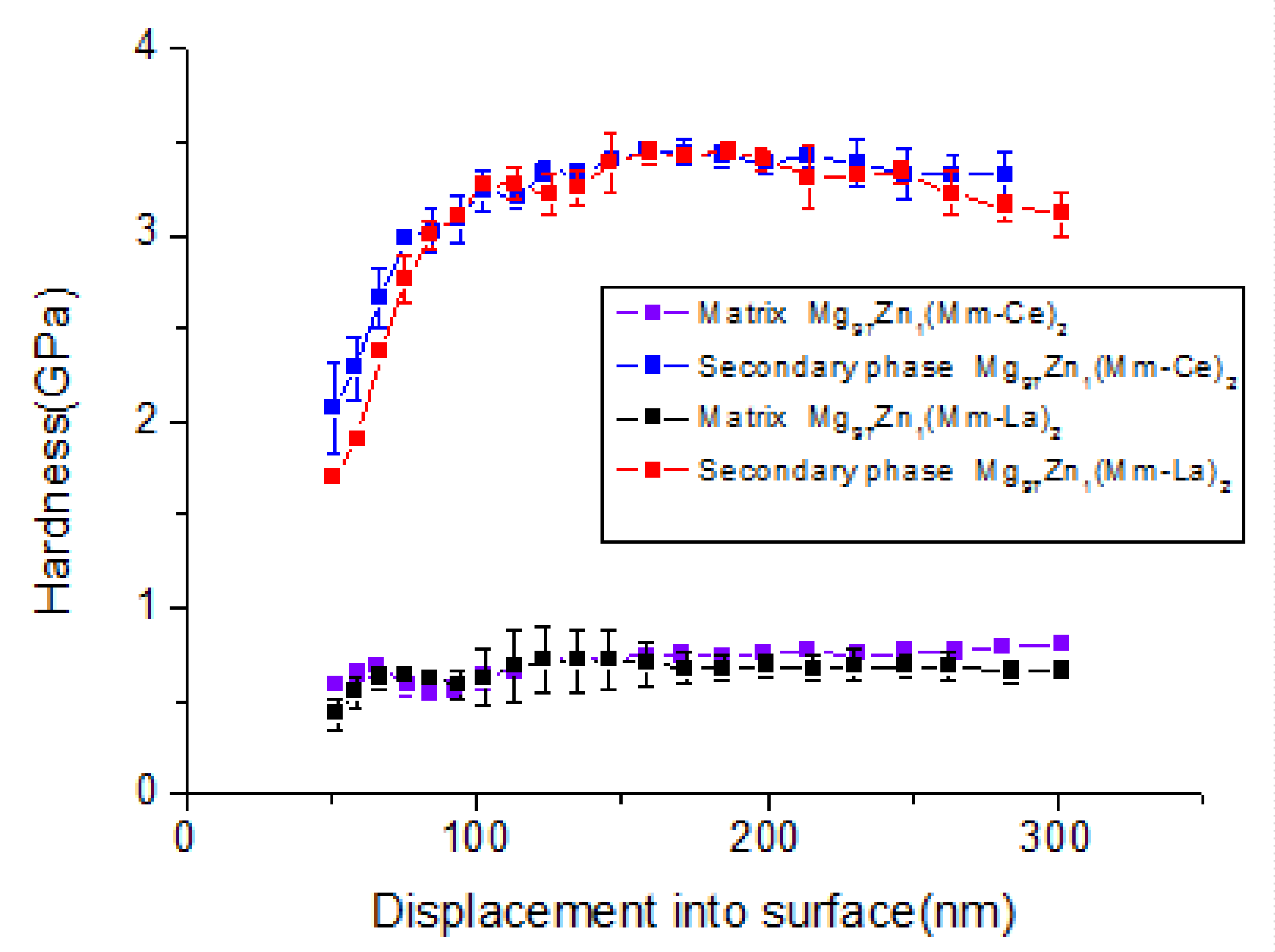
(c) $Mg_{97}Zn_1Y_2$

2nd phase: 86.9Hv

Mg: 64.2Hv

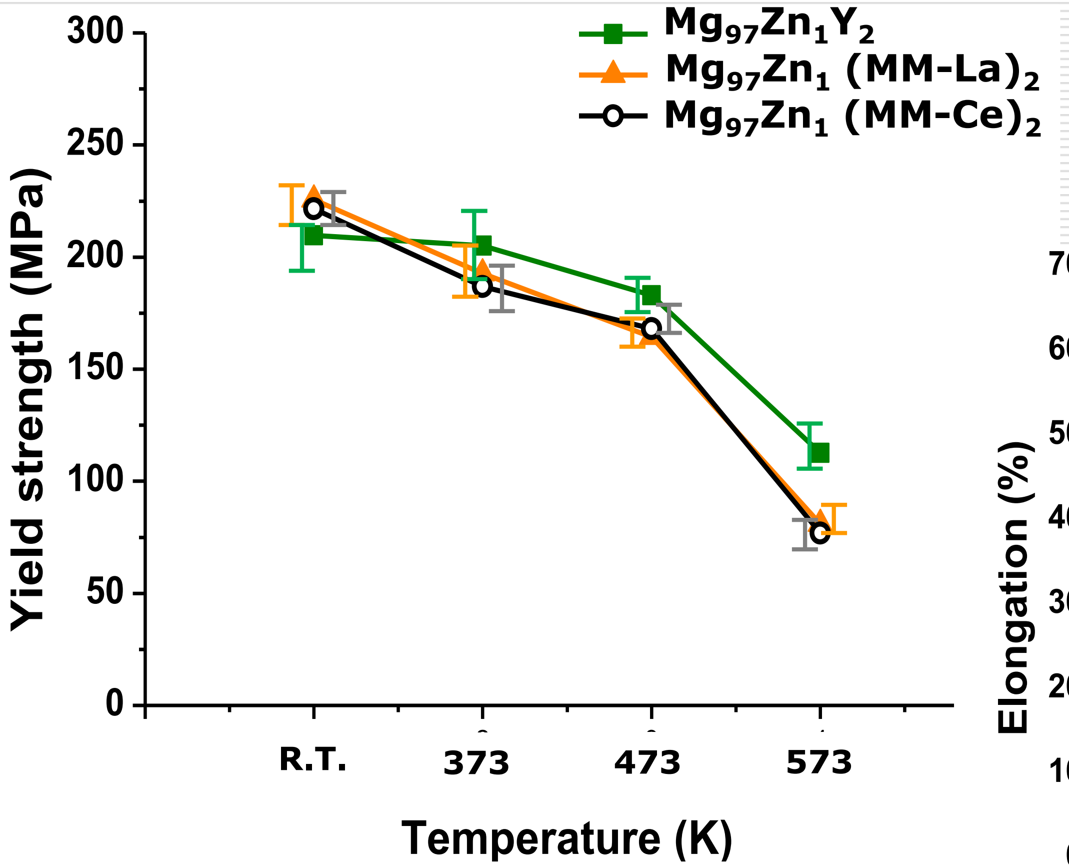
The dispersion strengthening effect is very obvious in the $Mg_{97}Zn_1MM_2$ alloys.

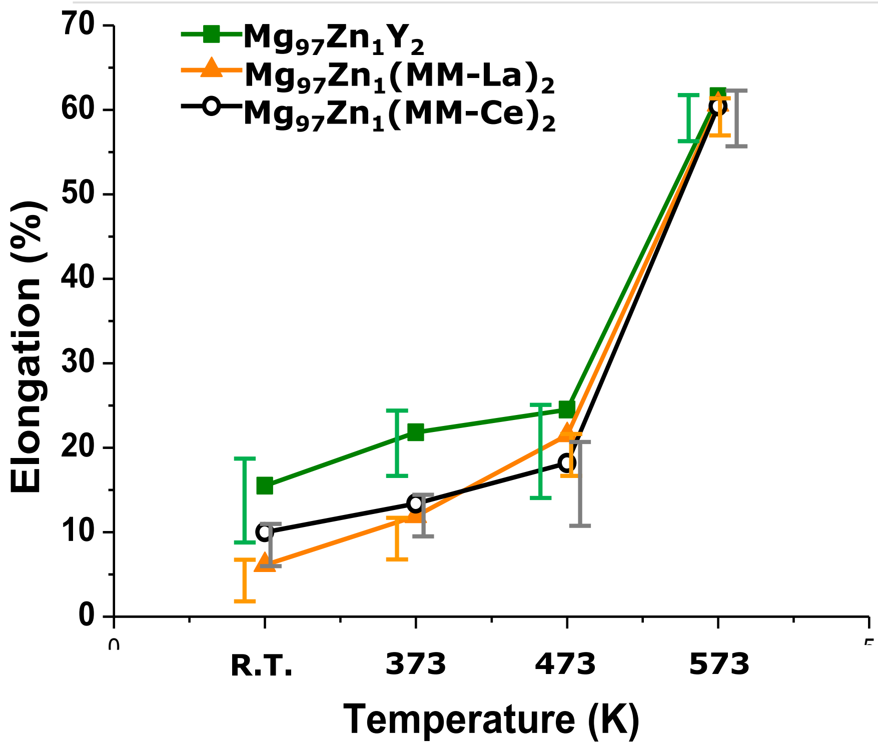
Nanoindentation of extruded $Mg_{97}Zn_1MM_2$ alloys



The hardness of second phase in $Mg_{97}Zn_1MM_2$ alloys is about 5 times higher than that of matrix.

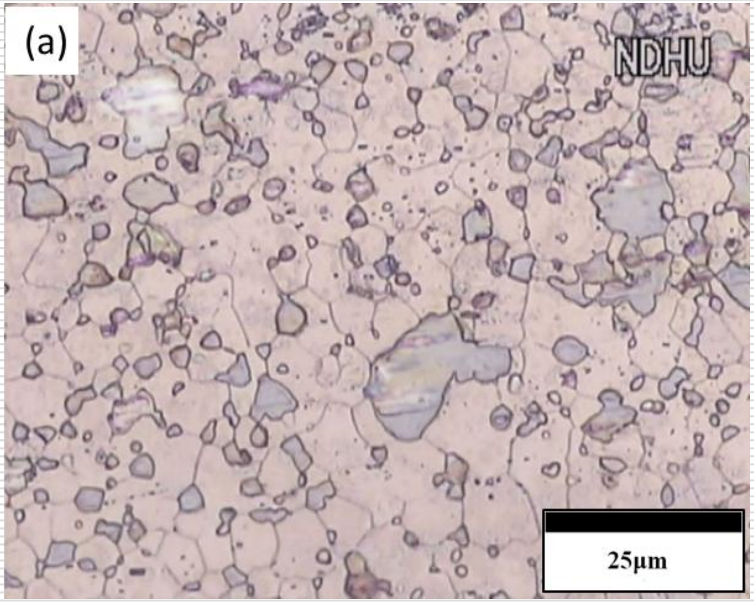
H.T. mechanical properties of extruded alloys



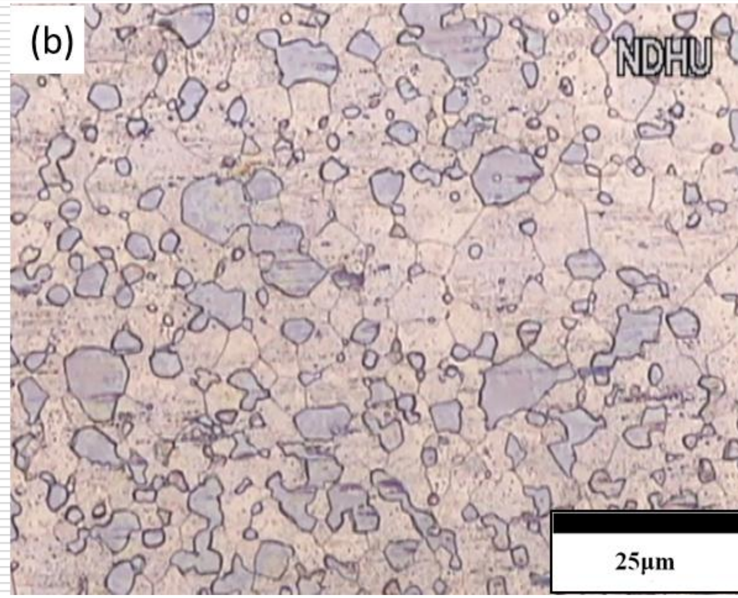


The high temperature mechanical properties of both $Mg_{97}Zn_1MM_2$ alloys are a slightly worse than that of $Mg_{97}Zn_1Y_2$. That means the LPSO phase have a stronger heat resistance than that of second phase in $Mg_{97}Zn_1MM_2$ alloys.

Microstructures of extruded alloys after annealing at 773K

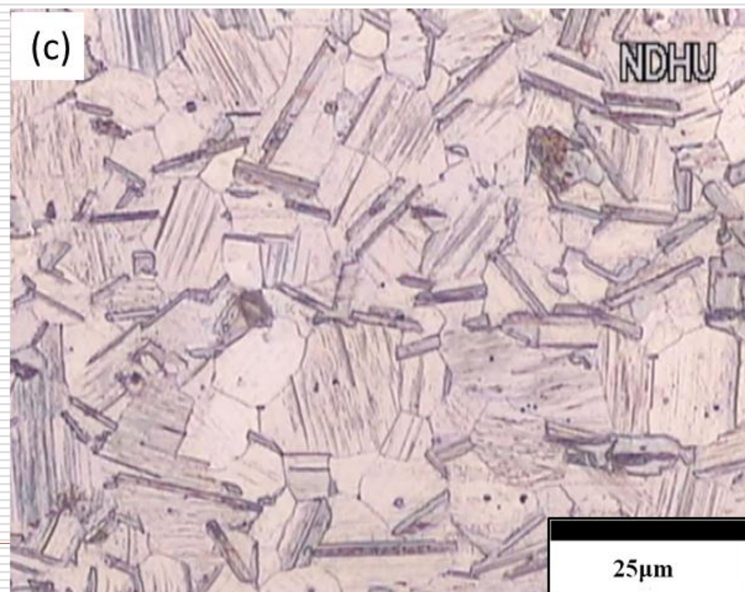


(a) $Mg_{97}Zn_1(MM\text{-}La)_2$



(b) $Mg_{97}Zn_1(MM\text{-}Ce)_2$

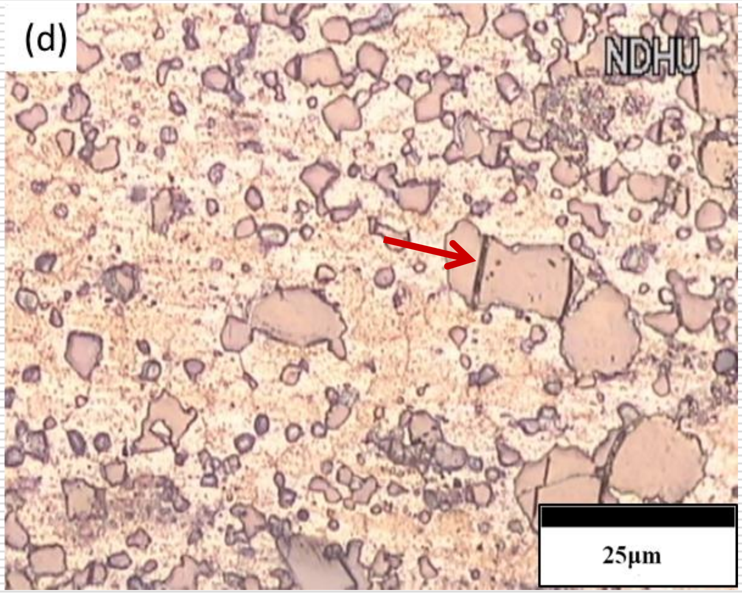
The shape of second phase particles in both $MgZnMM_2$ alloys is getting circular and uniform distribution.

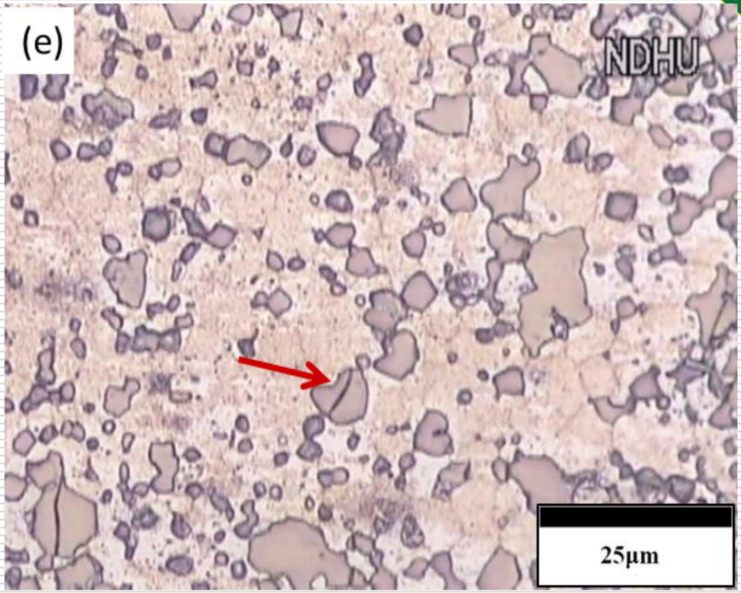


The lamellar structure of LPSO is more obvious.

(c) $Mg_{97}Zn_1Y_2$

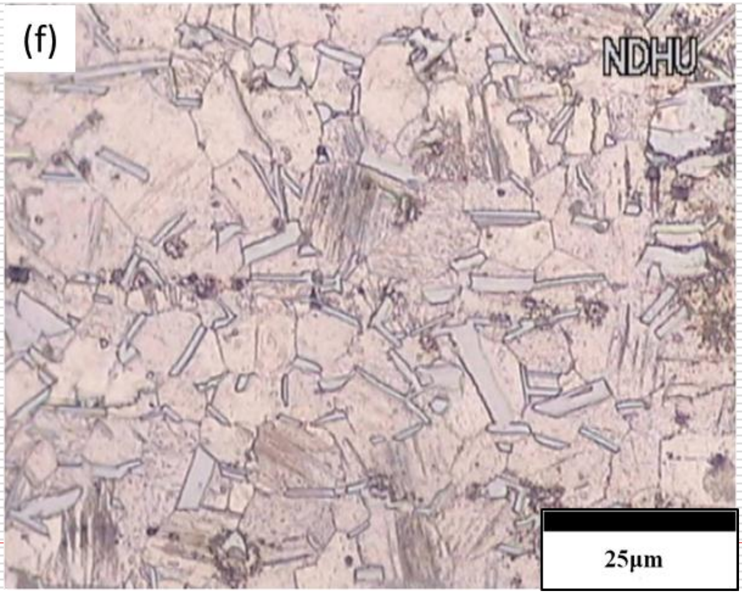
Microstructures of extruded alloys after annealing at 773K + 10% cold rolling





(d) $Mg_{97}Zn_1(MM\text{-}La)_2$

(e) $Mg_{97}Zn_1(MM\text{-}Ce)_2$

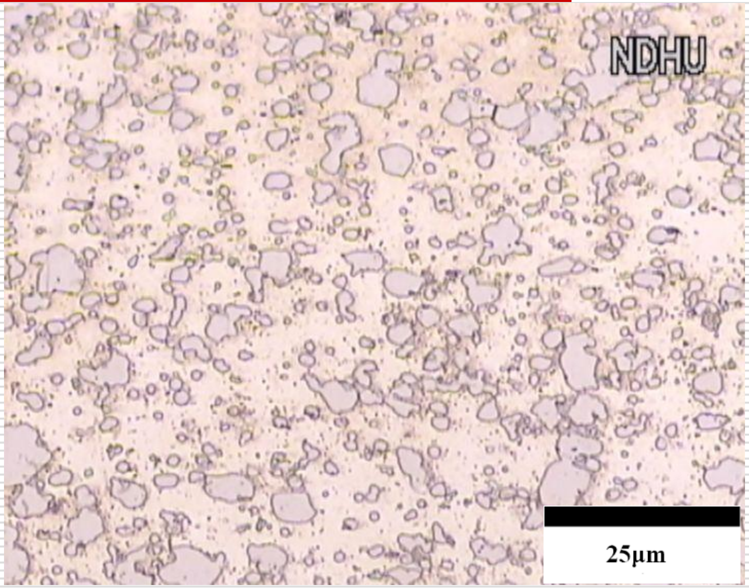


The microstructures did not have big change after cold rolling.

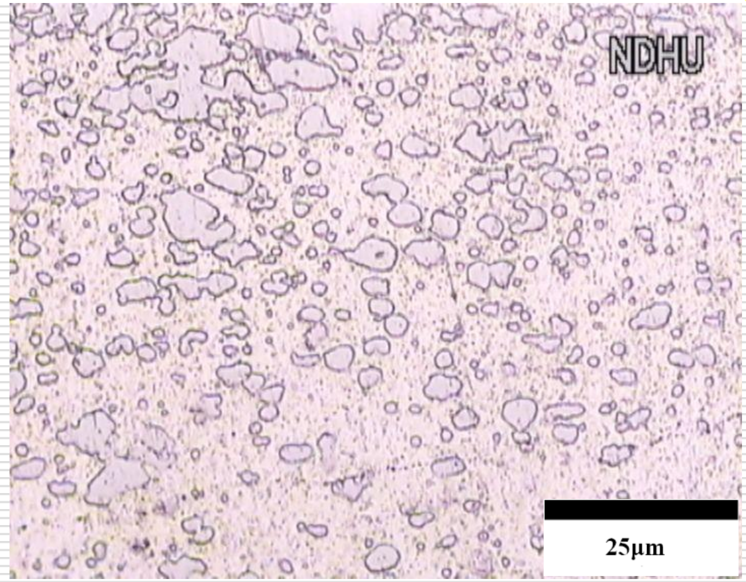
The brittle second phase particles is easily broken during cold rolling.

(f) $Mg_{97}Zn_1Y_2$

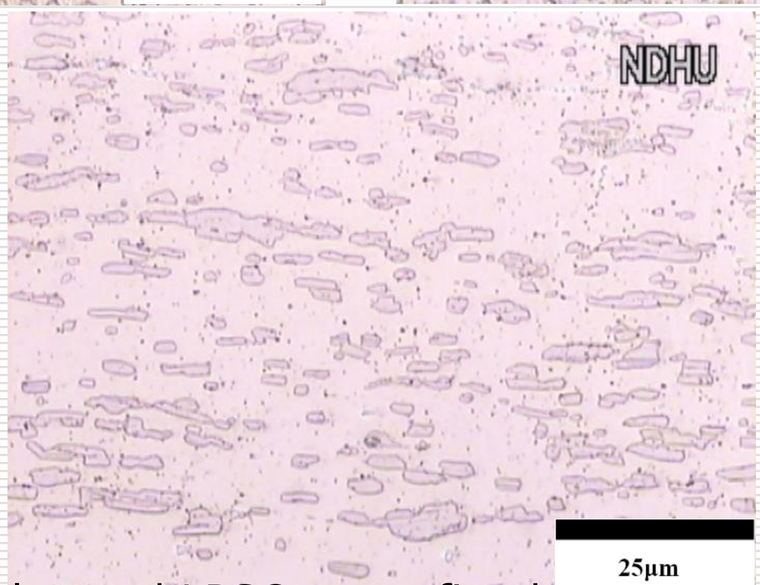
Microstructures of extruded alloys after 80% hot rolling at 673K



(a) $Mg_{97}Zn_1(MM\text{-}La)_2$



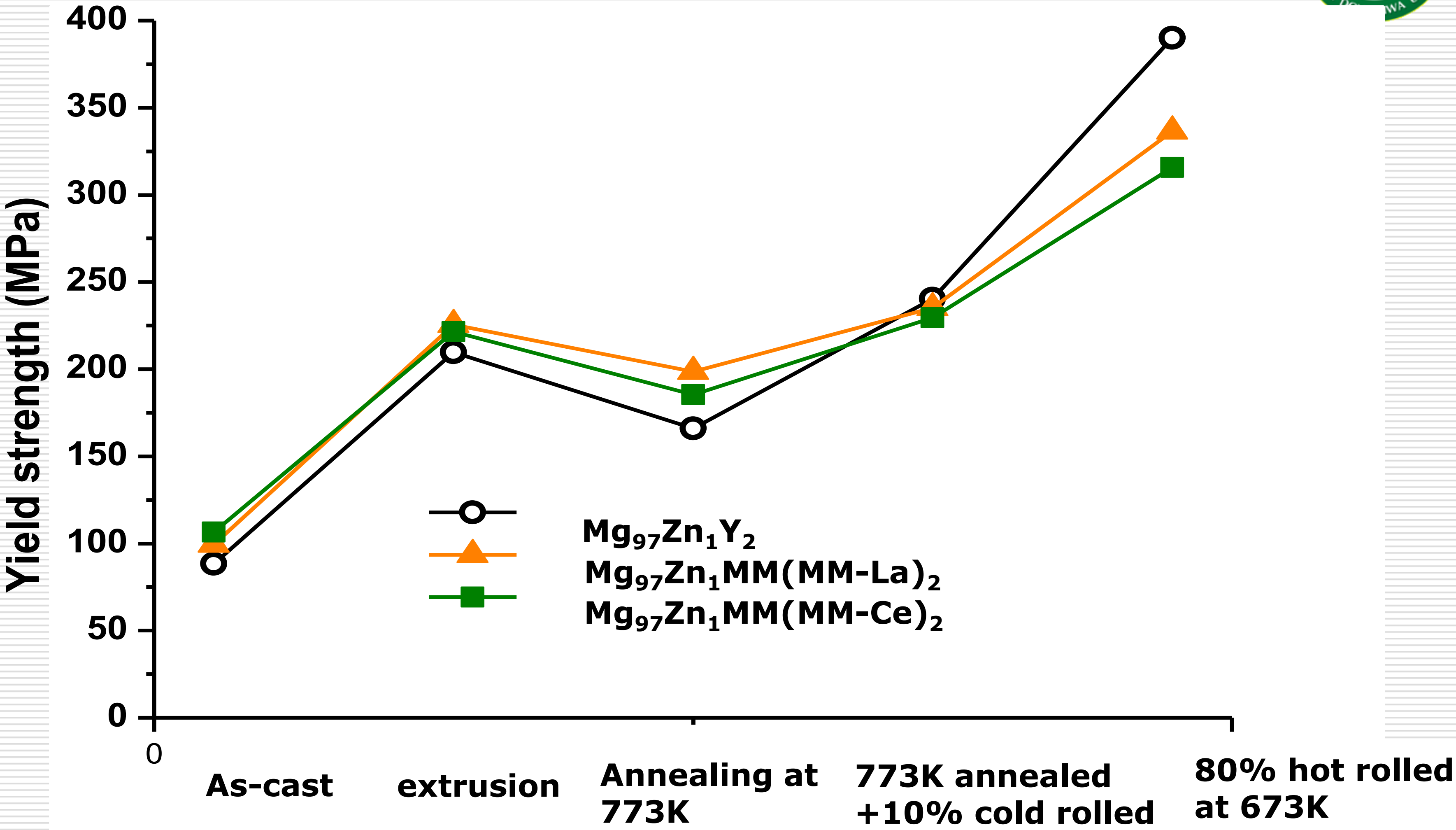
(b) $Mg_{97}Zn_1(MM\text{-}Ce)_2$



(c) $Mg_{97}Zn_1Y_2$

The second phase particles and LPSO are refined very remarkably, and consequently the high strengths can be obtained.

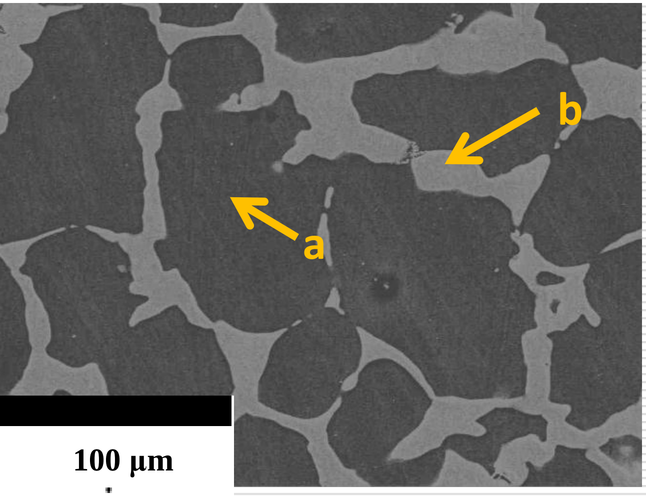
Yield strength of alloys after different processing



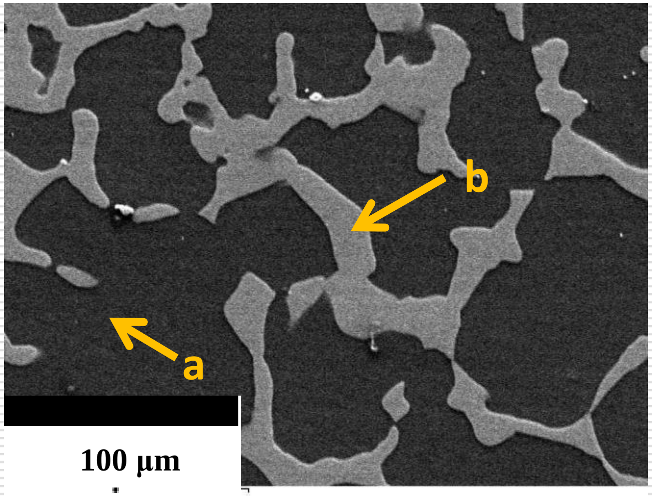
The extrusion improves the yield strength, annealing declines the strength due to the recrystallization, and cold or hot rolling can increase the yield strength because the particle size of second phase was refined.

FESEM and EDS results of as-cast alloys

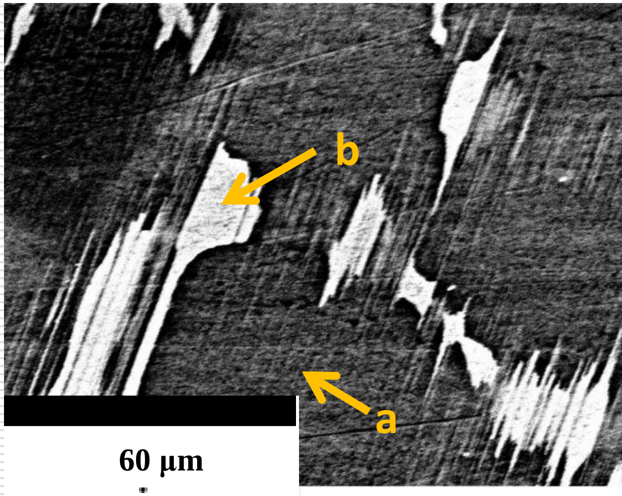
(a) $Mg_{97}Zn_1(MM\text{-}La)_2$



(b) $Mg_{97}Zn_1(MM\text{-}Ce)_2$



(c) $Mg_{97}Zn_1Y_2$



(a) $Mg_{97}Zn_1(MM\text{-}La)_2$:

ⓐ

Mg	Zn	La	Ce
99.4	0.4	0.1	0.1

ⓑ

Mg	Zn	La	Ce
87.6	4.3	6.1	2.0

(b) $Mg_{97}Zn_1(MM\text{-}Ce)_2$:

ⓐ

Mg	Zn	La	Ce
99.5	0.3	0.1	0.1

ⓑ

Mg	Zn	La	Ce
87.3	4.5	3.7	4.5

(c) $Mg_{97}Zn_1Y_2$:

ⓐ

Mg	Zn	Y
99.1	0.2	0.7

ⓑ

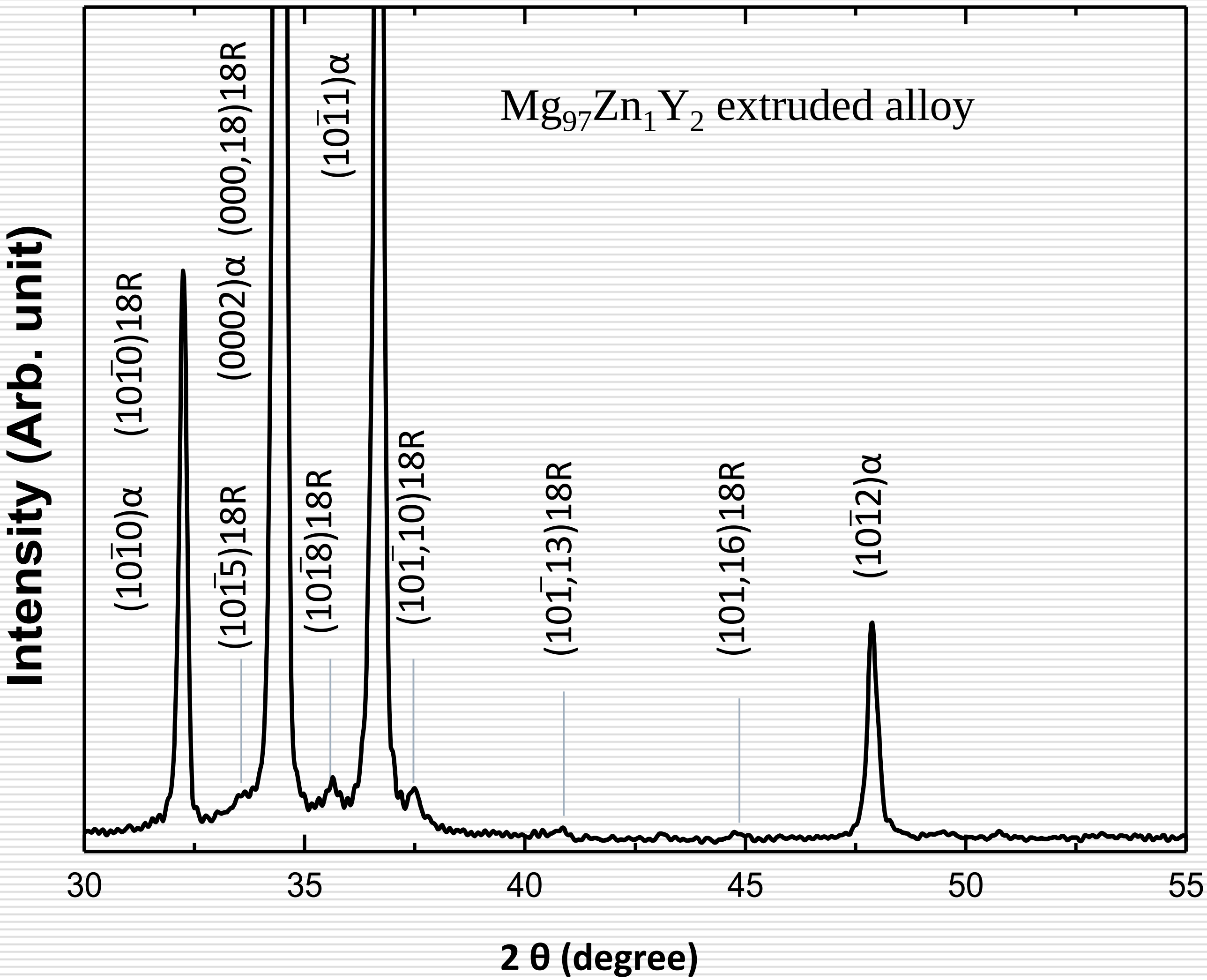
Mg	Zn	Y
87.1	6.1	6.8

(at%)

$(Mg,Zn)_{12}(La,Ce)$ $(Mg,Zn)_{12}(La,Ce)$ $Mg_{12}ZnY$

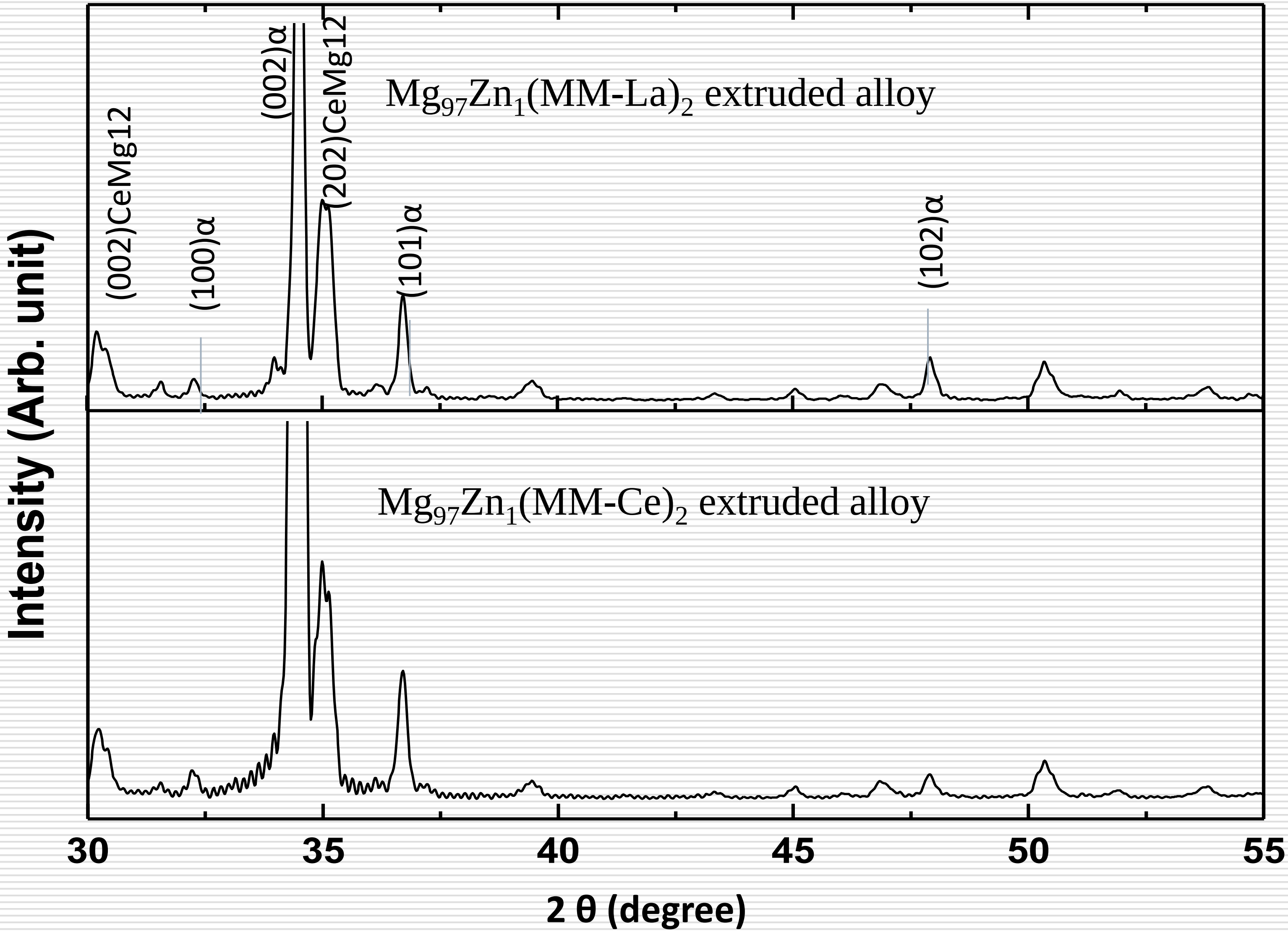
$(Mn_{12}Th)$-type structure **LPSO**

XRD pattern of extruded $Mg_{97}Zn_1Y_2$ alloy



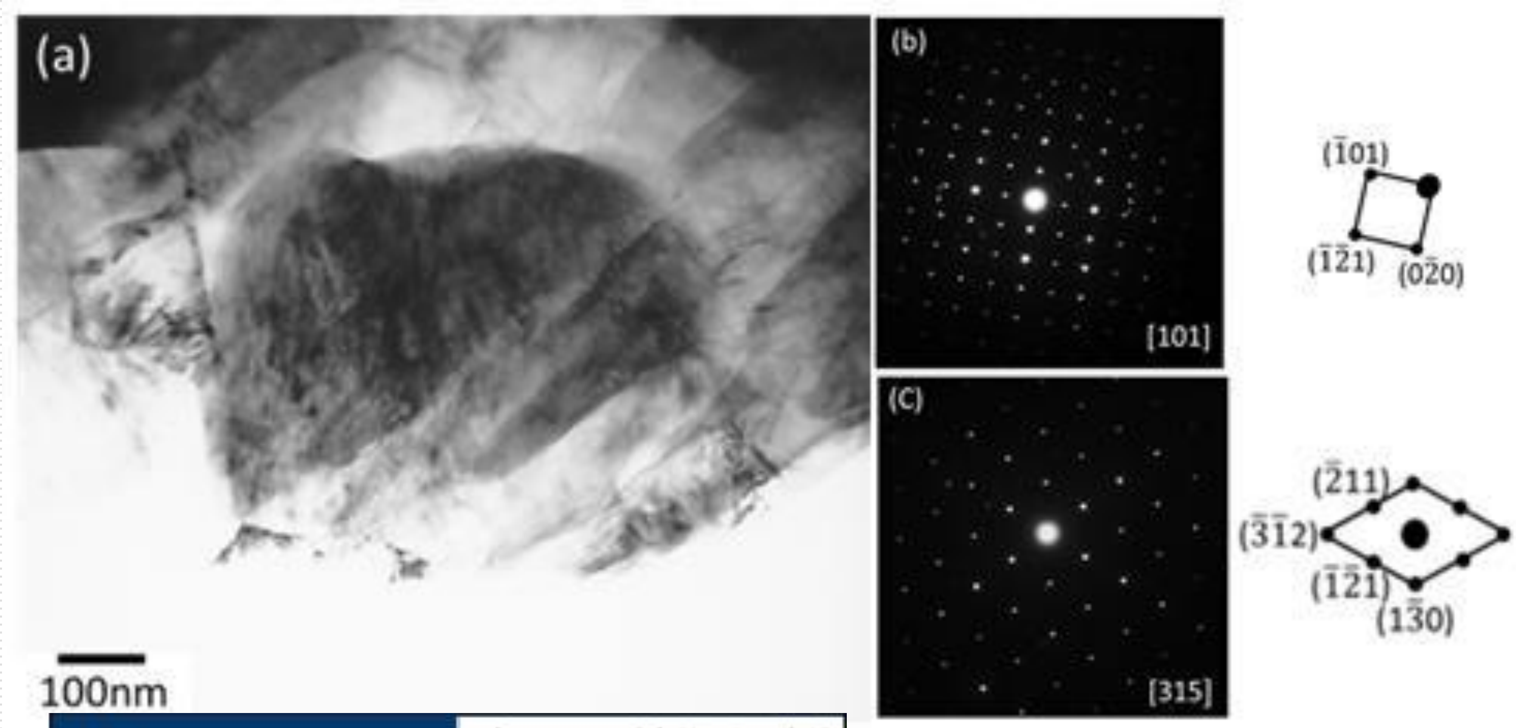
The second phase in $Mg_{97}Zn_1Y_2$ alloy is confirmed as 18R LPSO phase

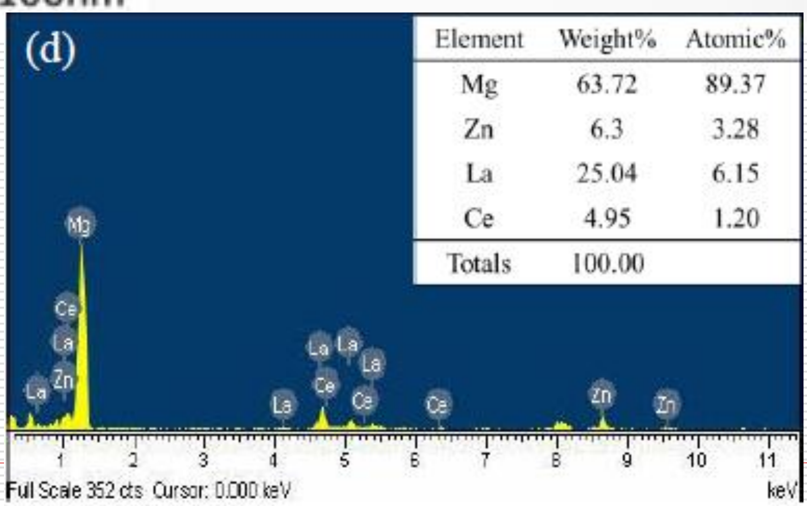
XRD patterns of extruded $Mg_{97}Zn_1(MM)_2$ alloys



The second phase in both $Mg_{97}Zn_1MM_2$ alloys is confirmed as $(Mg,Zn)_{12}(La,Ce)$.

TEM image and diffraction pattern of as-extruded $Mg_{97}Zn_1(MM\text{-}La)_2$



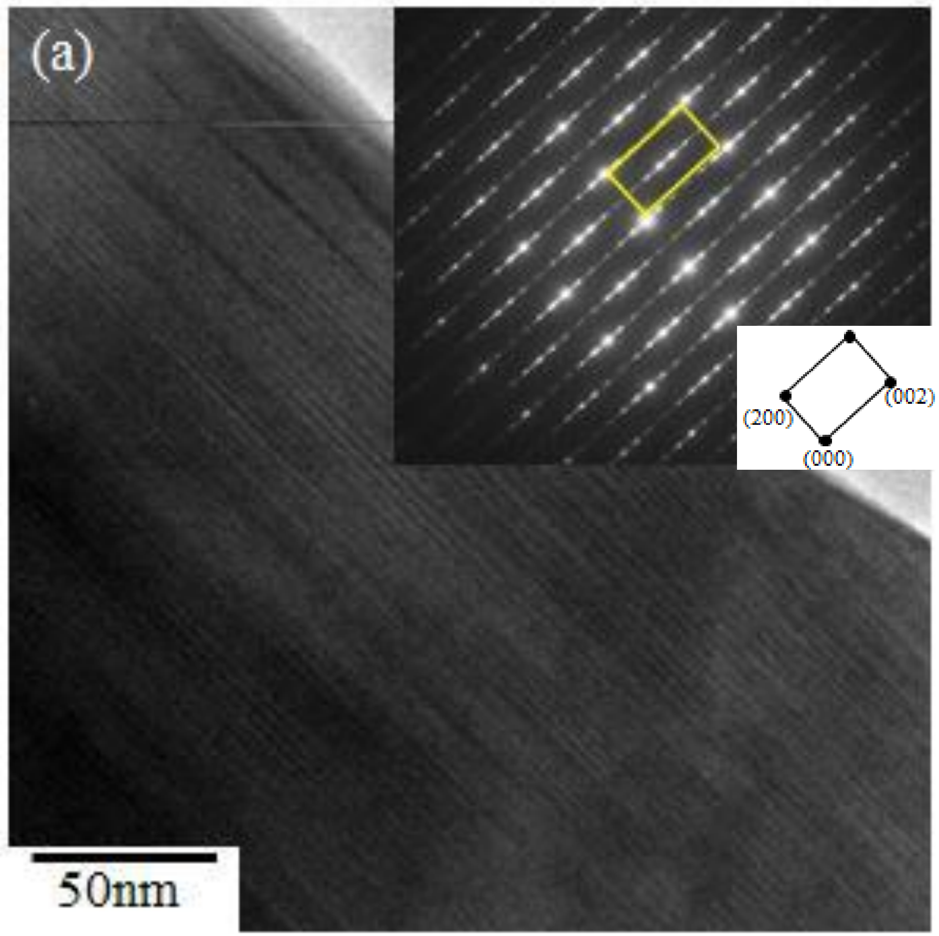


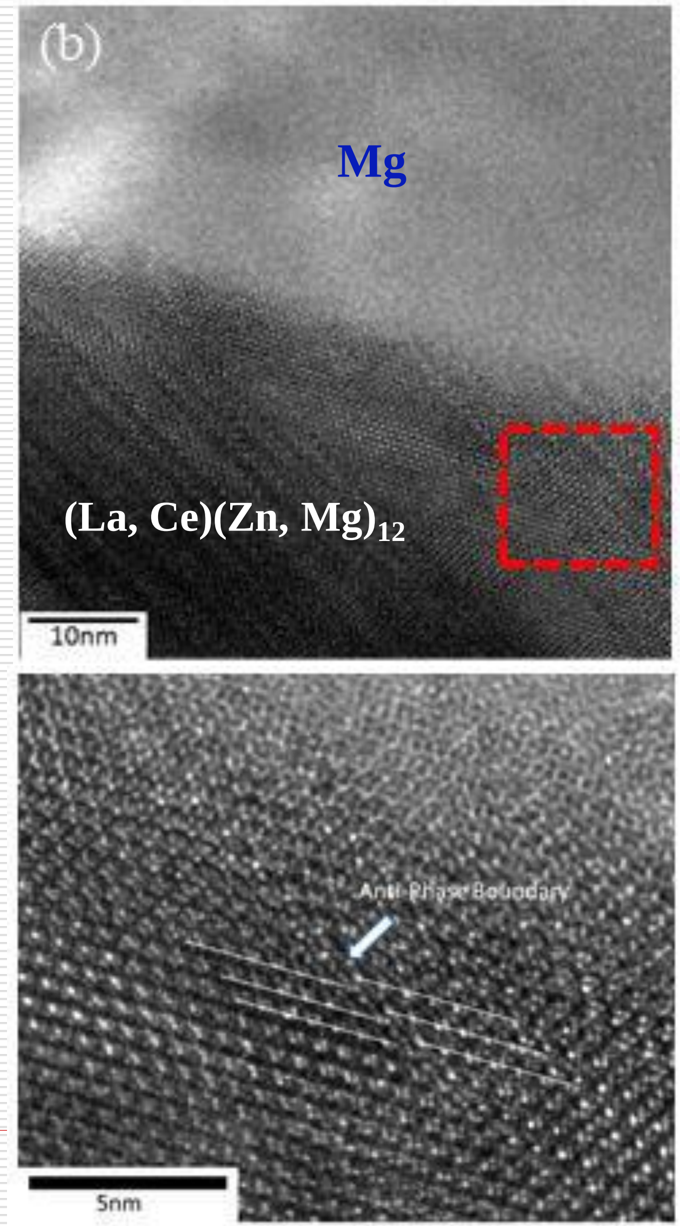
Element	Weight%	Atomic%
Mg	63.72	89.37
Zn	6.3	3.28
La	25.04	6.15
Ce	4.95	1.20
Totals	100.00	

(a) TEM image, (b) SADP of particle, (c) SADP of matrix, and (d) EDS result of particle.

The particle was identified as $(Mg, Zn)_{12}(La, Ce)$.

HR-TEM image of as-extruded $Mg_{97}Zn_1(MM\text{-}La)_2$

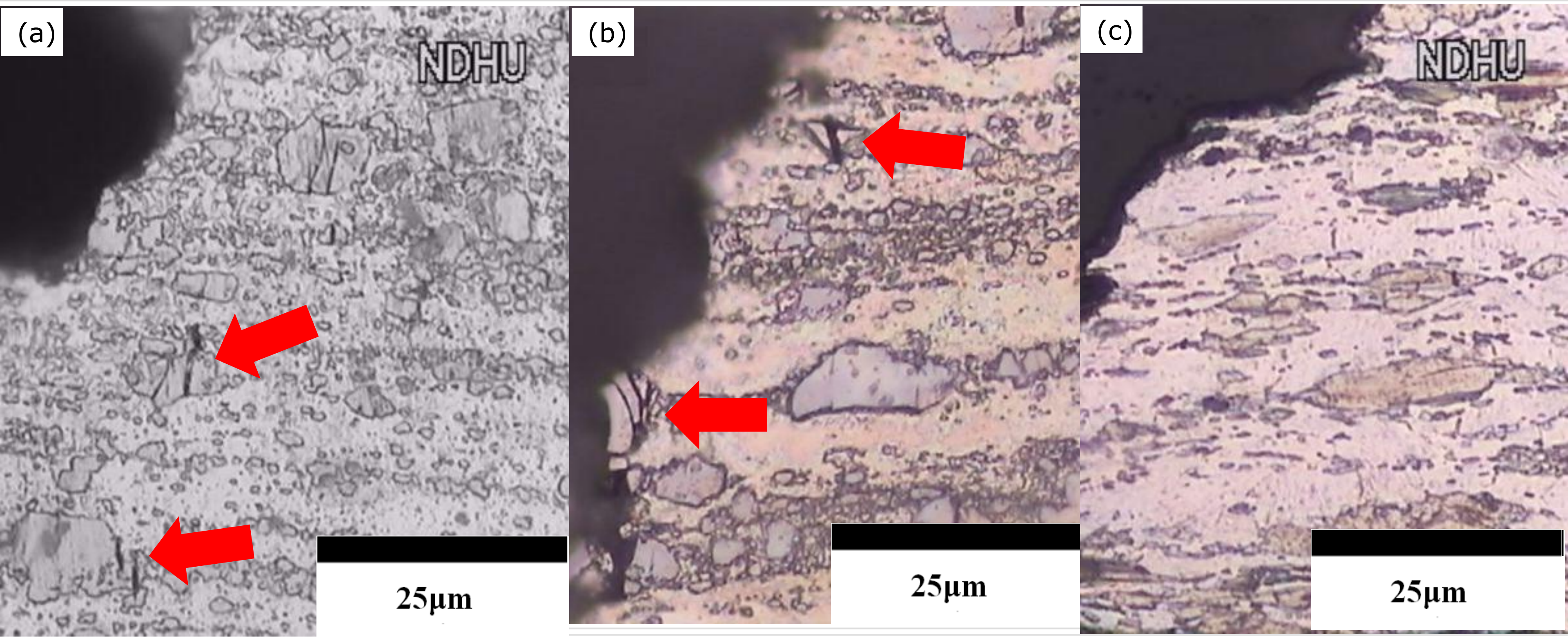




(a) HR-TEM lattice image and diffraction pattern, and (b) HRTEM image of interface between $(Mg, Zn)_{12}(La, Ce)$ and matrix.

No explicit orientation relationship between Mg matrix and compound.

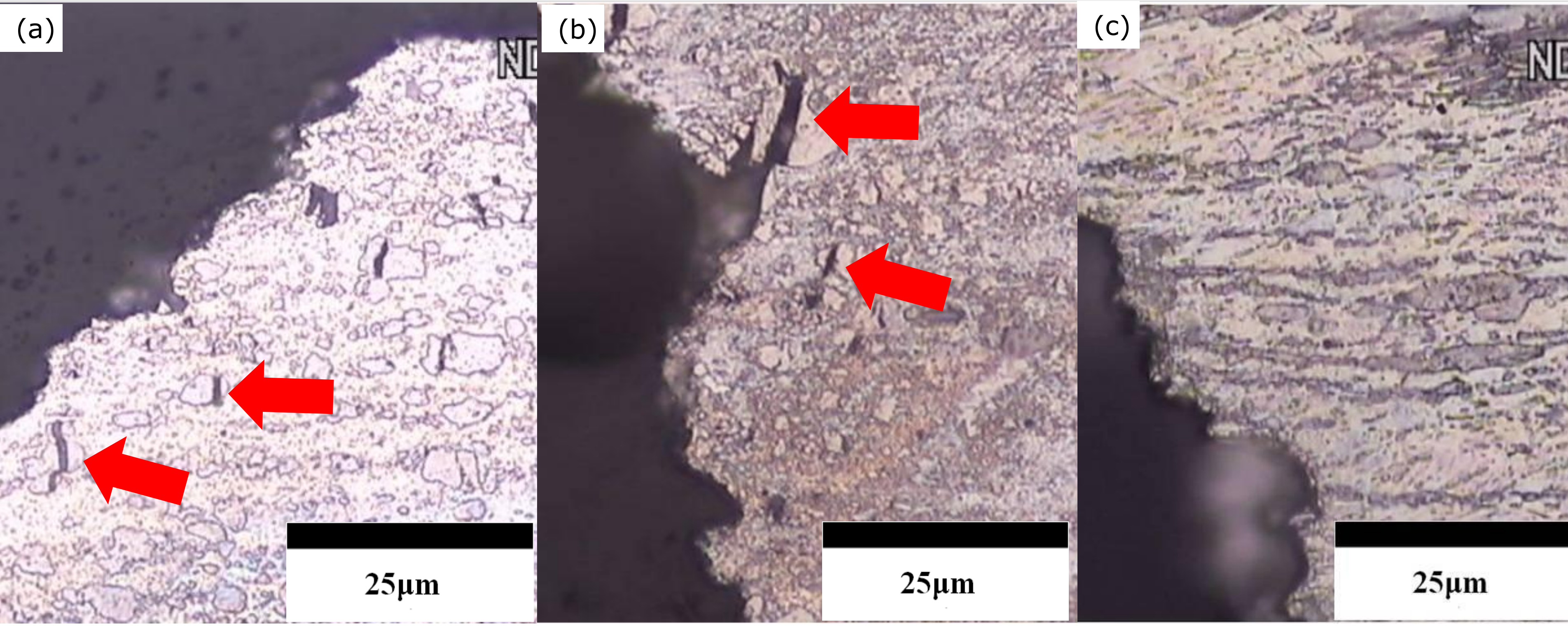
Fractography of extruded alloys after R.T. tensile test



(a), $Mg_{97}Zn_1(MM\text{-}La)_2$, (b) $Mg_{97}Zn_1(MM\text{-}Ce)_2$, (c) $Mg_{97}Zn_1Y_2$

The second phase particles in both $Mg_{97}Zn_1MM_2$ alloys are broken perpendicular to tensile direction.

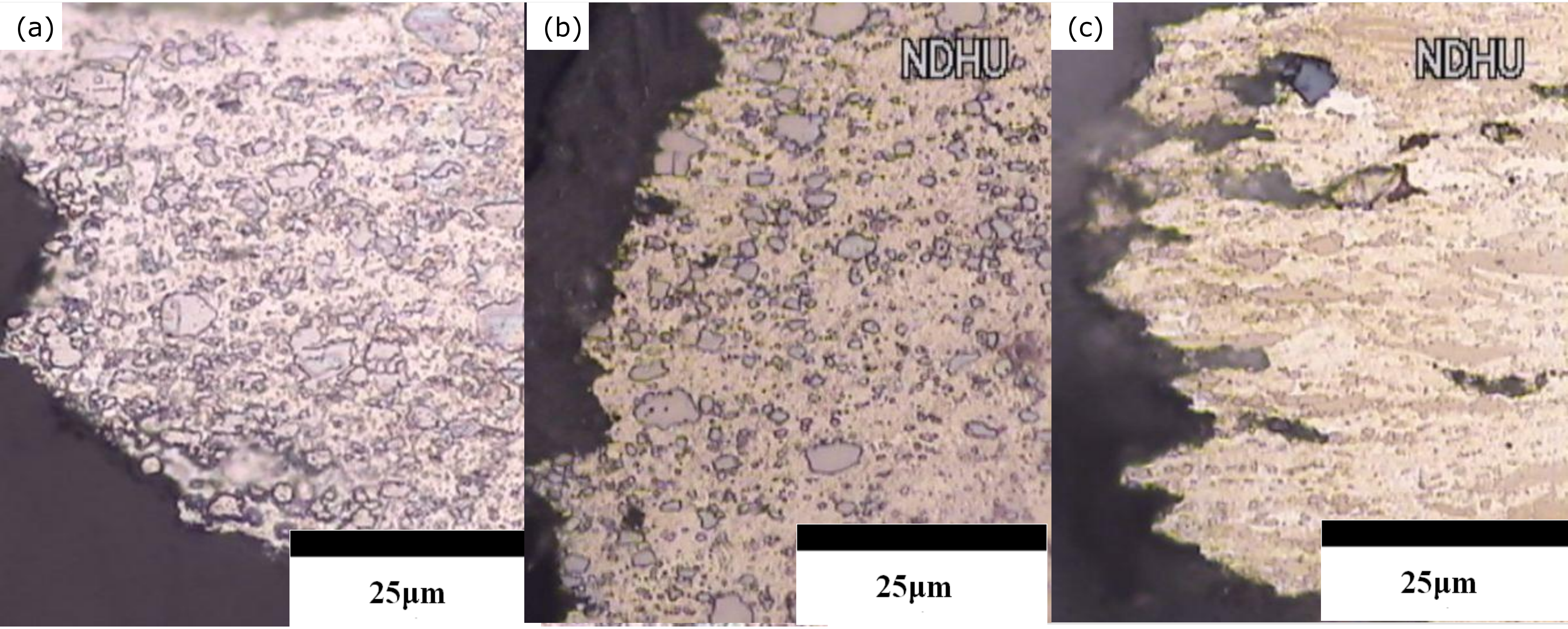
Fractography of extruded alloys after 473K tensile test



(a), $Mg_{97}Zn_1(MM\text{-}La)_2$, (b) $Mg_{97}Zn_1(MM\text{-}Ce)_2$, (c) $Mg_{97}Zn_1Y_2$

The second phase particles are so brittle to be easily broken even during high temperature tensile test, and consequently weaken the elevated temperature strength. However, if we can refine the second phase particles by high hot rolling, the dispersion strengthening can be expected.

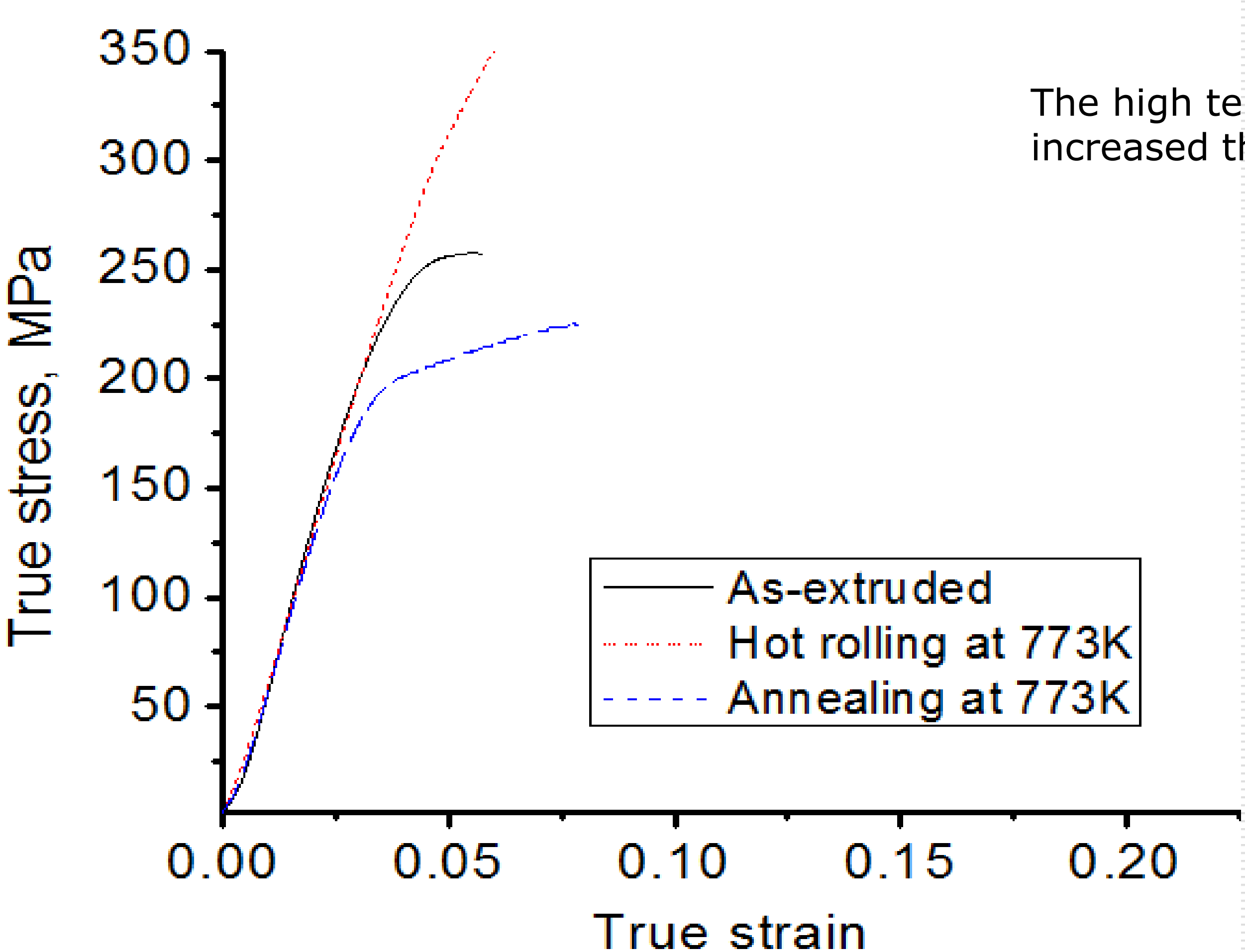
Fractography of extruded alloys after 573K tensile test



(a), $Mg_{97}Zn_1(MM\text{-}La)_2$, (b) $Mg_{97}Zn_1(MM\text{-}Ce)_2$, (c) $Mg_{97}Zn_1Y_2$

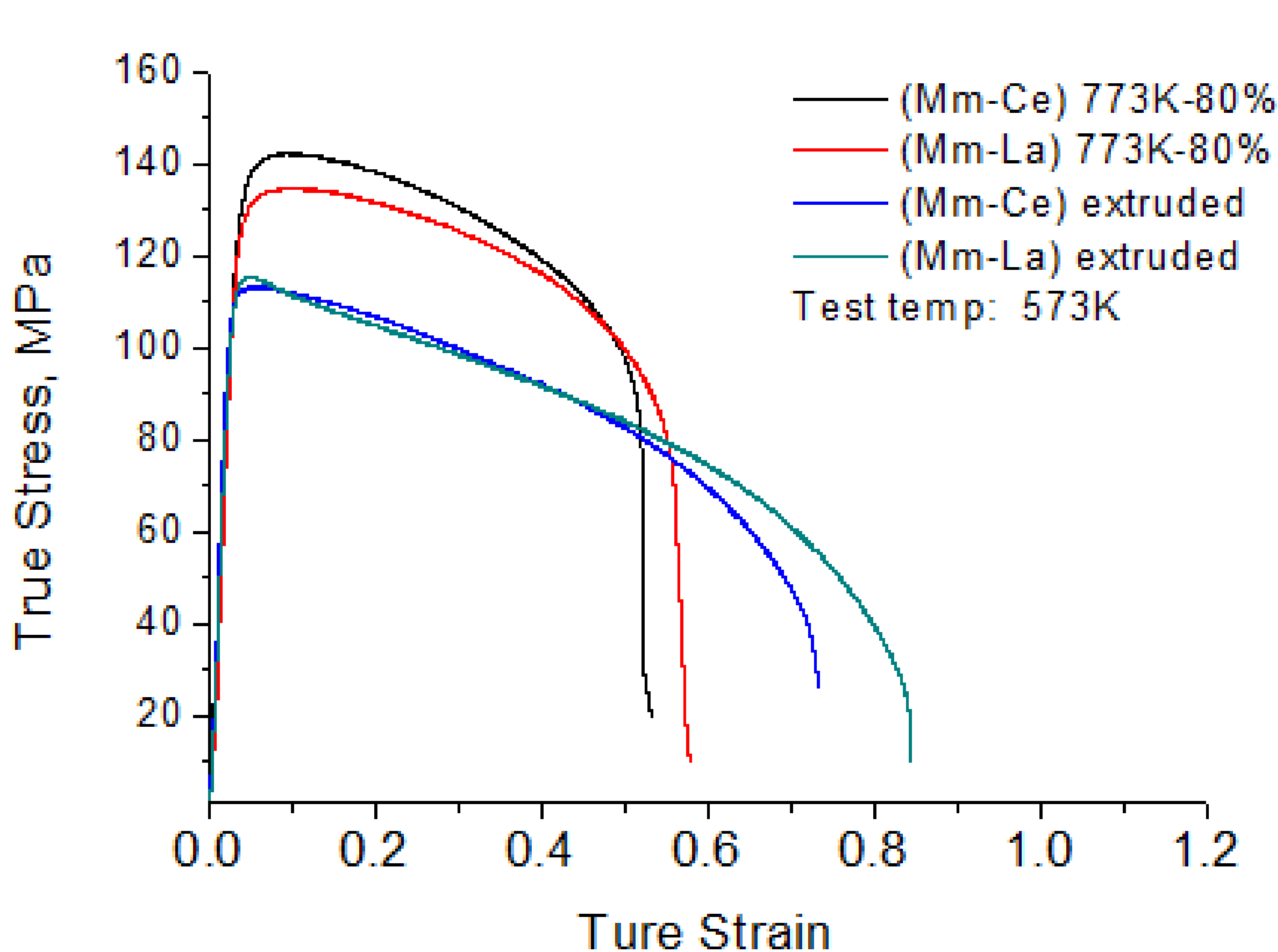
The cracks are no more existing in the second phase particles, instead of getting rounder and finer shape.

True stress-true strain curves of as-extruded, hot-rolled and annealed $Mg_{97}Zn_1(MM\text{-}La)_2$.



The high temperature rolling greatly increased the strength.

High temperature tensile test results of as-extruded and 80% hot rolled at 773K of $Mg_{97}Zn_1MM_2$.



D_L : degree of dispersion.

The degrees of dispersion in $Mg_{97}Zn_1(MM\text{-}La)_2$

$D_L/\mu m^{-1}$: dispersion level

$$D_L = \frac{\sum N_V}{\sum L_V}$$

L_V is the length of a vertical line segment drawn perpendicular to the extrusion direction, and N_V is the number of second phase intersected by segment L_V. The total length of segments must be more than 5mm.

	As-extruded	High temperature annealed	High temperature rolled
D_L/um^{-1}	0.013	0.05	0.06

High temperature rolling promoted the uniform dispersion and refinement of the second phase. Therefore, dispersion strengthening improved the mechanical properties the $Mg_{97}Zn_1MM_2$ alloys.

Conclusions

(1) The $Mg_{97}Zn_1MM_2$ alloys possess second phase $(Mg,Zn)_{12}(La,Ce)$ instead of LPSO phase in Kumadai alloy.

(2) The particles size of $(Mg,Zn)_{12}(La,Ce)$ in $Mg_{97}Zn_1MM_2$ alloys can be refined by cold rolling and even in hot rolling remarkably. Consequently, the mechanical properties can be improved.

(3) Due to the existence of distributed second phases, the high temperature strength of $MgZnMM_2$ alloys are comparable with that of $Mg_{97}Zn_1Y_2$ alloy.

(4)The dispersion strengthening is very effective in $Mg_{97}Zn_1MM_2$ alloys due to the fine and hard particle $(Mg,Zn)_{12}(La,Ce)$ phase.

Thanks for your attention