Microstructures and Mechanical Properties of Al/Mg-Li/Al Multilayer by Accumulative Roll Bonding (ARB)

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Background

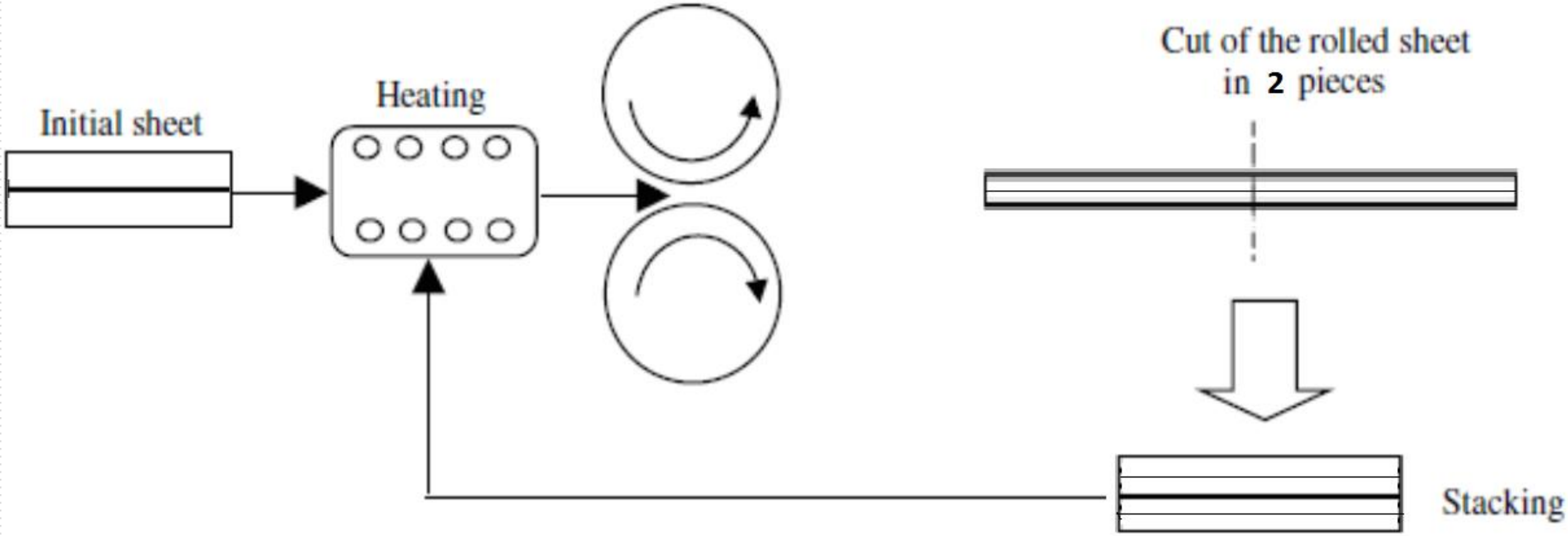
Mg-9%Li-1%Zn(LZ91) alloy possesses ultra-low density and good formability at ambient temperature. However, the low strength and poor corrosion resistance are its disadvantages.

Pure Al shows good formability and excellent corrosion resistance after anodizing treatment.

Therefore, clad rolling producing LZ91 plate sandwiched by Al sheets is one way to improve the poor corrosion resistance of LZ91 alloy plate.

Besides, by using the accumulate rolling bond(ARB) process, the mechanical properties of multilayer of Al/LZ91/Al can be improved.

Accumulative Roll Bonding (ARB)



First, two sheets are placed together. The two layers of material are joined by rolling, as in a conventional roll-bonding process.
Then, the length of rolled material is sectioned into two halves.
The sectioned sheets are again stacked and roll-bonded.
The whole process is repeated again and again.

⇨ A high strength multilayered composite of Al/LZ91/Al will be obtained, and the outer surface of Al will be as the corrosion protective layer after a proper surface treatment.

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Research purpose

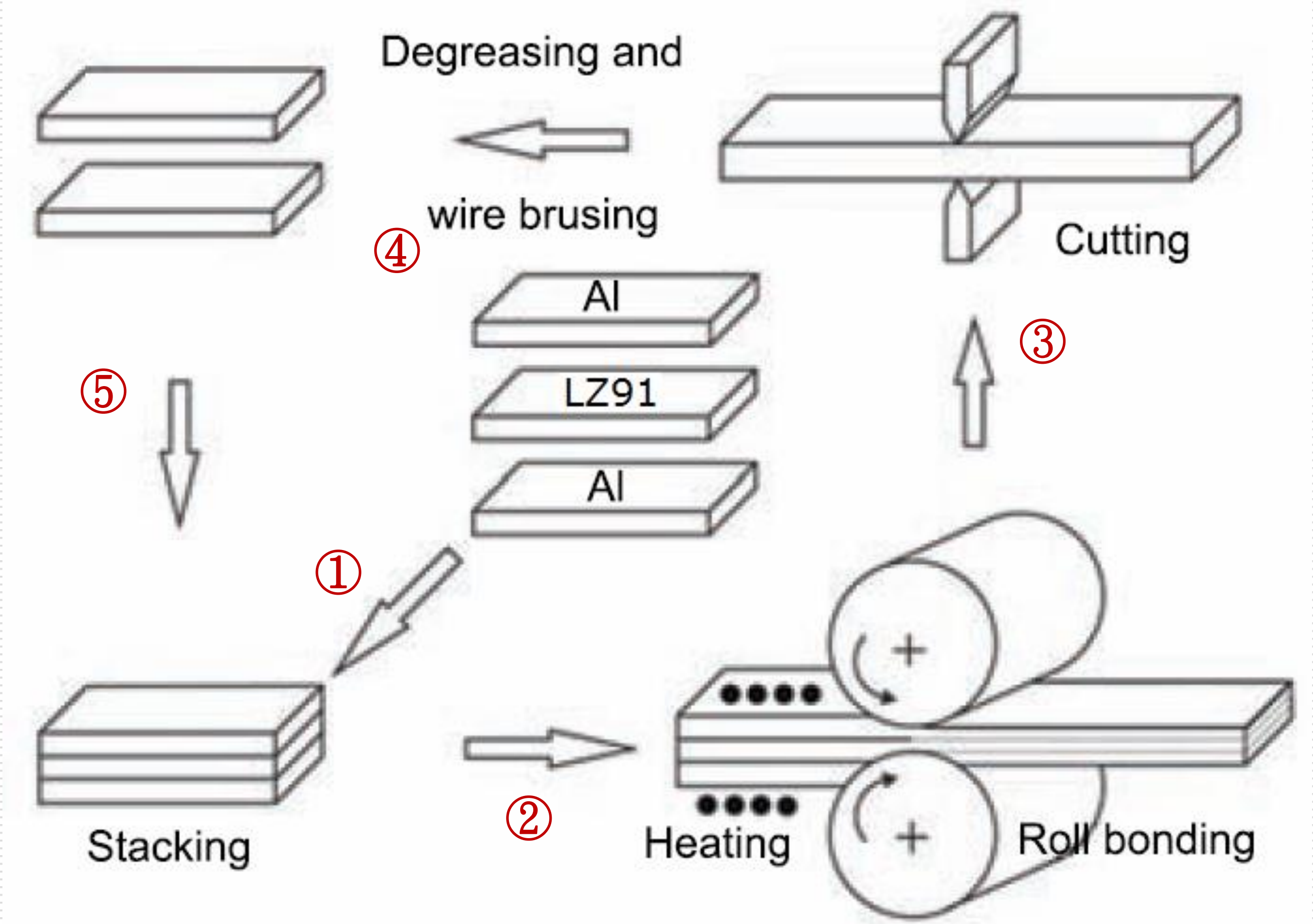
The motivation of this research is to investigate ARB processed Al/LZ91/Al multilayers, which is the combination of mechanical properties and formability as well as corrosion resistance improvement. (LZ91 - low density and high deformation capacity at ambient temperature; Al - good surface treatment ability and high strength).

The Al/LZ91/Al multilayers were fabricated by ARB process method.

The mechanical strengths of metallic Al/LZ91/Al multilayers will be increased due to the grain refining and work hardening after ARB process.

Annealing of as-ARBed multilayers were performed in order to enhance the interface bonding between LZ91 and Al.

Experimental



First, the Al and LZ91 sheet surfaces were cleaned and stacked together.
The stacked sheets were kept in a furnace and then hot roll-bonded.
Then the roll-bonded sheet was cut into two parts with the same dimensions.
After the surface cleaning, the two parts were stacked together ready for another ARB.

Materials

The materials used in this study were commercial pure aluminum (99.31wt%) and LZ91 alloy.
LZ91 plates (80 mm × 20 mm × 4 mm) were cut from the as-extruded plate and then rolled into sheets of thickness about 1mm at 473K.
The AA1050 was received in the form of a rolled sheet (80 mm × 20 mm × 5 mm) and annealed at 673K for 2 h. Then it was cold-rolled into sheets of thickness about 0.4 mm.

The compositions of materials used in this study.

wt.%	Si	Fe	Cu	Mn	Mg	Zn	Ti	Al
AA1050	0.20	0.35	0.03	0.02	0.04	0.03	0.02	bal.

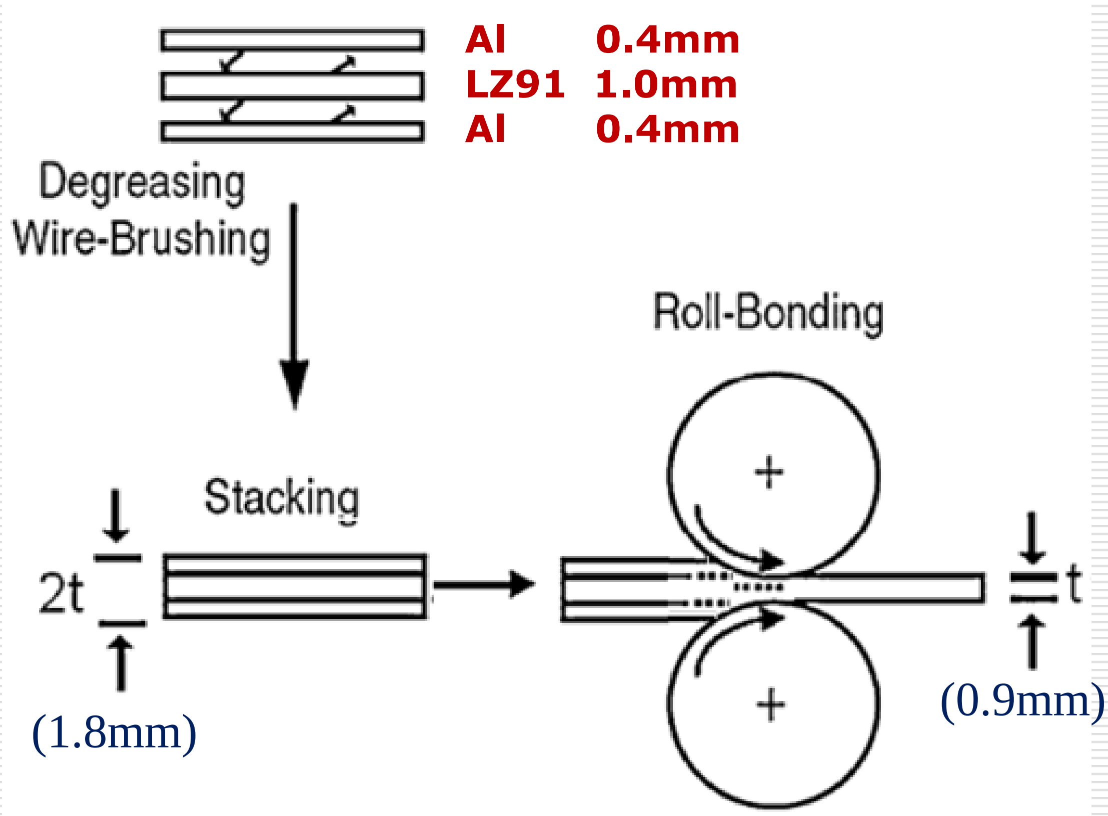
wt.%	Li	Zn	Mg
LZ91	8.85	0.75	bal.

Primary sandwich of Al/LZ91/Al

Two Al (0.4 mm^t) and one LZ91 (1 mm^t) sheets were degreased and wire-brushed, then stacked by the sequence of Al-Mg-Al.

The stack was held for 5min at 673K in a preheated furnace.

Then it was warm roll-bonded into the primary sandwich with about 50% reduction (thickness of 1.8mm rolled to 0.9mm).



Primary sandwich preparation

Multilayered Al/LZ91/Al by ARB

The prepared Al/LZ91/Al primary sandwich was cut into two halves. After degreasing and wire-brushing (on the outer Al layers), then fastened together.

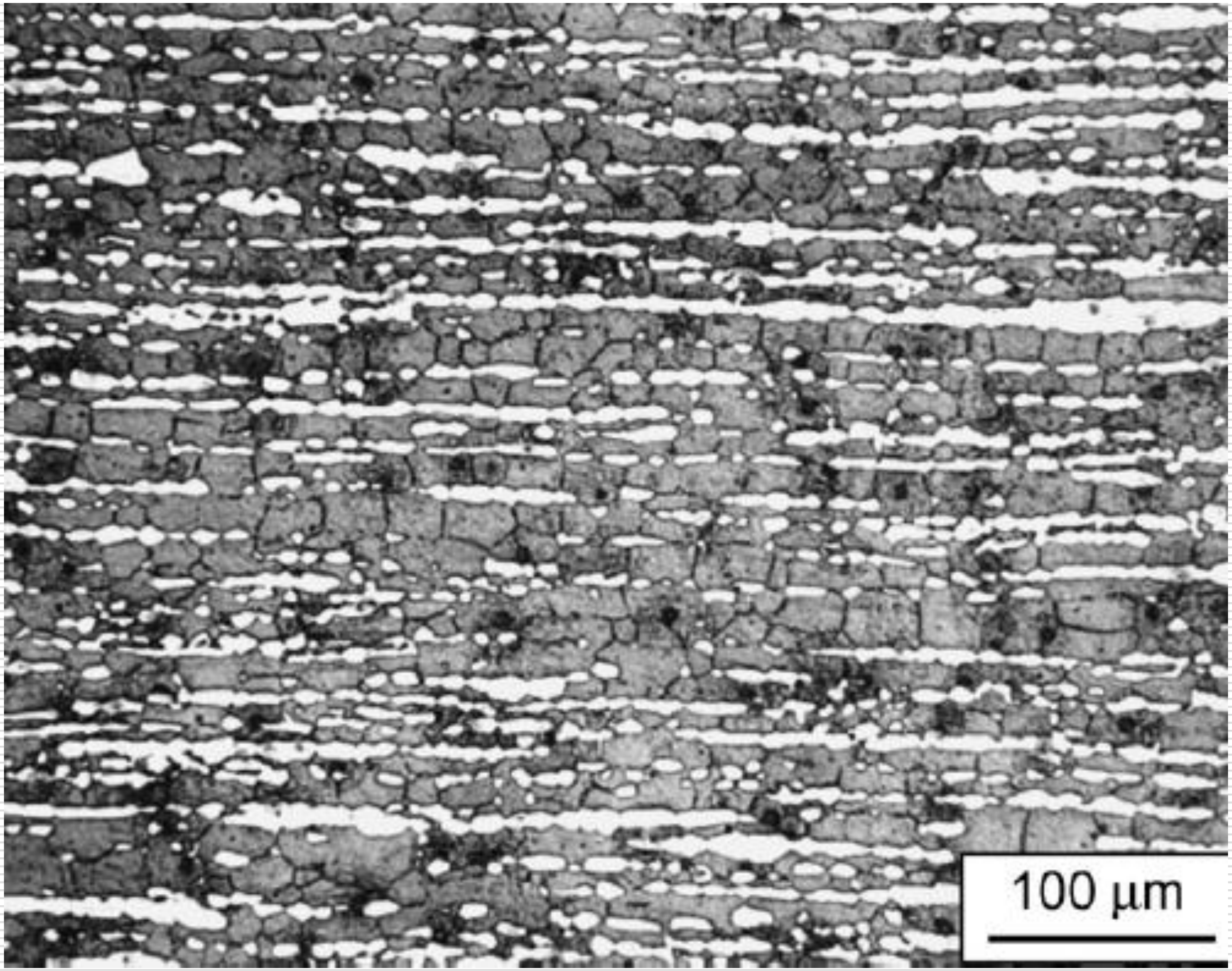
This stack was held 5min at 673K and then roll-bonded directly with reduction of 50% in one pass followed by air-cooling.
This procedure was called one cycle ARB and repeated up to five cycles.

The total number of layers was calculated by $2^{n+1} + 1$
where n is the number of ARB cycles.

All the experiments were conducted without lubricant on a roll-mill.
The roll diameter was 110mm with speed of 7m/min^{-1}.

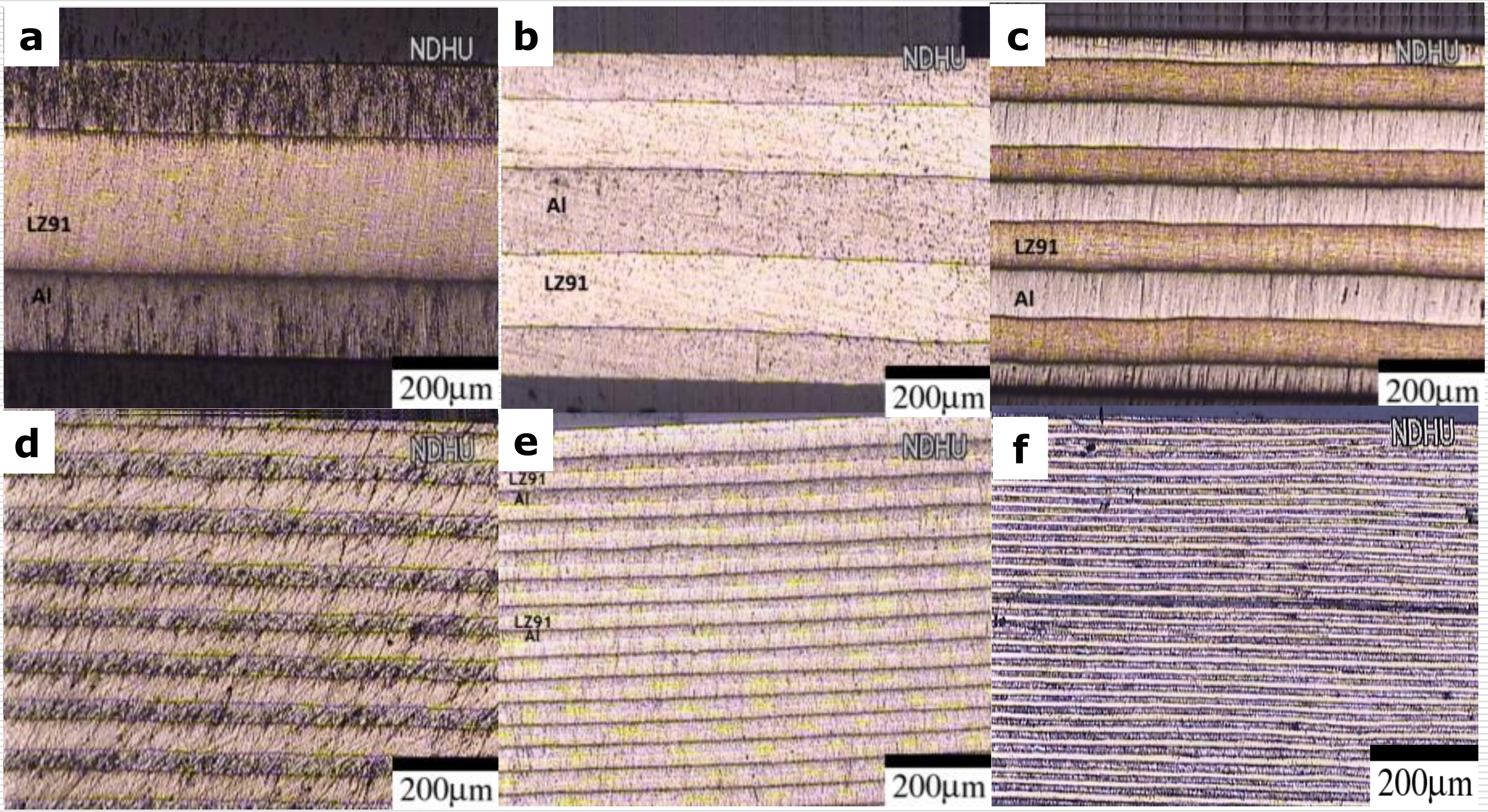
Multilayered composite produced by ARB process

Results and discussion



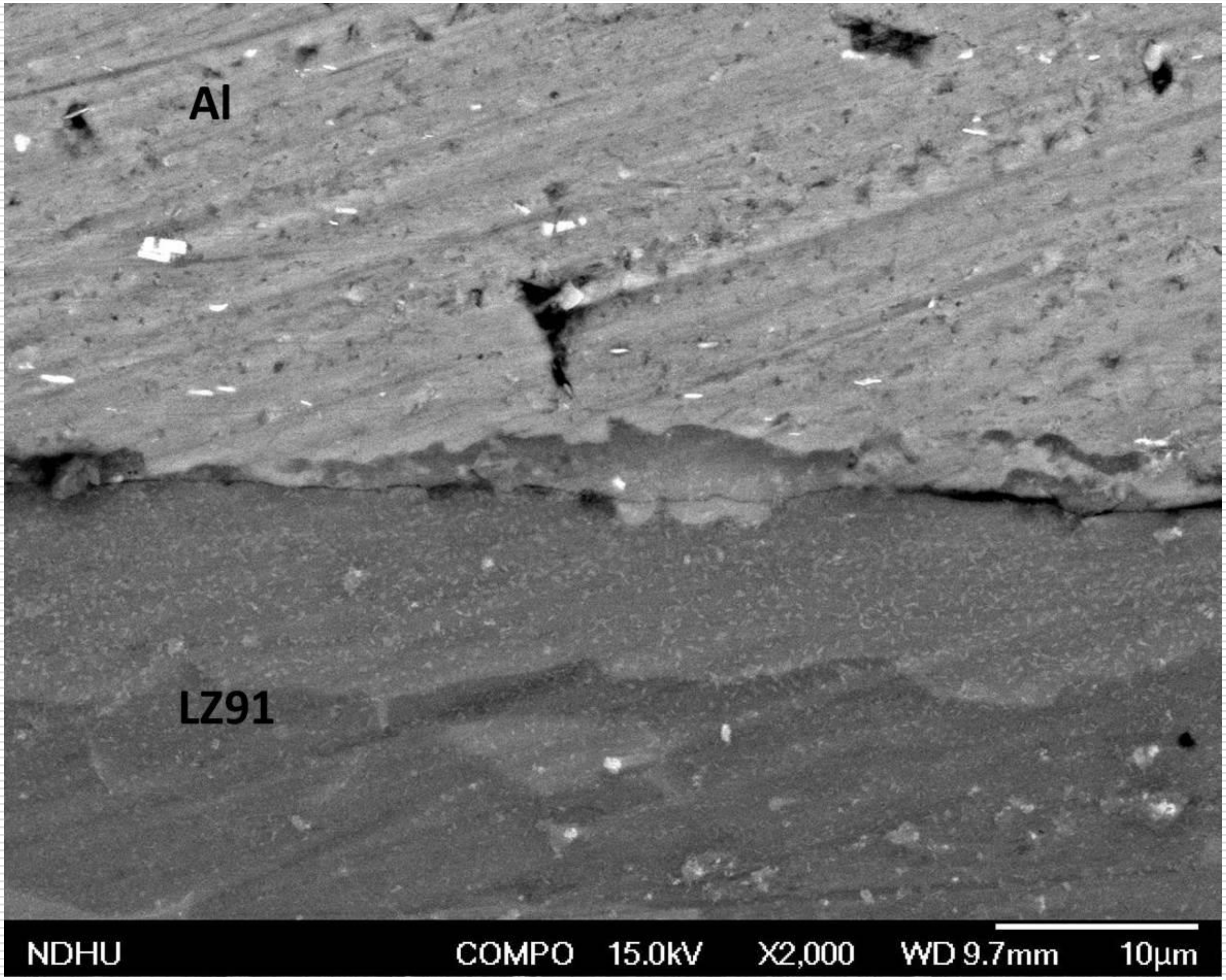
Optical microstructure of the starting LZ91(9wt.% Li-1wt.%Zn) sheet.
Dual phases of LZ91with α-Mg and β-Li. The grain sizes of α-Mg and β-Li were around 10-20μm .

Results and discussion



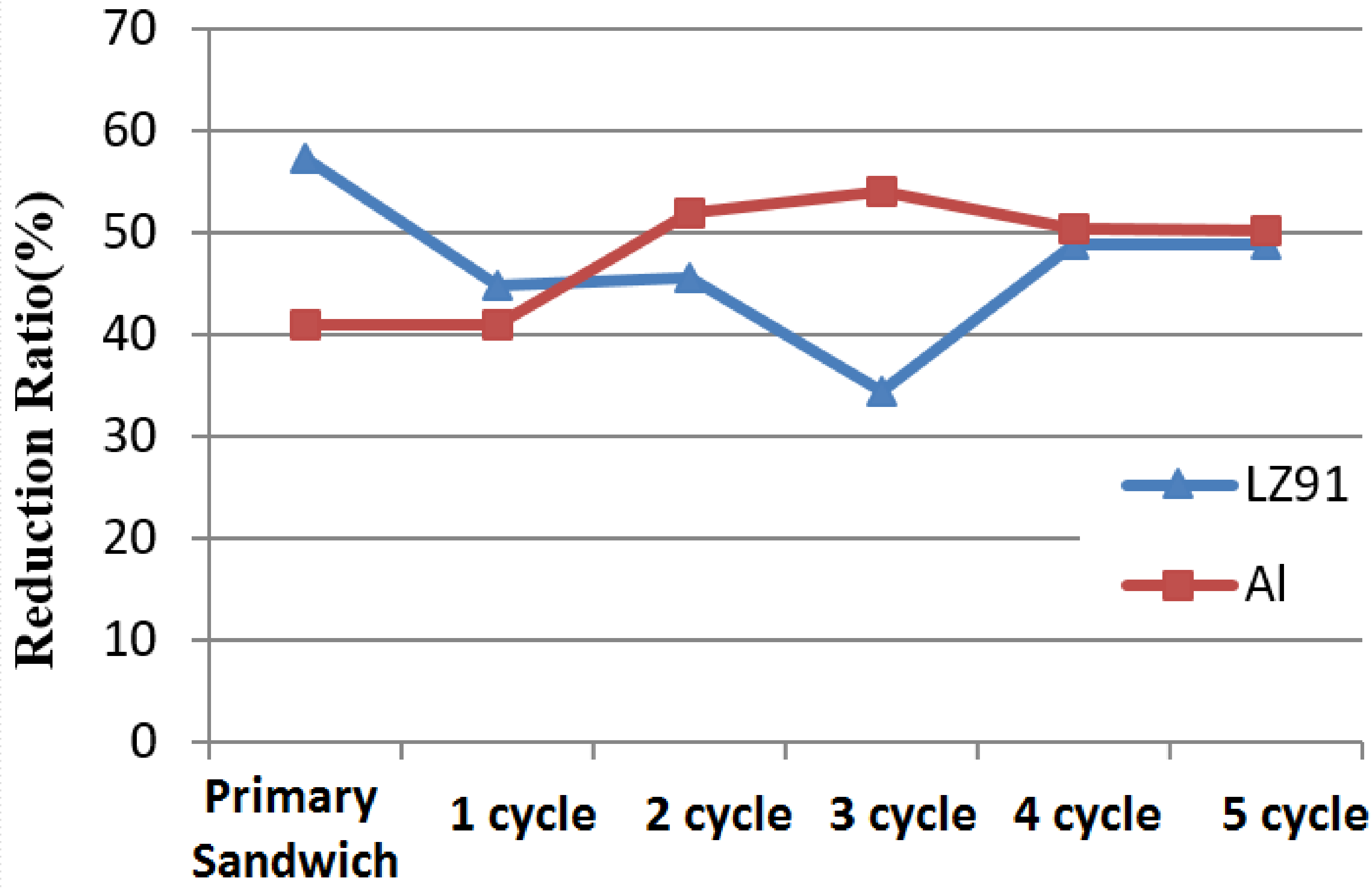
Optical micrographs of longitudinal cross-section of Al/LZ91/Al multilayered composites, (a) after primary sandwich preparation, (b) after 1 cycle, (c) after 2 cycles, (d) after 3 cycles, (e) after 4 cycles and (f) after 5 cycles.

Results and discussion



SEM image of the LZ91/Al interface after primary sandwich preparation.

Results and discussion

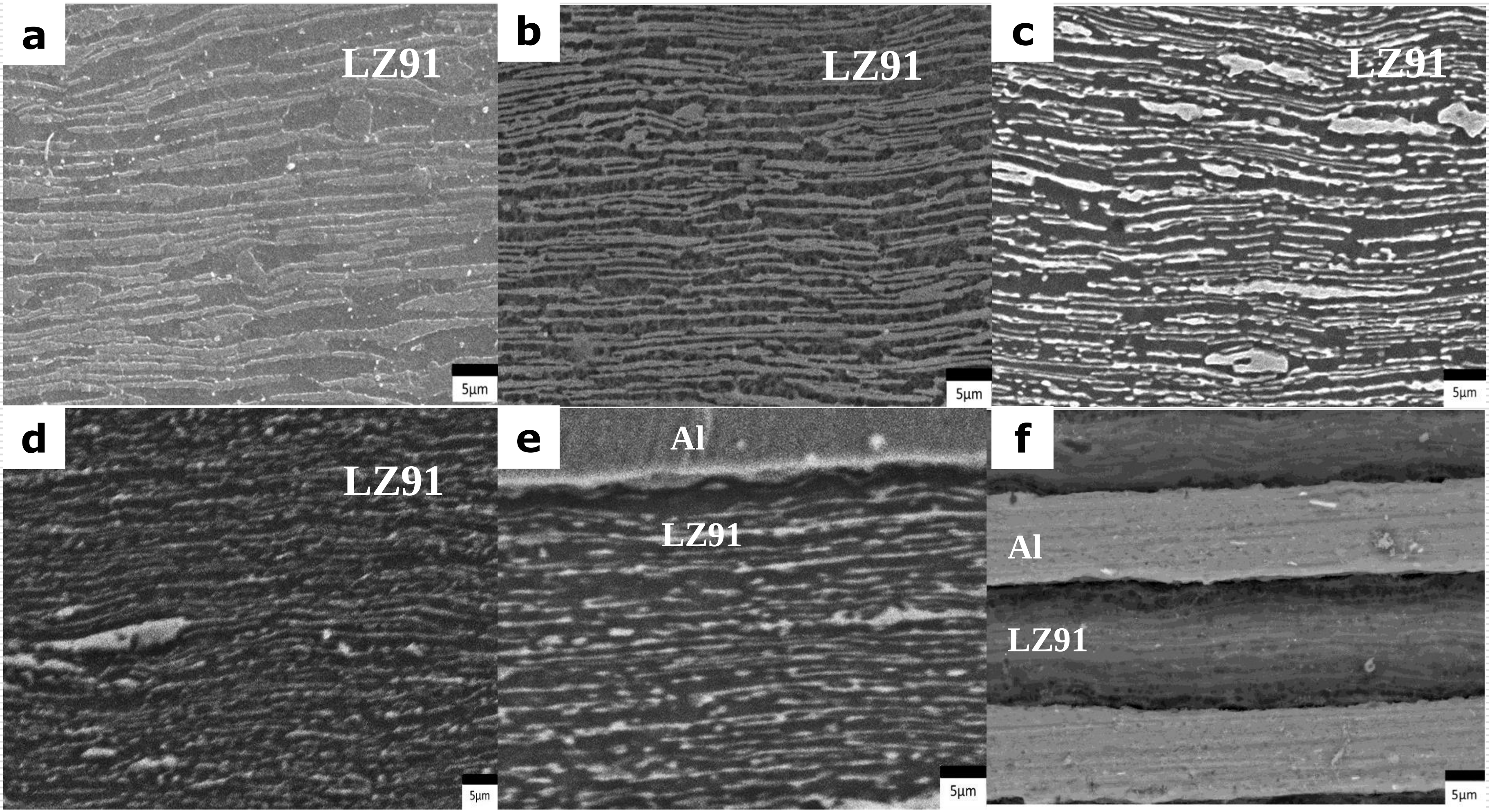


The thickness reduction ratio of the Al and LZ91 layers during each rolling process.

Thickness deformation ratio :

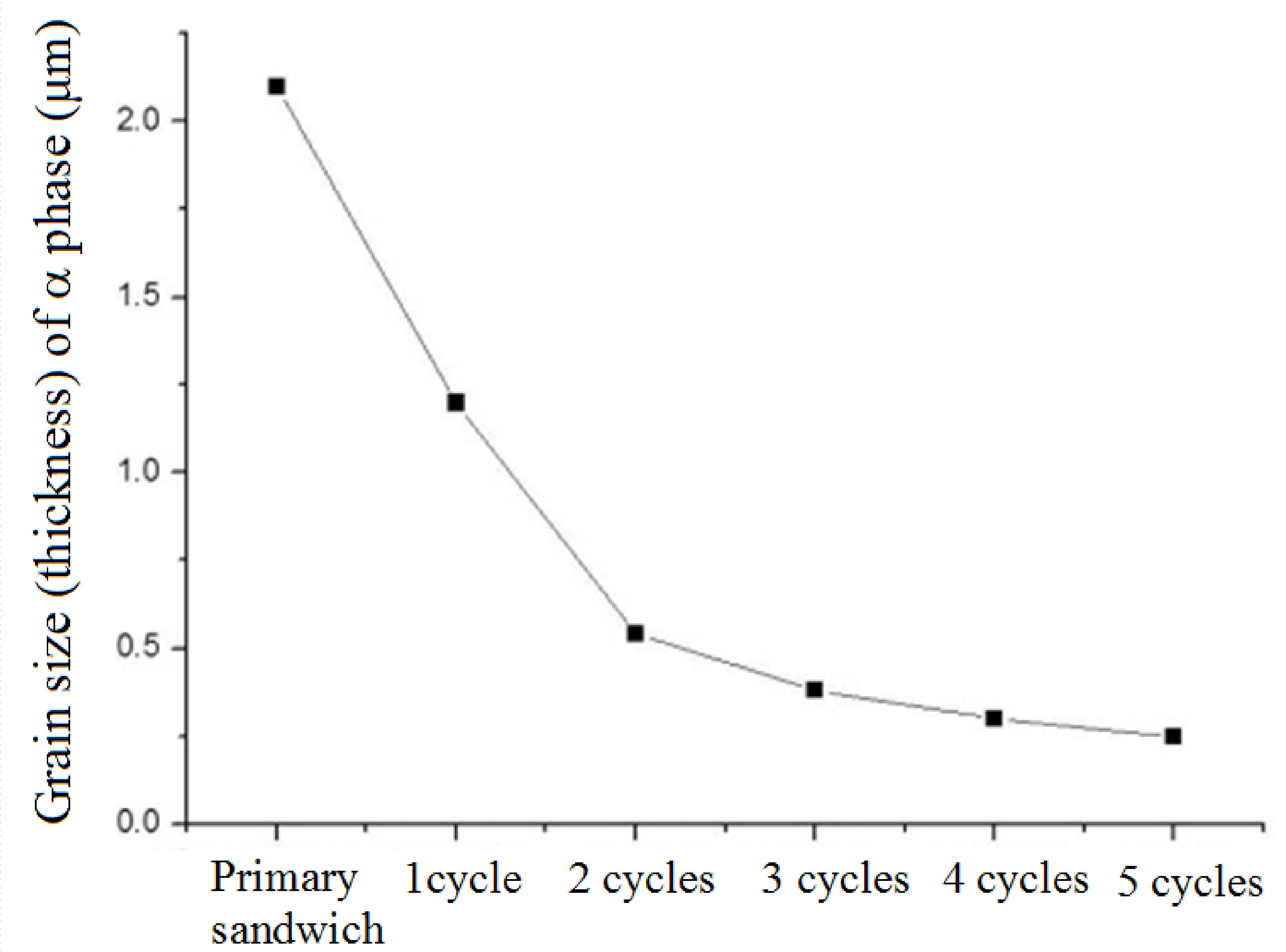
(original (previous) thickness - rolled thickness) / original (previous) thickness x 100%

Results and discussion



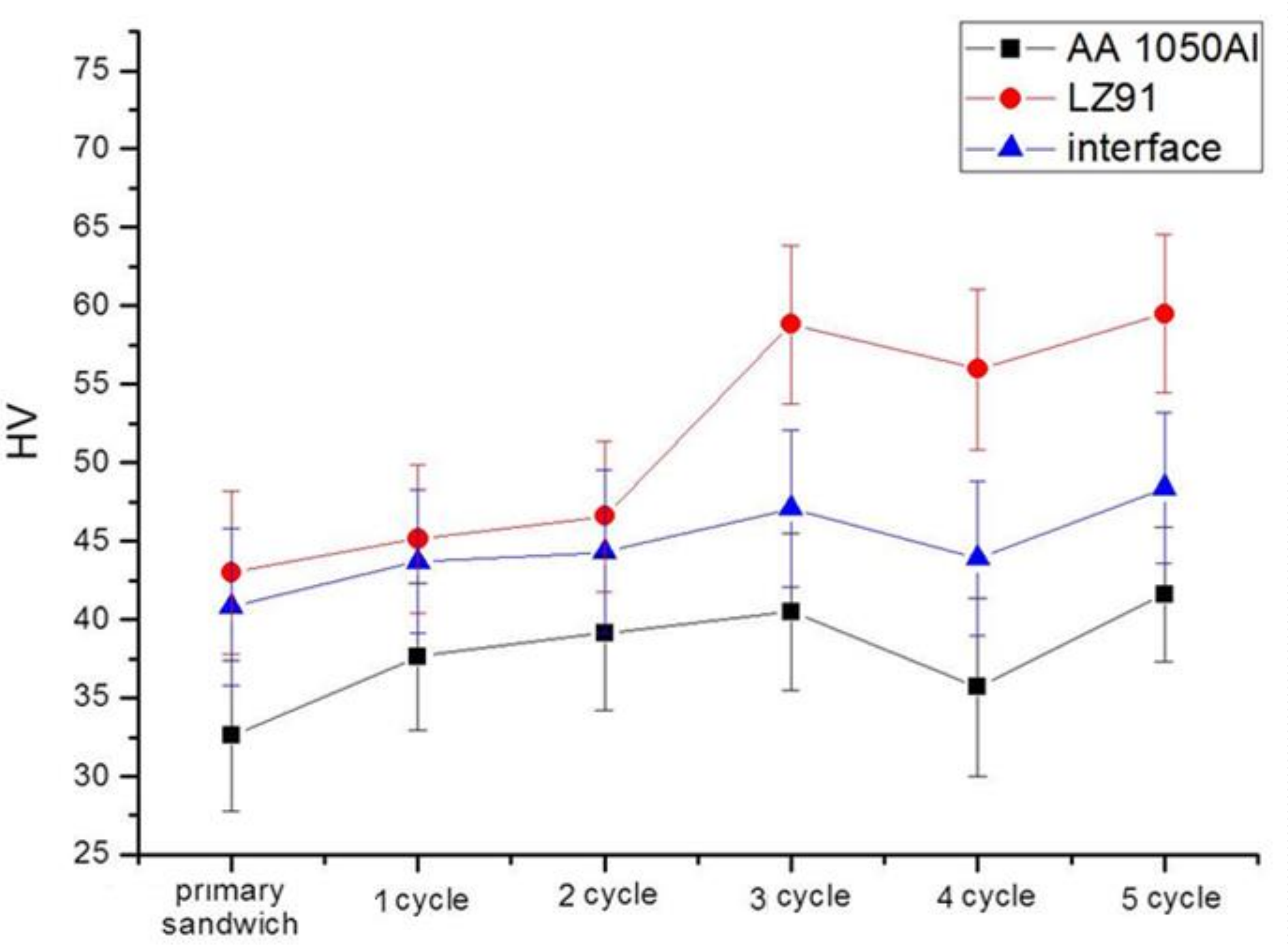
SEM microstructures of the LZ91 side in Al/LZ91/Al composite: (a) after primary sandwich preparation, (b) after 1 cycles, (c) after 2 cycles, (d) after 3 cycles, (e) after 4 cycles and (f) after 5 cycles.

Results and discussion



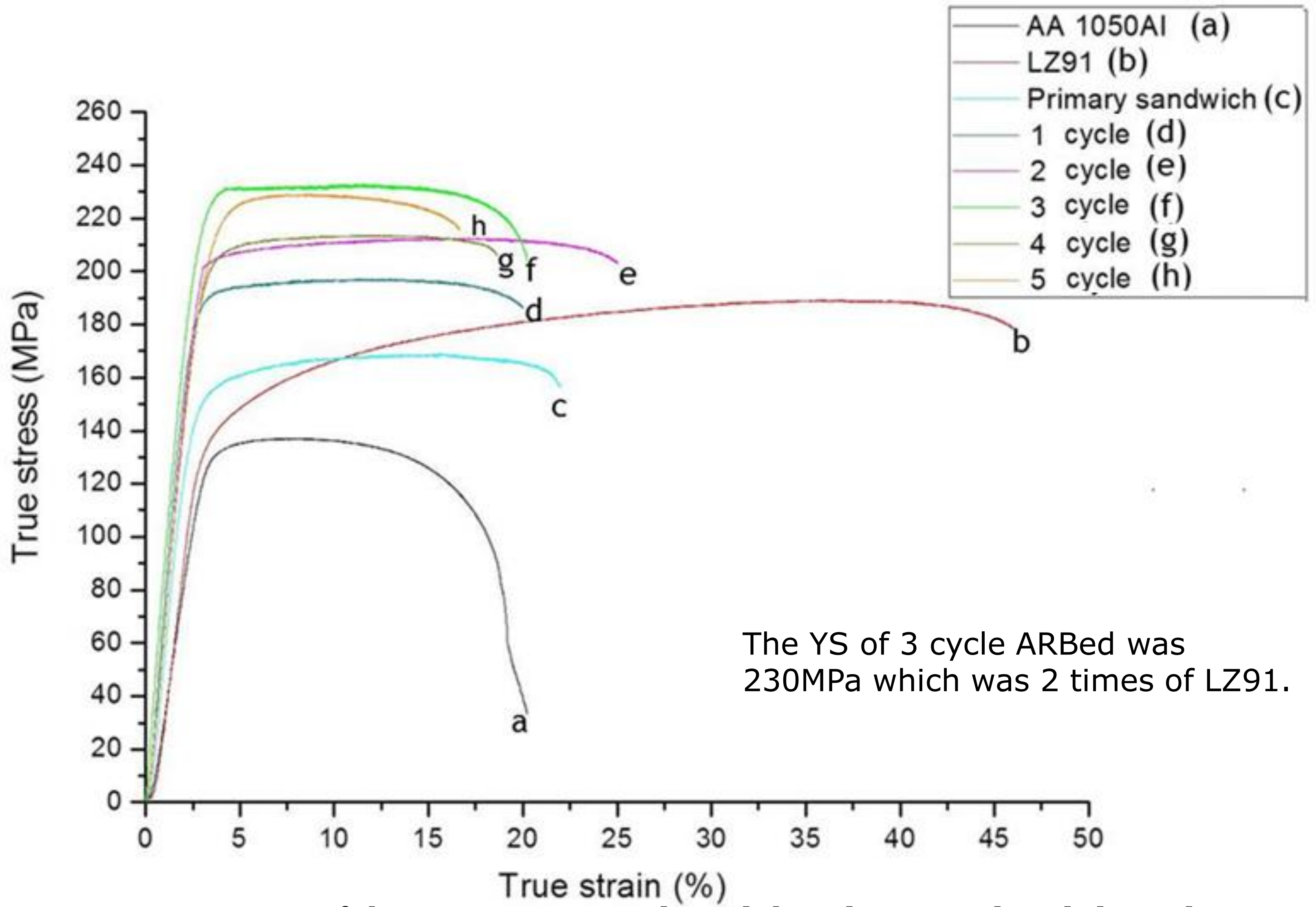
The grain size of α phase in LZ91 side of composite after different number of ARB cycles

Results and discussion



Variation of microhardness of Al layer, interface and LZ91 layer with increasing numbers of the ARB cycle.

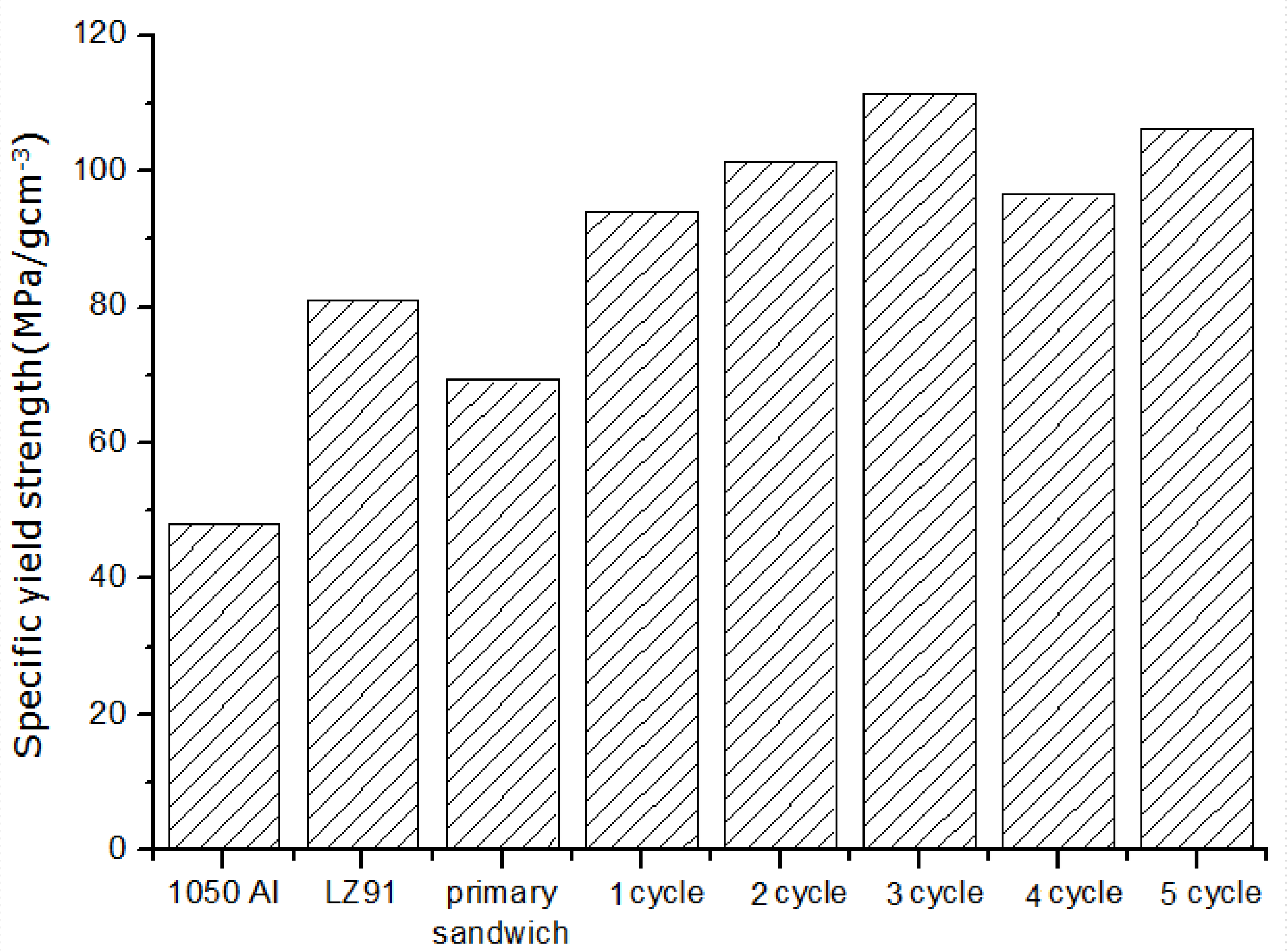
Results and discussion



The YS of 3 cycle ARBed was 230MPa which was 2 times of LZ91.

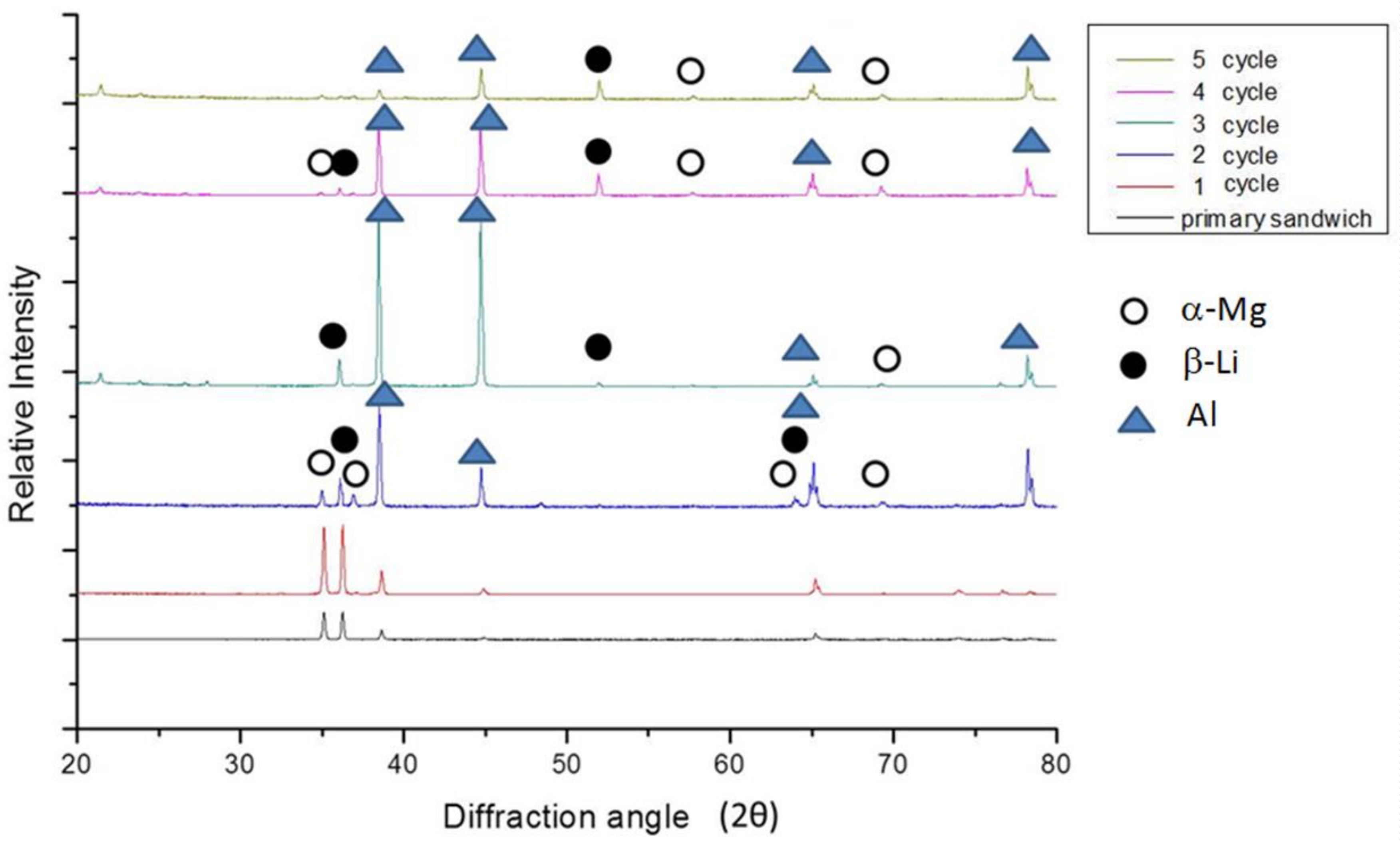
True stress-strain curves of the starting materials and the Al/LZ91/Al multilayred composite after different number of ARB cycles

Results and discussion



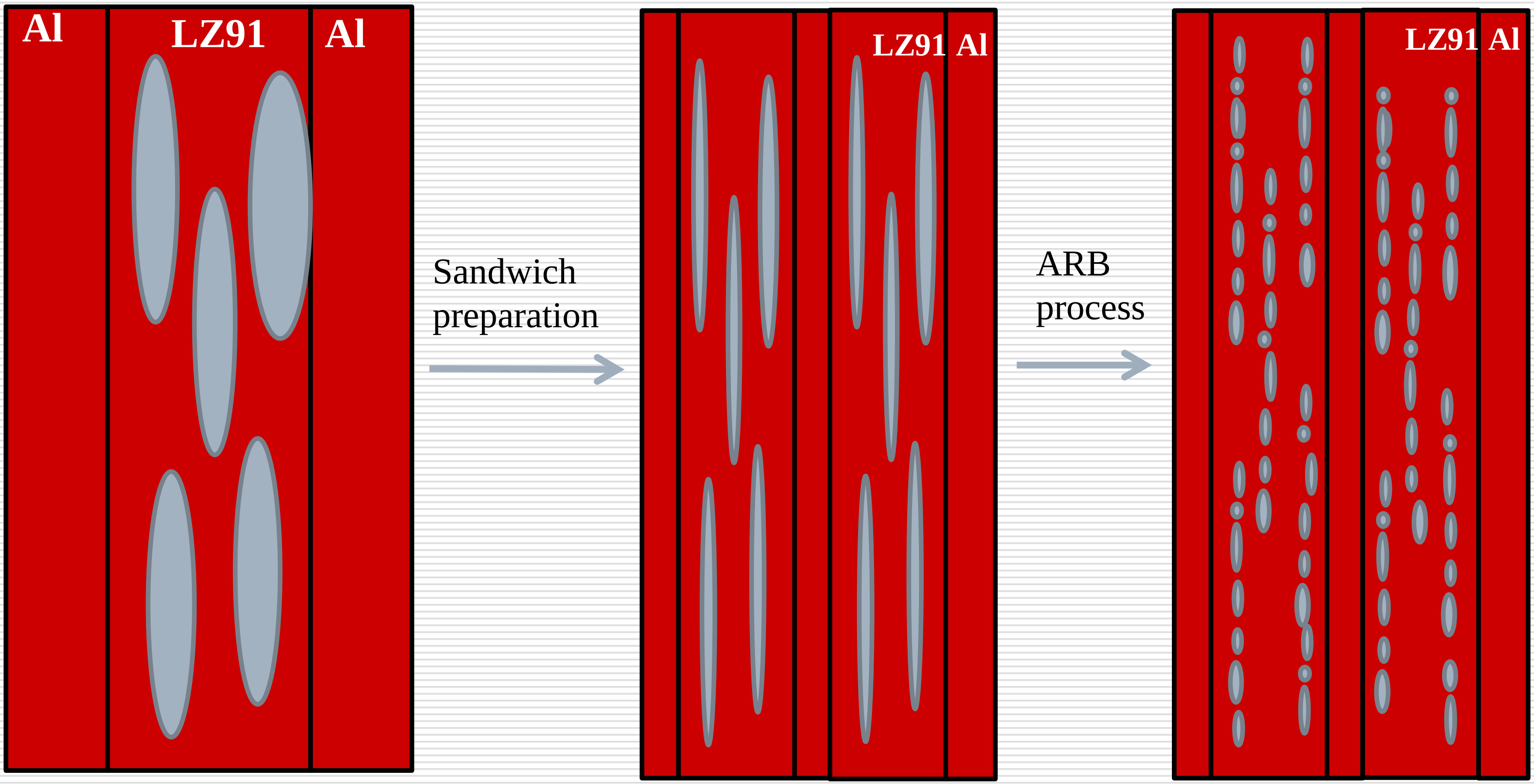
Specific yield strengths of the starting materials and the Al/LZ91/Al composite after different number of ARB cycles

Results and discussion



XRD patterns of LZ91/Al primary sandwich and after different number of ARB cycles

Summary for as-ARBed Al/LZ91/Al

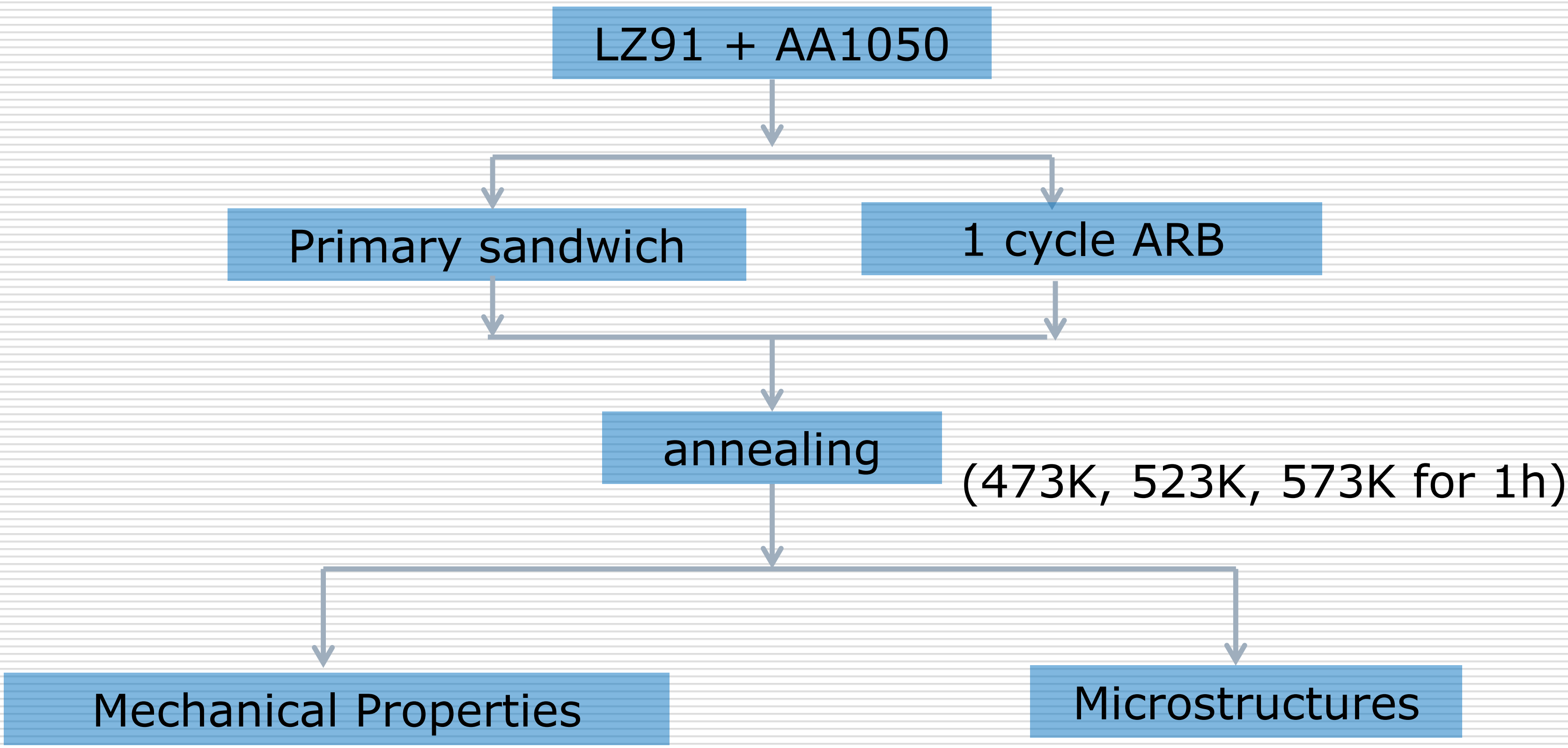


The size of α phase in LZ91 was thinned after primary sandwich and broken down to small particles after ARB process. Therefore, the grain refining and strain hardening of both materials increased the strengths of multilayered Al/LZ91/Al.

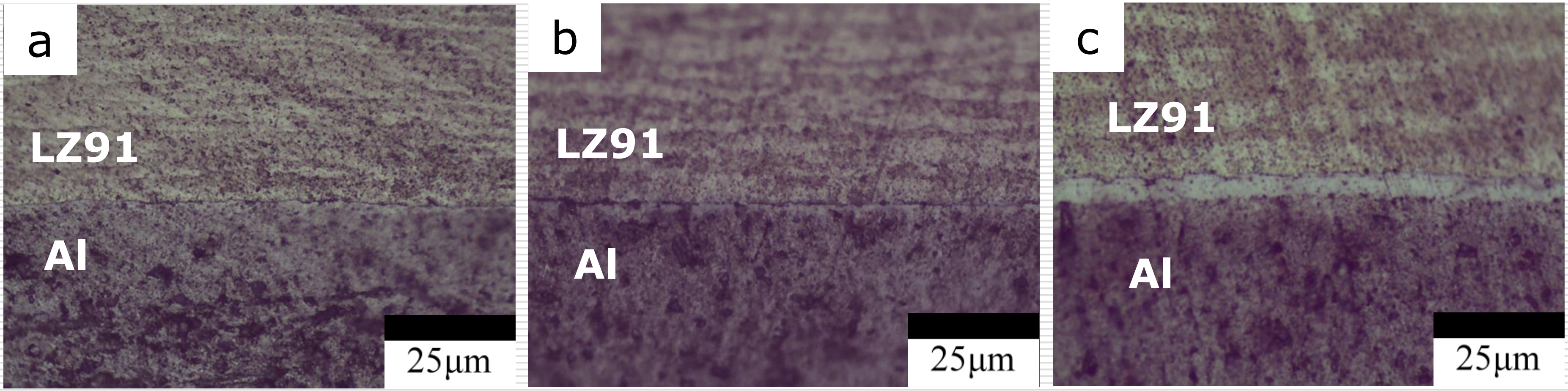
The yield stress after 3 cycles ARB process is about 2 times higher than that of LZ91. Besides, the elongation can be maintained around 20%.

Annealing of ARB processed LZ91/Al

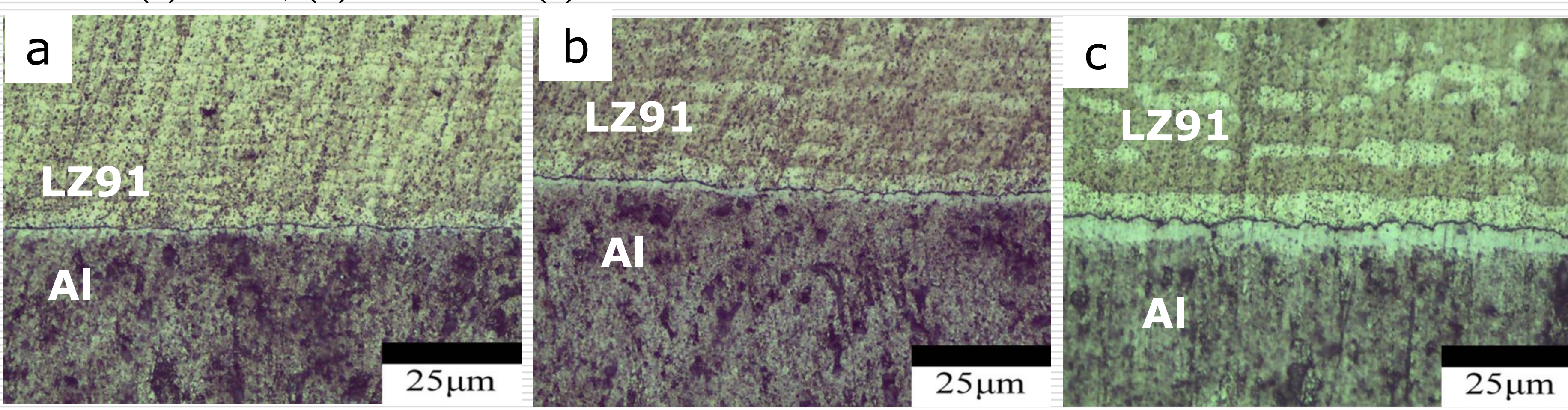
In order to improve the bonding strength between LZ91 and Al, annealing of as-ARBed Al/LZ91/Al was performed.



Annealing of multilayered LZ91/Al

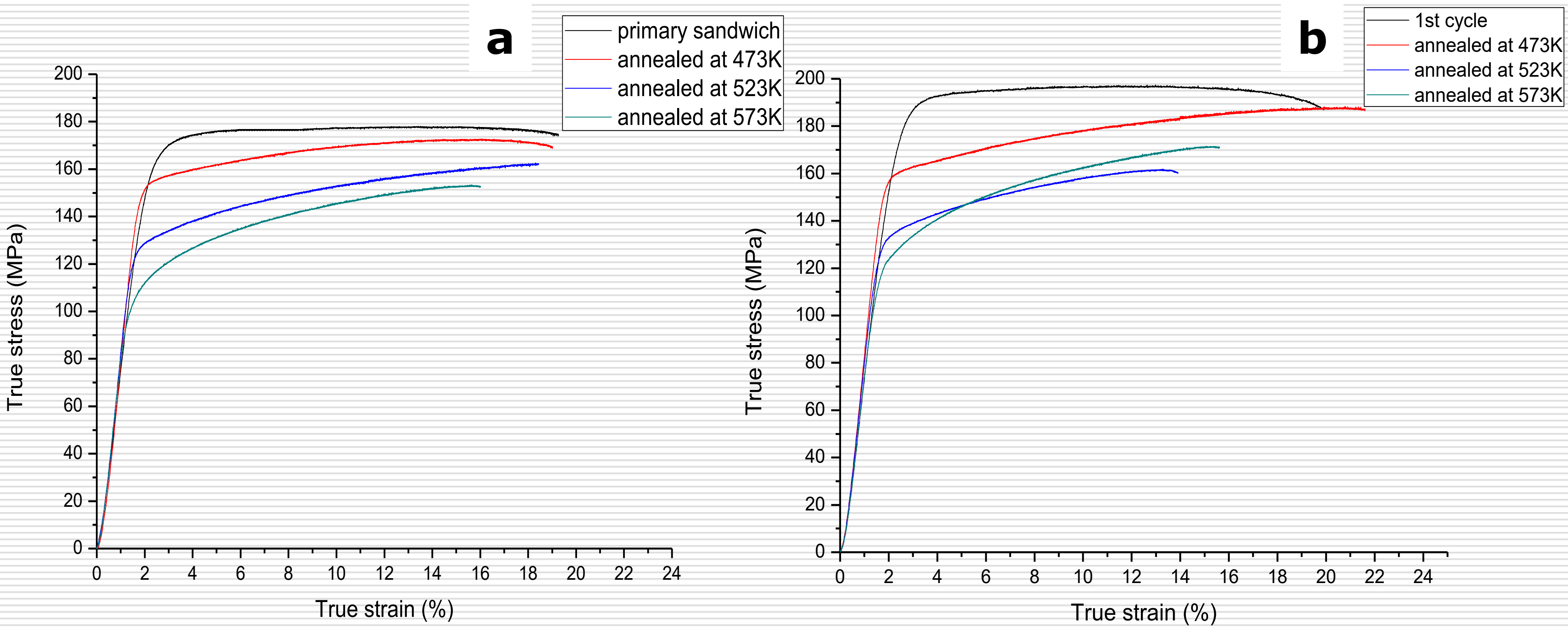


Cross-section optical micrographs of Al/LZ91/Al primary sandwich after annealing at (a) 473K, (b) 523K and (c) 573K.



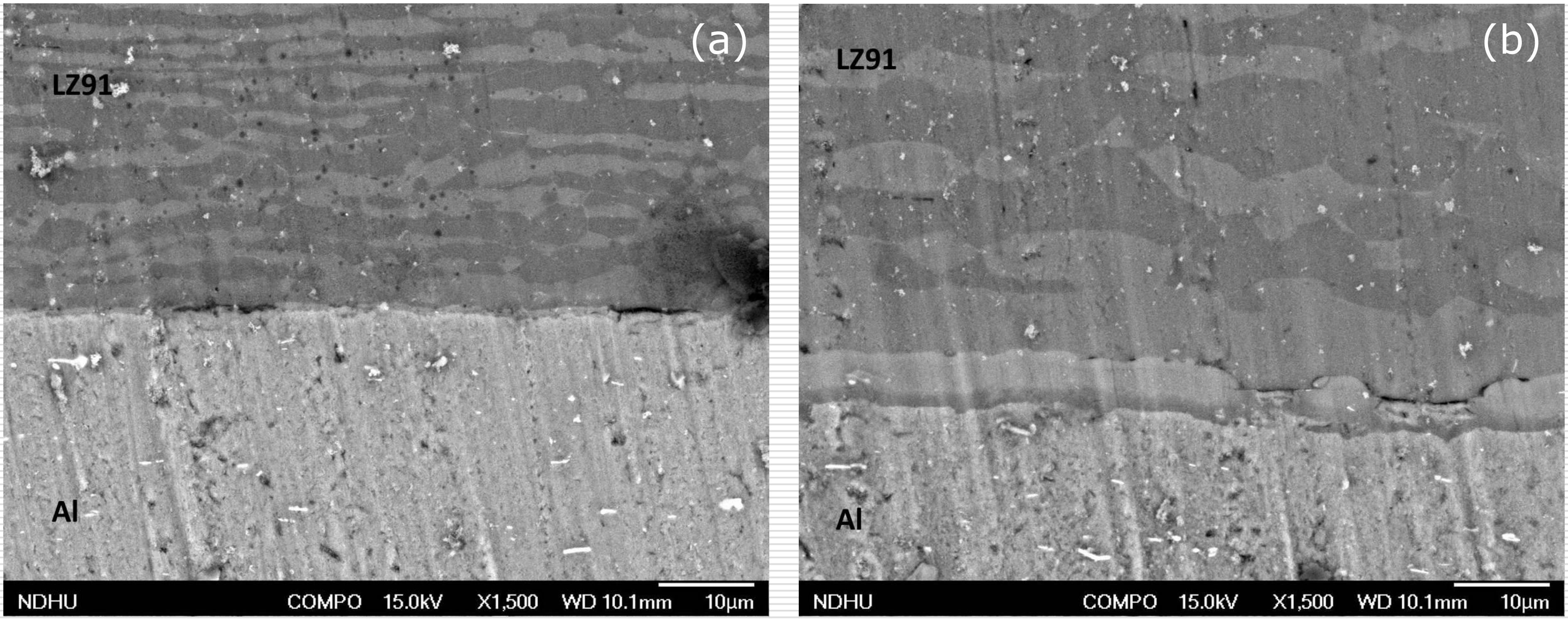
Cross-section optical micrographs of 1 cycle ARBed Al/LZ91/Al after annealing at (a) 473K, (b) 523K and (c) 573K.

Annealing of as-ARBed LZ91/Al



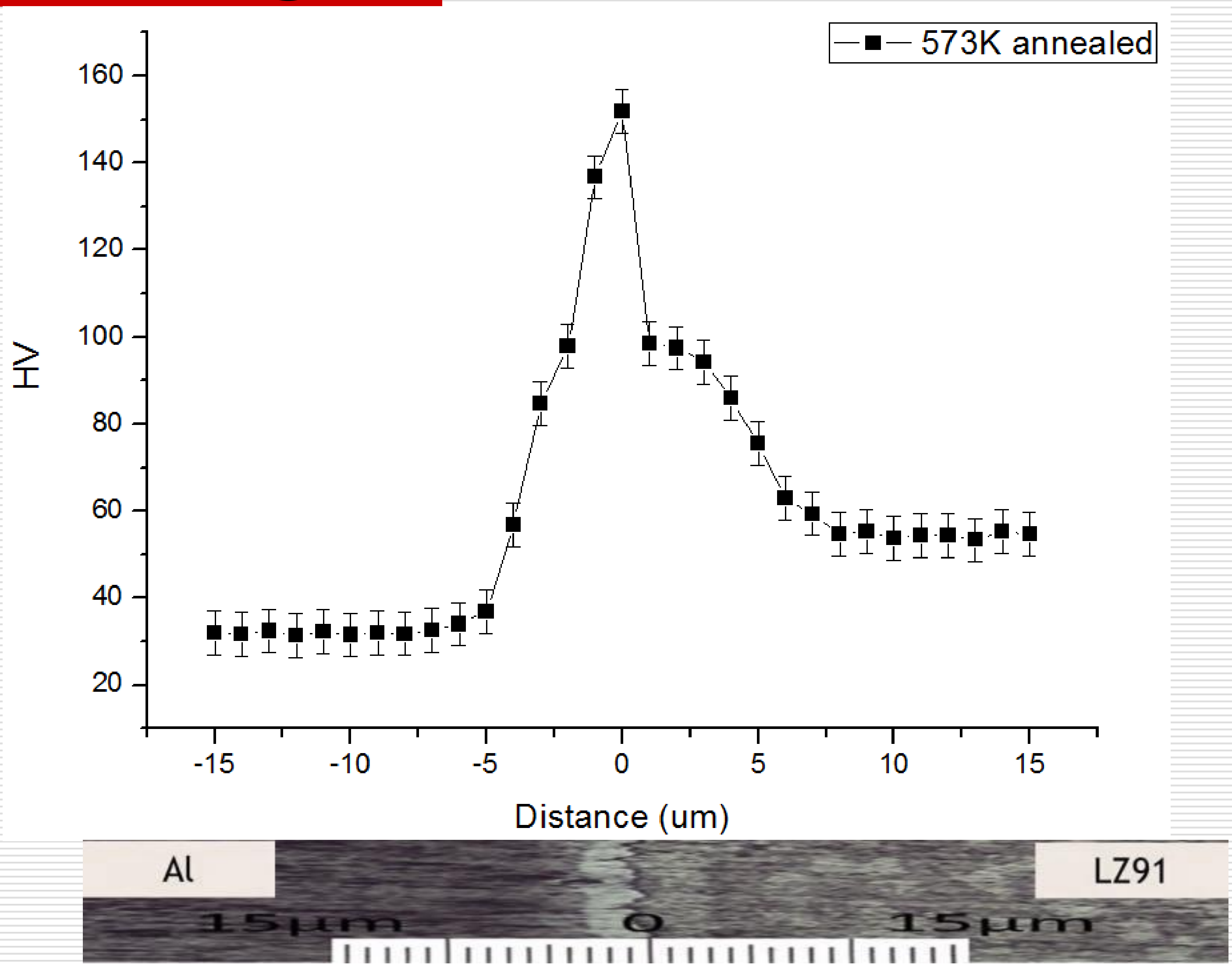
True stress-strain curves of (a) primary sandwich and (b) 1 cycle ARBed Al/LZ91/Al multilayers after annealing at different temperature.

Annealing of ARBed LZ91/Al



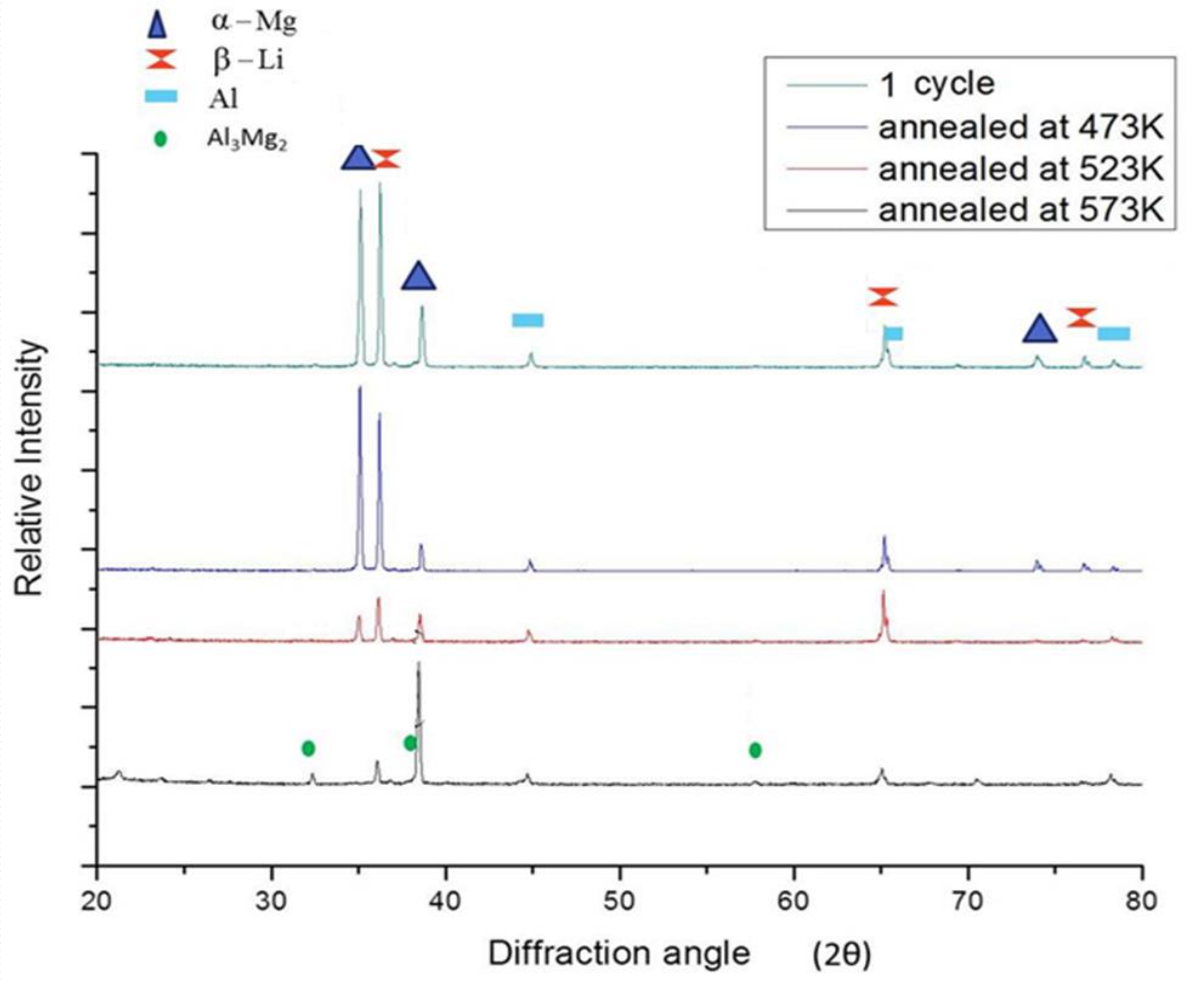
SEM cross-section images of 1 cycle ARBed Al/LZ91/Al after annealing at (a) 473K, (b) 573K.

Annealing of ARBed LZ91/Al



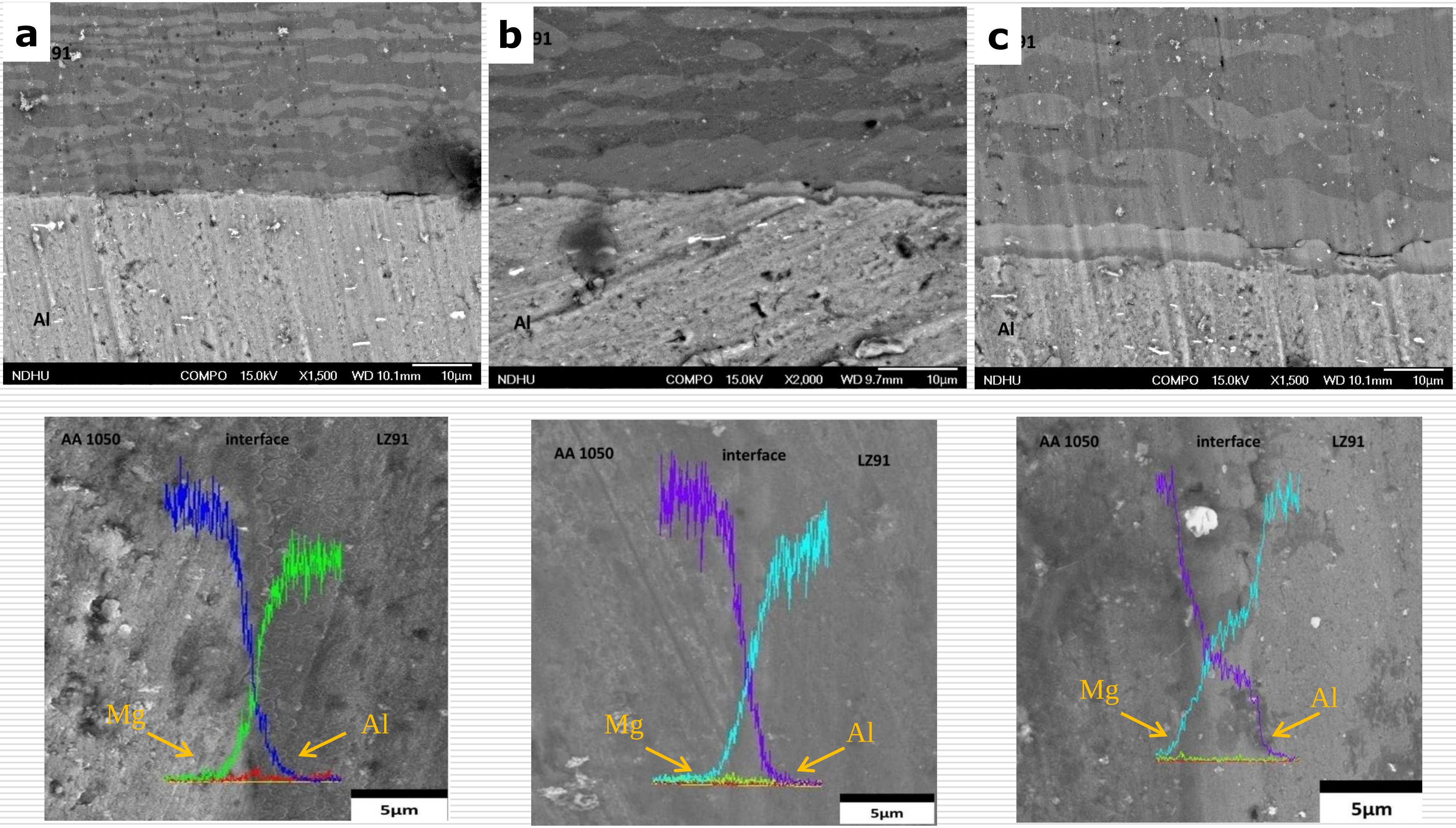
Micro-Vickers hardness distribution of 1 cycle ARBed Al/LZ91/Al after annealing at 573K.

Annealing of ARBed LZ91/Al



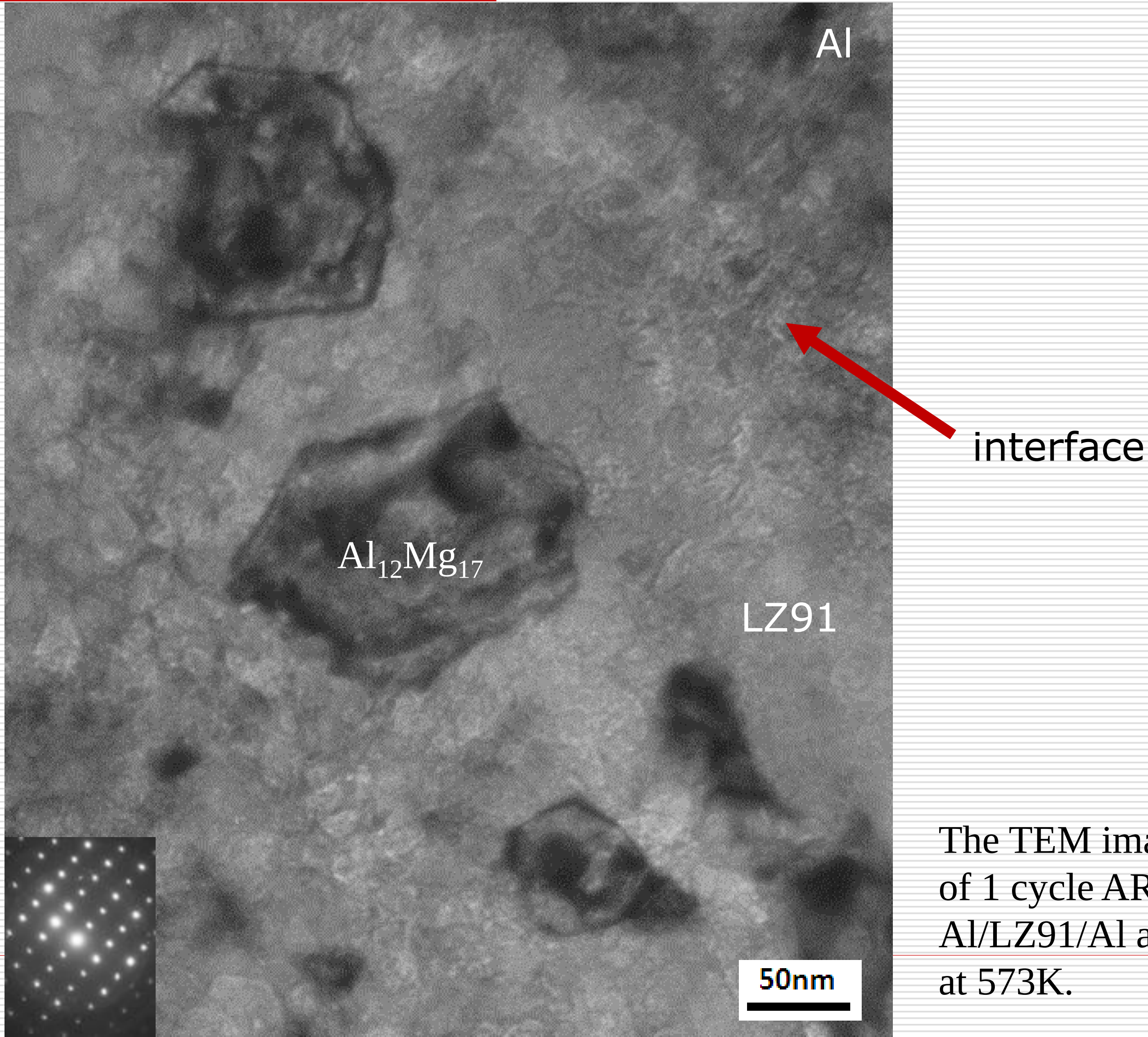
XRD spectrums of 1 cycle ARBed Al/LZ91/Al after annealing at (a) 473K, (b) 523K and (c) 573K.

Annealing of ARBed LZ91/Al



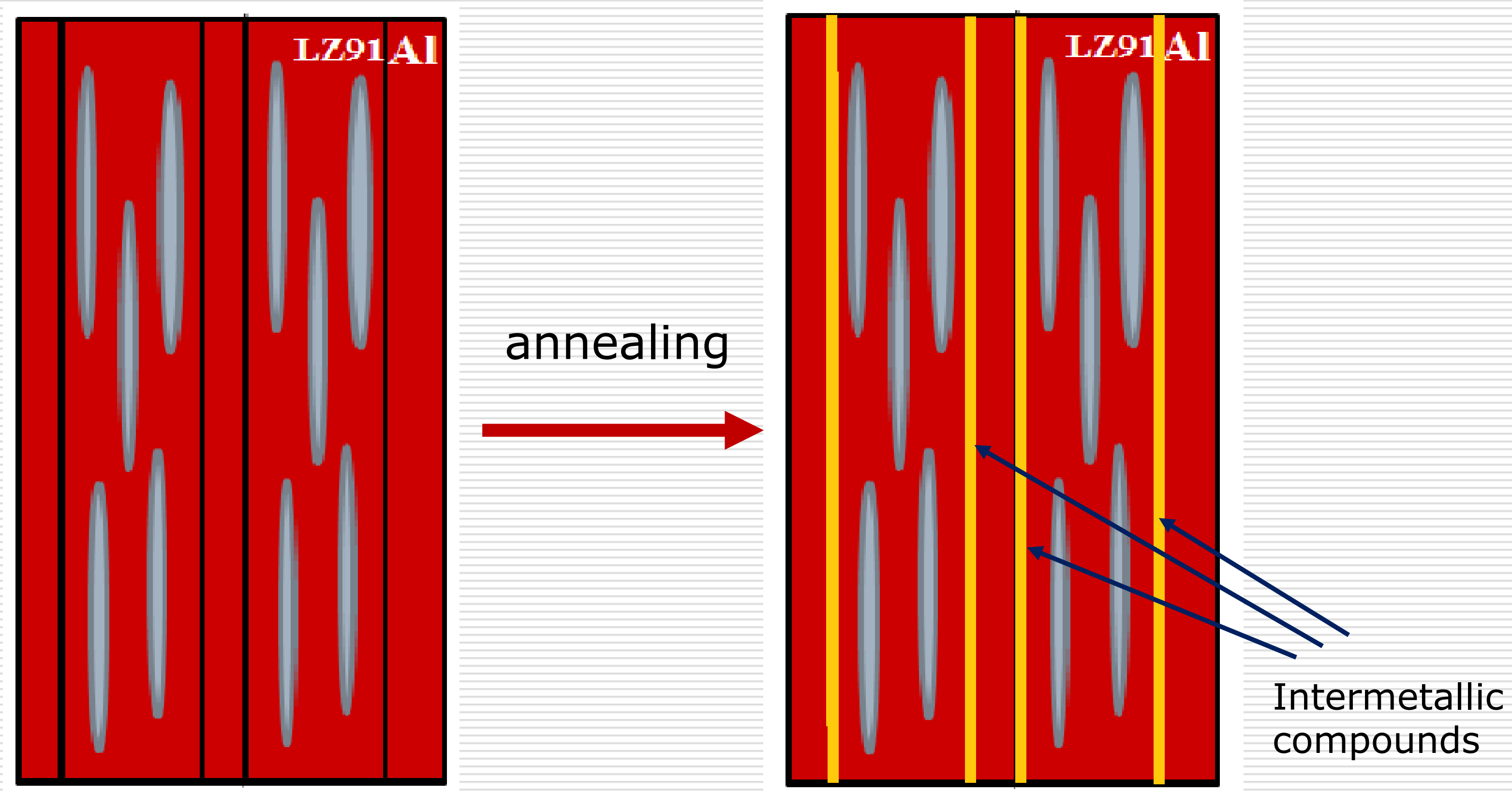
BSE images and EDS line scan of 1 cycle ARBed Al/LZ91/Al after annealing at (a) 473K, (b) 523K and (c) 573K.

Annealing of ARBed LZ91/Al



The TEM image of interface of 1 cycle ARBed Al/LZ91/Al after annealing at 573K.

Summary for annealing of LZ91/Al



Improving the bond interface by annealing:

1. Annealing at higher temperature will promote occurrence of intermetallic compounds.
2. At lower temperature, diffusion layer only might improve the bond condition.

Summary

1. The Al/LZ91/Al composites were successfully processed by ARB up to five cycles. Necking or rupture of both LZ91 and Al layers did not take place because the similar flow properties between them. The LZ91 and Al layers underwent different applied strain during each rolling process.
2. α phase of LZ91 was refined after primary sandwich preparation. During the following ARB process, the grain size of α phase further decreased with increasing of the accumulated strains.
3. Although the ARB process was conducted at warm temperature, no intermetallic compound can be found in the interface.
4. Both the yield strength and ultimate tensile strength of the Al/LZ91/Al multilayered composite increased gradually while the elongation still maintained around 20% with increasing of the ARB cycles. The yield strength of primary sandwich was 168MPa. However, the yield strength increased up to 230MPa after 3 cycles ARB process.

Summary

5. It is inferred that the grain refining of α phase and work hardening of LZ91 and Al are effective strengthening mechanism in these alloys.
6. After annealing treatment, the compounds hard to be found at the interface of LZ91/Al if the annealing temperature is below 523K. However, the compounds of Al_3Mg_2 and $Al_{12}Mg_{17}$ appeared at the interface after higher annealing temperature.
7. Because the compounds at the LZ91/Al interface are brittle, they consequently could not increase the strengths. However, the annealing temperatures below 523K might improve the bonding characteristic.


Thanks for your attention
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