MSE 307

Instructor: Pradipta Ghosh

Microstructural Evolution and Mechanical Behaviour of Cu/Nb Multilayer Composites Processed by Accumulative Roll Bonding

S N Saikumar(19110163)
Patel Vashisth(19110158)

ARB (Accumulative Roll Bonding)

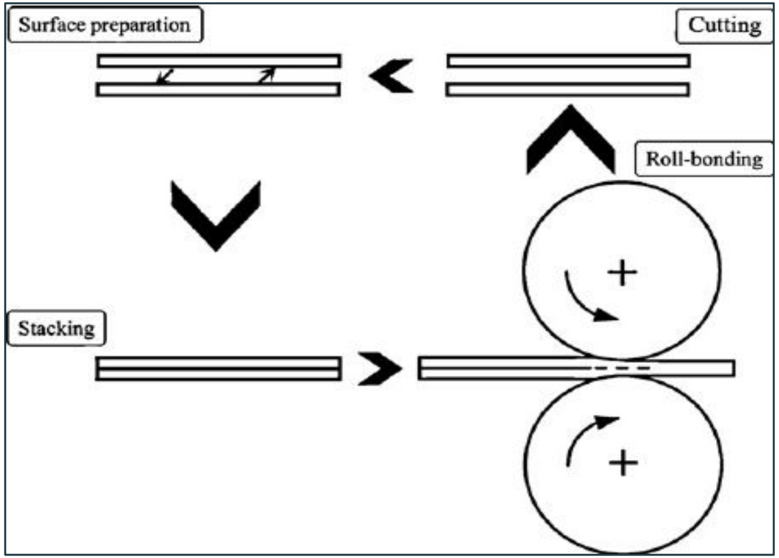

Figure 1: ARB diagram

- ARB processing is a type of Severe Plastic Deformation (SPD) technique.
- ARB is used to produce ultrafine - grains.
- ARB process consists of multiple cycles of rolling, stacking, roll bonding and cutting.
- In ARB we reduce the layer thickness to hundreds of nanometres.

ARB processing

- Recently the ARB technique was introduced to fabricate multilayered composite sheets with dissimilar metals.
- Due to simple processing and relatively low cost ARB process can be easily used in industries.
- Multilayer composite sheets with dissimilar metals are produced using ARB processing eg. Cu/Nb, Cu/Al, Cu/Ni, Al/Mg, etc.

Properties of Multilayer composite

- ❑ Multilayer composite materials processed by ARB exhibit improved material properties like High strength, High impact resistance, etc.
- ❑ With ARB process we can increase the strength of Cu/Nb multilayer composite upto 1200 MPa and ductility upto 8% by reducing individual layer thickness to 30nm.
- ❑ Cu/Nb composite along with their strength have high thermal stability, excellent formability and can sustain high radiation damage.

ARB processing of Cu/Nb

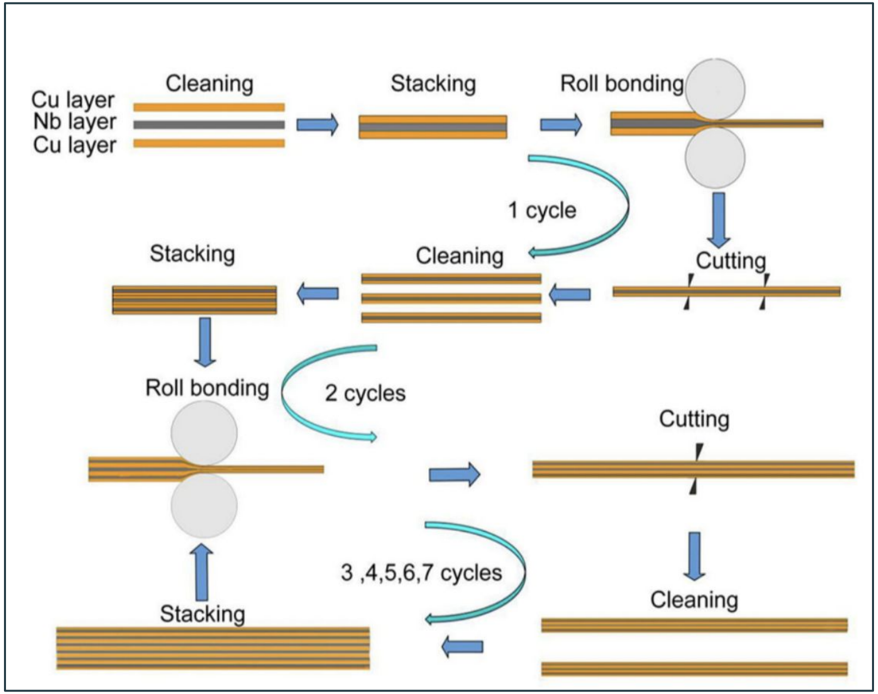

Figure 2: Schematic diagram of ARB processing

1) The initial step consists of wire brushing the contact surfaces and ultrasonic cleaning in acetone.
2) In the second step: Nb plate is sandwiched between the Cu plates and then fastened together by steel wire at the four corners.
3) In the third step: the sheets are rolled up to 77.7% reduction in thickness.
4) The sandwiches are cut into three parts.
5) Then again sandwiches are wire brushed, stacked and then roll bonded.
6) Then after the 2nd rolling cycle the sandwiches are annealed at 60 ℃ for 2hr. And then cut into 2 halves.
7) This process of wire brushing,stacking and fastened, rolling, annealing and cutting is continued till the 7th cycle.

Microstructural Evolution during ARB processing

Number of ARB cycles	Number of layers	Layer thickness [μm]	Total strain ε	Total rolling reduction [%]
1	3	223.3	1.7	77.7
2	9	105.6	2.6	89.4
3	18	50.0	3.5	95.0
4	36	22.2	4.4	97.8
5	72	11.1	5.2	98.9
6	144	5.6	6.0	99.4
7	288	2.8	6.8	99.7

$$\eta = \left(\frac{h_0 - h}{h_0}\right) \times 100$$

and

$$\varepsilon = \frac{2}{\sqrt{3}} \ln\left(\frac{h_0}{h}\right)$$

The percentage rolling reduction, η.
The equivalent plastic strain, ε.
Where, h0 and h are the initial layer thickness and the layer thickness after the ARB cycles.

Microstructure

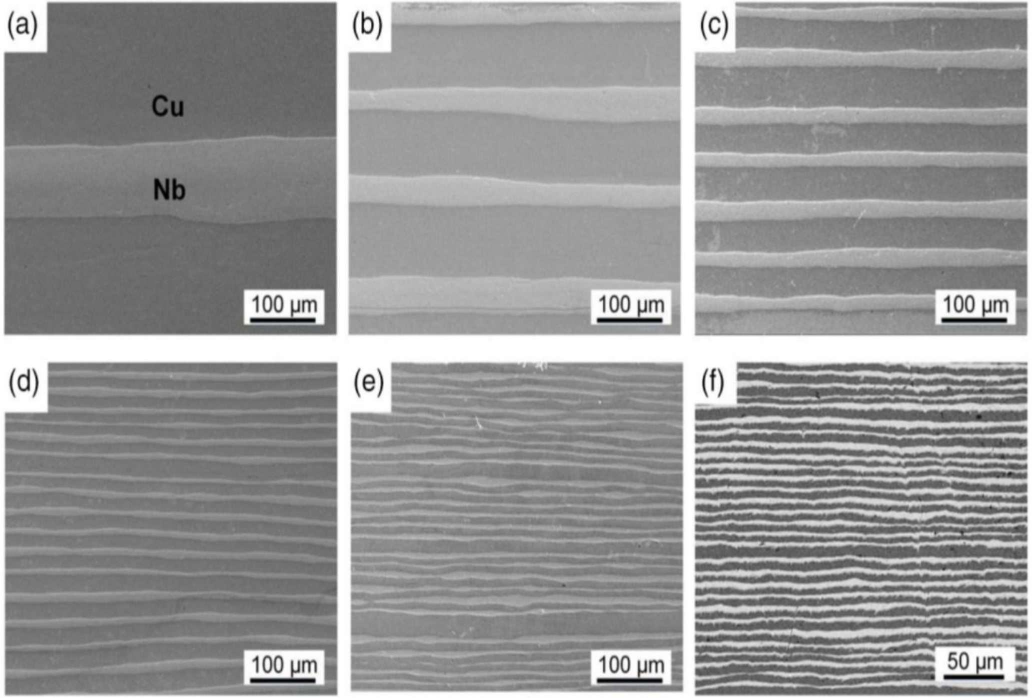

Figure 3: SEM micrographs of the Cu/Nb multilayer composites processed via ARB after a) two cycles, b) three cycles, c) four cycles, d) five cycles, e) six cycles, and f) seven cycles.

- Bright and dark layers denote the Nb and Cu layers.
- There is no necking and fracture in the Cu/Nb multilayer composites even after seven cycles of ARB.

Microstructure

- A straight and continuous laminated structure of the two phases is observed.
- No intermetallic compounds are formed.
- Low solubility of Cu/Nb system..

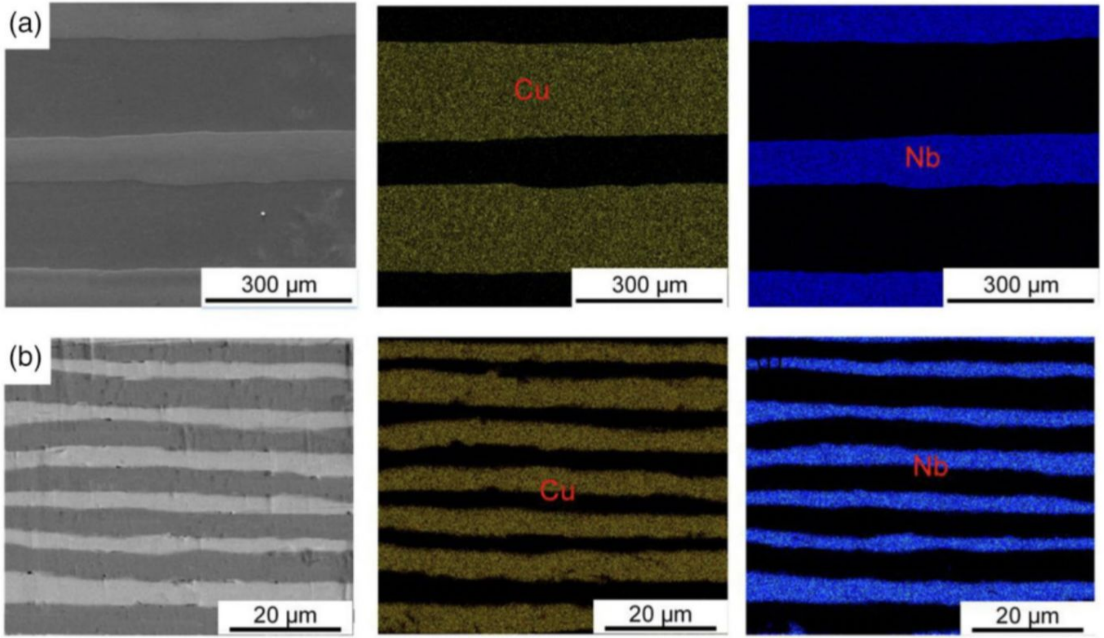

Figure 4: SEM images and elemental distribution map analysis of Cu/Nb multilayer composites: a) two cycles and b) seven cycles.

Inverse Pole Figure of Cu/Nb Multilayer composite

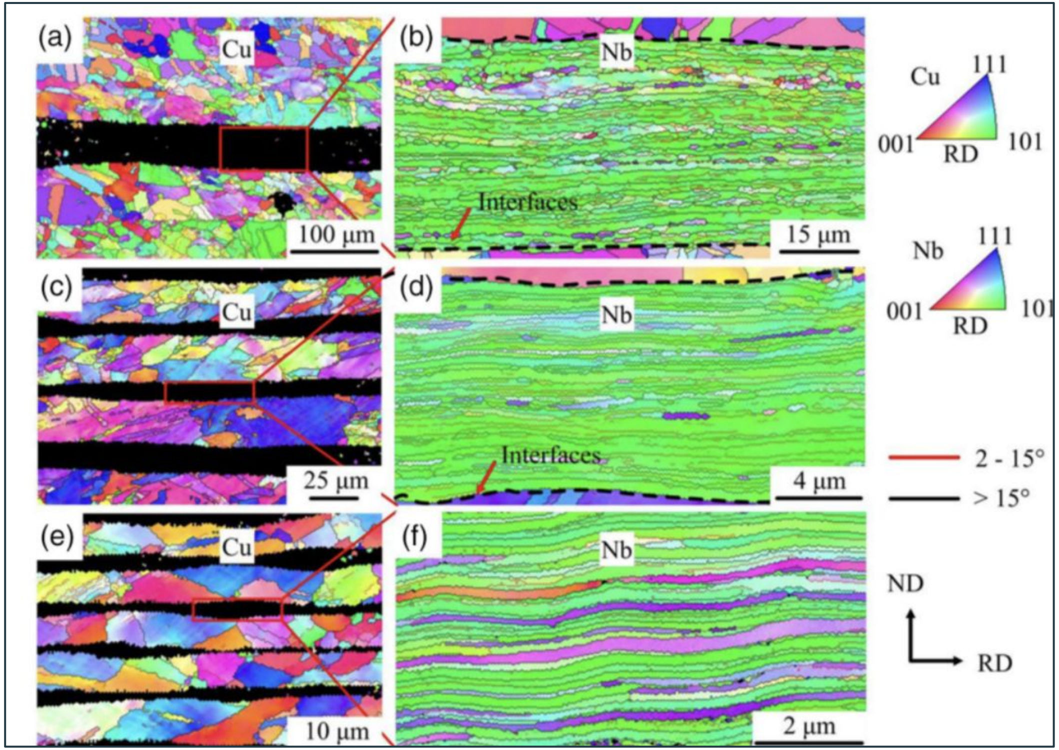

Figure 5: The IPF maps of the multilayer composites after ARB processing a,b) three cycles; c,d) five cycles; and e,f) seven cycles.

- In Nb grains are elongated, In Cu grains are not elongated.
- The number of cycles increases there is a decrease in grain size, and there is a decrease in grain number.

KAM (Kernal Average Misorientation)

- What is KAM?
  for a given point as the average misorientation from other points of the nearest neighbors inside the same grain.

- KAM qualitatively depict the local geometrically necessary dislocation (GND) density.

Average KAM valves/Number of cycles	KAM valves of Cu	KAM valves of Nb
3rd cycle	0.27°	0.75°
5th cycle	0.32°	0.75°
7th cycle	0.32°	0.75°

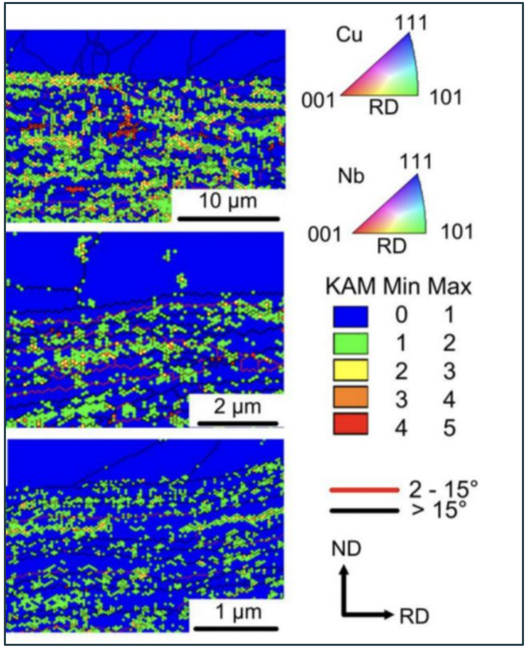

Figure 6: KAM maps of the multilayer composites after ARB processing:

Mechanical Properties of Cu/Nb composite

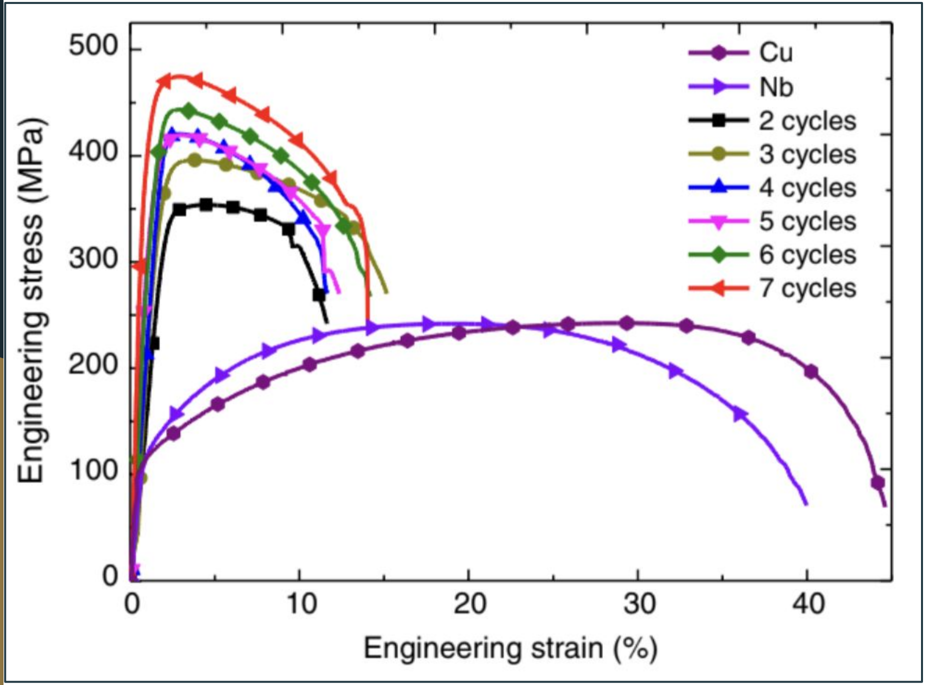

Fig 7: Engineering stress vs strain curve for Cu/Nb multilayer after many cycles of ARB compared to pure annealed metals

- ➢ Even after the 2nd cycle of ARB the yield strength is nearly three times higher than pure Cu or pure Nb.
- ➢ After 7 cycles the yield strength of composite is 475 MPa.

Mechanical Properties of Cu/Nb composite

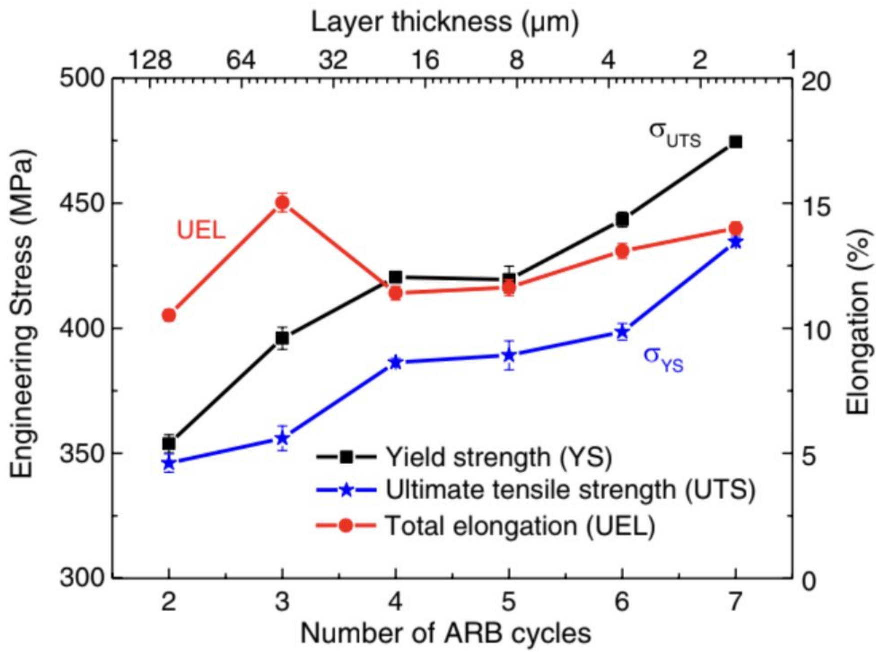

Fig 8: UTS, YS and UEL variation with number of ARB cycles

- The UTS value after 7th cycle is 34% higher than the UTS value 2nd cycle.
- The elongation after 7th cycle is 1.3 times higher than after 2nd cycle.

Tensile Fracture Morphology

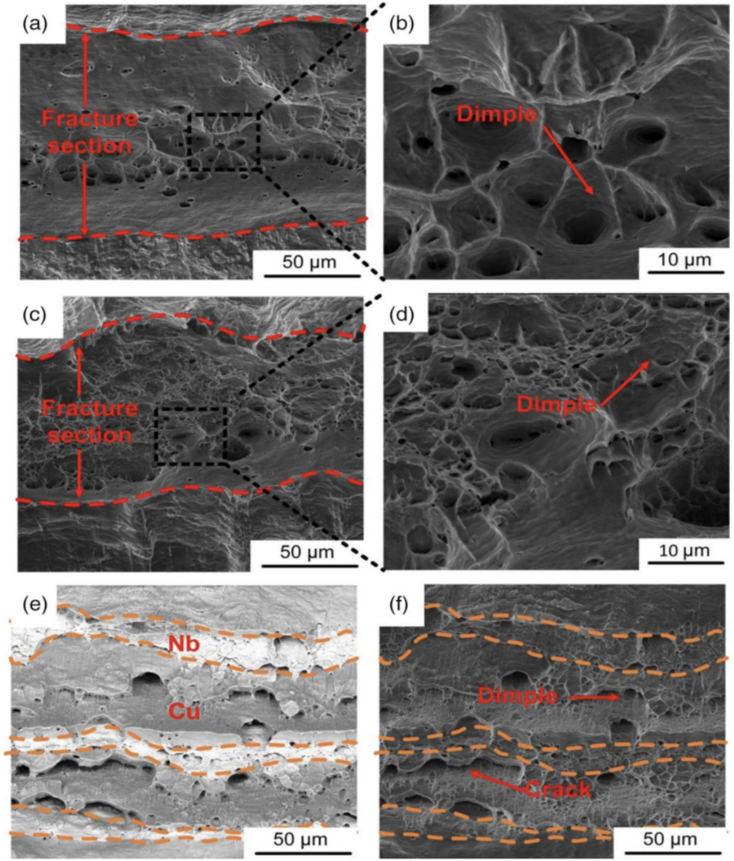

Fig 9: Tensile fracture surface morphology of pure Cu(a,b), pure Nb(c,d) and Cu/Nb multilayer after 3 ARB cycles.

- ❖ Figure a to d shows the fractured surface of annealed pure Cu and pure Nb.
- ❖ The fractured surface of composite has dimple formation on both Cu and Nb regions which depicts ductile fracture.
- ❖ The wedge shaped crack on interface implies weak bonding on the interface.

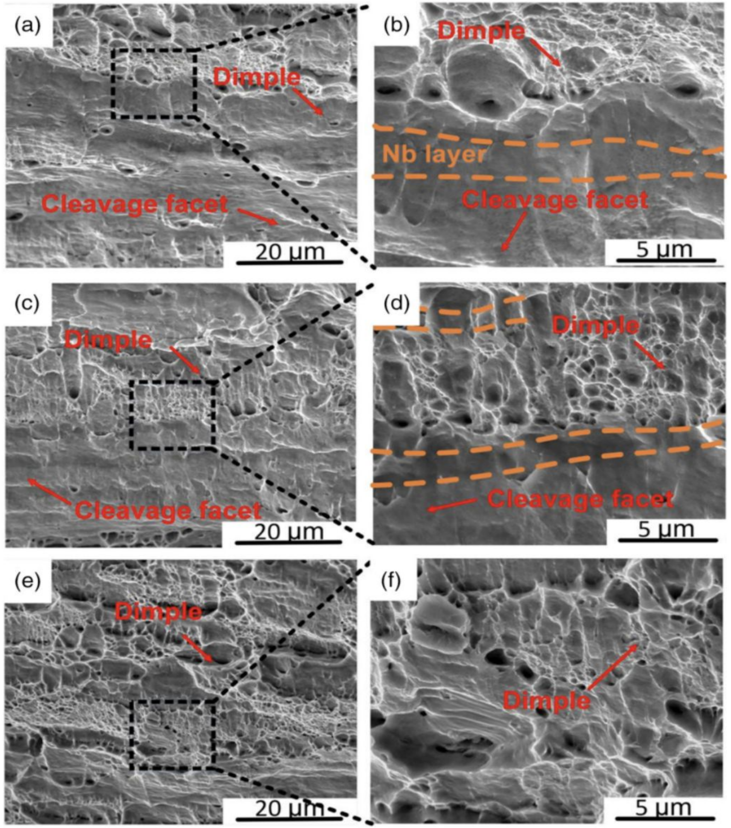

Fig 10: Tensile fracture surface image of Cu/Nb multilayer after 3 ARB cycles(a,b), 5 ARB cycles(c,d) and 7 ARB cycles(e,f)

Tensile Fracture Morphology

- The fracture surface indicates dimple formation in Cu and facet cleavage in Nb layer.
- With increasing number of cycles number of dimples also increases.
- Due to higher hardness of Nb after 7 rolling steps, more cracks form and more Cu atoms adjust themselves in them leading to more dimple formation.

Crack Propagation and fracture of Cu/Nb

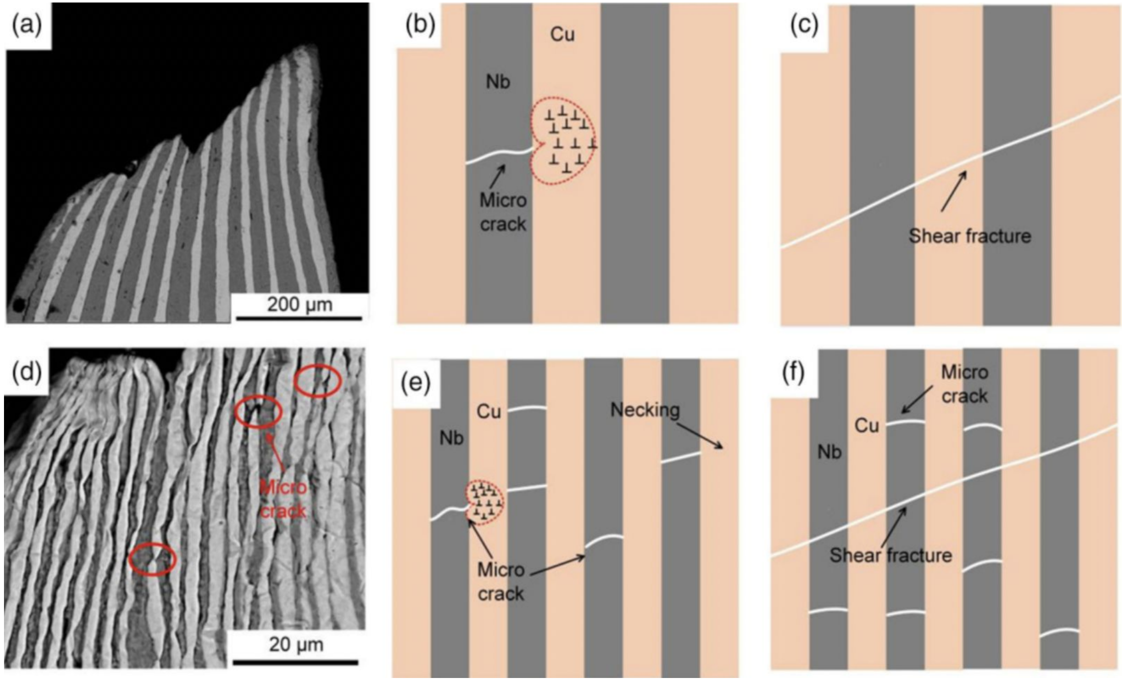

Fig 11: Side view of fracture surface after 4 ARB cycles(a), 6 ARB cycles(d) and relevant microstructural depictions.

- Fig (a) and (d) are the representations of different EBSD images of shear fracture for 22.2 µm and 2.8µm sheet thickness respectively.
- For 22.2µm layer one single microcrack is capable of fracturing while in case of 2.8µm layer there are multiple microcrack formation which after nucleating with each other fractures the surface.

Improvement of Mechanical Properties after ARB process

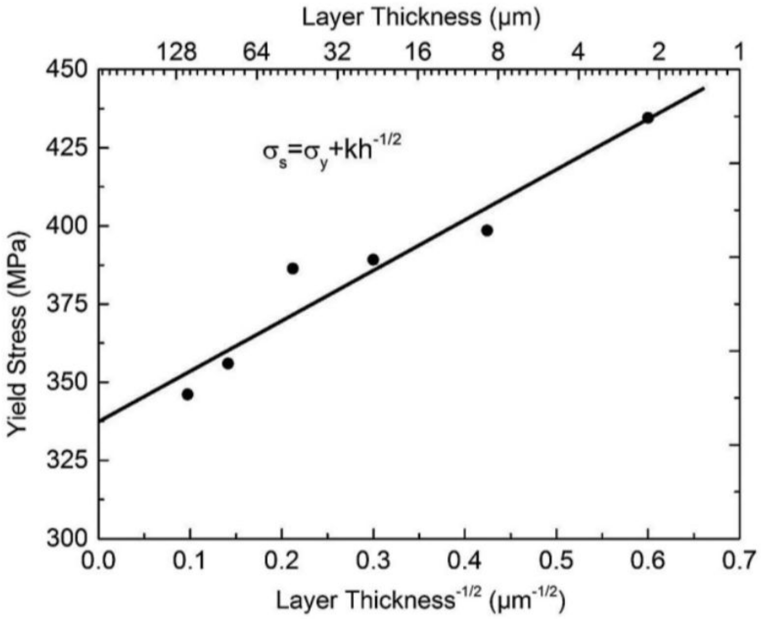

Fig 12: Yield stress change with inverse of layer thickness. Graph shows relation similar to Hall Patch relationship.

- The YS vs (Layer Thickness)$^{-1}$ shows similar relationship to that of Hall-Petch relation.
- The interface between Cu and Nb restricts the dislocation motion and dislocation pileup occurs.
- Due to decrease in dislocation motion the strength increases.
- Due to similar texture of Nb after many cycles of ARB the dislocation slip is easier in Nb.
- As we increase the number of ARB cycles the interface area increases which in-turn restricts the dislocation motion.

Mechanical properties of different Cu composites and pure Cu

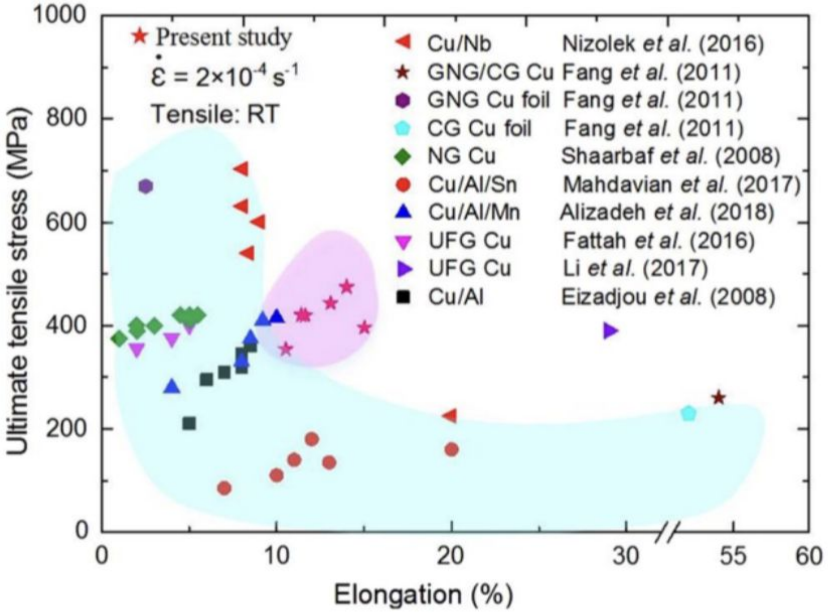

Fig 13: UTS relation to elongation at failure of different materials made with different processing techniques

- From the graph it can be concluded that the Cu/Nb multilayer composite exhibits excellent combination of strength and elongation.

Conclusion

- The Cu and Nb does not form intermetallic compound even after 7 cycles of ARB which is a big advantage in generating the needed interface to increase respective mechanical properties.
- The interface acts as a barrier for dislocation motion due to which strength of the material increases.
- The interface also holds the propagation of microcracks which leads to higher need of deformation to fracture the material.

Thank You!