Finite Element Analysis of Bulk Material Properties for Accumulative Roll Bonding Magnesium and Niobium Layered Composites

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Introduction and Scope: The severe plastic deformation process, Accumulative Roll Bonding (ARB), is modeled using Finite Element Analysis (FEA) to explore the level of equivalent strain at the interfaces of magnesium (Mg) and niobium (Nb). Literature suggests that a strain of 0.5 is needed for bonding to occur.(1) The scope of this study varies the number of interfaces, rolling reduction percentage, and composition ratio (Mg:Nb) from 1:1 to 3:1, respectively to identify influence on the strain accumulated on the interfaces.

Introduction/Background: ARB is a severe plastic deformation process in which metal plates are repeatedly bonded through the stacking, rolling, cutting, and re-stacking procedure shown in Figure 1. The deformation causes a solid state bond to form between the layers. Bulk properties such as material strength and hardness are well known for pure constituent metals, however as layers of the metals are joined and refined by the ARB process new, more desired material properties including strength, ductility, and toughness emerge.

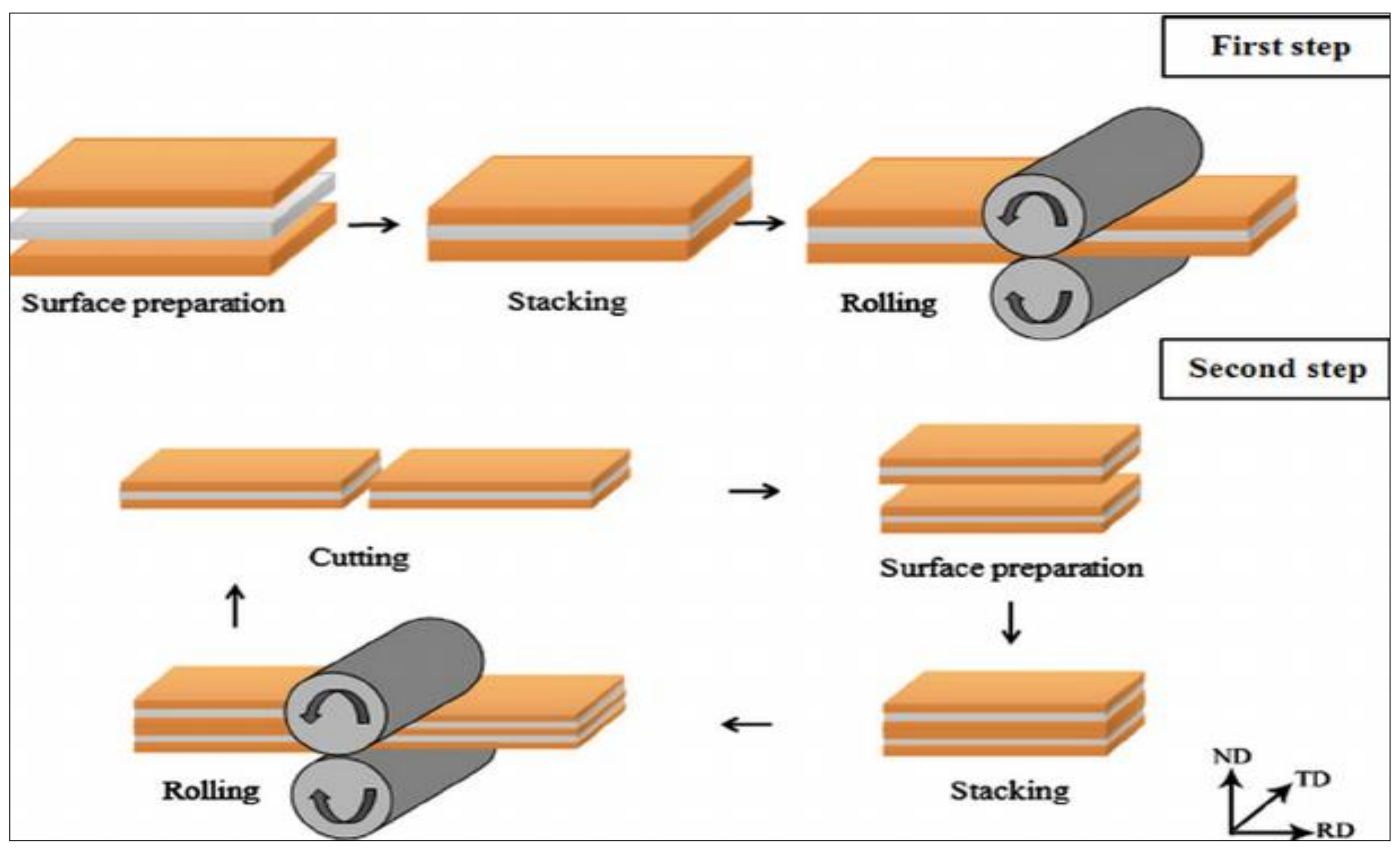

Figure 1: The ARB process[2]

Methods: All Finite Element Analysis (FEA) models are generated in SIMULA ABAQUS. The following Mg and Nb bulk properties form inputs to the computer-generated models:

- Stress-hardened stress-strain test data
- Plastic deformation coefficients
- Friction
- Young's moduli

Outputs of the study provide 2D stress/strain profiles of a layered ARB metal sample viewed from the billet transverse direction (TD) perpendicular to both the normal (ND) and roll(RD) directions.

Half Model Layer Stack

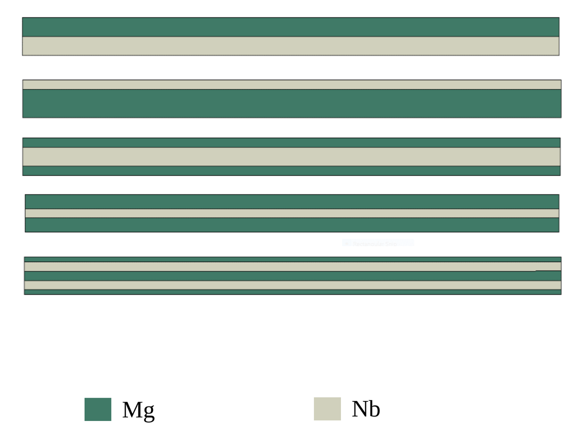

Figure 2: The rolling process is assumed to be symmetric about the center of the billet. Only one half of the full model is shown.

Test Matrix

Number of Layers	Material Ratio Mg to Nb	Percent Reduction
2	1:1	30
2	1:1	50
2	1:1	60
2	3:1	30
2	3:1	50
2	3:1	60
4	1:1	30
4	1:1	50
4	1:1	60
4	3:1	30
4	3:1	50
4	3:1	60
8	1:1	30
8	1:1	50
8	1:1	60
8	3:1	30
8	3:1	50
8	3:1	60

Figure 3: Test matrix for the entire set of billets modeled.

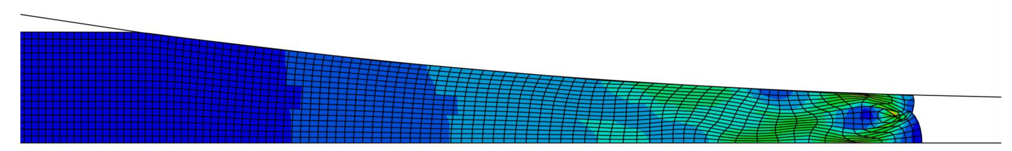

Figure 4: The billet is shown at the beginning roll process. Contour lines represent equivalent von Mises stress calculated by ABAQUS.

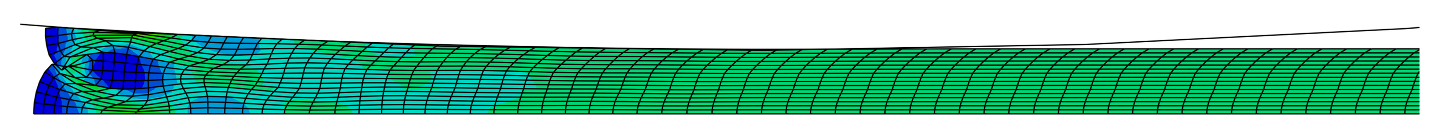

Figure 5: Steady state shear strain becomes more consistent between oscillatory states at each end of the billet. Original billet length must be long enough to allow steady state to develop, away from the ends of he billet.

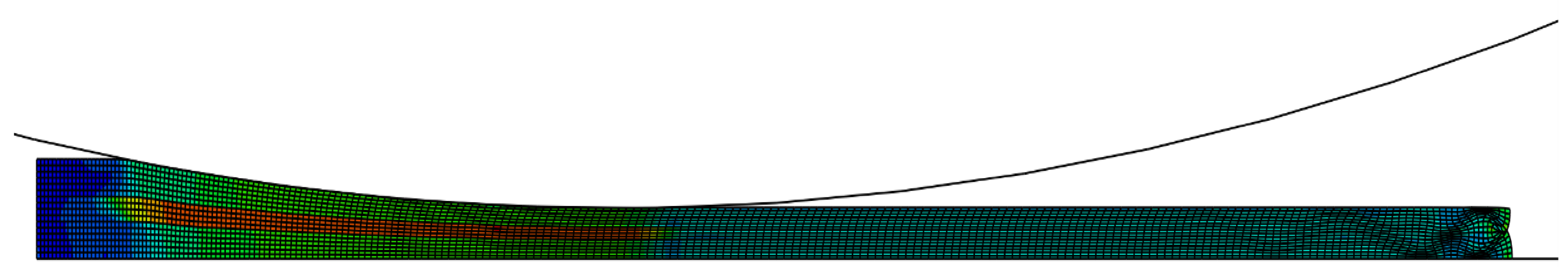

Figure 6: A visible gradient result from the constituent material property differences.

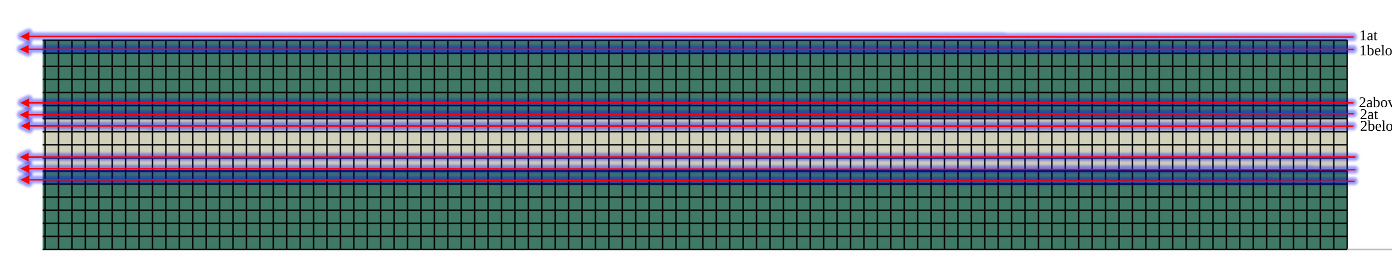

Figure 7: Strain plots normalized along the length are generated from node paths directed above, at, and below all interfaces between Mg and Nb.

Citations:
(1) D. Terada et al., "Microstructure and Mechanical Properties of Al-0.5 at.% X (=Si, Ag, Mg) Alloys Highly Deformed by ARB Process", Materials Science Forum, Vols. 584-586, pp. 547-552, 2008
(2) *V. Yousefi Mehr et al. / Materials Science & Engineering A 601 (2014) 40–4746*

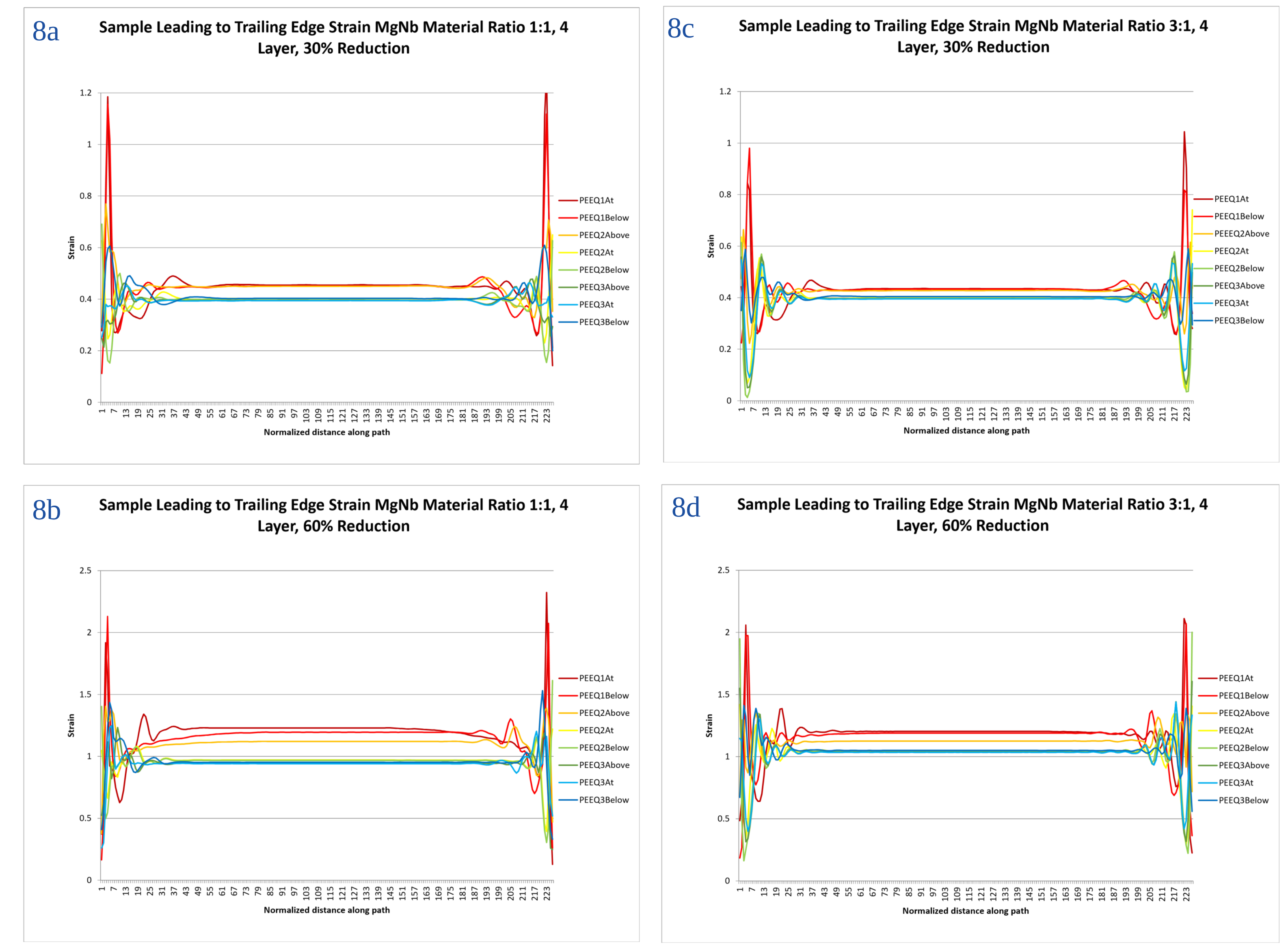

Figure 8. Plots shown in Figure 8a-8d provide a strain profile along the node paths shown in Figure 7. Fluctuations in strain occur at both the leading and trailing edge of each billet due to boundary conditions.

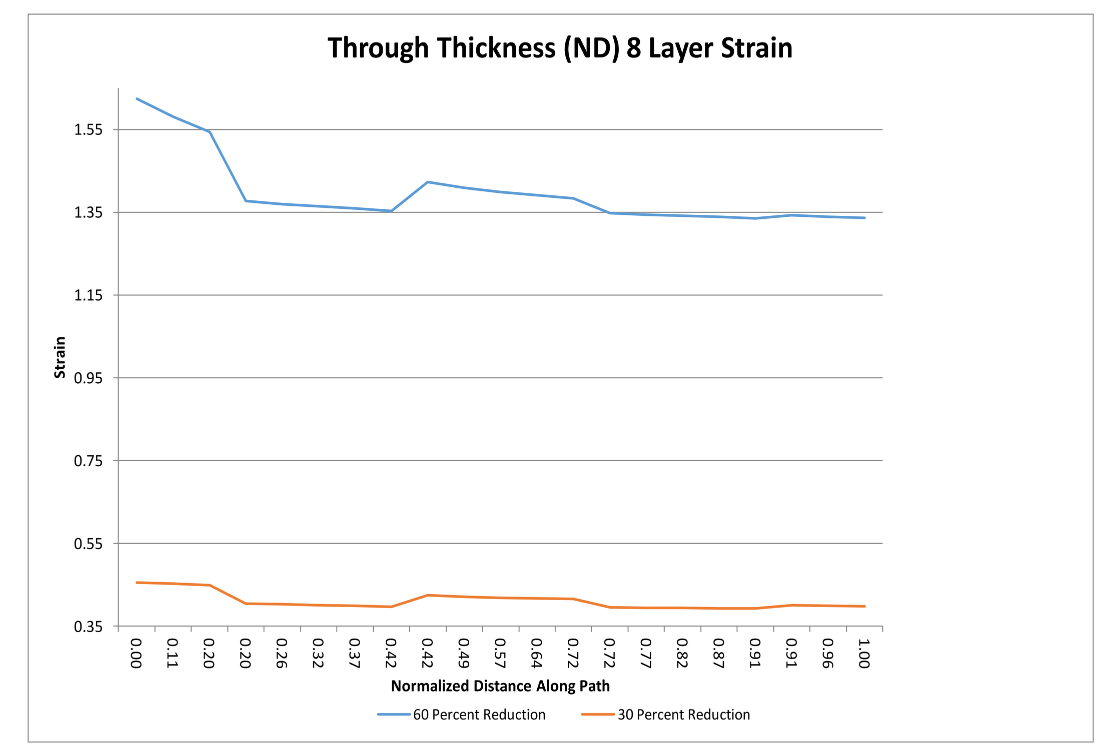

Figure 9: When examined along a path through the thickness (ND) of the deformed billet, strain gradient is apparent in individual layers. Regions of high strain are typical of Mg which is softer than Nb.

Discussion/Conclusion:

- Higher strains occur close to the billet surface due to shear created by the rolls.
- Rolling reductions of 30% are not enough to bond Mg and Nb.
- A roll reduction of 50% (not shown) and 60% achieve critical bonding strains of 0.5 or more in all cases.
- Deviation in layer strains through thickness (ND) decrease as the number of layers increases.
- A billet aspect ratio of 14:1 or more allows for steady state rolling results without edge effects.

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