Contact interactions and layer stability of multilayered metals during cold roll bonding

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Motivation

In order to identify the onset and development of layer instabilities in Cu/Ta multilayered metals during cold roll bonding, and thus their interface morphology and mechanical performance, we carried out finite element simulations using an isotropic elestoplastic material model to model Cu and Ta layers in a representative volume element with different interaction conditions between layers.

Background

I. Accumulative roll bonding

The processing of multilayered metals requires a severe plastic deformation method known as accumulative roll bonding (ARB), as shown in **Figure 1**. In order to understand the onset of instability within the metal composite, we reduce the simulation to solely represent the point of bonding between the rollers as shown in **Figure 2**.

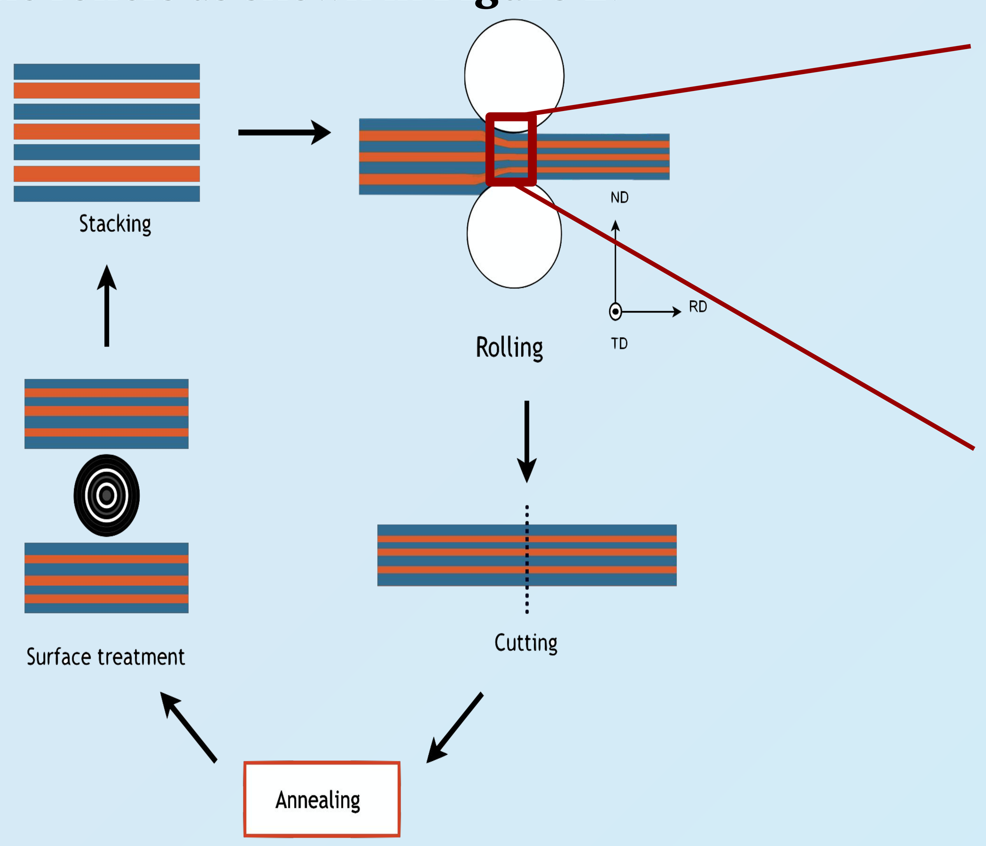

Figure 1. Schematic of ARB process

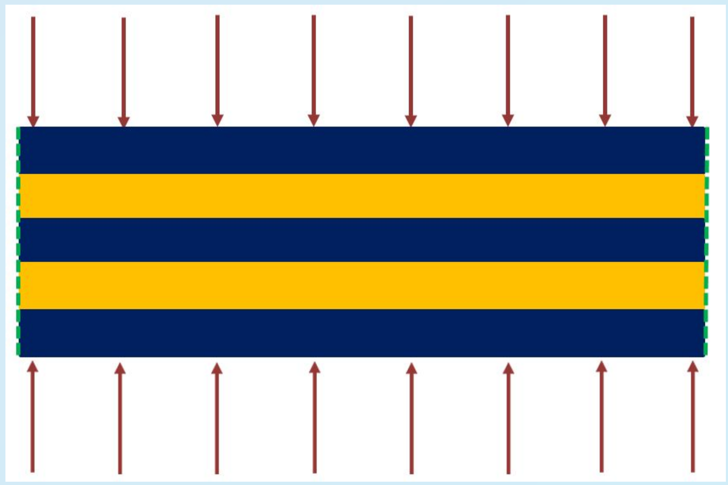

Figure 2. RVE of Cu/Ta multilayered metal as simple 2D uniaxial plane strain compression

II. Importance of Layer Continuity

i. Improved fatigue strength and toughness in roll bonded multilayers only if layers are continuous [1]
ii. High temperature thermal stability [2]

A higher coefficient of friction between surfaces indicates improved bonding of cold roll bonded multilayered metals, whereas areas of low friction indicates poor bonding [3], however the extent of frictionless sliding between contact surfaces of dissimilar metals under compression and the effect on layer stability has yet to be explored.

Conclusions and Future Work

- Multilayers with non-perturbed interfaces and perfect bonding do not develop layer instabilities at any amount of deformation.
- Multilayers with non-perturbed interfaces and frictionless sliding contact develop layer instabilities once sliding takes place (2.5% total deformation). The regions of instability develop layer thickness reduction along a zigzag pattern.
- Multilayers with perturbed interfaces and perfect bonding develop localized shear bands that do not translate across layers or allow for thickness reduction within the layers.
- Multilayers with perturbed interfaces and frictionless sliding contact restrict the plastic strain to the region of pre-existing perturbed surface.
- The amount of plastic strain is maximized when a perturbation is introduced.
- The contact displacement, or extent of sliding, between Cu and Ta surfaces is increased in areas of reduced layer thickness.
- In the future we explore varying layer thickness proportions to identify optimal conditions for layer stability.

FE problem set-up

- Terra cluster, 12 cores, 32GB, Total CPU time (s) = 435, Abaqus2020
- 50% reduction is required for "good" mechanical bonding [3]; we apply a displacement boundary condition along the y-axis and allow for free expansion in the x-direction.
- All layers are displaced uniformly in the x-direction
- Constraint Equations:

$$u_2^{bottom} = 0$$
$$u_2^{top} = -10\ mm$$
$$u_1^{LHS} = -u_1^{RP}$$
$$u_1^{RHS} = u_1^{RP}$$
$$u_1^{CN} = 0$$

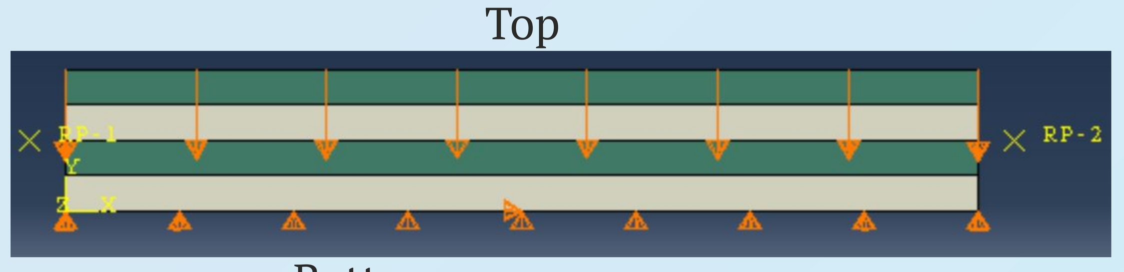

Figure 3. schematic of loading conditions

- We use surface-to-surface with finite sliding contact formulation
- We neglect contact interactions between the rollers and the material
- The simulation can be represented using minimum number of layers

Role of sliding on layer stability

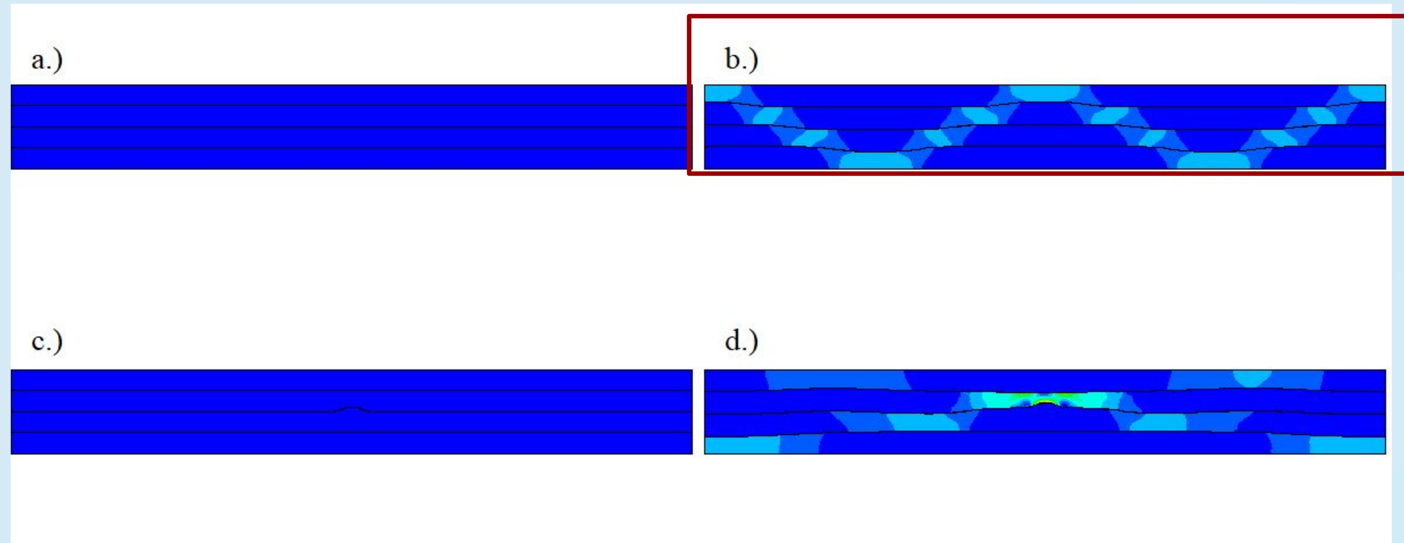

Figure 4. Cu/Ta multilayer response after 10% total deformation and equivalent plastic strain limits between 0 and 150% for four interface conditions: a.) Non-perturbed surface & bonded interlayer contact, b.) Non-perturbed surface & frictionless sliding interlayer contacts, c.) Perturbed surface & bonded interlayer contacts, d.) Perturbed surface & frictionless sliding interlayer contact

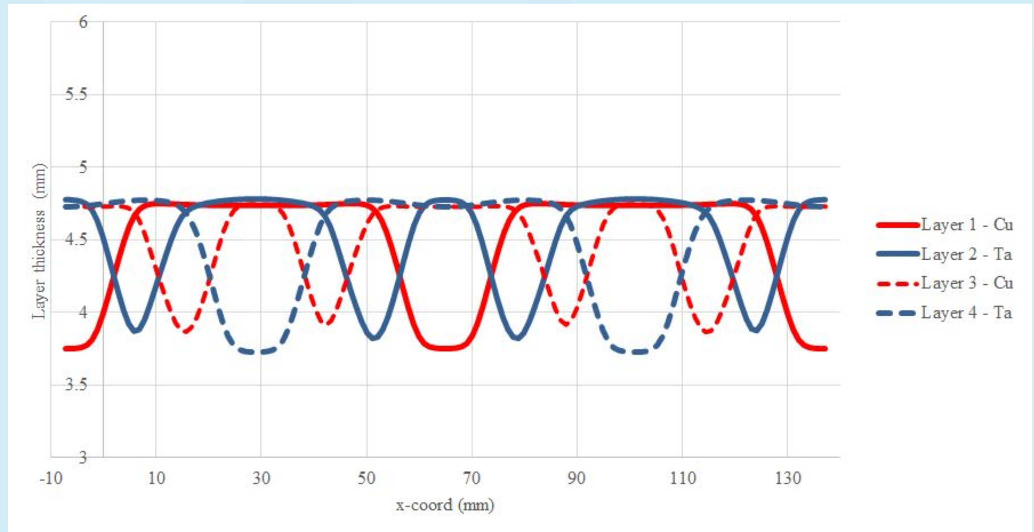

Figure 5. The layer thickness varies across the length of the horizontal direction in a wavy pattern along a shearing direction

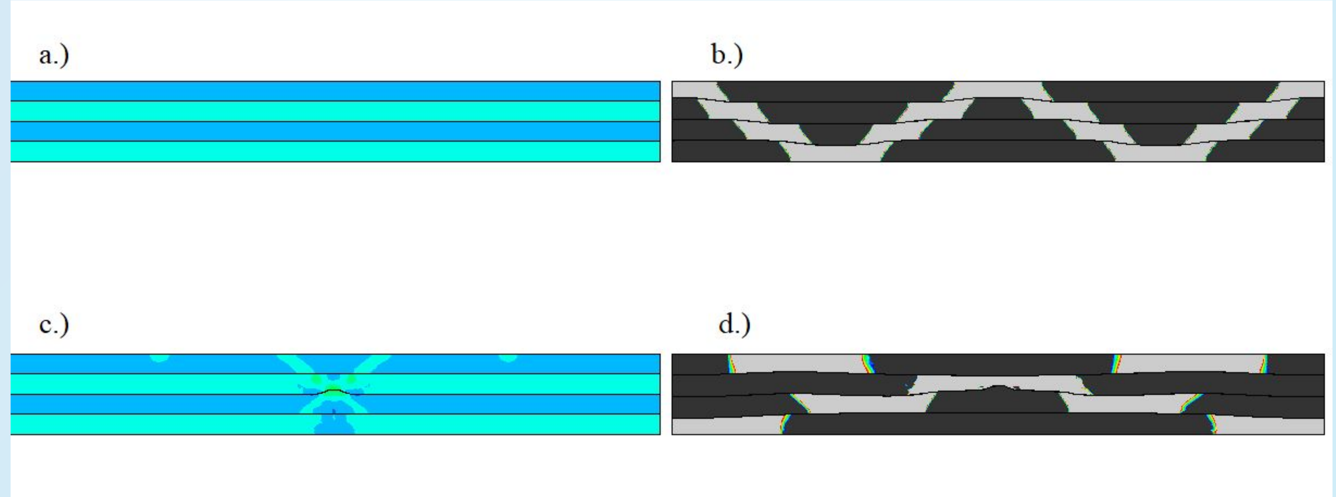

Figure 6. Cu/Ta interface conditions at 10% total deformation: a.) Nonperturbed surface, bonded contact, b.) Nonperturbed surface, frictionless sliding contact, c.) Perturbed surface, bonded contacts, d.) Perturbed surface, frictionless sliding contact

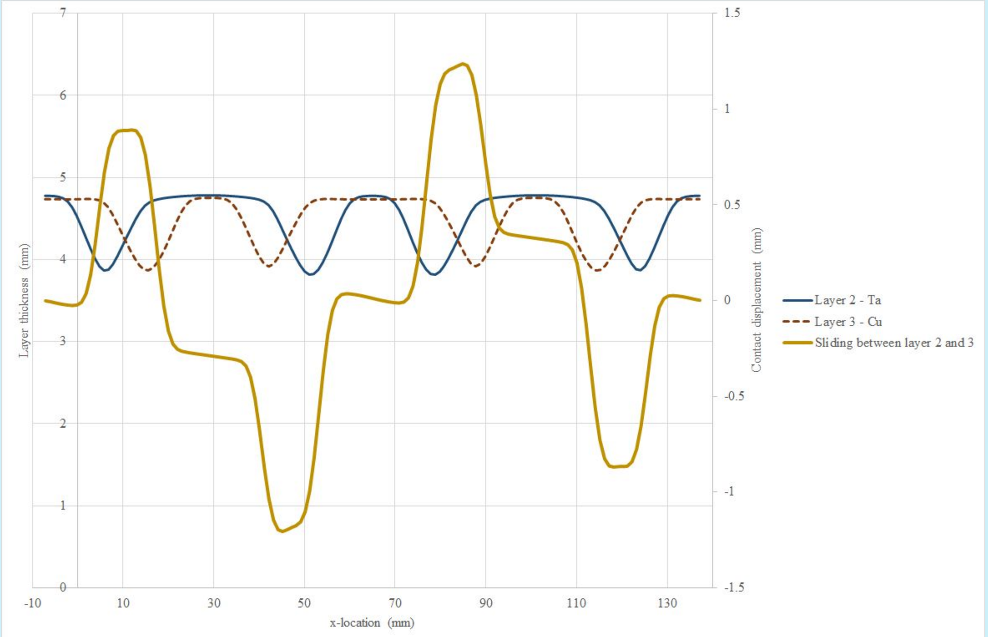

Figure 7. The contact displacement between the top (Ta) and bottom (Cu) surfaces of the middle layer is near-constant when the layer thickness is constant; once thinning occurs in the corresponding layers, large contact displacements are present.

The range of plastic strain between the four models is large, when we have sliding contact the range of plastic strain increases by 10x from the bonded conditions and 100x when we introduce a perturbation with sliding; the equivalent plastic strain is represented respect to the scale of the bonded model case (Figure 4) and the sliding contact model case (Figure 6).

Acknowledgements & References

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Refs: [1]K. Ramesh. Springer Handbook of Experimental Solid Mechanics. 2008:874. [2] G. Gray III. Shock Wave Testing of Ductile Materials. 2000:8:530-538. [3] R Jamaati & M R Toroghinejad (2011) Cold roll bonding bond strengths: review, Materials Science and Technology, 27:7, 1101-1108