Origins of Time-Dependent Aluminum Springback

Summer 2020 Videoconference

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Student: Dawson Tong (Mines Undergraduate)

Faculty: Kester Clarke (Mines)

Industrial Mentors: TBD (Novelis)

Project: Origin of Time-Dependent Springback

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- Student: Dawson Tong (Mines)
- Advisor(s): Kester Clarke (Mines)

Project Duration
May 2020-May 2021 (REU & MURF)

- Problem: Aluminum sheets experience time-dependent springback after forming, resulting in unpredictable final dimensions.
- Objective: Measure time-dependent springback after stretch bending, and better understand underlying causes.
- Benefit: Deeper understanding will help generate new ways to limit the amount of springback that occurs.

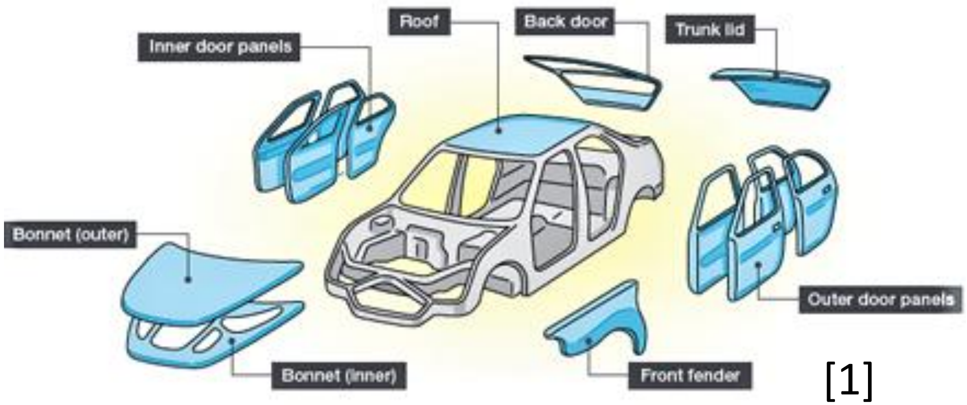
Recent Progress

- Literature review of the current understanding of time-dependent springback
- Evaluating experimental procedures for draw bending tests and tensile tests

Metrics

Description	% Complete	Status
1. Literature review	40%	●
2. Acquisition of materials	10%	●
3. Tensile testing for anelasticity	0%	●
4. Draw bend testing for time-dependent springback	0%	●
5. Microstructural characterization	0%	●

Industrial Relevance



[1]

- Benefits
- Better dimensional control
- Less wasted material and time
- Higher quality parts
- Increase use of aluminum in automobiles
- Creating different forming techniques to minimize springback
- Utilize with other metals

Creep and anelasticity in the springback of aluminum [2]

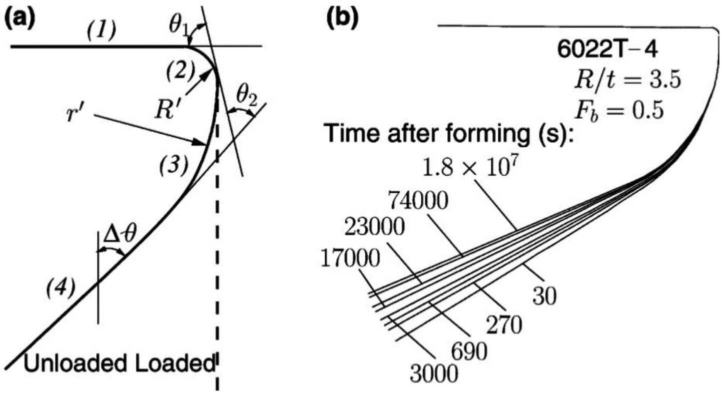


Fig. 3. Draw-bend specimens: (a) schematic geometry before and after springback, (b) tracings for various times following forming and unloading for 6022-T4 aluminum.

- 2008-T4, 5182-O, 6022-T4, and 6111-T4 were draw bend tested
- Springback occurred up to 7 years later, but largely occurred in the first 20 days at room temperature
- They concluded that the springback is residual stress driven creep over long periods while anelasticity contributes to the initial response (1-2 hours) after unloading

The investigation of time-dependent springback for AC170PX aluminum alloy at room temperature [3]

- Tensile and anelastic testing was conducted on a 1mm thick AC170PX
- Anisotropy seems to play a role in the recovery behavior
- As strain increased, more mobile dislocations became engaged
- Microscopically the driving force may be dislocation movement and atomic diffusion
- With X-ray diffraction they were able to determine a slight displacement in the diffraction peaks after the material had been strained

Time-dependent springback of various sheet metals [4]

- Aluminum (A5052), Magnesium (AZ31B), and Commercially Pure Titanium (CP-Ti) alloy sheet metals were all stress relaxation and creep tested
  - The results from the stress relaxation seemed to show anelastic behavior for the sheet metals
  - The creep test showed varying results based upon a pre-strained sheet versus an unstrained sheet

Unstrained

10% Pre-strained

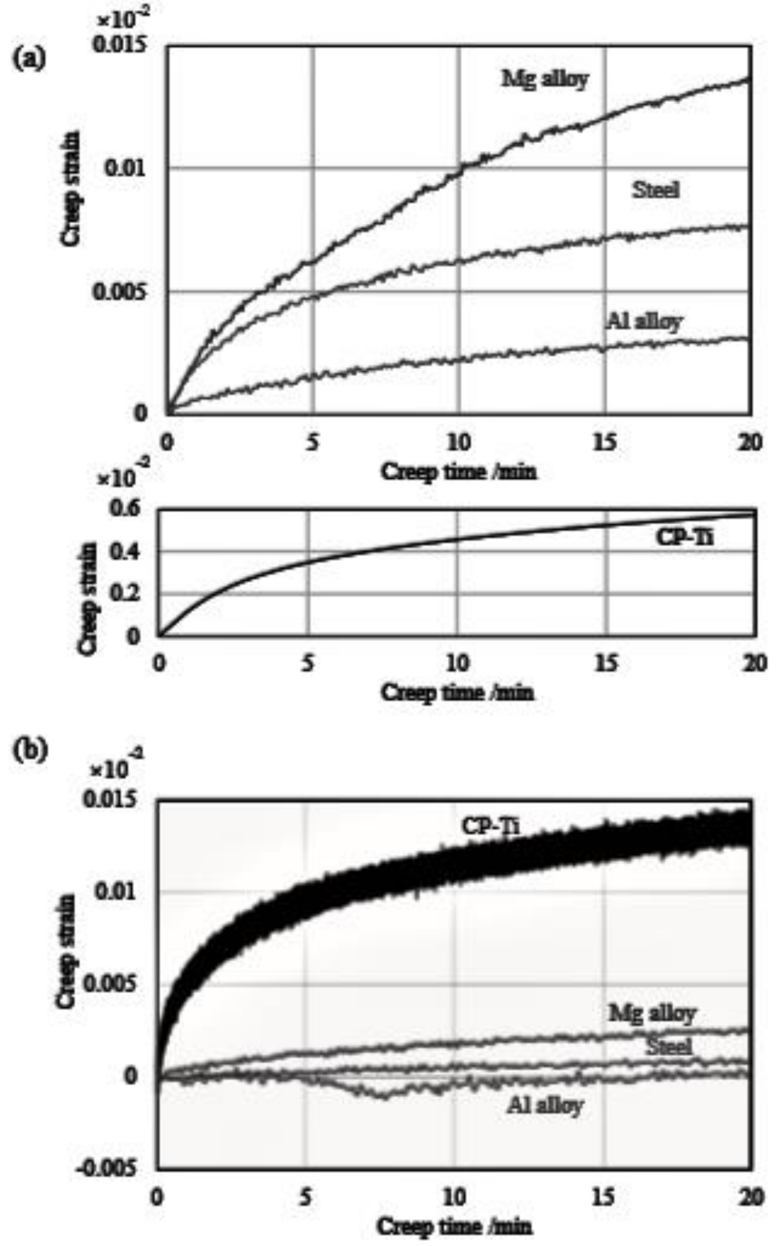


Fig. 5 Relationship between creep strain and creep time. (a) Virgin sample and (b) pre-strained sample.

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- There is a larger amount of creep strain in the unstrained for the Mg and CP-Ti

- The differences from unstrained to pre strained suggest more than just a creep mechanism specifically for Al especially given the small amount

- Possible mechanism for the CP-Ti and Mg could be from crystal structure, twinning activities, and slip system activities

Time-dependent springback of a commercially pure titanium sheet [5]

- JIS grade 2 CP-Ti was draw bend tested

- The rolling direction and transverse direction were investigated with respect to hold time, strain rate, and elapsed time on the springback angle

- They suggest that twinning activities contribute to the time dependent springback

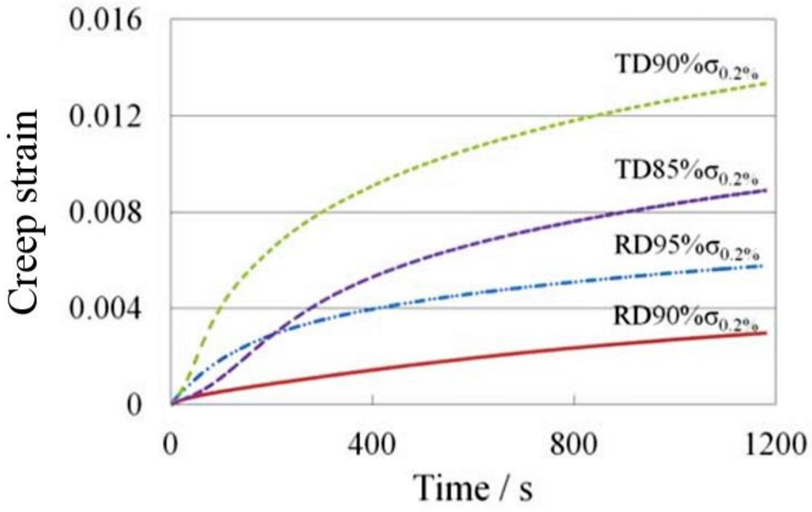


Fig. 4 Evolution of creep strain under different stresses.

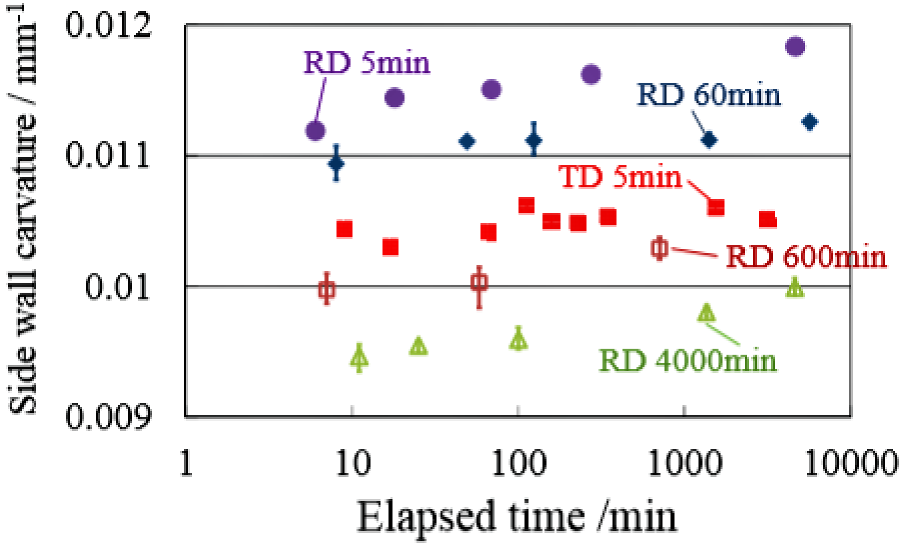


Fig. 7 Variation of springback with elapsed time after unloading for samples subjected to different holding times.

- The above figures show the results for the elapsed time and the creep tests
- The initial RD side wall curvature at a 5 minute hold time is higher than the transverse direction meaning there is more residual strain
- If creep strain were the main mechanism, then the TD would have a larger side wall curvature based upon the creep test

On the underlying micromechanisms in time-dependent anelasticity in Al-(1 wt%) Cu thin films [6]

- An aluminum thin film was solution heat treated and aged

- It was then mechanically characterized using a micro beam bending method

- The suggested mechanism for is back stress driven diffusion limited dislocation glide or climb

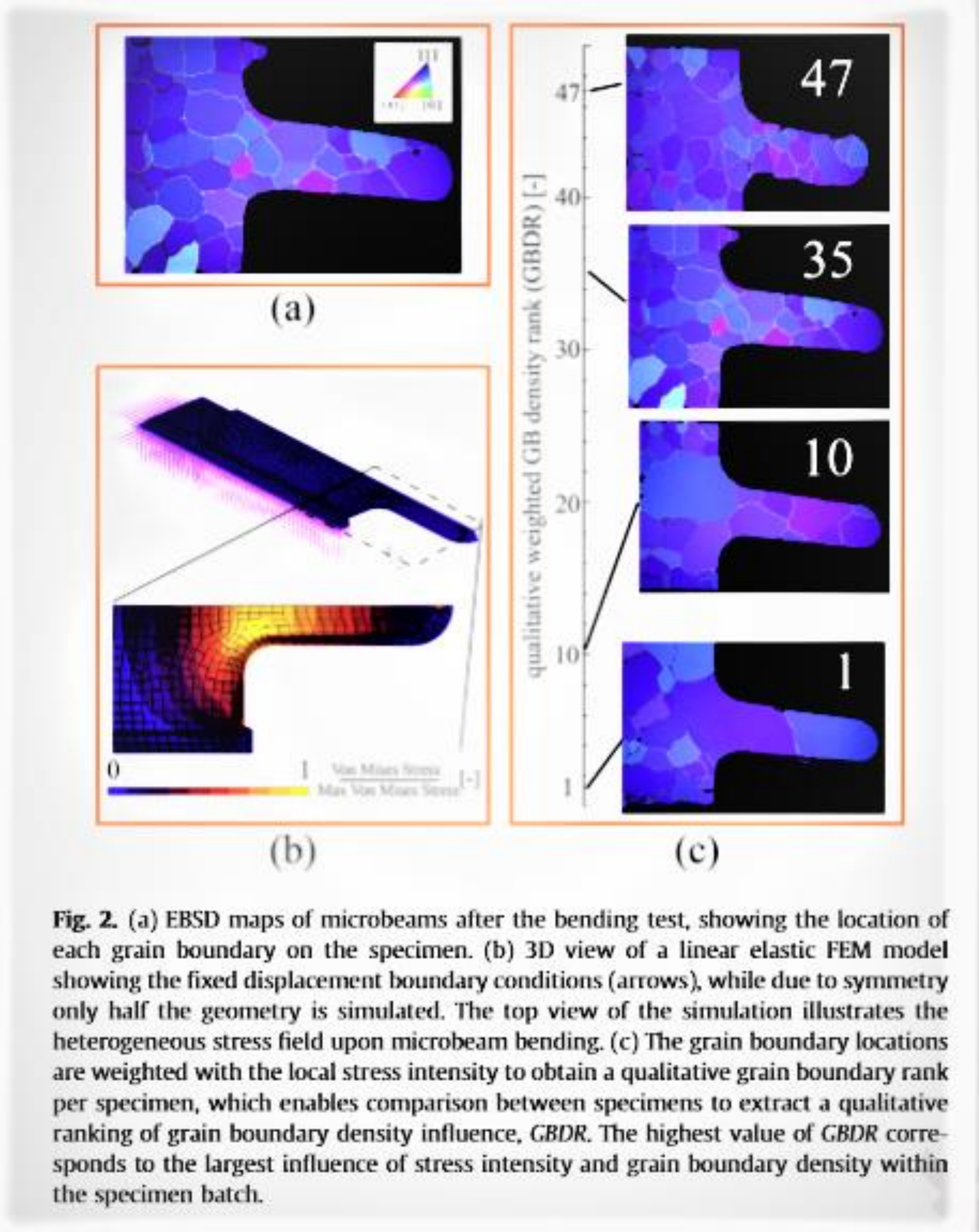


Fig. 2. (a) EBSD maps of microbeams after the bending test, showing the location of each grain boundary on the specimen. (b) 3D view of a linear elastic FEM model showing the fixed displacement boundary conditions (arrows), while due to symmetry only half the geometry is simulated. The top view of the simulation illustrates the heterogeneous stress field upon microbeam bending. (c) The grain boundary locations are weighted with the local stress intensity to obtain a qualitative grain boundary rank per specimen, which enables comparison between specimens to extract a qualitative ranking of grain boundary density influence, *GBDR*. The highest value of *GBDR* corresponds to the largest influence of stress intensity and grain boundary density within the specimen batch.

- At a 5 micron scale, the micro beam showed heterogenous strain over the grains
- Each grain contributes to the initial anelastic behavior
- Grain boundary density influence/rank (GBDR)

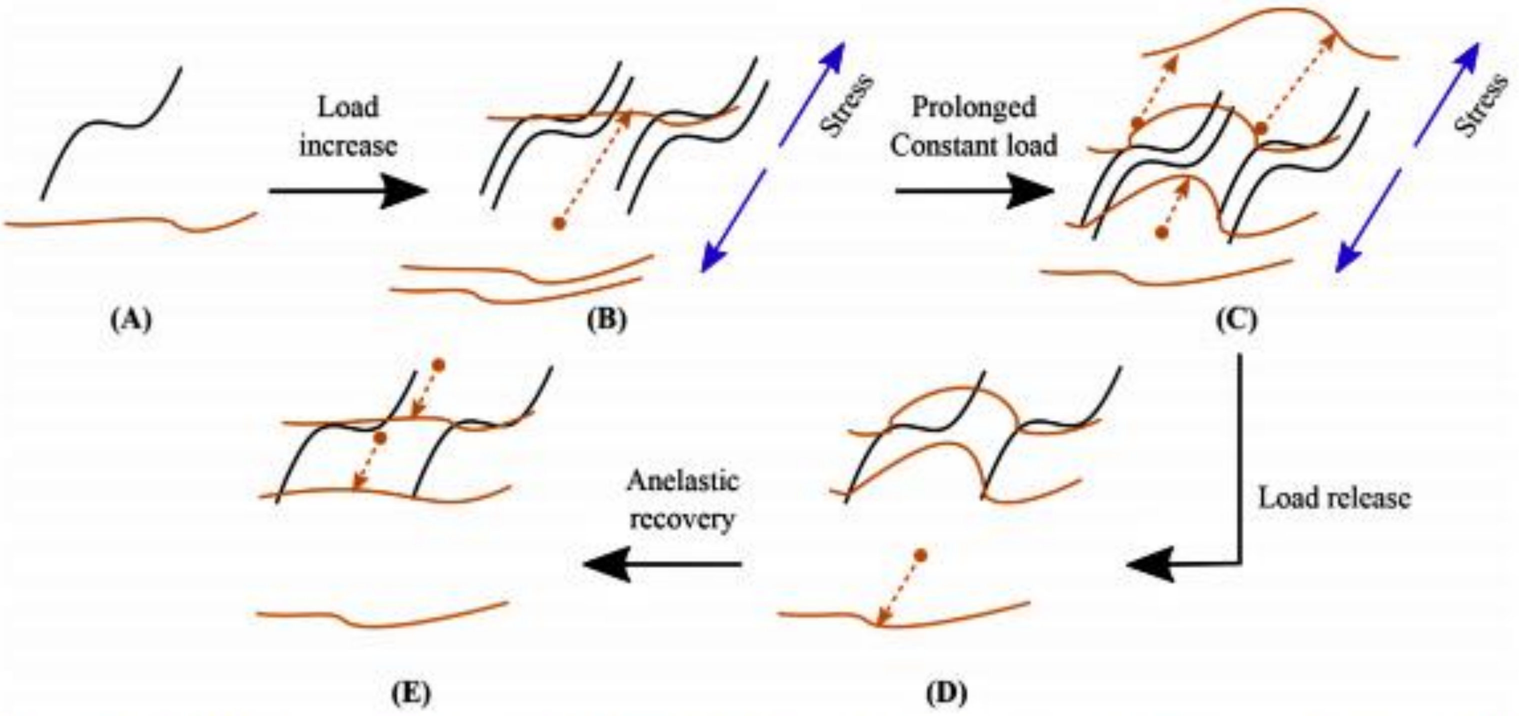
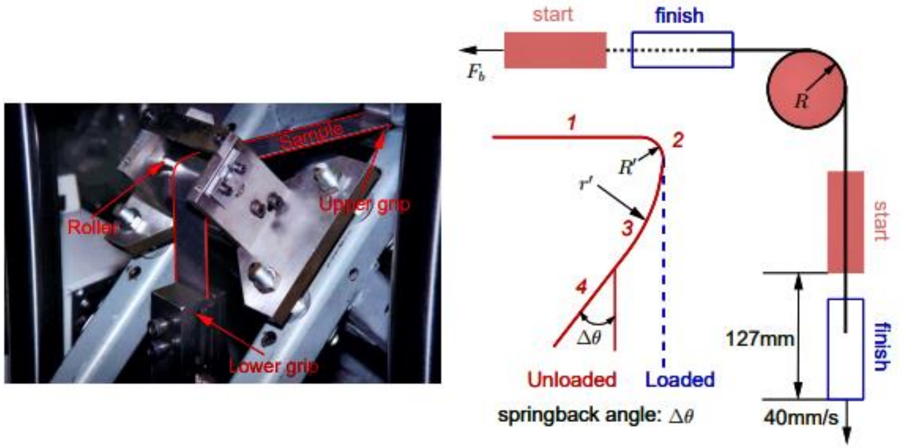


Fig. 11. Sketch illustration proposing a hypothesis of back-stress driven, diffusion-limited dislocation mechanism for observed time-dependent anelasticity in Al/Al-alloy thin films. Orange lines represent dislocation segments residing in one slipplane. The black lines are dislocation segments in other planes which intersect the planes of the orange lines. Orange arrows highlight dislocation motion to the final position in each state. a) The initial state containing few dislocations. b) These are mobilized and multiplied under loading where they may also be pinned by each other. c) The load is maintained causing dislocation loop extension through diffusion-limited climb or glide. Some dislocations might escape the pinned situation. d) Upon load removal, back-stresses reverse the motion of the unpinned dislocations. e) The extended dislocation loops slowly shrink under the influence of the remaining back-stresses and the reverse diffusion-limited glide or climb, resulting in anelastic recovery. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

CSM Capabilities

- Draw bend testing
- Tensile testing
- Stretch Forming



(a) (b)

Figure 4.1: Draw-bend experiment: (a) equipment at Colorado School of Mines, and (b) schematics of test procedure and geometry of a deformed sheet after springback

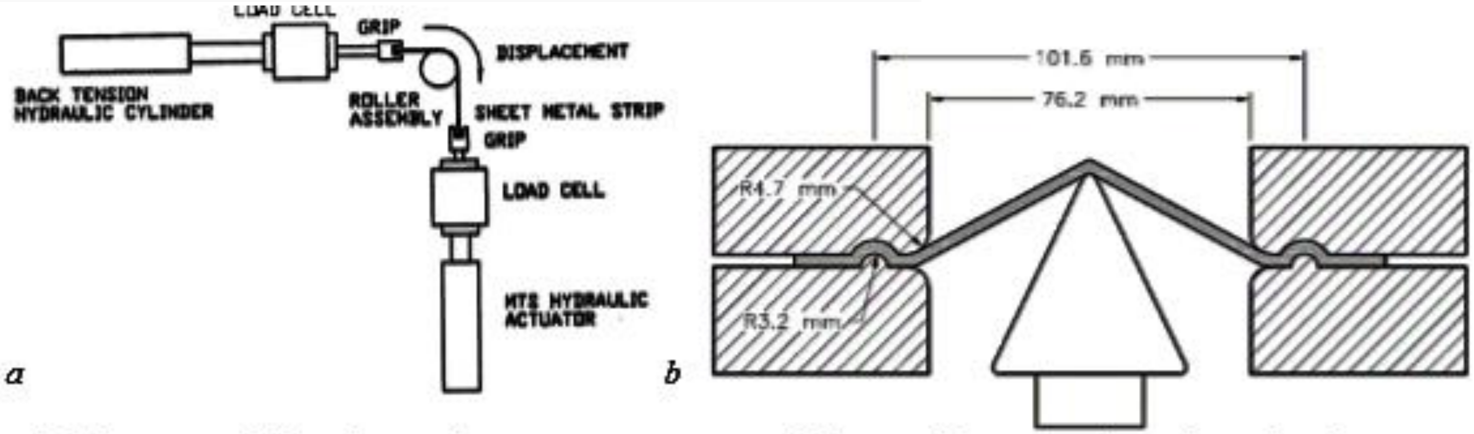


Figure 2 Schematic of a) bending under tension operation and b) stretch forming; die and punch radii were varied for each test, respectively

Material Selection

- Suggested aluminum alloys of interest
    - 5182-O, 1.0 mm thick
    - 6xxx-T4, approximately 2.0 mm thick
    - 7xxx-Tx, depending upon availability

Challenges & Opportunities

- Starting lab testing as soon as possible (COVID dependent)
  - Given the amount of time for the springback to occur draw bend tests should hopefully be done in the coming months
  - Discussion of materials of interest

Thank you!
Dawson Tong
dawsontong@mymail.mines.edu

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