



# Internal Friction and Backscattering Measurements of CW Stainless Steel

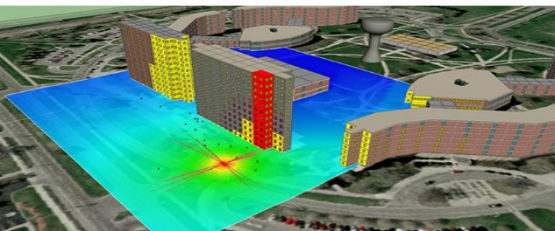
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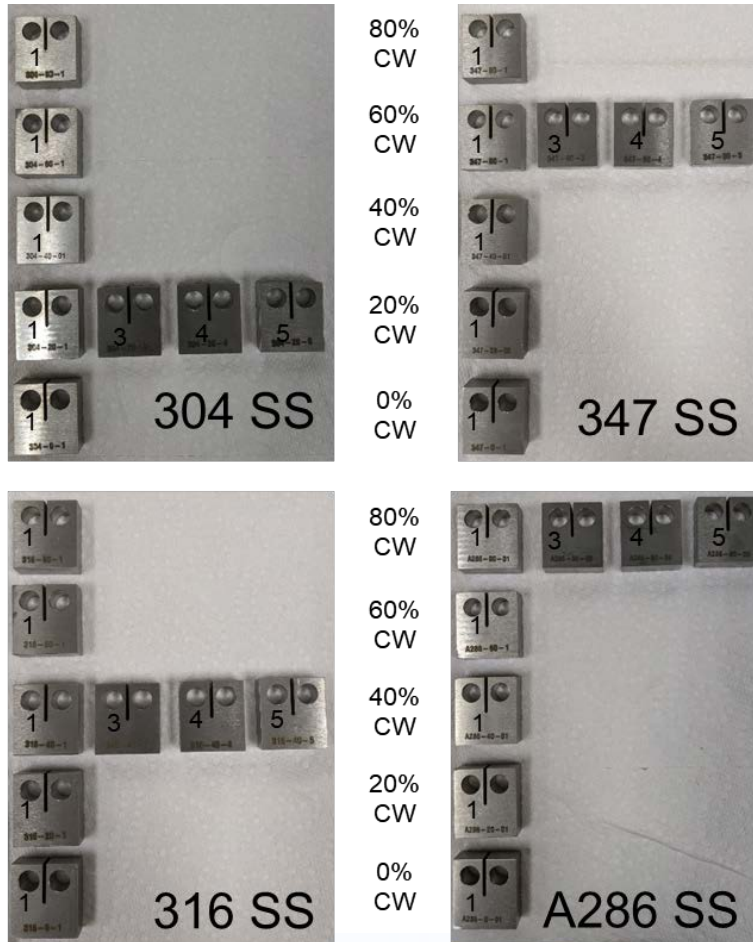
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# Samples and Ultrasonic Measurements

## Samples



## Ultrasonic Internal Friction Measurement

- 2.25 MHz
- 3.5 MHz

## Ultrasonic Backscattering Measurements

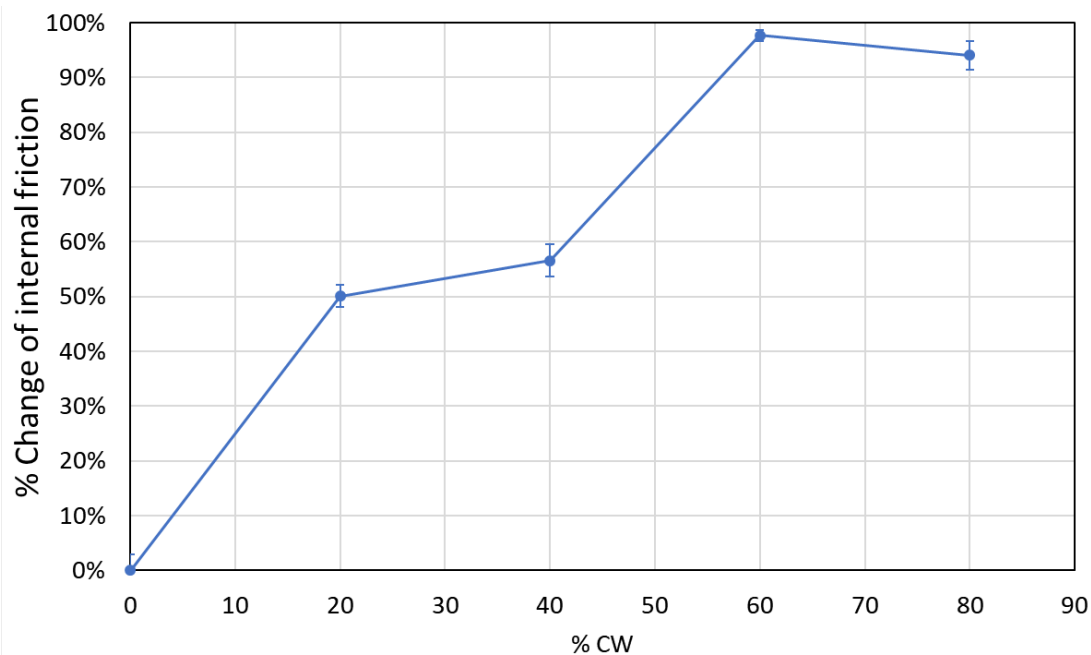
- 15 MHz





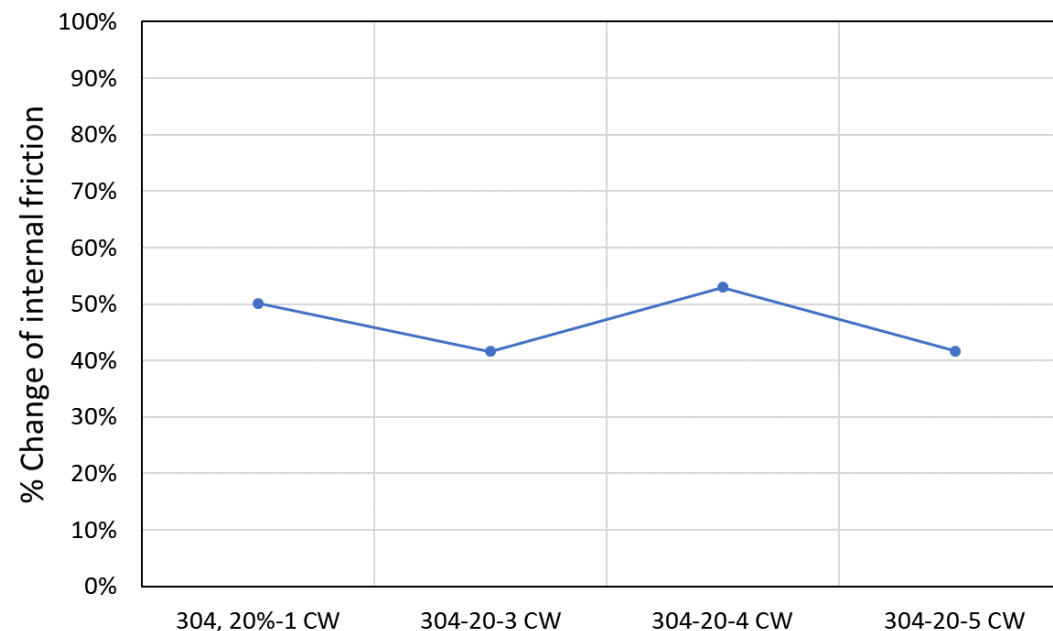
# Internal Friction, 304 SS

## Internal Friction 304 SS vs % CW



Sample ID	% CW	Q <sup>-1</sup>	% change from 0% CW	Standard Error	Standard Error (%)
304, 0% - 1 CW	0	0.46	0%	0.013	2.9%
304, 20% - 1 CW	20	0.69	50%	0.014	2.0%
304, 40% - 1 CW	40	0.72	57%	0.022	3.0%
304, 60% - 1 CW	60	0.91	98%	0.010	1.1%
304, 80% - 1 CW	80	0.89	94%	0.024	2.7%

## Reproducibility Internal Friction 304 SS 20% CW

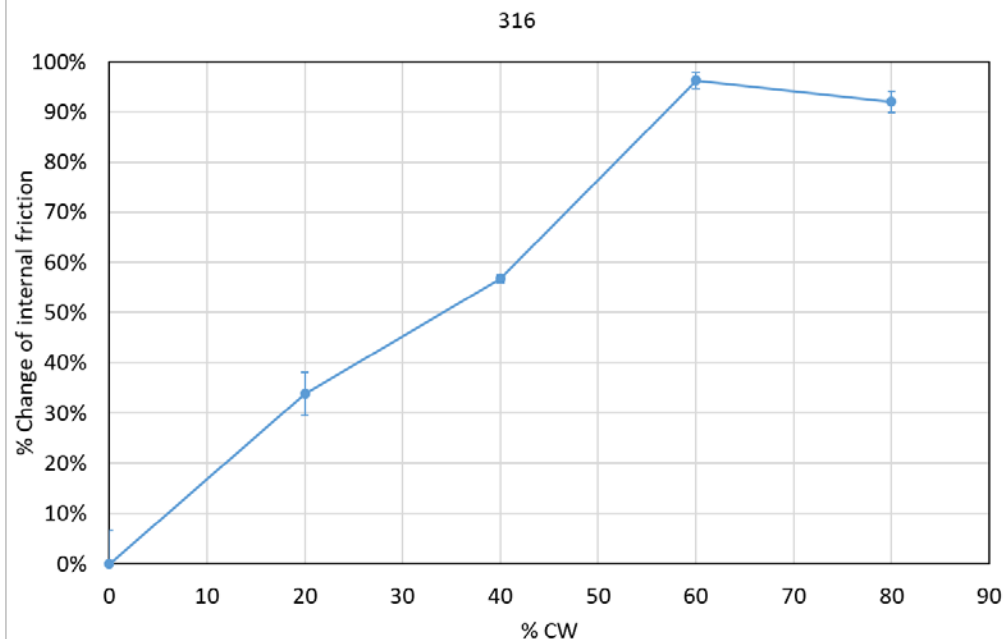


Sample	Q <sup>-1</sup>	% change from 0% CW	Standard Error	Standard Error (%)
304, 20% - 1 CW	0.69	50%	0.014	2.0%
304-20-3 CW	0.65	42%	0.014	2.1%
304-20-4 CW	0.70	53%	0.022	3.1%
304-20-5 CW	0.65	42%	0.012	1.9%



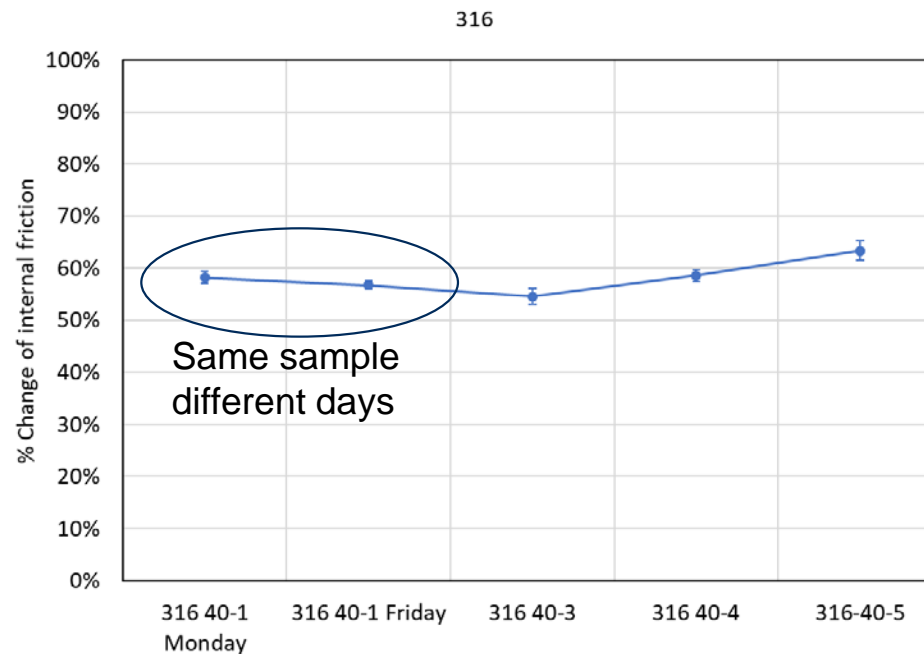
# Internal Friction, 316 SS

## Internal Friction 316 SS vs % CW



Sample ID	% CW	Q <sup>-1</sup>	% change from 0% CW	Standard Error	Standard Error (%)
316, 0% - 1 CW	0	0.46	0%	0.030	6.5%
316, 20% - 1 CW	20	0.61	34%	0.026	4.3%
316, 40% - 1 CW	40	0.71	57%	0.006	0.8%
316, 60% - 1 CW	60	0.89	96%	0.014	1.6%
316, 80% - 1 CW	80	0.88	92%	0.018	2.1%

## Reproducibility Internal Friction 316 SS 40% CW

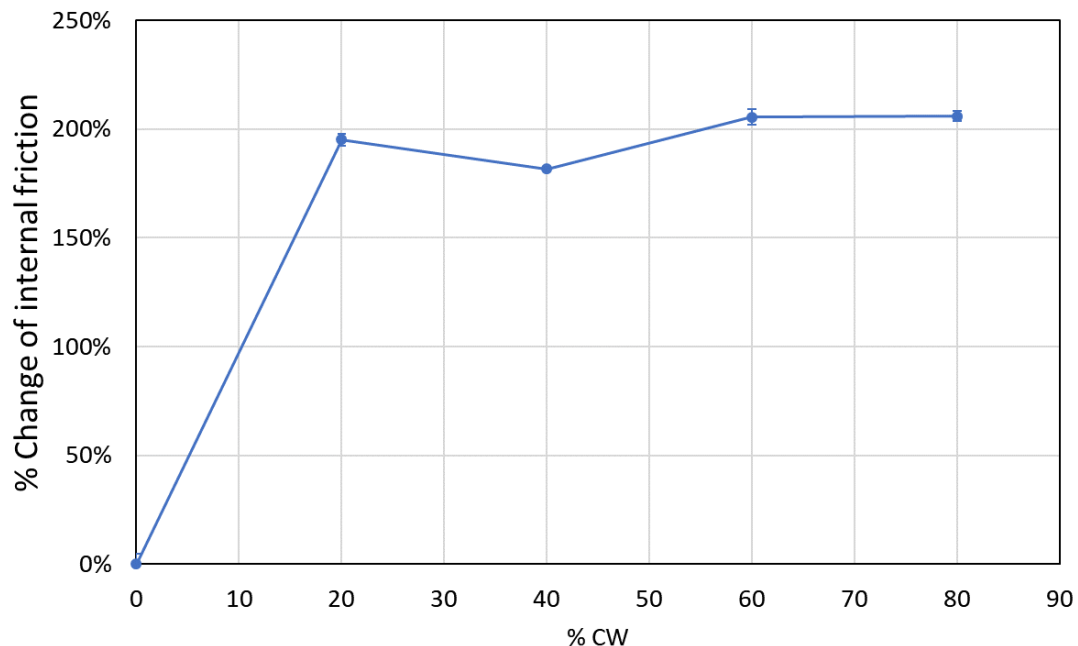


Sample	Q <sup>-1</sup>	% change from 0% CW	Standard Error	Standard Error (%)
316 40%-1 Monday	0.72	58%	0.009	1.2%
316 40%-1 Friday	0.71	57%	0.006	0.8%
316 40%-3	0.71	55%	0.011	1.5%
316 40%-4	0.72	59%	0.008	1.1%
316-40%-5	0.75	63%	0.014	1.9%



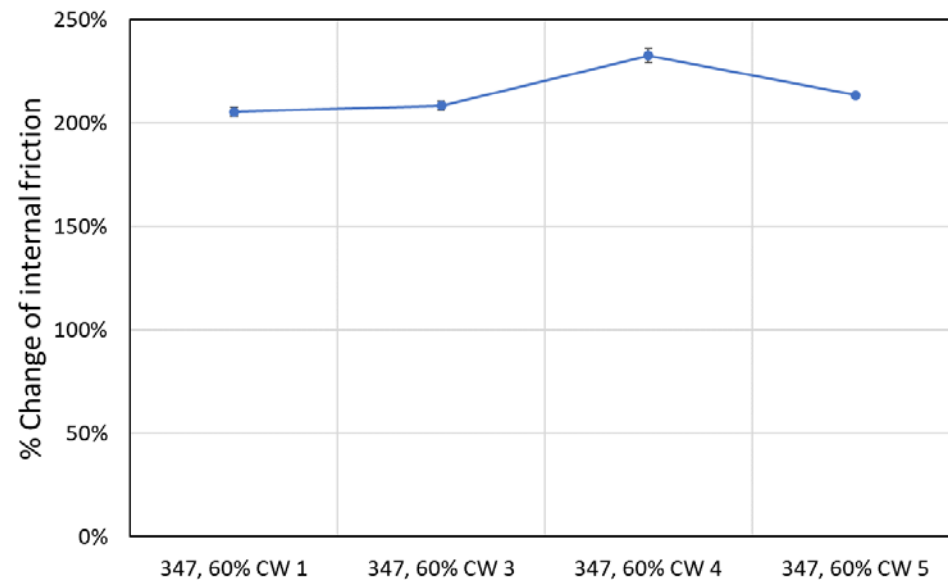
# Internal Friction, 347 SS

## Internal Friction 347 SS vs % CW



Sample ID	% CW	Q <sup>-1</sup>	% change from 0% CW	Standard Error	Standard Error (%)
347, 0% CW	0	0.27	0%	0.012	4.6%
347, 20% CW 1	20	0.79	195%	0.022	2.7%
347, 40% CW	40	0.75	182%	0.006	0.8%
347, 60% CW 1	60	0.82	206%	0.030	3.7%
347, 80% CW	80	0.82	206%	0.018	2.2%

## Reproducibility Internal Friction 347 SS 60% CW

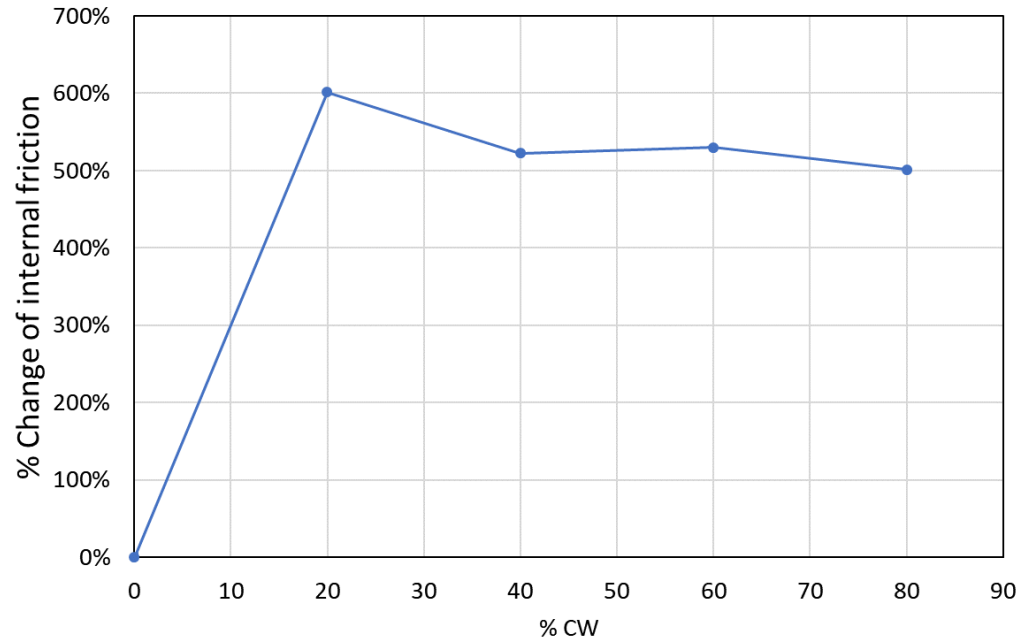


Sample	Q <sup>-1</sup>	% change from 0% CW	Standard Error	Standard Error (%)
347, 60% CW 1	0.82	206%	0.030	3.7%
347, 60% CW 3	0.83	208%	0.019	2.3%
347, 60% CW 4	0.89	233%	0.019	2.1%
347, 60% CW 5	0.84	214%	0.029	3.5%



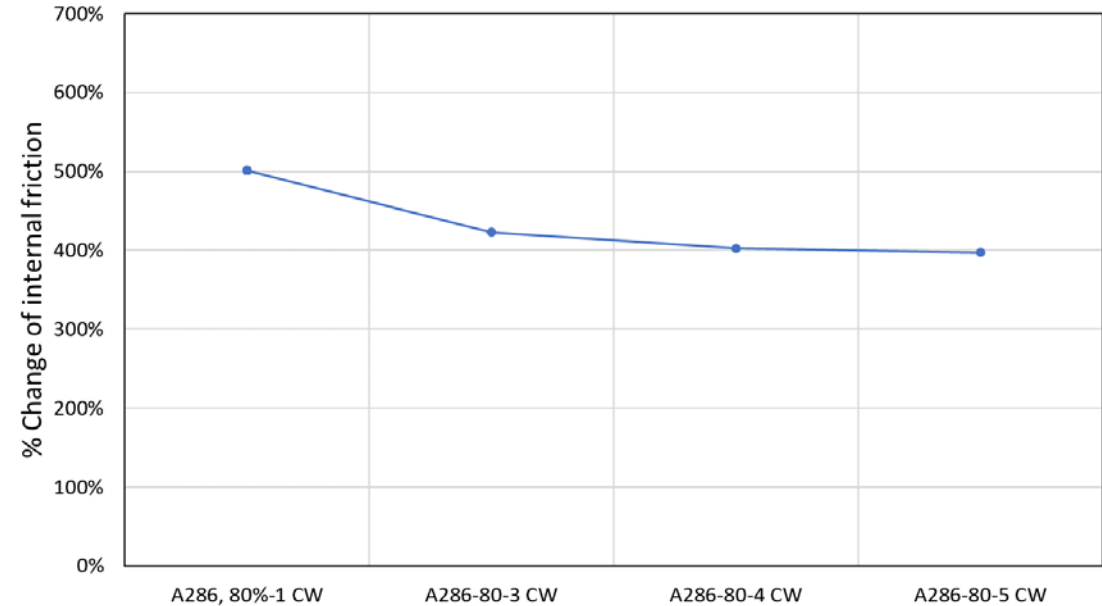
# Internal Friction, A286 SS

Internal Friction A286 SS vs % CW



Sample ID	% CW	Q <sup>-1</sup>	% change from 0% CW	Standard Error	Standard Error (%)
A286, 0% CW	0	0.2	0%	0.010	4.6%
A286, 20% CW	20	1.5	601%	0.023	1.6%
A286, 40% CW	40	1.3	523%	0.023	1.8%
A286, 60% CW	60	1.3	530%	0.013	1.0%
A286, 80%-1 CW	80	1.2	501%	0.025	2.0%

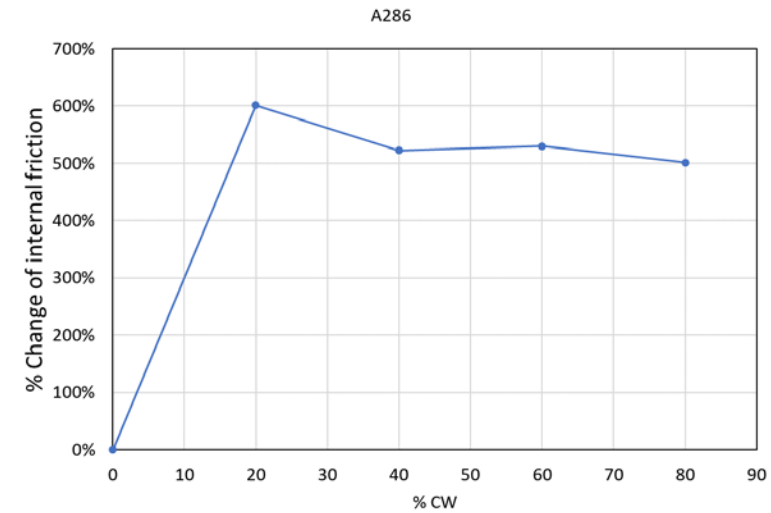
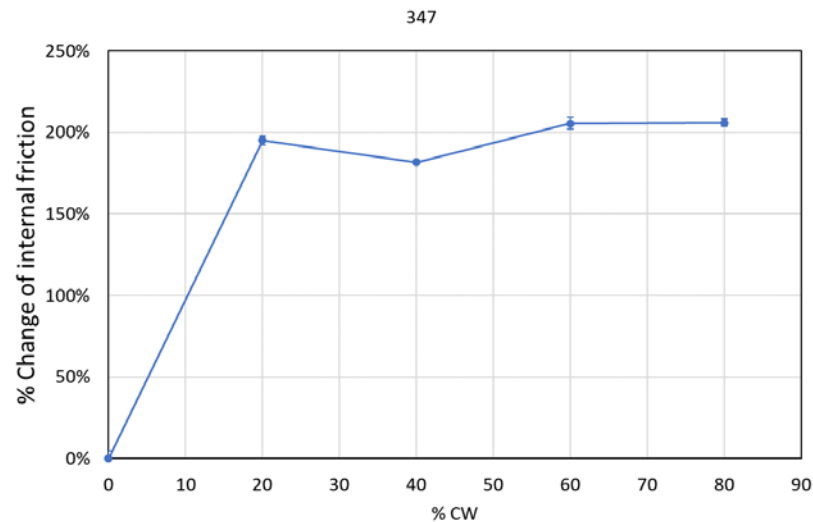
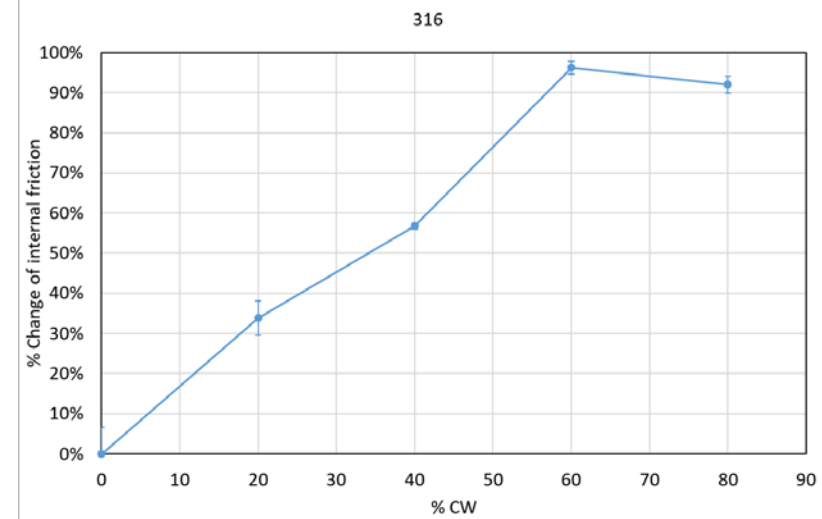
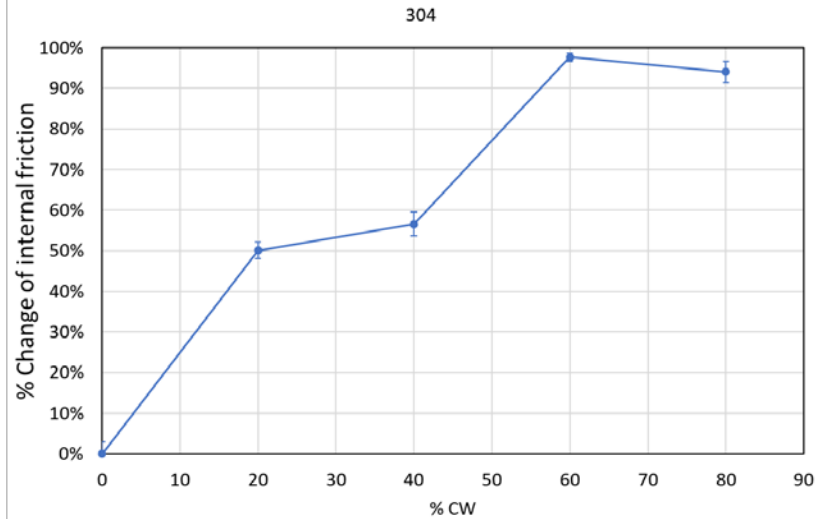
Reproducibility  
Internal Friction A286 SS 80% CW



Sample	Q <sup>-1</sup>	% change from 0% CW	Standard Error	Standard Error (%)
A286, 80%-1 CW	1.2	501%	0.025	2.0%
A286-80-3 CW	1.1	423%	0.007	0.6%
A286-80-4 CW	1.0	403%	0.032	3.1%
A286-80-5 CW	1.0	397%	0.028	2.7%

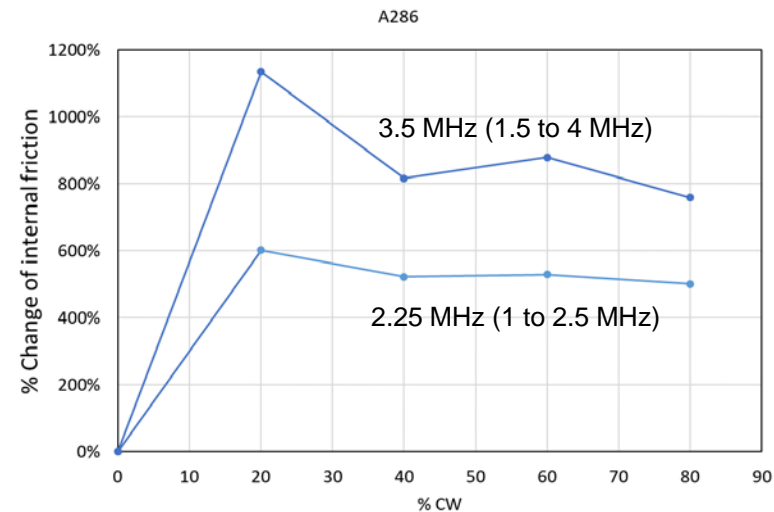
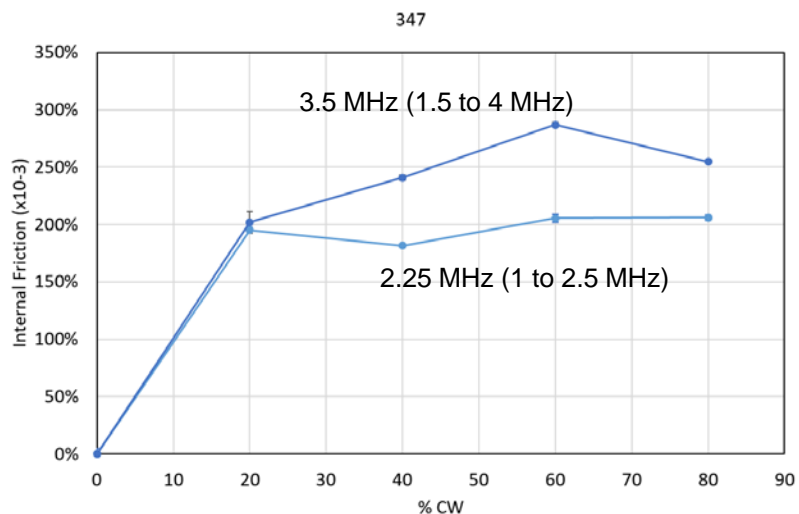
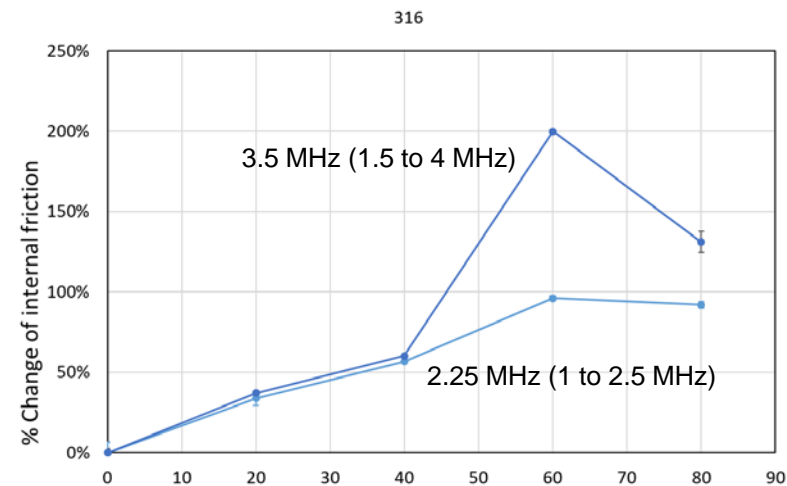
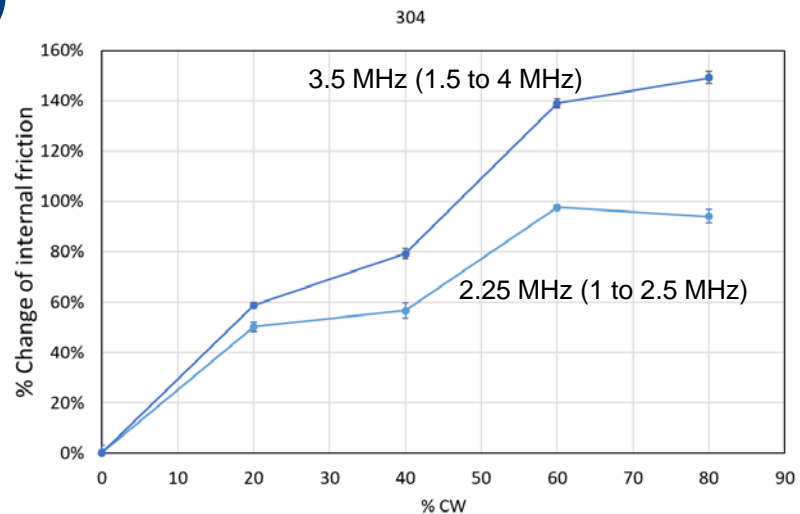


# Internal Friction vs. % CW for 304, 316, 347, A286 (2.25 MHz)





# Internal Friction vs. % CW for 304, 316, 347, A286 (2.25 MHz and 3.5 MHz)







# Internal friction, 3.5 MHz Data Tables

Sample ID	% CW	Q <sup>-1</sup>	% change from 0% CW	Standard Error	Standard Error (%)
304, 0% - 1 CW	0	0.4	0%	0.005	1.3%
304, 20% - 1 CW	20	0.6	59%	0.006	1.1%
304, 40% - 1 CW	40	0.6	79%	0.012	1.9%
304, 60% - 1 CW	60	0.8	139%	0.015	1.7%
304, 80% - 1 CW	80	0.9	149%	0.021	2.4%

Sample ID	% CW	Q <sup>-1</sup>	% change from 0% CW	Standard Error	Standard Error (%)
347, 0% CW	0	0.2	0%	0.002	1.0%
347, 20% CW 1	20	0.6	202%	0.060	9.5%
347, 40% CW	40	0.7	241%	0.017	2.3%
347, 60% CW 1	60	0.8	287%	0.015	1.8%
347, 80% CW	80	0.7	255%	0.008	1.0%

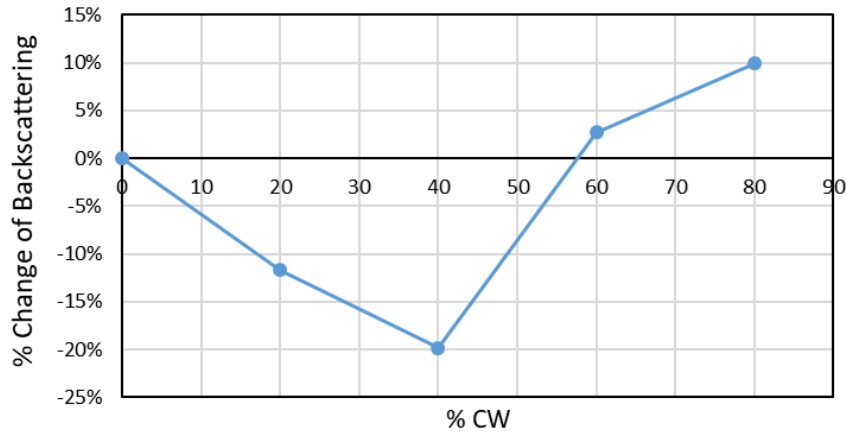
Sample ID	% CW	Q <sup>-1</sup>	% change from 0% CW	Standard Error	Standard Error (%)
316, 0% - 1 CW	0	0.4	0%	0.010	2.4%
316, 20% - 1 CW	20	0.6	37%	0.004	0.7%
316, 40% - 1 CW	40	0.7	60%	0.005	0.8%
316, 60% - 1 CW	60	1.2	200%	0.013	1.0%
316, 80% - 1 CW	80	1.0	131%	0.063	6.6%

Sample ID	% CW	Q <sup>-1</sup>	% change from 0% CW	Standard Error	Standard Error (%)
A286, 0% CW	0	0.2	0%	0.003	1.7%
A286, 20% CW	20	2.1	1136%	0.011	0.5%
A286, 40% CW	40	1.6	817%	0.015	1.0%
A286, 60% CW	60	1.7	880%	0.016	0.9%
A286, 80%-1 CW	80	1.5	759%	0.022	1.5%

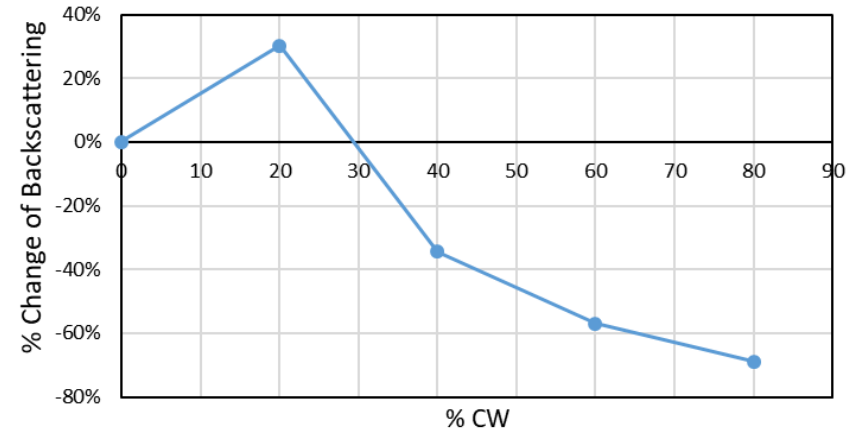


# Backscattering vs cold work

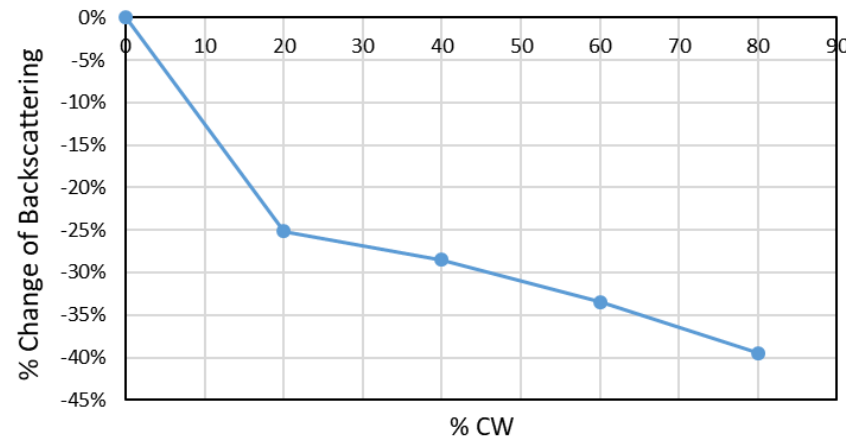
304



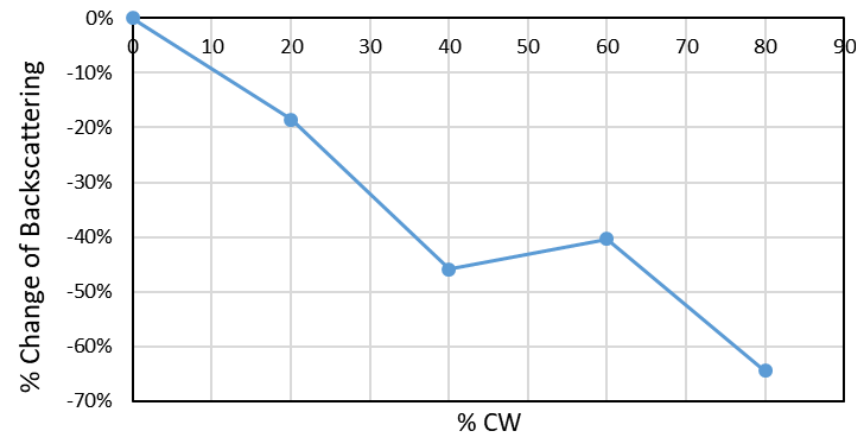
316



347



A 286





# Backscattering data tables

Sample ID	% CW	Backscattering Amplitude	% change from 0% CW	Sample ID	Backscattering Amplitude	% change from 0% CW	Sample ID	Backscattering Amplitude	% change from 0% CW	Sample ID	Backscattering Amplitude	% change from 0% CW
304, 0% - 1 CW	0	11.1	0%	316, 0% - 1 CW	10.72	0%	347, 0% CW	15.44	0%	A286, 0% CW	9.63	0%
304, 20% - 1 CW	20	9.8	-12%	316, 20% - 1 CW	13.97	30%	347, 20% CW 1	11.56	-25%	A286, 20% CW	7.85	-18%
304, 40% - 1 CW	40	8.9	-20%	316, 40% - 1 CW	7.03	-34%	347, 40% CW	11.04	-28%	A286, 40% CW	5.21	-46%
304, 60% - 1 CW	60	11.4	3%	316, 60% - 1 CW	4.61	-57%	347, 60% CW 1	10.27	-33%	A286, 60% CW	5.74	-40%
304, 80% - 1 CW	80	12.2	10%	316, 80% - 1 CW	3.34	-69%	347, 80% CW	9.35	-39%	A286, 80%-1 CW	3.42	-64%



# Conclusions

- Microstructural changes caused by CW can be measured by internal friction
  - 150% change for 304 SS
  - 200% change for 316 SS
  - 300% change for 347 SS
  - 1100% change for A286 SS
- Measurements are highly reproducible and precise
- Higher frequency (3.5 MHz) measurements of internal friction are generally more sensitive to CW than lower frequency (2.25 MHz)
- Backscattering measurements are sensitive changes that occur in CW
- Need to perform microscopy to determine microstructure changes in dislocation and grain size