Technical Disclosure Commons

Defensive Publications Series

June 2020

Continuous Casting Methods For Preparing High-Strength 5xxx Series Aluminum Alloys For Can Ends

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CONTINUOUS CASTING METHODS FOR PREPARING HIGH-STRENGTH 5XXX SERIES ALUMINUM ALLOYS FOR CAN ENDS

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Described herein are methods for preparing high-strength 5xxx series aluminum alloys for can ends, including beverage can ends and food containers. The aluminum alloy products and methods described herein can also be used in automotive, marine, architectural, aerospace, and specialty markets.

The methods described herein include continuous casting, hot rolling to a low gauge, water quenching, annealing at an elevated temperature, slow cooling, and cold rolling to final gauge. Continuous casting (CC), including hot roll to gauge (HRTG) continuous casting, produces a final product with finer constituent particles and a super saturated solid solution matrix. In particular, slabs produced from continuous casting contain smaller constituent particles in the matrix due to high solidification rate, preventing coarse precipitation of strengthening phases (e.g., Mg_2Si phase). The high cooling rate of the continuous cast slab results in a high degree of solute supersaturation in the CC hot band, which affects the evolution of microstructure and texture during subsequent thermo-mechanical processing. The methods described herein, including direct hot roll to gauge, allows more hot work on the slab to avoid stringer while maintaining the material flow around the constituent particles.

The described methods, which are outlined below in Example 1, produce superior performing material with high strength and better formability compared to traditional hot rolled and cold rolled direct chill (DC) cast alloys. In particular, the process described herein results in isotropic mechanical properties in all directions, which overcomes anisotropic formability in certain directions (e.g., diagonal). The continuously cast can end stock material surprisingly matches the DC lab processed material and also meets requirements for commercial can end production. Specifically, based on the lab trials, the tensile strength of the coated CC stock is equivalent to DC stock and the formability of the CC stock is comparable to DC material with successful rivets formed. The earing of the CC material is greater than the DC material, and the buckle pressure was above 90 psi for a sheet having a gauge of 0.208 mm. The CC material also exhibited similar performance to the DC material in terms of can end fabrication and testing. No score fractures occurred in the samples that were tested. A comparison of strength and earing for a CC and traditional DC 5XXX series aluminum alloy samples is shown below in Example 1.

Example 1:

AA5182 samples were cast using continuous casting (Sample CC-5182 in Table 1) and direct chill casting (Sample DC-5182 in Table 1) to directly compare the impact of the casting methods on the final processed material. In Table 1, all values are in weight percent, with up to 0.15 wt. % impurities (0.05 wt. % or less for each impurity) and the remainder Al.

Table 1: Chemical Compositions of AA5182 Samples

Sample ID	**Cu**	**Fe**	**Mg**	**Mn**	**Si**	**Ti**
CC-5182	0.02	0.18	4.30	0.31	0.07	0.02
DC-5182	0.04	0.22	4.64	0.41	0.08	0.006

The two variants were further processed to final gauge following the hot and cold rolling process paths shown in Figure 1. The samples were hot rolled to 2.8 mm and water quenched, following by annealing at 400 °C for two hours. The samples were then slow cooled in a furnace and then cold rolled to final gauge. For the DC material, a production sample (labeled in the figures provided herein as “DC-5182 Production”) and a lab-rolled sample (labeled in the figures provided herein as “DC-5182 Lab Rolled”) were prepared. Depending on the final product requirements, the cold rolled material was tested in fully hardened temper-H19 and H48 temper after curing.

Mechanical properties were measured for the CC and DC variants. Based on the lab rolled material, the following conclusions were drawn. The continuous casting process resulted in material having slightly smaller grains compared to DC cast material, which is attributed to the fast solidification and unique thermo-mechanical processing of the continuous casting process. See Figure 2A. The CC material had a similar strength to the DC cast material in an H19 temper, but softened readily in an H48 temper. See Figures 2C and 2D. The CC material had a higher deformation texture in both hot band and in final gauge, which can be attributed to the earing balance observed in the CC material. See Figure 2E. The CC material had a slightly higher number of alpha and Mg_2Si particles compared to DC cast material, but the overall number density of particles turned out to be similar in both CC and DC cast production. See Figure 2E. Compared to the DC material prepared at the same hot band gauge, the CC material had higher mean earing and more negative earing balance. See Figure 2F. The deeper valleys at

90º and 270º and higher peaks at 45º might show up as a different uncurled lip height pattern on the shells. See Figure 2F.

Test variables were performed on the samples described above using shell and conversion presses. The sample panels were hand lubricated using petrolatum prior to forming. Shells were produced to North American CDL+ specifications and converted into Stolle Can Ends. All test variables were run with the shell press in single stroke mode and with the conversion press in continuous mode. Figures 3-8 show the results of different tests performed on the materials from the trial.

A buckle pressure test was performed on the materials by clamping a shell or end against an O-ring and pressurizing until the end buckled (meaning that the end expanded to increase volume and prevented explosion of the can). The pressure was then measured and recorded. Figure 3 shows the Buckle Strength results of the variants after gauge adjustment. The adjustment was necessary given the extremely high gauge variation between sheet samples and variables. Once adjusted, the DC-5182 Lab Rolled and CC-5182 were within 3 psi of each other, on average.

The uncurled lip height was measured from the outside edge of the can end for the materials described herein. To perform the test, when placed upside down on a flat surface, the lip pointing up is measured with a depth gauge. The lip height varies around the circumference of the end and is one of the key measurements taken to evaluate differences in material forming in the shell press. The uncurled lip must be measured after a shell is formed in the shell press, before curling, which is the next step that enables to shell to be seamed onto a can body later. Figure 4 shows the uncurled lip height of the DC-5182 Lab Rolled and the CC-5182 samples in comparison to the DC-5182 Production sample. All materials all fell within the spec limits and the uncurled lip heights of the CC-5182 material appeared to be better suited to the non-round cut edge profile used in shell production than the DC-5182 material.

The rivet form is the most extreme forming step in can end making. Therefore, it is critical to inspect for stress, cracks, or fractures. Figure 5 shows optical images of the ends formed in the trial described above. The rivets on all samples passed visual inspection. Lab processed samples could be seen to have scratches or residual rolling oil, but the rivet forms were acceptable. Figure 6 shows optical images of the bubble/button, formed during the trial described above. All samples passed visual inspection. The button form (shown in Figure 6) comes before the stake station (shown in Figure 5) in the forming sequence.

The score is what allows the end to open, but is also a vulnerable area to corrosion. Previous work on continuously cast CES was said to have had issues with cracking in the score that made ends more vulnerable to score corrosion. Figure 7 shows the cross-section of the score fracture area on the DC-5182 Lab Rolled and the CC-5182 samples. Neither sample showed any cracking from this location. Both passed visual inspection.

The panel wall is the area most likely to thin and fracture during shell forming, so it was critical to inspect. This forming step happens in the shell press and before the button, score, and stake stations shown in previous figures. Figure 8 shows the panel wall area on the DC-5182 Lab Rolled and the CC-5182 samples in comparison to the DC-5182 Production sample. None of the samples showed any signs or cracking or fracture from this location, and all passed visual inspection.

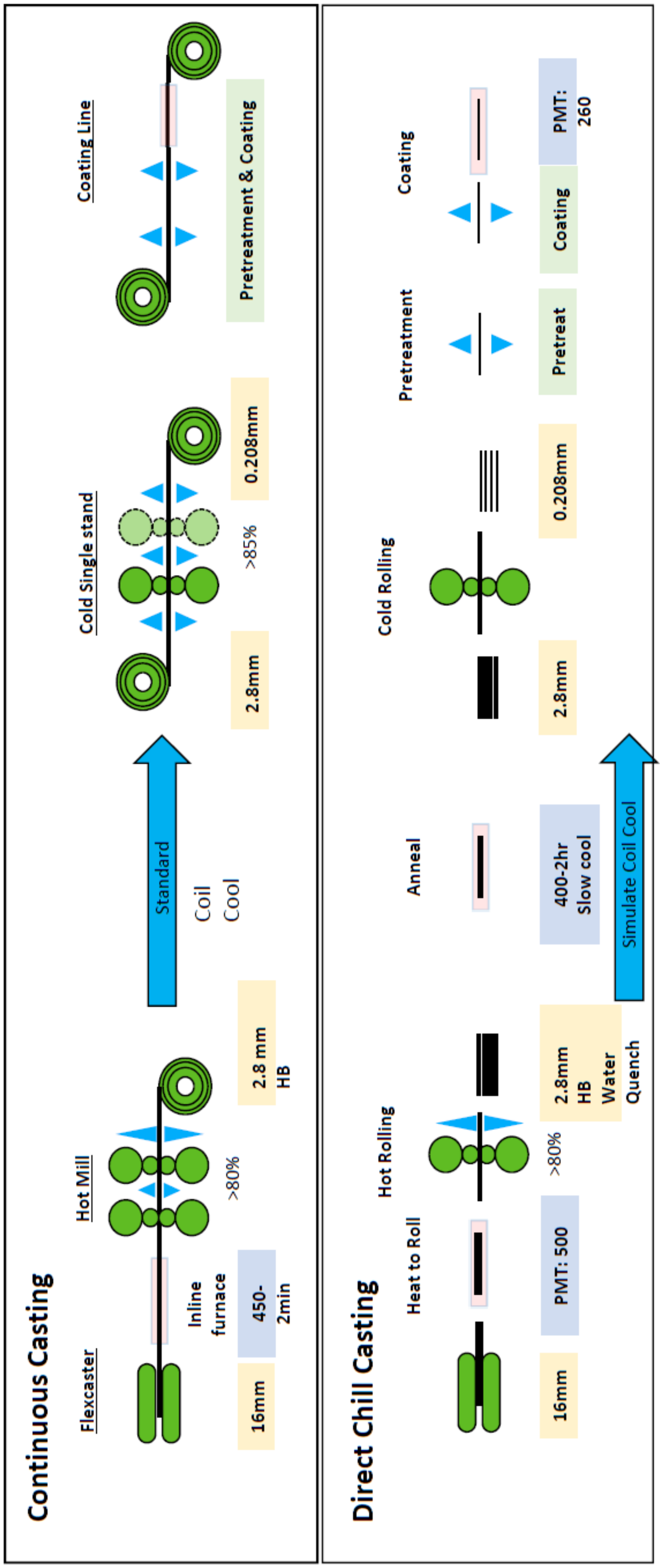
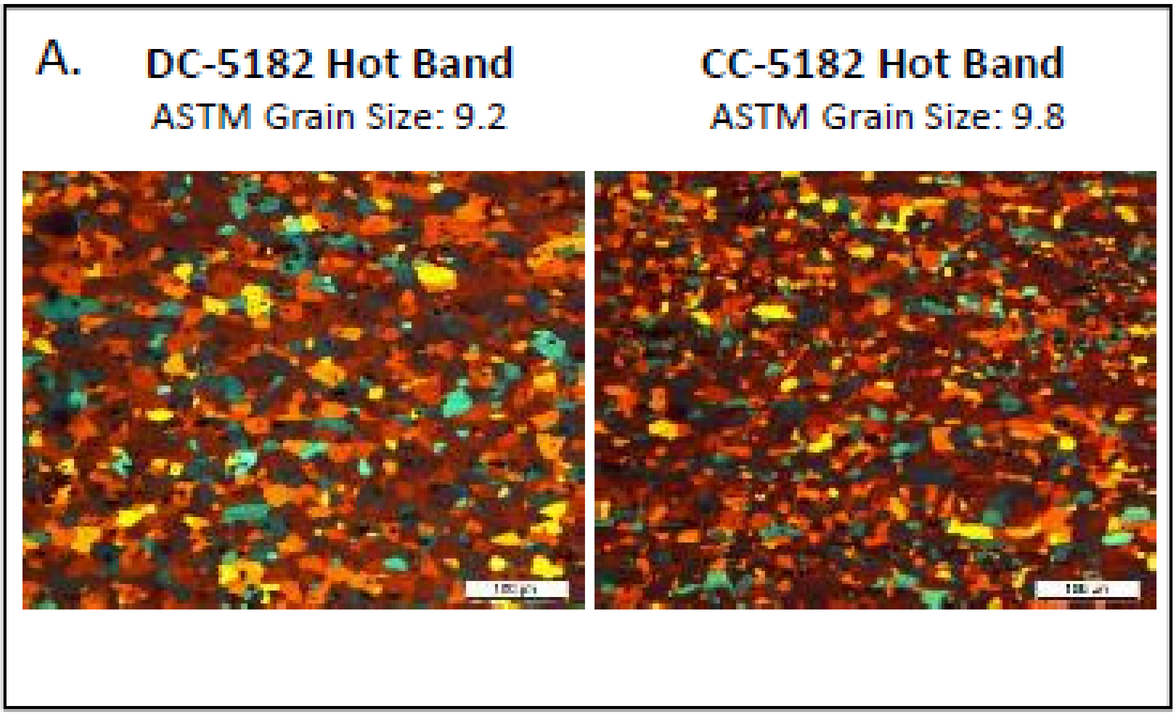
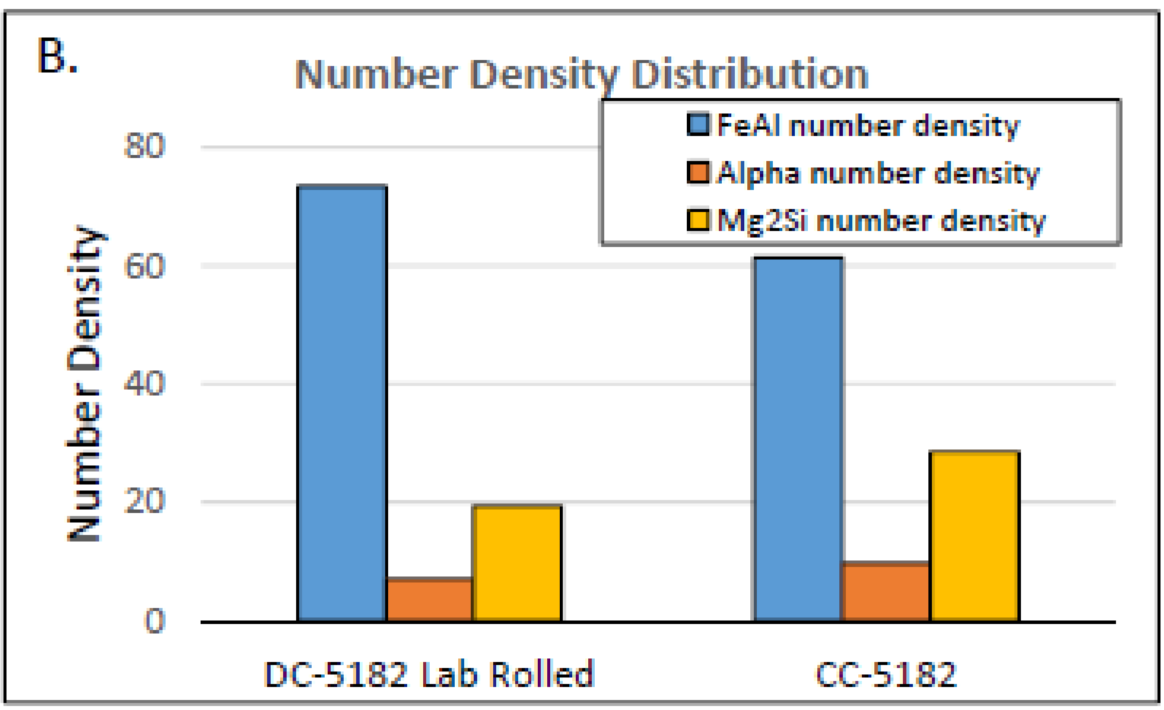
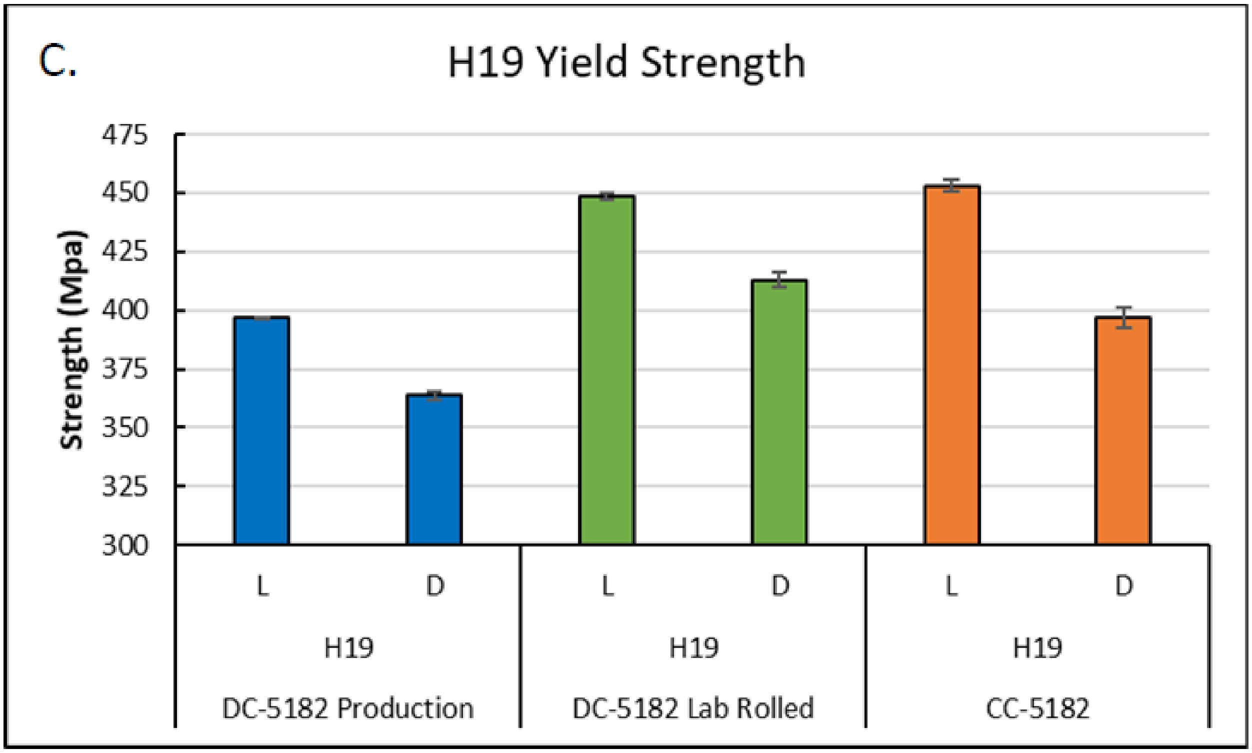
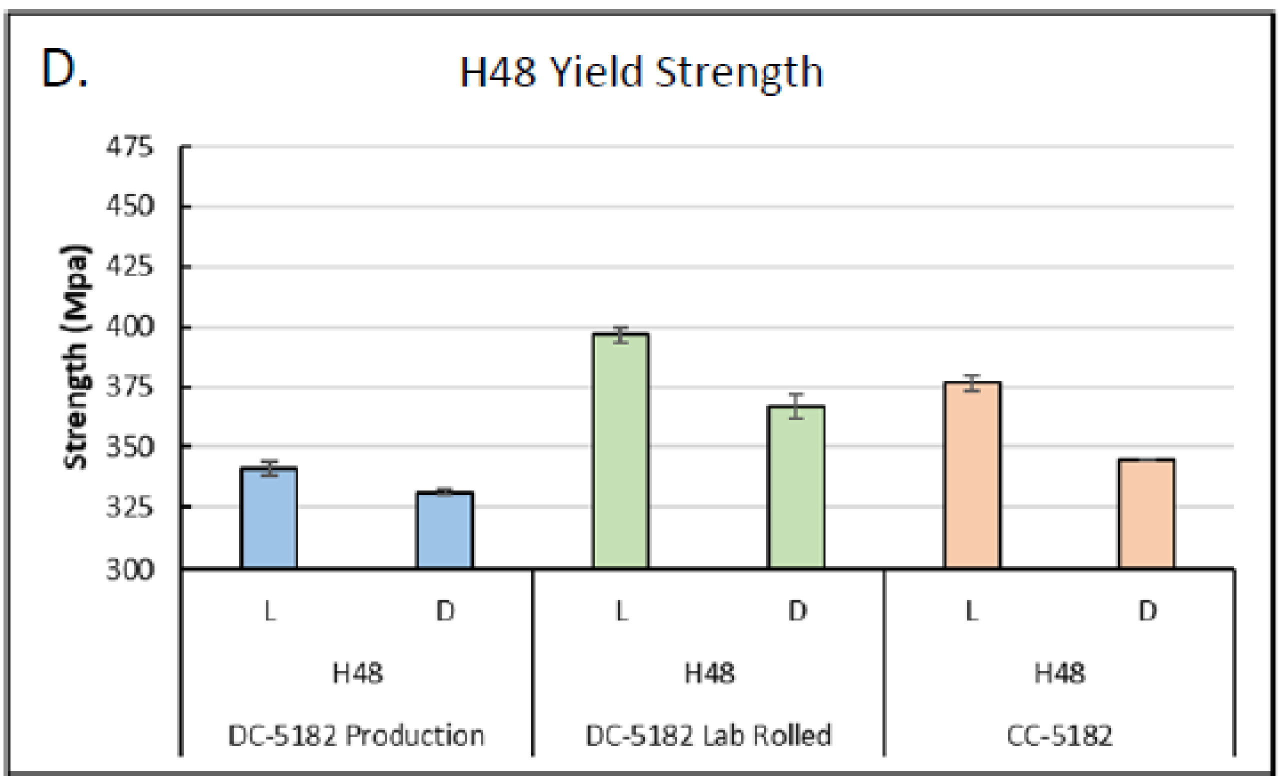


Figure 1 – Processing Routes

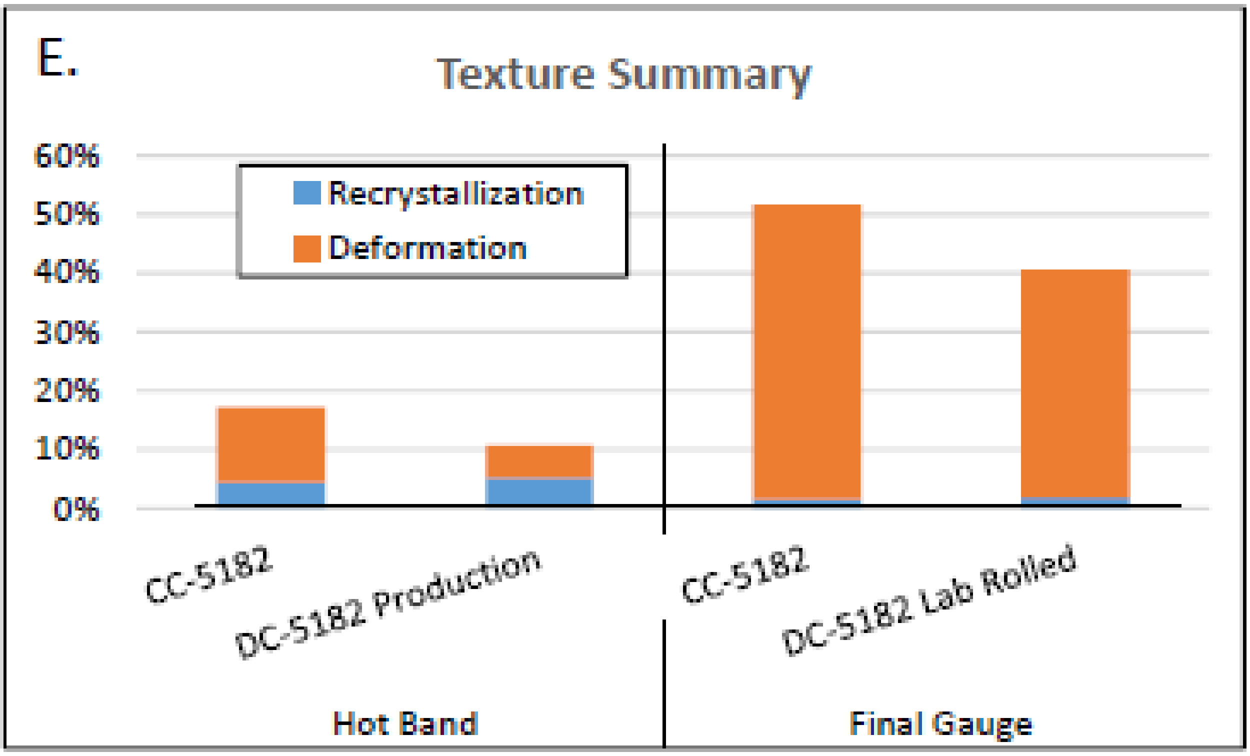

A.
DC-5182 Hot Band
ASTM Grain Size: 9.2
CC-5182 Hot Band
ASTM Grain Size: 9.8


B.
Number Density Distribution
FeAl number density
Alpha number density
Mg2Si number density
Number Density
80
60
40
20
0
DC-5182 Lab Rolled
CC-5182


C.
H19 Yield Strength
Strength (Mpa)
475
450
425
400
375
350
325
300
L
D
L
D
L
D
H19
H19
H19
DC-5182 Production
DC-5182 Lab Rolled
CC-5182


D.
H48 Yield Strength
Strength (Mpa)
475
450
425
400
375
350
325
300
L
D
L
D
L
D
H48
H48
H48
DC-5182 Production
DC-5182 Lab Rolled
CC-5182

7



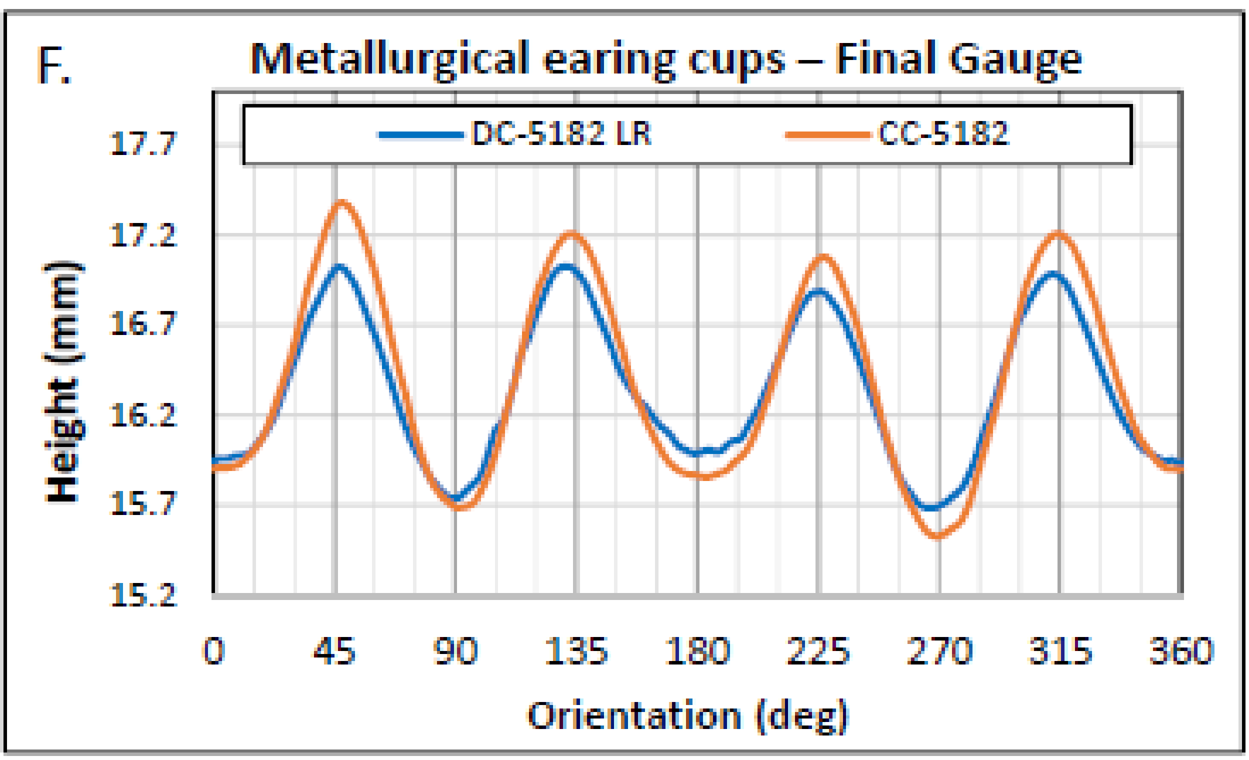


Figure 2 – Metallurgical evaluation of CC-5182 and DC-5182

8

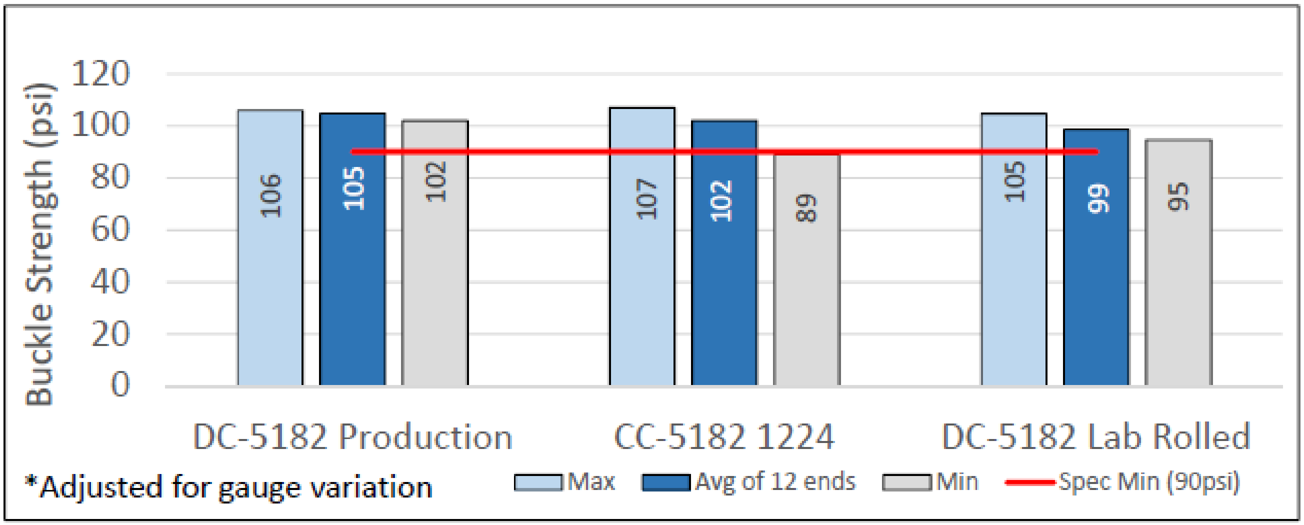


Figure 3 – End buckle strengths of CC and DC 5182

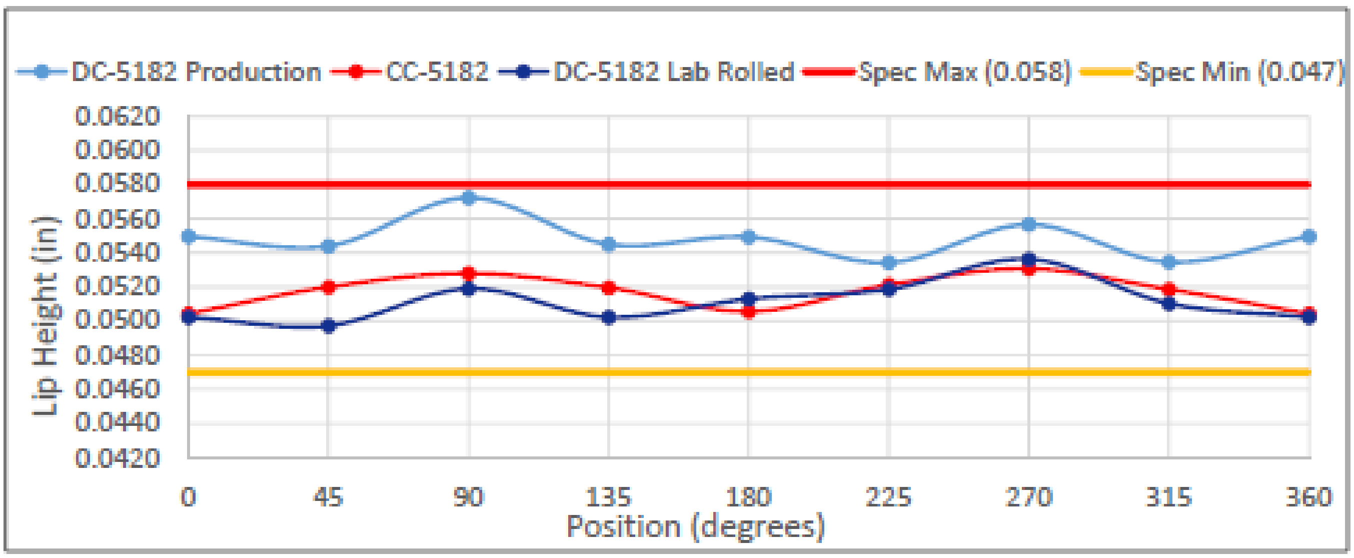


Figure 4 – Uncurl Lip Height Results of CC and DC 5182

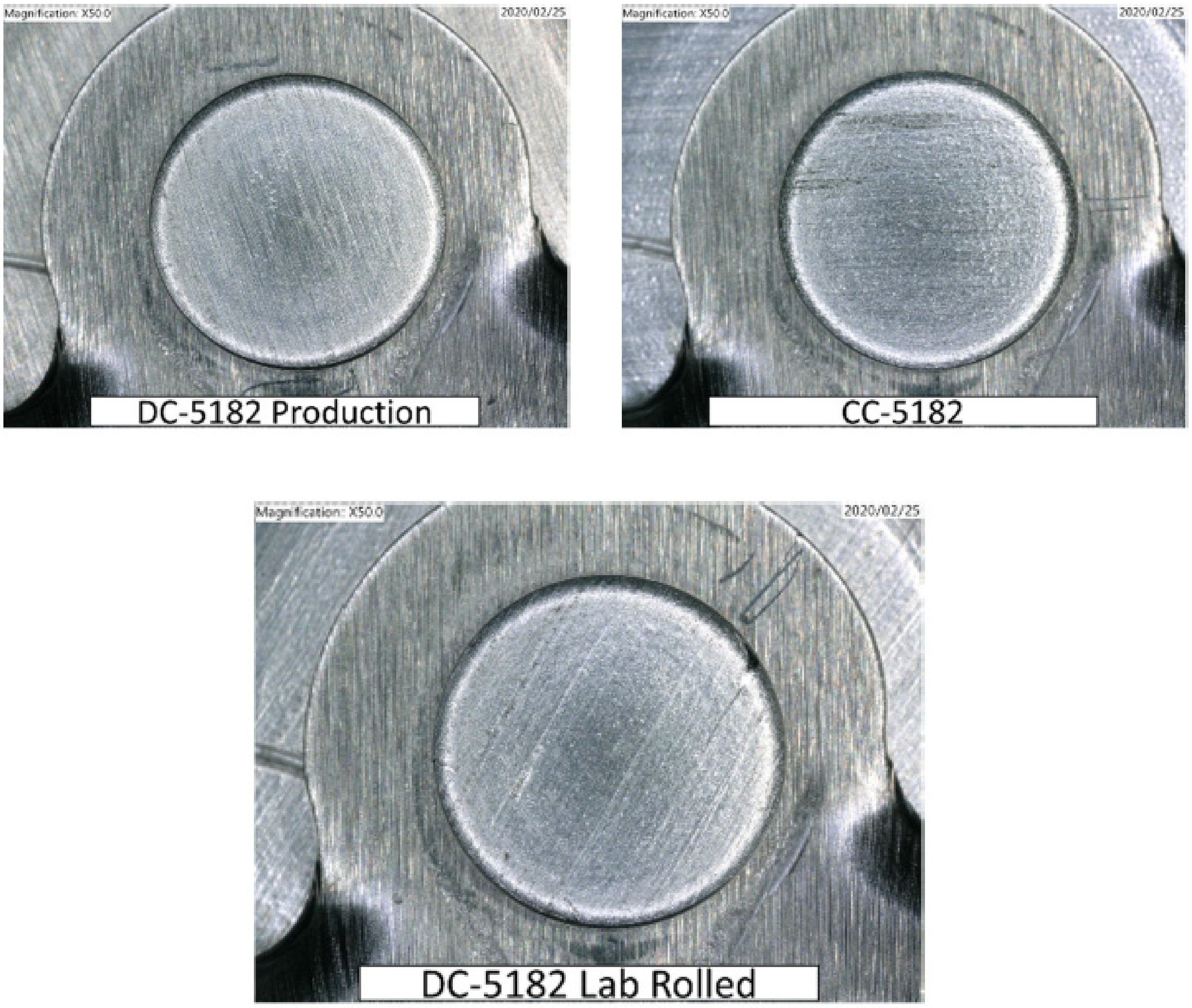


Figure 5 – Rivet inspection of CC-5182 and DC-5182

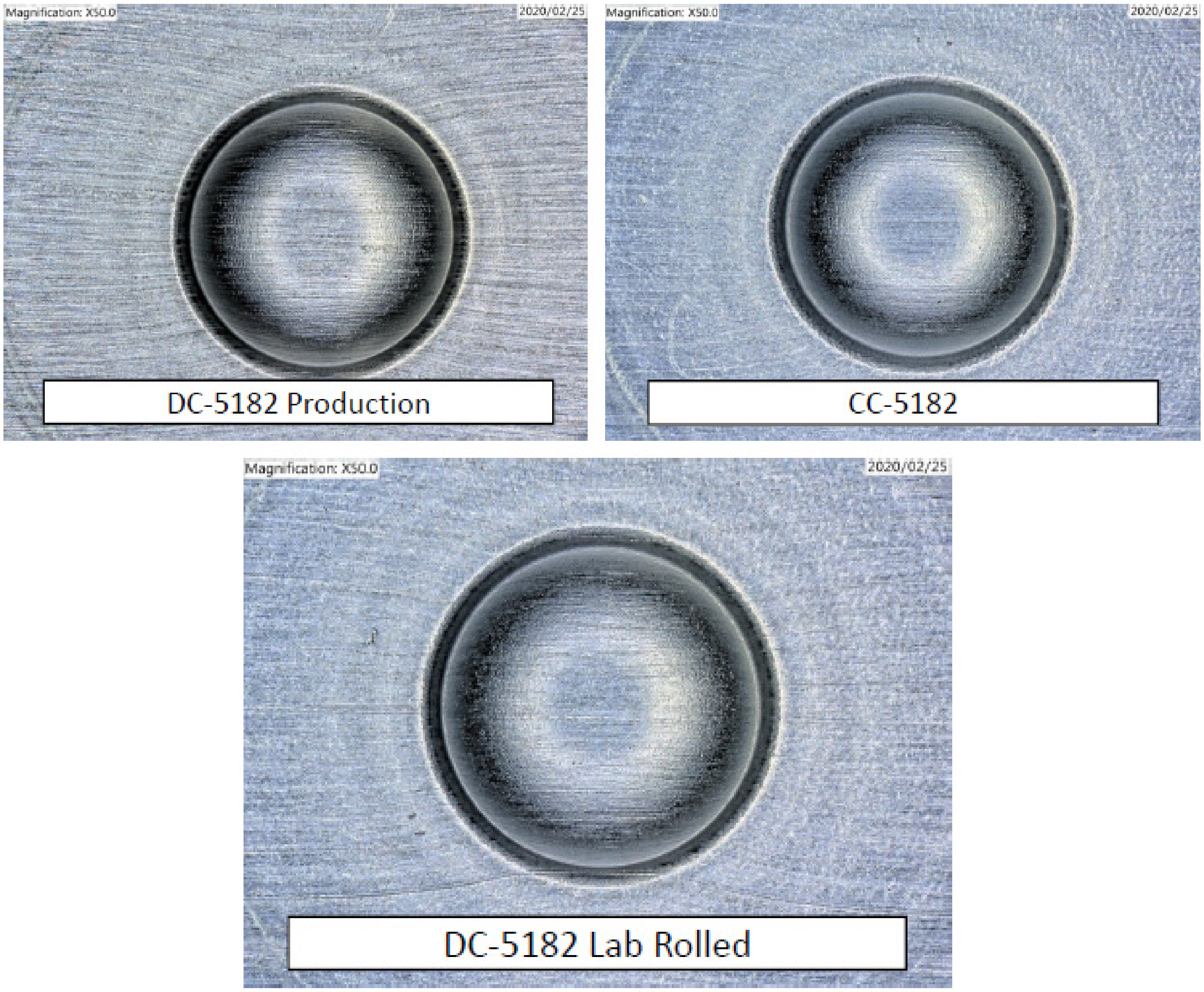


Figure 6 – Bubble/Button Formability Evaluation of CC-5182 and DC-5182

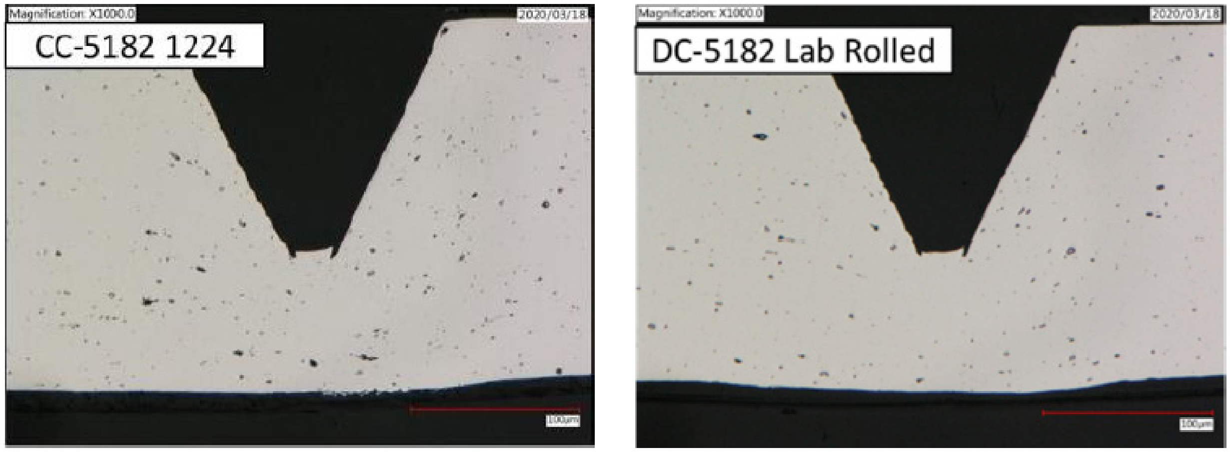


Figure 7 – Score fracture evaluation of CC-5182 and DC-5182

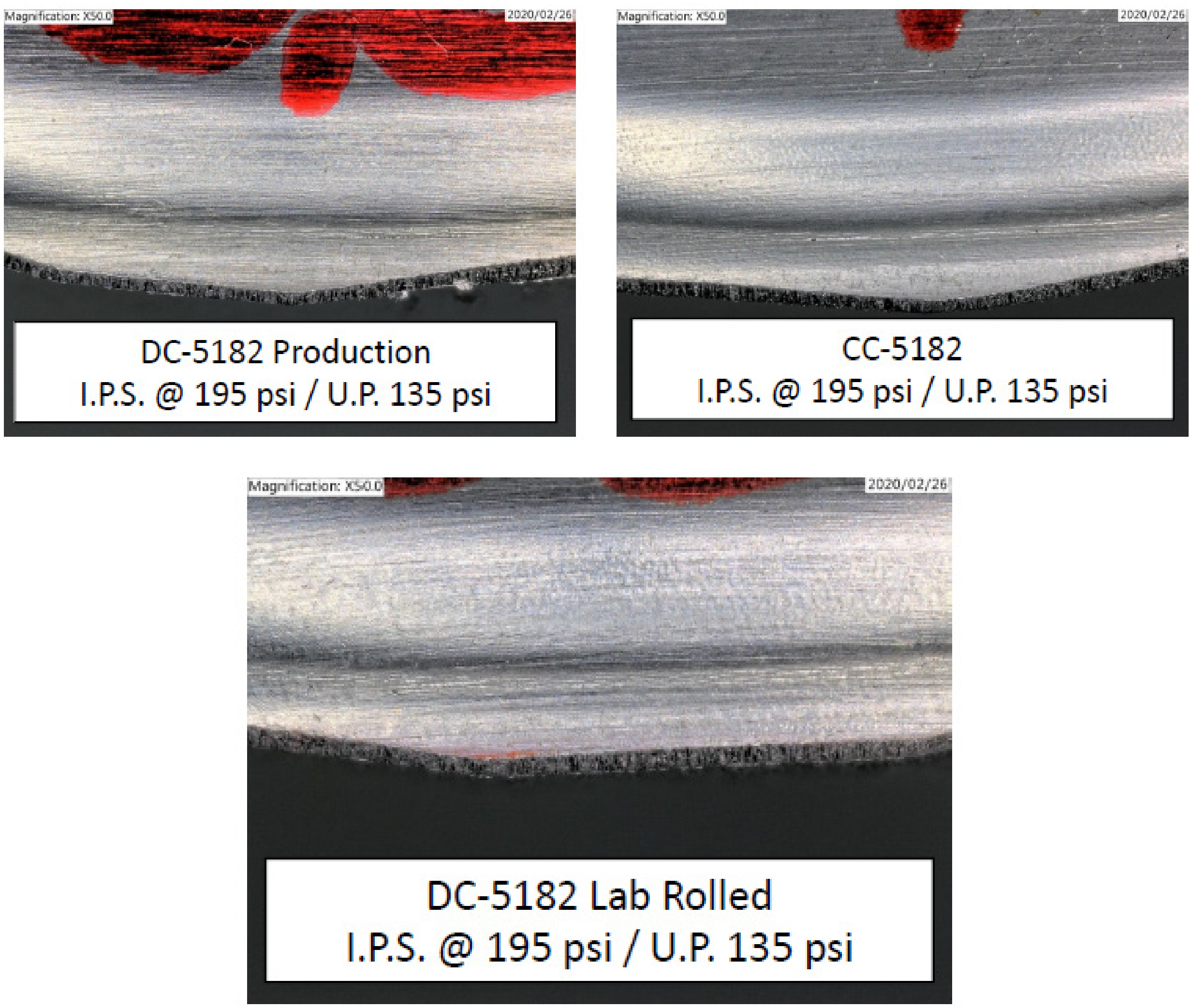


Figure 8 – Panel wall evaluation of CC-5182 and DC-5182