AverEdge32 – Evaluating measurement techniques for calculating the Plastic Strain ratio (*r*-value) of sheet metal

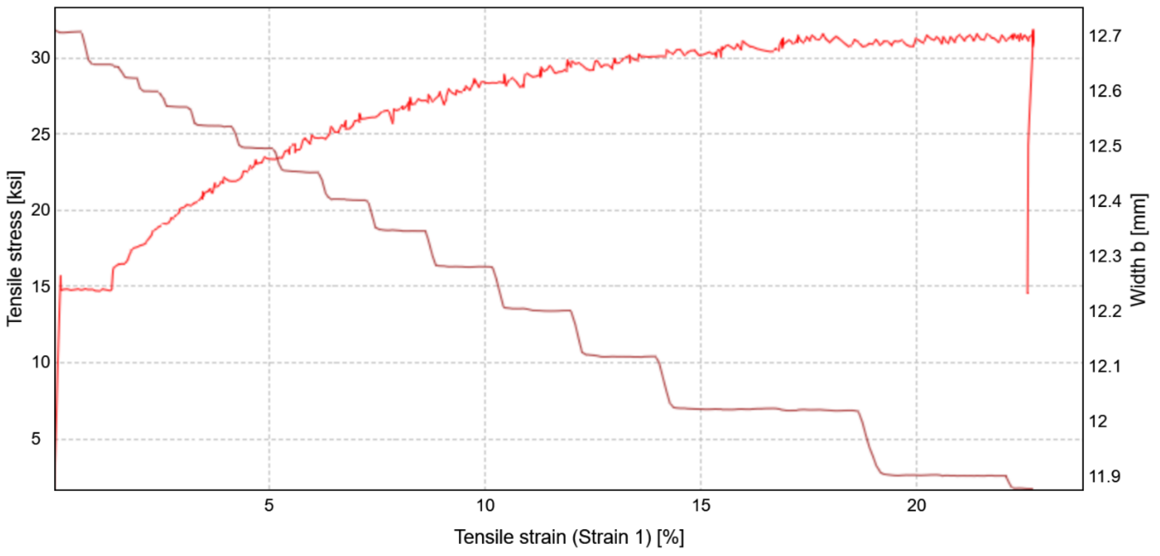
Introduction

The ability to form sheet metal into finished products such as cars, airplanes, and consumer appliances has been invaluable to modern life for the last 100 years or more. Though this technology is well-established, new demands for product requirements and design are still pushing the boundaries of sheet metal formability as well as the testing capabilities required to develop new, stronger, and lighter sheet metals.

A primary measurement of sheet metal formability is the plastic strain ratio, or the '*r*-value'. This is the ratio of a material's reduction in width versus its reduction in thickness when a uniaxial stress is applied, i.e. stretched during the forming process (see ISO 10113, ASTM E517, or JIS Z2254 for the derivation and further explanation).

Strain measurement is the principal requirement for calculating the *r*-value. Transverse strain (percent reduction in width) measurement is required and presents the greatest challenge for accurate and repeatable strain data, especially for inhomogeneous materials (such as 5000 series aluminum alloy) which exhibit the Portevin-LeChatelier (PLC) effect, or a saw-tooth strain curve. This behavior of localized plastic deformation is especially unfavorable when measuring transverse strain as shown by the steps in Figure 1.

Figure 1: PLC effect on specimen width during tensile loading



This can result in artificially high or low instantaneous transverse strain values for a given location along a specimen at a specific time during a test, and increased scatter between tests.

To address this challenge, the ISO 10113 test standard was revised in 2020 to include the recommendation of a multi-point measurement for transverse strain. The extensometer should measure the change in width at a minimum of three locations evenly distributed across the axial gauge length, which should then be averaged into a single transverse strain value for calculating the *r*-value.

This document purports to show the improvement in *r*-value results when using the averaged multi-point measurement compared to a single-point measurement.

Experimental Design

All tests were run on an Instron 68TM-50 materials testing system with Bluehill® Universal software and hydraulic wedge grips to provide repeatable gripping force. All tests used the same test method criteria for consistency.

Multiple strain measurement devices were used to compare the different techniques of single-point versus averaged multi-point transverse strain measurement. Automatic extensometers were used to eliminate operator influence on the measurement.

The AutoXbiax is an automatic contacting biaxial extensometer that uses a single-point transverse strain measurement.

The AVE2 is a non-contacting biaxial video extensometer that has traditionally provided single-point transverse strain measurement by tracking marks on the specimen surface. See Image 1.

AverEdge32™ is an optional capability for any AVE2 that provides an averaged multi-point transverse strain measurement by tracking the edges of the specimen. It provides the average value of 32 axes, or gauge-widths, evenly spaced between the axial gauge marks with no transverse marks needed. It uses a patented reflective backscreen that uses no power and defines the specimen edges. See Image 2. This capability was designed to exceed the requirements of ISO 10113:2020 and provide a fundamentally better transverse strain measurement.

Both the AutoXbiax and AVE2 measure axial and transverse strain simultaneously.

The material tested was 5000 series aluminum alloy (contains magnesium) and is inhomogeneous, displaying significant PLC effect, as seen in Figures 3, 4, 6 and 7.

Both ISO and ASTM geometries were tested.

Image 1: AVE2 mark-based transverse

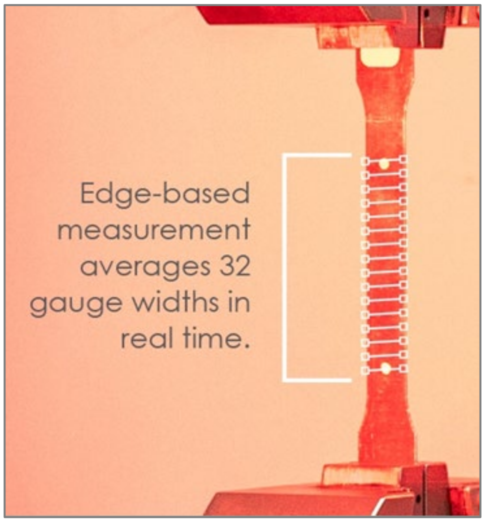


Image 2: AverEdge32™ transverse

Results and Discussion

Results for *r*-value were produced using a single-point calculation at 10% axial strain with elastic strains removed, following the ISO standard, for all tests.

The AverEdge32 measurement showed a significant reduction in range and coefficient of variation (COV) for each sample (see Table 1), but the numbers do not tell the whole story.

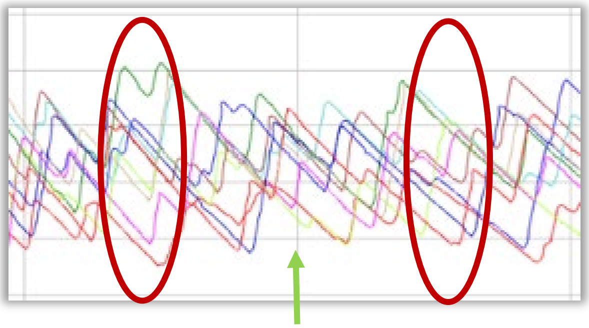
Table 1: Statistics for *r*-value result at 10% for 5000 series Aluminum

Specimen Geometry	Device	Mean	Range	COV	Std Dev
ISO	AutoX	0.76	0.09	4.44	0.03
ISO	AVE2 Marks	0.74	0.18	6.62	0.05
ISO	AverEdge32	0.76	**0.02**	**0.70**	0.01
ASTM	AutoX	0.78	0.17	6.27	0.05
ASTM	AVE2 Marks	0.71	0.10	4.07	0.03
ASTM	AverEdge32	0.73	**0.03**	**1.66**	0.01

Bluehill Universal software is able to calculate *r*-value at every data point in real time, which also allows for convenient graphing of *r*-value throughout the test, providing a visual indication of the challenge of calculating *r*-value on inhomogeneous material. The graphs below are for each sample.

Figures 3 & 4 use single-point transverse-strain measurements and clearly show the magnitude of the PLC effect. The *r*-value result for any individual specimen is greatly affected by the timing of the peaks and valleys. For example, the plots at 10% (green arrow) are much closer together than at 9% or 11% (red circles). See Figure 2.

Figure 2: Scatter between tests using single-point measurement, due to PLC effect



For some tests the *r*-value may be artificially high at a peak, and some may fail specification if in a valley.

Figure 3: AutoXbiax - ISO

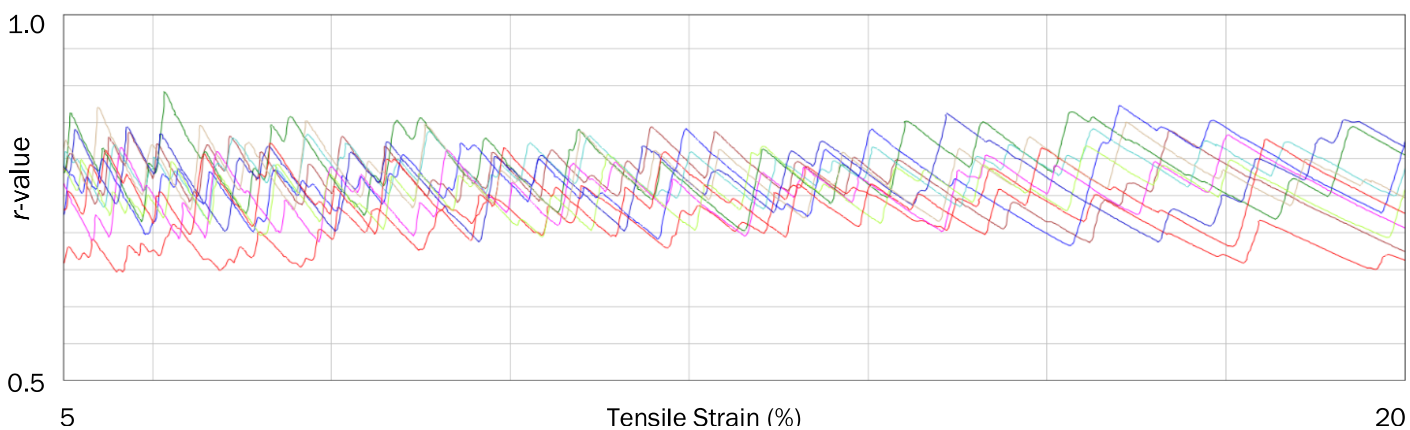


Figure 4: AVE2 Marks – ISO

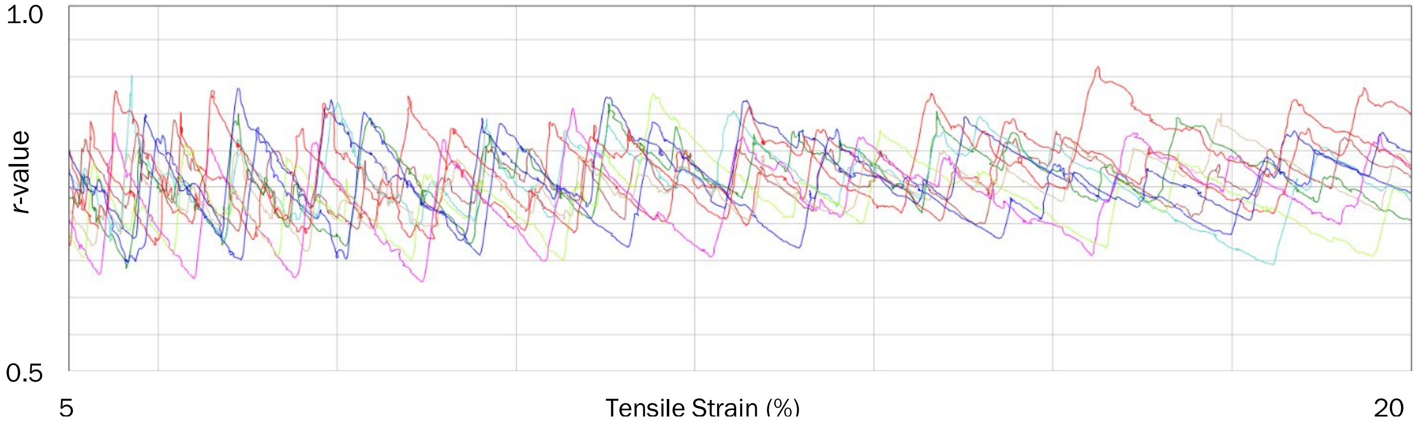
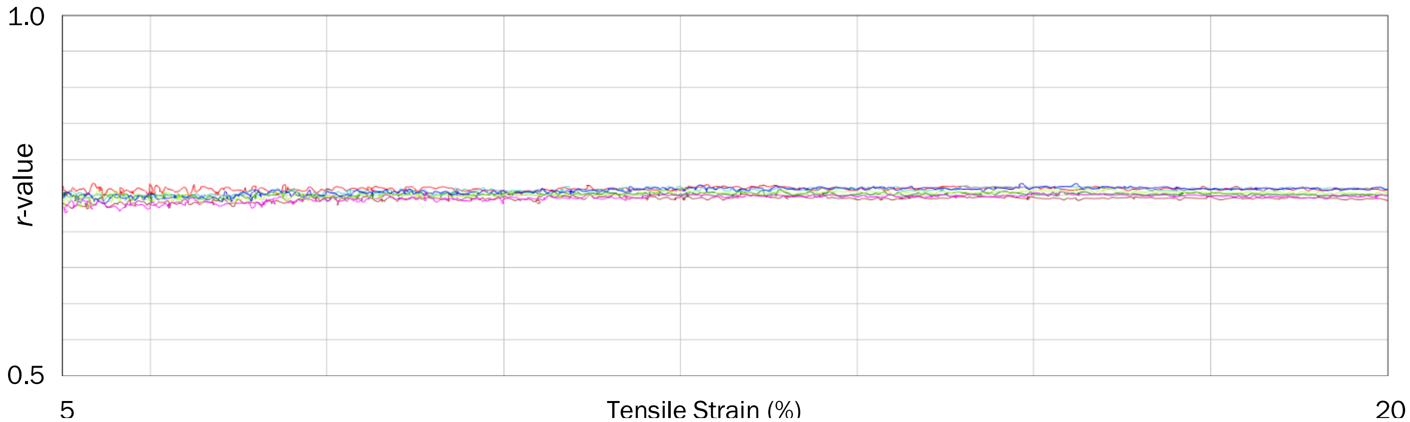


Figure 5 shows the benefit of an averaged multi-point transverse-strain measurement. The *r*-value result will be nearly the same at any point in the test (between yield and ultimate tensile strength, as prescribed in the standards).

Figure 5: AverEdge32™ – ISO



Similar results were seen for the ASTM specimens in Figures 6-8.

Figure 6: AutoXbiax – ASTM

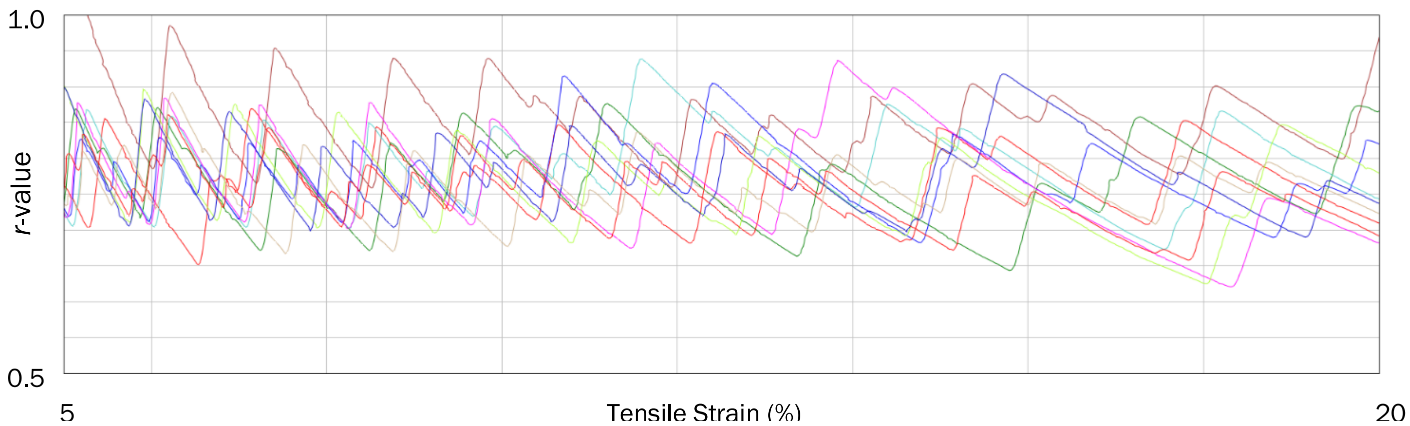


Figure 7: AVE2 Marks – ASTM

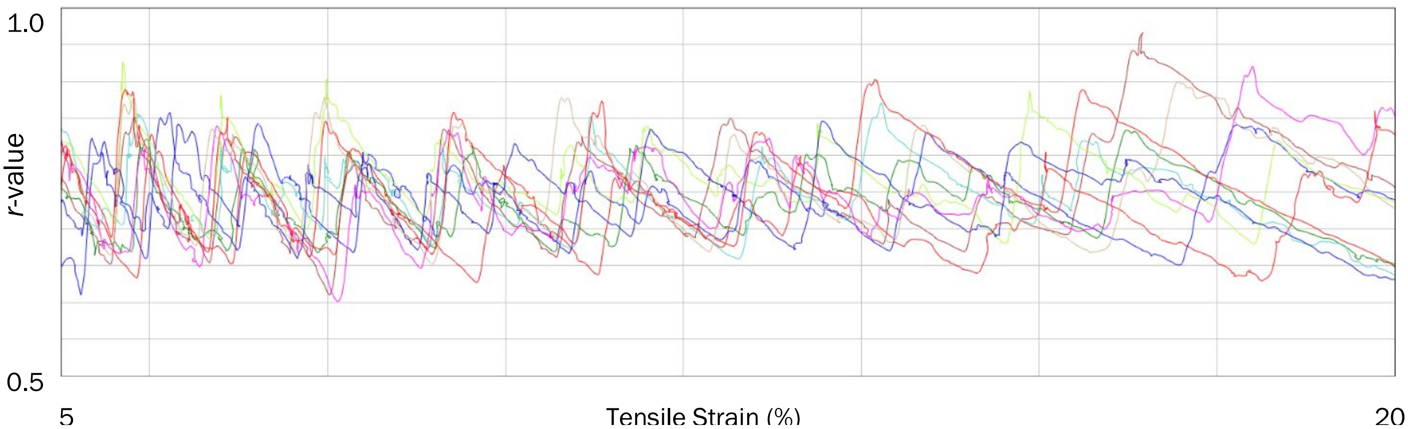
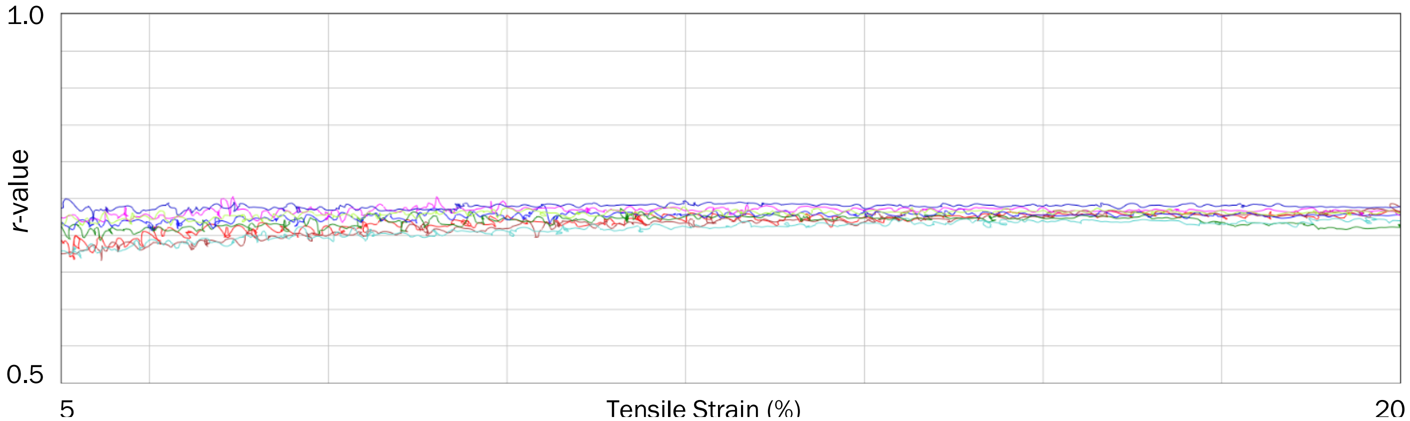


Figure 8: AverEdge32™ - ASTM



Conclusion

Instron's AverEdge32™ capability outperformed both the AutoXbiax and the mark-based AVE2 when measuring transverse strain in metals. It also provides a consistent *r*-value, eliminating the need for re-testing due to low *r*-value.