The Importance of Specimen Alignment when Tensile Testing Thin Films and Foils

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Introduction:

Historically, thin films and foils have been most notably used to manufacture packaging for consumer goods, medical devices, and food products. However, their use in applications related to Electric Vehicle (EV) manufacturing has been growing exponentially alongside the rest of that industry.

Tensile testing of thin films and foils presents more challenges than that of rigid specimens. ASTM classifies a film as anything equal to or less than 1 millimeter in thickness. Most thin films and foils used in EV batteries are extremely thin, often no more than 15 microns thick. These materials are easily damaged by mishandling; even the simple act of gripping a thin film or foil can damage the specimen. This creates a need to prepare and test a large number of specimens to fully understand the properties of the materials.

Arguably the biggest challenge is related to inserting and aligning the specimens. Improper specimen alignment can cause wide variations in test results. Specimens are difficult to load into tensile grips and operators frequently need to contort themselves into uncomfortable positions to load specimens and check for alignment after the specimen has been gripped. The repeatability with which operators align specimens is influenced by their experience; but even highly experienced operators can struggle with this aspect of testing.

Why Specimen Alignment is Important:

Our customers in the EV battery market have anecdotally informed us that specimen alignment/insertion is their #1 pain point while tensile testing both thin films and foils. In-house validation testing found alignment to be one of the biggest factors affecting test result repeatability. Poor specimen alignment was found to reduce repeatability, force at break, and displacement/strain values. Good alignment produced more consistent results with higher mean strain values and higher force at break values.

Specimen alignment has long been a factor in tensile testing. There are many devices on the market to improve specimen alignment and help customers ensure that their data is repeatable. However, the available devices fall short when testing thin, fragile materials.

Theory:

Alignment in Film and Foil specimens is critical for two key reasons:

1. Accurate strain measurement depends on good specimen alignment in the load string.
    a. If a specimen is not aligned with the axial load line, even if it is otherwise free of wrinkles and imperfections, there will always be some error in measuring the strain, whether by crosshead displacement or optical methods.
    b. If a specimen has good angular alignment relative to the grips/load string but has twist or angular deviation in another axis, then there is a distinct possibility of including artificial strain in the specimen.
2. If a specimen is angled, twisted, or off-center in the grips, then the load applied to the specimen will no longer be distributed evenly.
    a. The effect of any existing edge imperfections can be exacerbated by the uneven load distribution.
    b. Certain cases of misalignment can increase stress concentration at the jaw faces leading the specimen to prematurely tear at this location.

Experimental Setup:

The effect of specimen alignment has been measured by performing experiments that compare two or more different alignment conditions. The default, or control alignment method in all these experiments is the Instron Precision Specimen Loader – Thin Films. The other alignment conditions tested were angular misalignment, and twisted misalignment. The two misalignment conditions were created by making 3D-printed versions of the alignment clip which were designed to repeatably insert the specimens with a planned amount of misalignment.

Twist/wrinkling present at pre-load (1 N)

Well-aligned specimen at pre-load (1 N)

Results:

Misalignment significantly affects the deviation of strain measurements when tensile testing both films and foils. In films there is a relatively minor effect on the mean stress (-3.5%) and strain values (6.5%), despite the increased scatter. In foils alignment becomes even more critical as misalignment produces significantly lower mean strain values (18-30%). Misalignment produces a smaller 1-5% reduction in mean stress values, depending on material.

When testing copper foil, 3.5° angular misalignment produced mean crosshead strain 32% lower than that of well-aligned specimens. In this data set the well-aligned specimens produced a coefficient of variation of strain of 13.6%. The misaligned specimens produced a coefficient of variation of 28%. In addition, misaligned specimens broke at the jaw interface 50% of the time whereas well-aligned specimens always broke within the gauge length. As previously discussed, the orientation/angle of the specimen relative to the grips is not the only consideration. When loading a specimen, it is possible for minor twists or wrinkles to occur during the specimen insertion process. When aligning a specimen by hand it is difficult to guarantee its exact orientation in every axis. The Instron Precision Specimen Loader for Thin Films greatly reduces this issue by ensuring that the specimen is always inserted in the same position and orientation.

Specimens with some twist in their alignment exhibited mean strains 30% lower when measured by the Advanced Video Extensometer and 19% lower when measured by crosshead displacement. The difference between these two measurements highlights one of the key issues that can occur when alignment is not controlled. Relatively well-aligned specimens, even those that possess some wrinkles or twisting may not produce premature failures causing the effects of misalignment to go unnoticed. A key difference, though, is that there is significantly more variation in strain from specimen to specimen when twist is present. Specimens with twist present had a coefficient of variation of 42.9% compared to 13.6% in well-aligned specimens. This variation comes from the two sources mentioned in the theory section.

In practice alignment varies in less predictable ways than these test scenarios due to the nature of it being done by hand. The amount of error introduced by hand-alignment is highly operator dependent and often means that data tested by two different operators cannot be compared. Hand alignment can have up to 3x the deviation when compared to assisted alignment for a new user. For an experienced user it may be possible to match the consistency of the Precision Specimen loader on a single dataset, but across multiple datasets hand loading specimens could produce 2x the variation. The Precision Specimen Loader then makes the process faster, more ergonomic, and more repeatable.

Conclusion:

Good alignment of thin film and foil specimens is critical to ensuring accurate and repeatable results. This is a challenge with delicate materials, one that is significantly impacted by operator skill and experience. This impact is only amplified in fast-growing industries, such as EV manufacturing, where there is a need to hire and train new operators to perform tensile testing. A specimen alignment and insertion device minimizes human influence, ensuring that the specimen is always inserted in the same position and orientation. It ensures good specimen alignment which helps to reduce data variation and increases confidence in results.

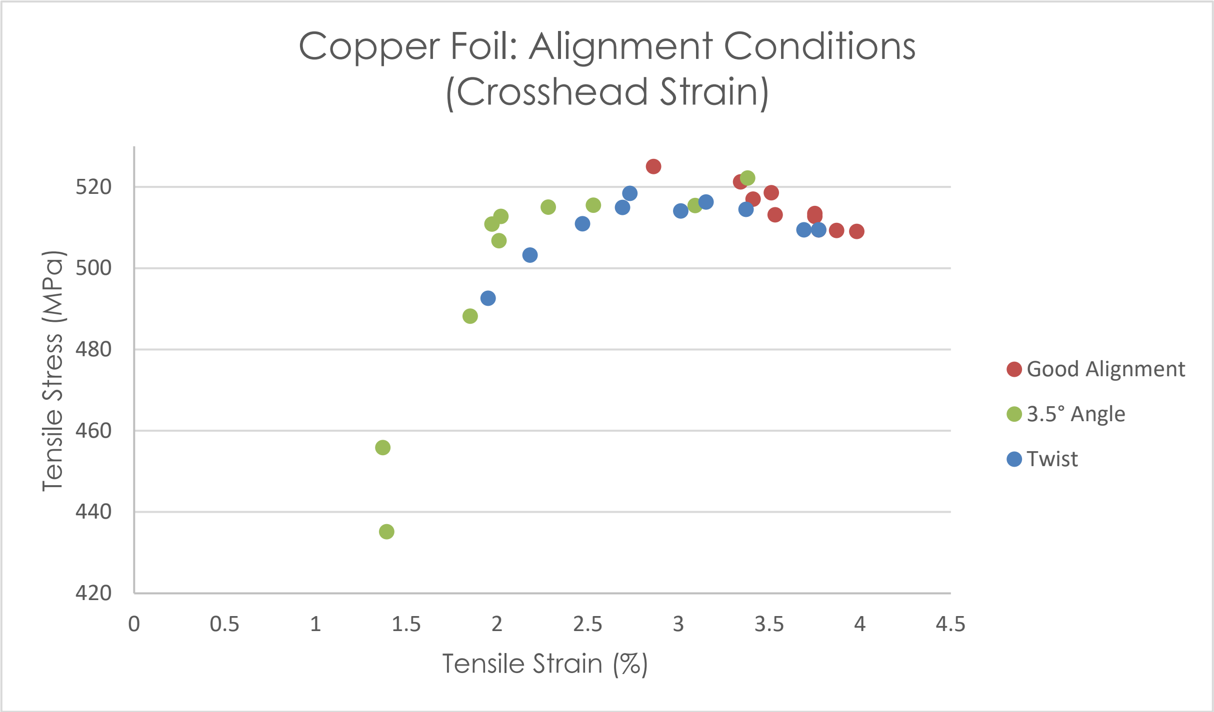

Figure 1

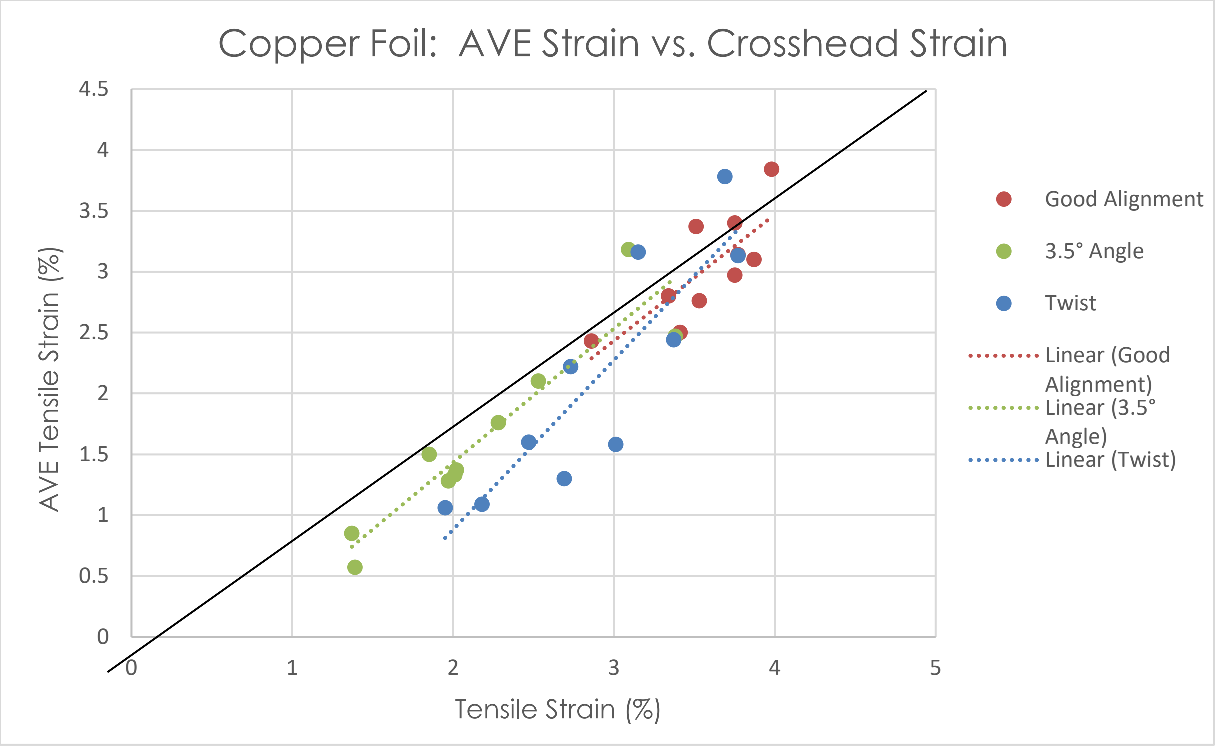

Figure 2