WELD PREPARATION & ANALYSIS SYLLABUS

COURTESY OF BUEHLER

Strong Partner, Reliable Solutions

AutoMet™ 300 in use

OUTLINE

SAMPLE PREPARATION OVERVIEW

I. ITW TEST AND MEASUREMENT GROUP AND BUEHLER HISTORY
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III. SECTIONING
IV. MOUNTING
V. GRINDING AND POLISHING
VI. INSPECTION AND ANALYSIS
A. MACRO INSPECTION – VISUAL
B. MICRO INSPECTION – ETCHED
C. MICROSCOPIC ANALYSIS
D. HARDNESS TESTING

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VIII. MOUNTING
IX. GRINDING AND POLISHING
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COMMON WELD DEFECT PHOTOGRAPHS

ABOUT US

ITW is a Fortune 200 global diversified industrial manufacture of value-added consumables, equipment, and related service businesses. In 2017, ITW had annual revenues of $14.3B with 51,000 employees across 56 countries.

ITW Operating Segments

Automotive OEM

Food Equipment

Polymers & Fluids

ITW TEST AND MEASUREMENT GROUP

ITW's Test & Measurement business provides specialized test and measurement solutions with leading technology to a diverse set of customers operating in highly regulated, demanding environments. Strong brand positions, technological expertise, and market knowledge enable ITW to provide value-added testing and measuring equipment with service and aftermarket capabilities that customers value.

Welding

Construction Products

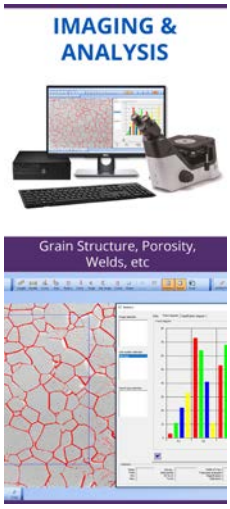
Specialty Products

PRODUCT OVERVIEW

Buehler is a premier manufacturer of scientific equipment and supplies for use in material preparation and analysis; offering products in the following categories:

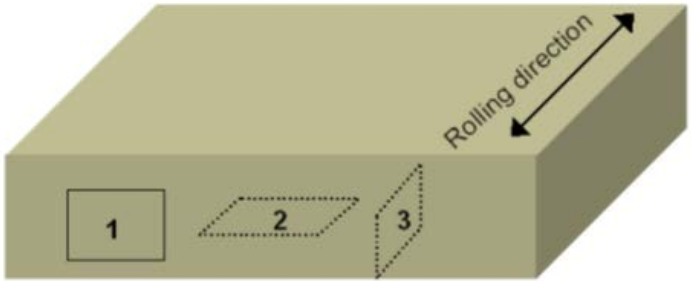
- **Sectioning**
- **Mounting**
- **Grinding & Polishing**
- **Imaging & Analysis**
- **Hardness Testing**

Buehler also provides expert applications and technical support.



SAMPLING

Sectioning Key Concepts



Longitudinal – With flow of material

Transverse – Across flow of material

- Arrows used to indicate down direction in the mount
- X is sometimes used to indicate the face to be polished

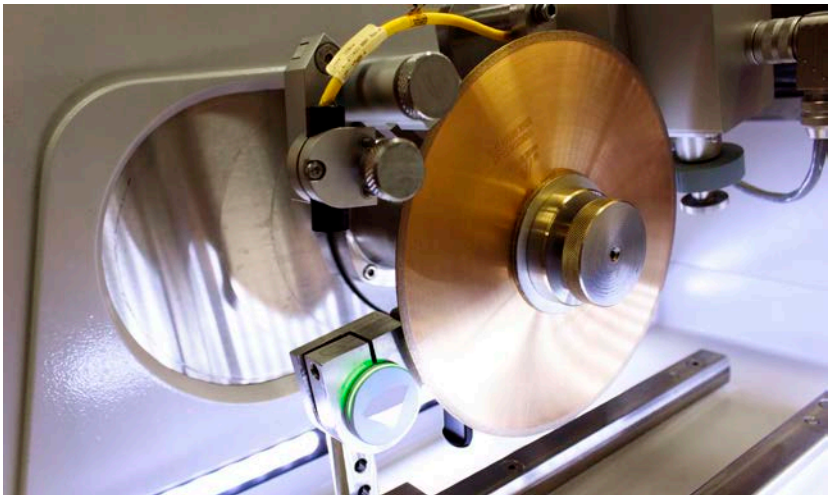
Random locations

Engineered locations

Selected by Metallographer

What am I trying to see?

- Defects
- Manufacturing artifacts
- Inclusions
- Grain size



SECTIONING

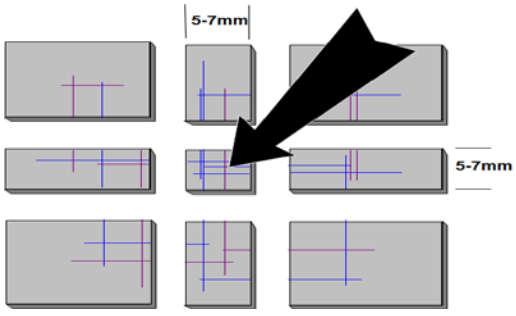
Minimize Mechanical and Thermal Damage

Method	Type of Damage	Possible Depth
Cutting Torch	Severe thermal damage	>15 mm
Shearing	Deep mechanical damage	5 mm
Band/hack saw lubricated but not cooled	Moderate thermal and mechanical damage	2.5 mm
Dry abrasive cutting	Moderate to severe thermal damage	1.5 mm
Wet abrasive cut-off saw	Minimal thermal and mechanical damage	250 µm
Diamond/precision saw	Minimal thermal and mechanical damage	50 µm

Remove specimen from larger component

Reduce sample to manageable size

Minimize the time spent on secondary preparation



Cut near the area of interest

Wheel breakage

Sample clamping

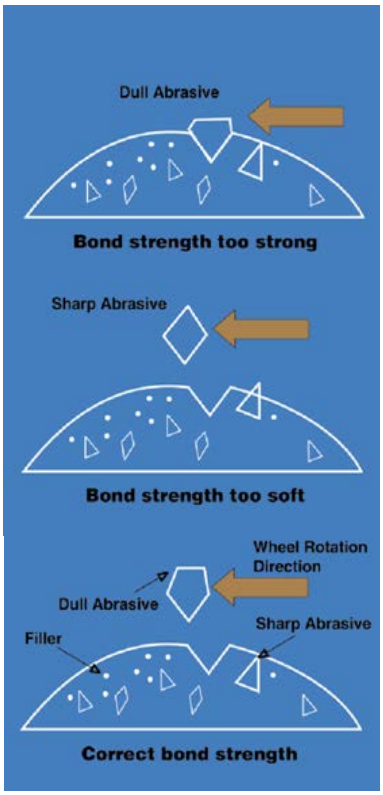
- Firm clamping
- Try to move the part – *wiggle test*
- Do not strain sample – *compression or tension can roll the part into the blade and lead to pinching.*

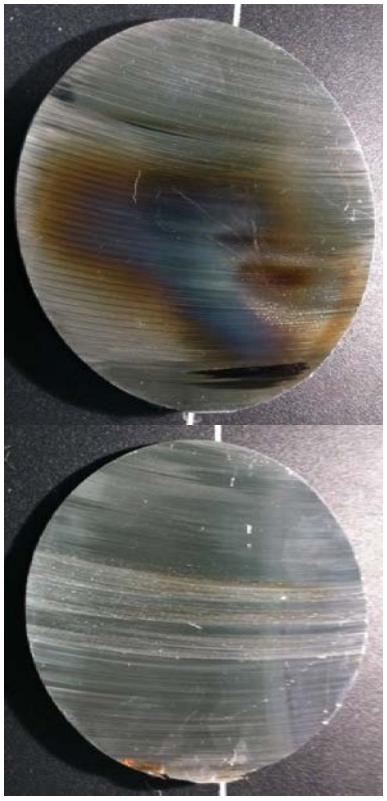
Wheel selection

- Bond and abrasive designed for material type and hardness

Pressure/Feedrate

- Too low of pressure can cause blade to not break-down properly - *Dull cutting points slip on material instead of removing*
- Too high of pressure can cause the blade to bend since it will not breakdown fast enough.





Sample burning

Coolant flow

- Check lines for clogs
- Check coolant spray pattern – *coolant in contact area of cut path*

Wheel selection

- Softer bond will prevent dull abrasive from staying in the wheel

Pressure/Feedrate

- Decrease – *wheel bending / struggling*
- Increase – *wheel glazing / chatter*

Sample heat capacity

- Switch to diamond / cubic boron nitride

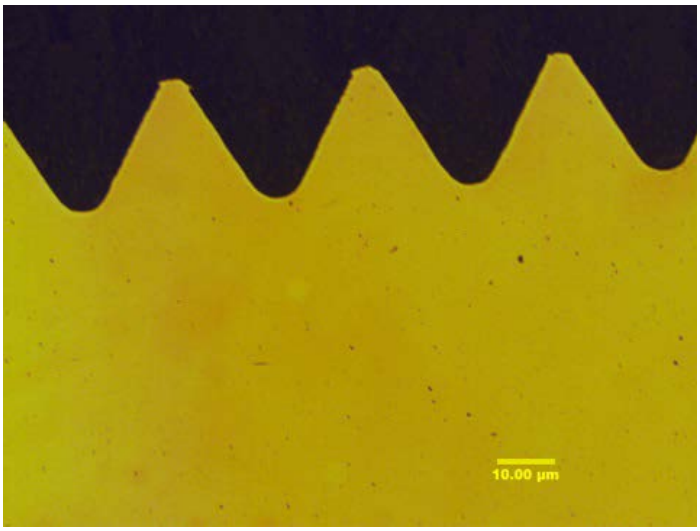
MOUNTING

Automated compression mounting presses, vacuum systems and over 20 types of mounting media

- Fully automated hydraulic presses with programmable heating and pressure cycles, integrated cooling
- Thermoplastic and thermoset compression mounting compounds
- Vacuum systems with rotating dispensing system
- Cold mounting acrylic and epoxy systems

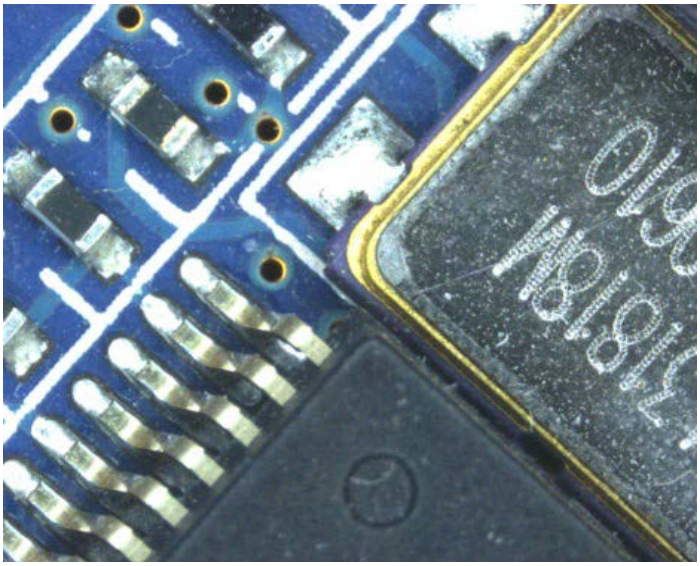
Compression (Hot) Mounting

- A powdered media is heated under pressure to form the mount
- Sample must be robust
- Typically faster with good edge retention



Castable (Cold) Mounting

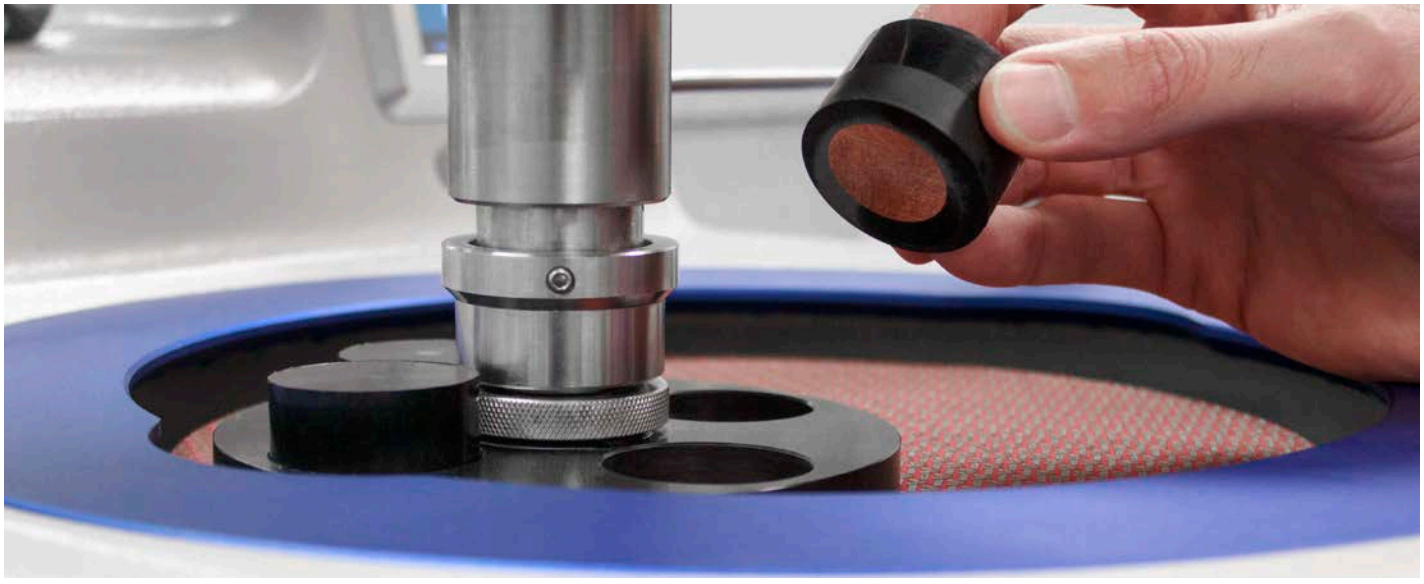
- A viscous polymer liquid is cast in a mount shape
- Delicate samples or heat sensitive samples
- Can infiltrate porous samples with vacuum impregnation to prevent plucking of friable materials



GRINDING & POLISHING

Automated and manual grinders and polishers with consumables for any lab

- Planar grinder provides flat plane samples in seconds
- Semi-automatic grinder/polishers allow up to 12 samples at a time with variable platen and head rotation speeds
- Abrasive paper and diamond grinding discs
- Unique polishing cloths for the best quality surfaces
- High quality diamond suspensions and oxide polishing suspensions for every process

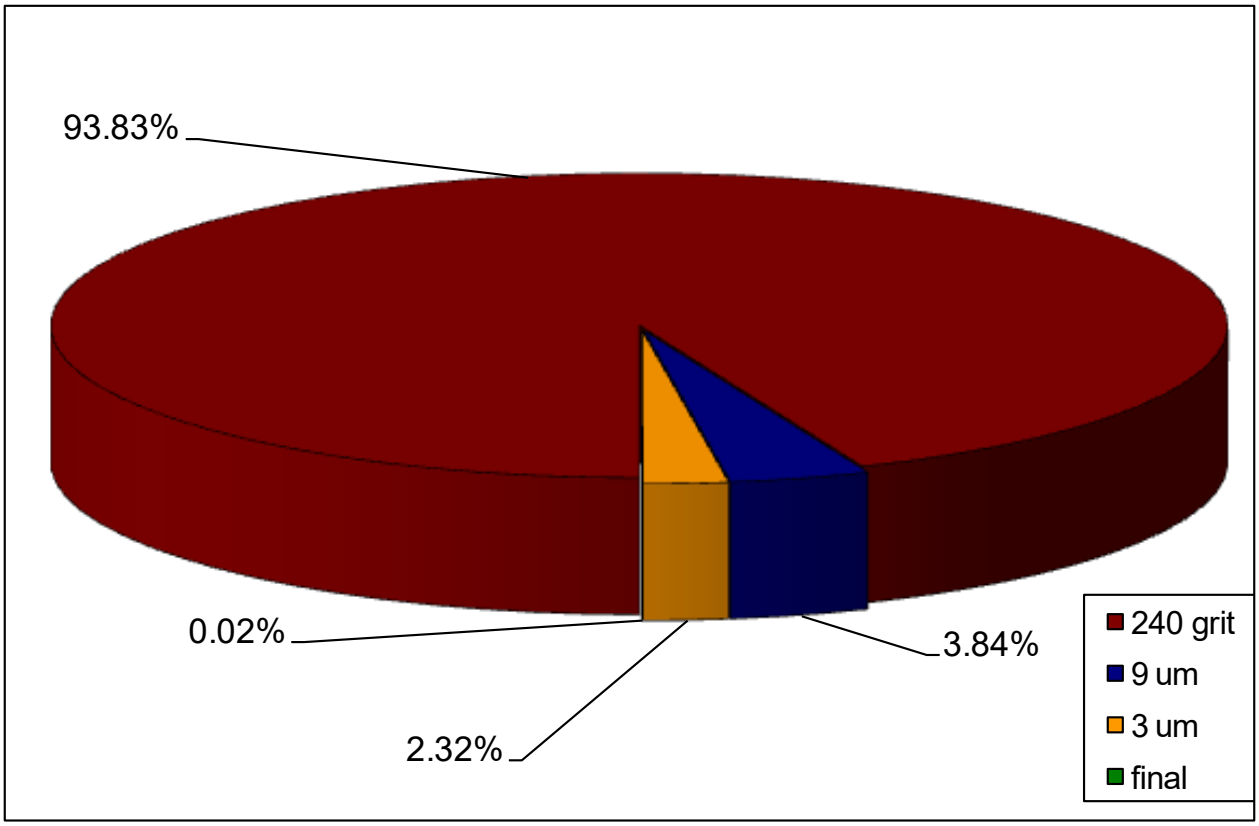


Grinding

- Remove damage from sectioning
- Prepare a single plane for polishing
- Create uniform deformation pattern

Polishing

- Remove damage from previous grinding steps
- Create finer and finer uniform deformation patterns
- Present deformation free surface for examination



Graph showing relative percent of material removed during stages of grinding and polishing

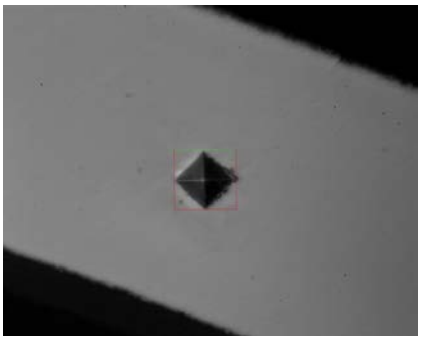
VISUAL INSPECTION

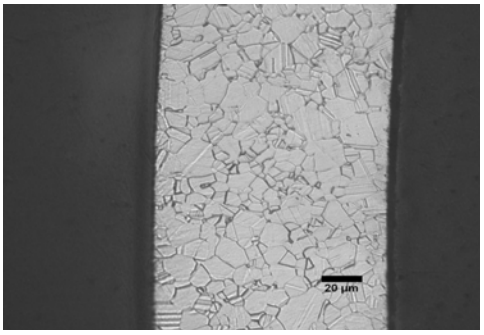
Without Magnification

- Verify preparation is adequate
- Identify large features
- Look for areas to be evaluated at high magnification

With Magnification

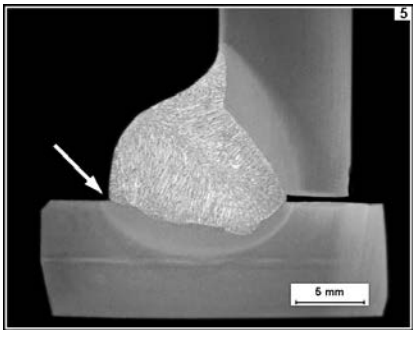
- Identify and document features
- Document features that may be destroyed in etching

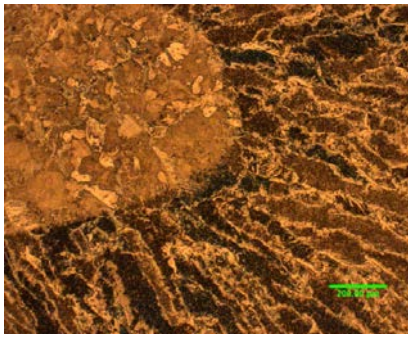




Etching

- Reveal the microstructure of the material
- Selective etching
- Electrolytic etching
- Anodizing
- Heat tinting

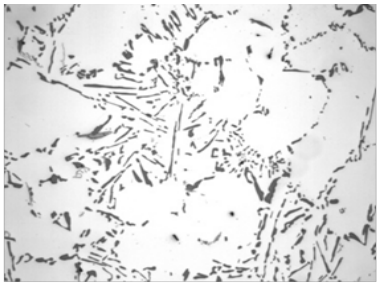




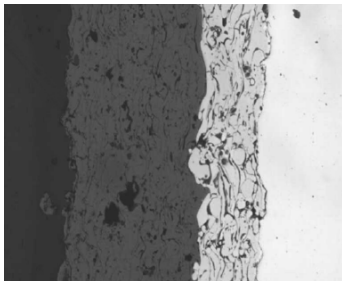
ANALYSIS

Analysis

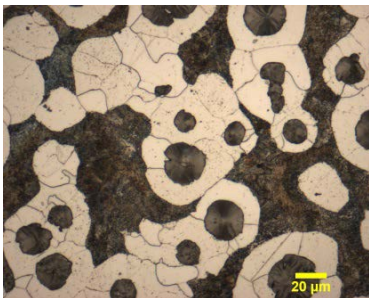
- Microstructure
  - Grain Size
  - Porosity
  - Inclusions
  - Phases
  - Dendrites
  - Layer Thickness



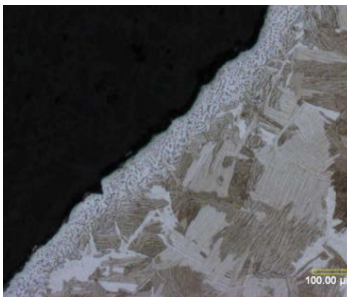
Dendrites in cast Al alloy



Wear coating



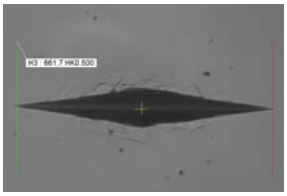
Ductile iron etched

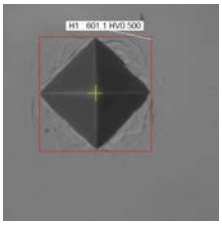


6al4v Ti alpha case

Physical Testing

- Hardness Testing
  - Knoop
  - Vickers





Microscopy

- Illumination Modes
  - Brightfield
  - Darkfield
  - Polarized Light
  - Differential Interference Contrast (DIC)

SAMPLE PREPARATION METHODOLOGY

SECTIONING

Locate the area of interest to section and document if needed prior to sectioning. Place the weld in the saw and section in either the transverse (across the weld) or longitudinal (with the length of the weld). A good rule is to use a permanent marker to place an X on the face that is to be polished. This will help when positioning in the mounting press.

MOUNTING

Apply a light coating of Buehler Release Agent (20-8186 or equivalent) to the mold wall and upper and lower ram. Place the weld in the center of the SimpliMet 4000 with the face to be polished facing downward on the lower ram. Lower the ram by pressing the retract button and add one scoop of EpoMet G (20-3380) followed by 2 scoops of Phenocure Mounting compound to ensure that the upper ram does not contact the weld when being compressed; allowing the weld to come in contact with the upper ram will cause damage(!). Use the following parameters to mount the sample.

Heat	Cool	Pressure (psi)	Temp (F)
4:30	3:30	4200	350 F

Once the cycle completes (shown by lighted section in the status panel) rotate the handle counter clockwise to the unlocked position and press the extend button. The sample will eject and lower ram will raise to the home location.

Refer to the Buehler SimpliMet 4000 manual for troubleshooting, diagnostic and maintenance checklist.

POLISHING

The AutoMet 250 can be used to prepare one to six samples in single force mode. When preparing samples in single force mode the amount of force is applied to individual specimen through fingers.

*Note - If you are running a high volume lab, you should consider the PlanarMet300/AutoMet 300 to automate grinding with no need of further preparation. Contact your Buehler Account Manager for the details and process.

Place the single force specimen holder into the AutoMet 250 head by lifting the lift-lock chuck. Rotate the knurled ring on the sample holder upwards until it seats against the bottom of the lift-lock chuck. Apply abrasive surface; paper for grinding steps or Trident cloth for intermediate polishing, Microcloth for final polishing to the platen. Press and hold the two green buttons on right and left side of the AutoMet 250 head to lower the sample carrier to the platen surface. Once the sample holder has touched the platen release the two green buttons; the sample carrier will retract slightly off the platen surface. Load the samples (up to 6 at a time) into the sample holder and press the two green buttons. At this point the head and base of the AutoMet 250 will begin rotating and the fingers will lower and meet the specimen.

A standard method for preparing steel welds can be followed. Adjustment of the CarbiMet 2 Silicon Carbide (SiC) can be altered coarser (120 grit) for large samples or rough surfaces and finer (600 grit) for samples that only need Rockwell hardness testing.

4-Step Method for Steel Welds

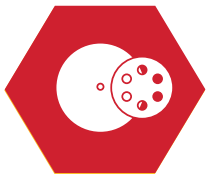
Surface	Abrasive/Size	Load lb. (N)/Specimen	Base Speed (RPM)	Relative Rotation*	Time (min:s)
CarbiMet 2	320- (P400) Grit SiC	5 (22)	240-300	>>	Until Plane
Trident	9-µm MetaDi Supreme Diamond	5 (22)	150-200	><	5:00
Trident	3-µm MetaDi Supreme Diamond	5 (22)	120-180	>>	4:00
MicroCloth	0.05-µm MasterPrep Alumina	5 (22)	100-150	><	1:30

*>> = Complimentary (platen and specimen holder rotate in the same direction)
>< = Contra (platen and specimen holder rotate in opposite directions)

When dosing diamond abrasive onto a cloth, ensure that there is enough lubrication to prevent the cloth from drying but not excessively to create hydroplaning. A general rule is to apply 1.5 ml (roughly 1 -2 sprays) of the MetaDi Supreme suspension per minute of run time. Visually the cloth should have a sheen to it but excessive diamond casting should not occur.

Between steps ensure that the samples, holder and cloths are rinsed with water to prevent cross contamination. Contamination of cloths will result in large rogue scratches running along the surface of the sample, randomly, that are not equal in size. If a cloth becomes contaminated, shows excessive wear or requires a significant increase in polishing time requires to obtain a satisfactory surface finish, discard and replace.

SAMPLE PREPARATION METHODOLOGY



ETCHING

There are several factors to consider when etching samples; is the sample to be macro etched or for microscopic evaluation. Things like time, etchant type and concentration will play a factor in recommendations.

Some basic guidelines are as follows:

1. Use appropriate Personal Protection Equipment when mixing, handling or storing any etchants.
2. Make sure all stored etchants are properly labeled with SDS hazard statements readily shown.
3. Use a clean organized area to etch; report any spills and hazards to ensure a safe working environment.
4. The use of cotton balls and tongs when using swab etchants and small glass beakers for immersion etchants is useful.
5. Once samples have been etched rinse with ethanol to clean and dry the surface.
6. If a sample has been over etched it will require re-polishing of the surface; in some instances, it is easier to etch lightly, review and etch further until a comfort level has been established.

The most common etchant for steel welds will be 2% Nital etchant. This is an etchant that can be stored and readily available for usage in a laboratory. Good for swabbing etchant for microstructure (15-30 seconds) and good for macro etching (1-2 minutes) on most steel samples.
98 ml of ethanol
2 ml HNO3 (nitric acid)

****NOTES OF CAUTION****
Do not store if concentration of nitric acid is higher than 5% as it will be unstable. If you see the solution turning yellowish / brown it should be discarded as it is creating unstable nitrous, nitrogen dioxide and nitric oxide.

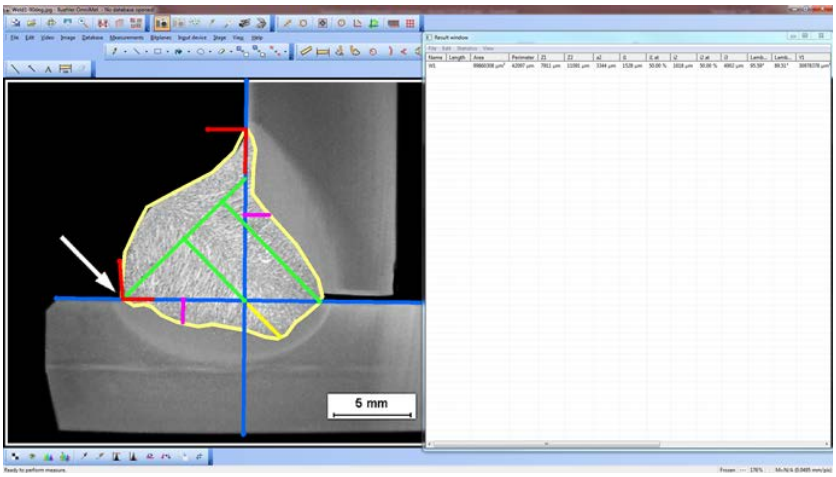
Where to find etchants?

- ASM Handbook
  - Metallography and Microstructures, Vol. 9, 10th ed.
  - Atlas of Microstructures Vol. 7, 8th ed.
  - Metallographic Etching by Gunter Petzow
- Buehler's Solutions page
  - https://www.buehler.com/solutions.php
- Buehler's SumMet book
  - https://www.buehler.com/3DISSUE/SumMetGuide/index.html

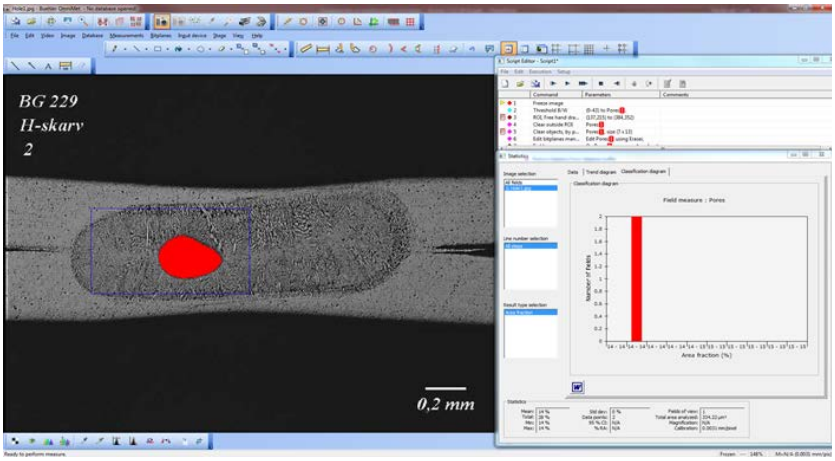
EVALUATION

For microscopy evaluation of samples, we can utilize stereomicroscopes such as the Nikon SMZ800 and Brightfield inverted microscopes such as the Nikon MA100. The stereo microscope can be used to capture larger field of view (FOV) for analysis such as weld measurements or large pores/inclusions. The Brightfield inverted microscope can be used to capture smaller detail such as grain size or resolution in heat affect zones (HAZ).

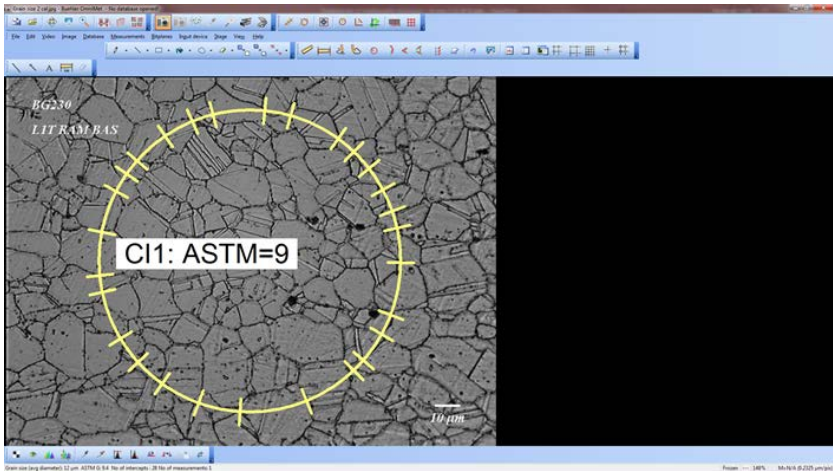
Examples of stereo microscopy work using the OmniMet Weld Module



Examples of stereo microscopy work using the OmniMet Pore assessment



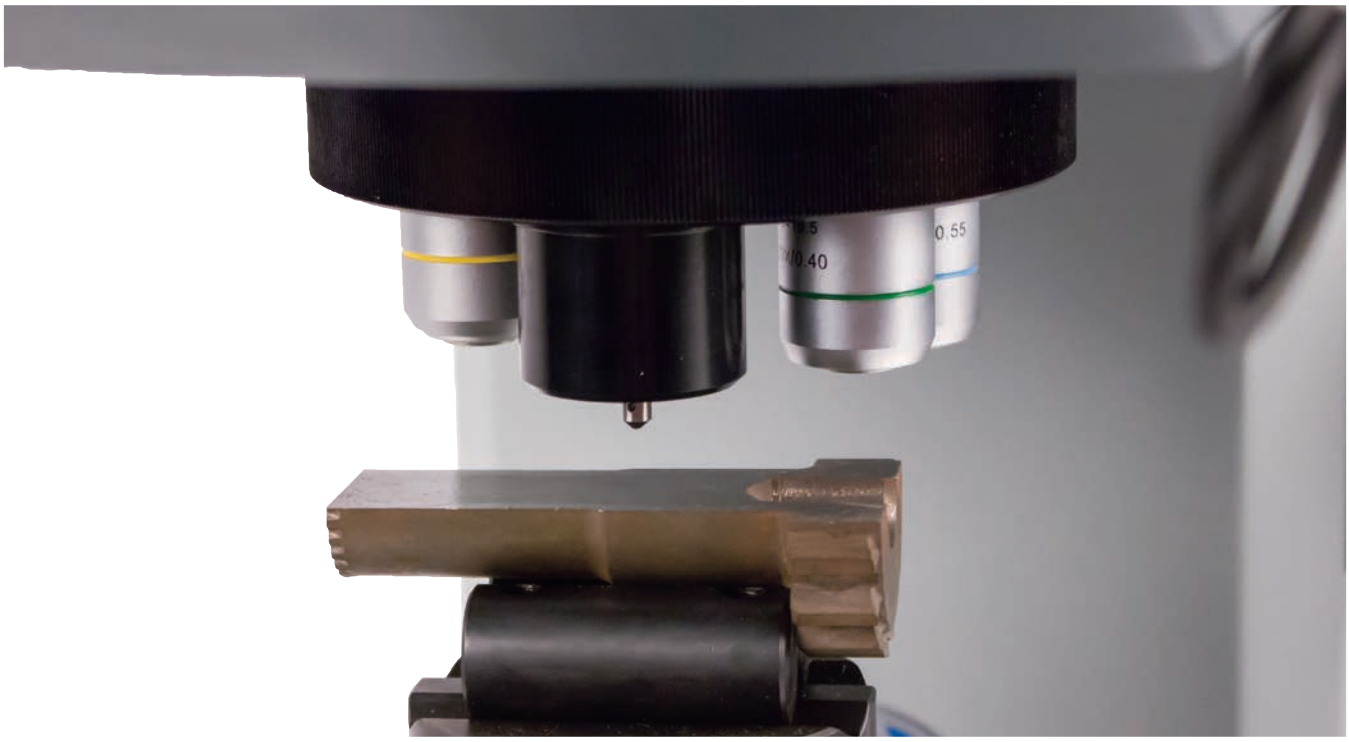
Examples of Brightfield Inverted microscopy work using the OmniMet E-112 grain size module



SAMPLE PREPARATION METHODOLOGY

HARDNESS TESTING

For hardness testing ensure that the sample has a 600-grit surface finish or better for Rockwell testing. Verify the Wilson 574 Rockwell Hardness tester by using the calibration block and referencing the certification paperwork to confirm the hardness value range. Select the scale on screen and associated load weight by rotating the knob, place the specimen securely on the anvil and turn the handle until the electronic brake lock engages the machine will then apply the preload and major load. Data will show on the screen and can be exported through USB if desired.

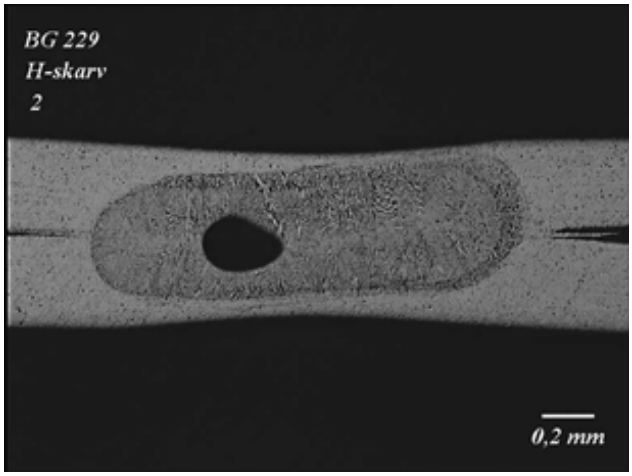


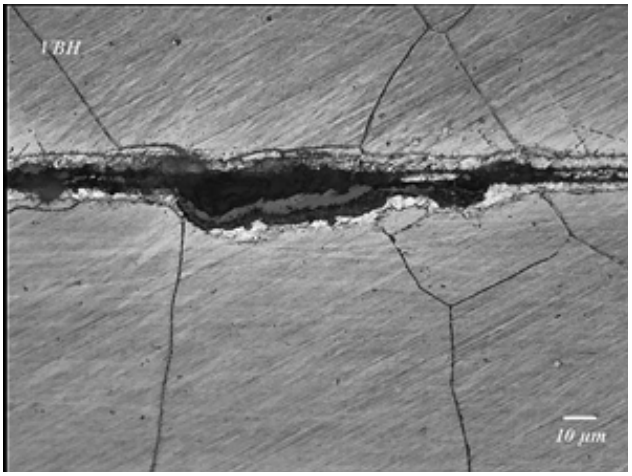
SUMMARY

- Metallographic preparation techniques play a critical role in analysis and can lead to significant impact if done improperly.
- If done improperly, components that meet specification may be rejected or those that do not accepted, leading to failures in the field.
- Care must be taken to ensure the true structure is revealed, free from preparation-induced artifacts.
- Modern material preparation processes exhibit improved preparation quality with greater efficiency relative to traditional methods.
- Understanding how to approach and develop a process along with the challenges to overcome difficulties is becoming ever more important.

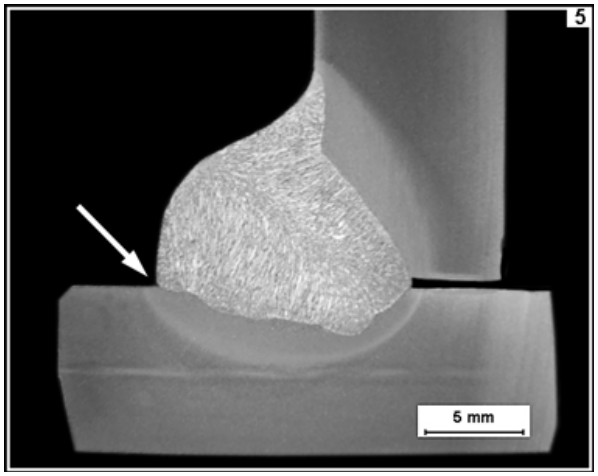
ADDENDUM

Common weld defect photographs

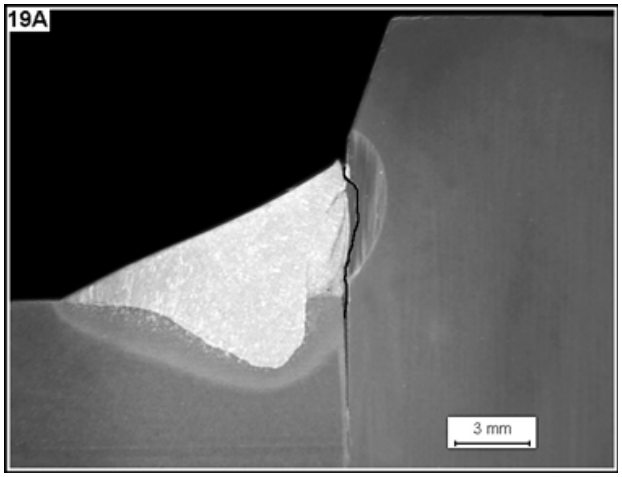




Pores and slag in weld



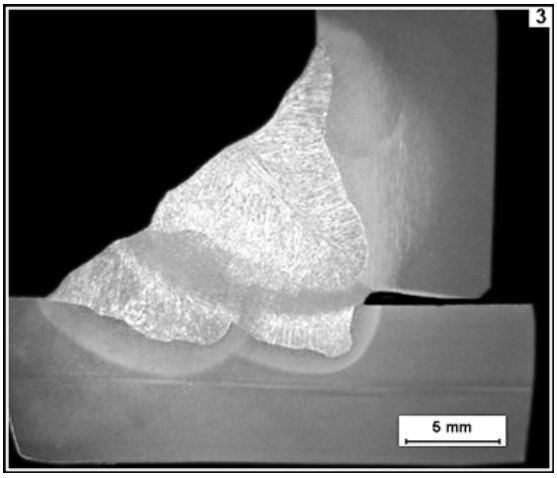
Undercut



Improper placement low heat (note cracking)

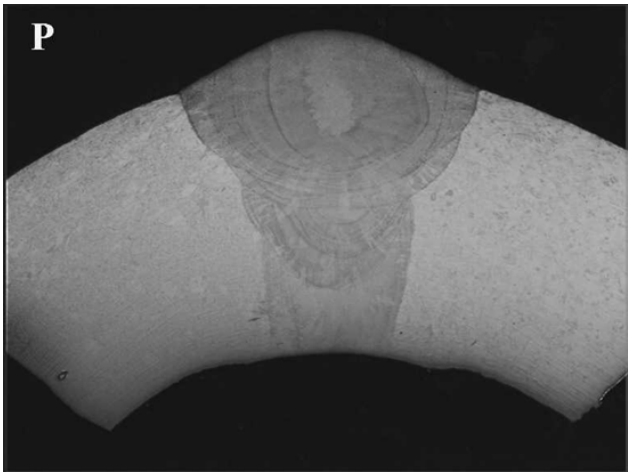
ADDENDUM

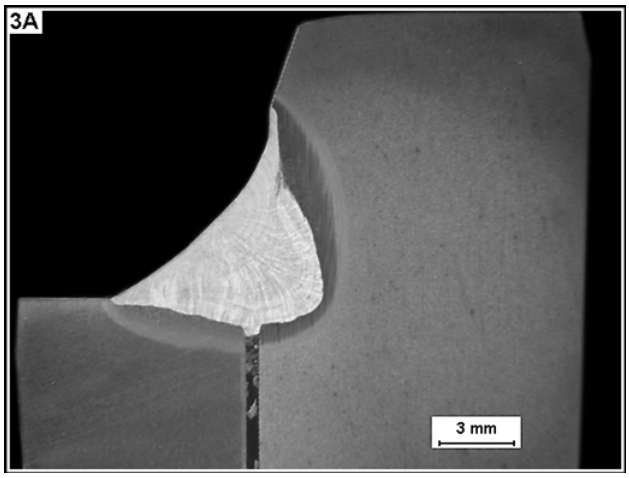
Common weld defect photographs *(continued)*

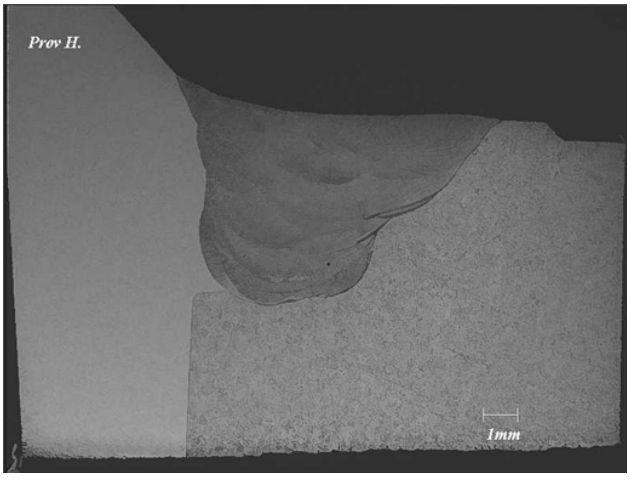


High heat in upper weld (LargeHAZ)

Proper weldments







For specific applications, contact your Buehler Sales Representative.

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