No. 11

LECO MET-TIPS Ideas for Metallographic Procedures

Grinding: Make or Break Your Metallographic Analyses

The most common metallographic procedures follow a six-step process: (1) sectioning, (2) mounting, (3) grinding), (4) polishing, (5) etching, and (6) microscopic examination. One step that is often overlooked is grinding, but failing to optimize this critical step can lead to poor results. Regardless of the etching technique used, or if the newest and most sophisticated equipment is used for examination, the information obtained can be quite misleading if poor grinding procedures are performed. Without proper grinding, deformation can be present to such a degree that false microstructures can be obtained when the specimen is etched; or if quantitative analyses are being performed for the volume-fraction of porosity present and nonmetallic inclusions have been removed, the vacancies left by the removed inclusions will appear as pores and an erroneous value will be the result. If the inclusions are removed, then inclusion identification analyses cannot be performed.

Grinding Abrasives

Grinding can be accomplished with several different grinding abrasives: silicon carbide, aluminum oxide, zirconium oxide, or diamonds. Silicon carbide is by far the most widely used for almost all ferrous and nonferrous alloys. Not only is it economical, but it does an excellent job in preparing a specimen for metallographic polishing. Silicon carbide is sold as discs (either plain-backed or coated with pressure-sensitive adhesive), sheets, or cloth-backed belts.

Certain alloys—like titanium, tungsten, and molybdenum—are outliers. With these, the use of other abrasives produces a better surface finish with less effort required during an intermediate polish to remove the effects of a grinding operation. Metal carbides, metal borides, ceramics, and cermets are more effectively ground on diamond abrasive discs. Materials are removed more rapidly, and flatness and edge retention are more readily achieved.

The effective cutting life of fixed abrasive papers is relatively short—approximately 20 to 30 seconds—especially in the finer grit sizes of 400 and 600. The small grit sizes, by virtue of their size, tend to become clogged rapidly with metal and mounting debris and soon cause a burnishing action, rather than cutting action.

What's the Point of Grinding?

The purpose of grinding is to reduce the amount of deformation brought about by the sectioning operation. Each grinding step removes previous deformation but also introduces deformation of its own. As grinding proceeds through the succeeding finer grit sizes, the depth of deformation decreases until the final grinding step (usually a 600-grit), which leaves a shallow layer that can be removed by the subsequent intermediate and final polishing steps.

Grinding can be considered a microscopic version of a milling machine—except, with grinding, there are thousands of "planing" points on a fixed abrasive paper as opposed to one large planing point on a milling machine. Each fixed abrasive particle acts as a single point planing tool. Chips are formed that have definite rake angles—angles that are formed between the start of a chip and an abrasive particle. Abrasive particles may be oriented such that some chips produce a positive rake angle (cutting action) in one direction only as the surface of a specimen is drawn across it. Yet, other particles are oriented such that a cutting action is achieved in either direction. Each abrasive particle, regardless of orientation, will cut the material being abraded. Some particles will produce well-defined chips and some will produce smaller chips, but with a plowing action that leaves an underlying trough. It is believed that of the two types of scratches being formed (i.e. those with well-defined chips and others will less-defined chips but with deeper troughs beneath them), the latter produces deeper deformation. Abrasive particles that produce well-defined chips remove metal more rapidly than those that plough deep troughs.

How To Properly Grind a Sample

Good grinding techniques constitute approximately 90% of the effort involved in preparing a metallographic specimen and will make the difference between a mediocre and a well-prepared specimen. If a good grind is not achieved, the specimen will likely need to be taken back to a grinding step after it has already gone through the final polishing stages.

A normal grinding sequence will consist of several grinding steps, always in a decreasing grit size, and usually will commence with a 180-grit followed by 240-, 320-, 400-, and 600-grit.

A grinding sequence should always start with the finest grit size that will produce a flat surface and remove the effects of the sectioning operation. Sectioned surfaces obtained from an abrasive cut-off wheel can usually start with a 180-grit grind, while surfaces obtained from sectioning with band saws, hacksaws, or other rough sectioning equipment will require beginning with a coarser grit size, such as 80 to 150.

Grinding procedures can be carried out using any of several methods: vertical disc grinding, horizontal disc grinding, hand grinding, or belt grinding (although this type of grinding is usually reserved for the coarser grinding steps). Each method is effective; one is not superior to the other. A metallographer will typically choose the one they have had the most training on or feel the most comfortable with.

Water should be used as a coolant to avoid damage to the specimen's surface. The grinding process should continue until all scratches are uniform in size and unidirectional. The sample should be rotated 45 to 90 degrees to the previous grind to enable a visual examination of the progress of grinding. Not only should the specimen surface be visually inspected, but also the mounting media if used. Uniform grinding scratches should extend across the specimen surface and well into the mounting media. If there are large scratches observed in the mounting media, then the coarse scratches will often extend into the specimen edges. However, they may not be seen until the specimen has been taken through the polishing steps and viewed with a microscope. Only a re-grind will remove them, so it's important to properly inspect the mounting media. Failure to do so could result in wasted time.

Automatic Grinding Systems

An automatic system incorporates the latest technology to give the ability to program selected parameters such as wheel speed, time, pressure (in psi), type of liquid being dispersed as lubricant/coolant, frequency of dispersion, and in some units, spindle speed, direction of spindle rotation, stock removal (either in inches or millimeters), and oscillation.

A large selection of specimen holders will accommodate unmounted samples having non-uniform morphologies as well as the universal sizes of mounted specimens. A specimen leveler ensures all samples start at a common plane.

A competent metallographer can prepare a specimen manually form the mounting stage and have it ready for microscopic examination in the etched condition in approximately fifteen minutes, depending upon the alloy being prepared. An automatic polisher can do up to twelve specimens in the same time and have flatter edges, less disturbed metal, and use less grinding/polishing steps than in manual preparation. For example, the accepted procedures used in manual preparation consist of a series of grinding steps commencing with a 180 SiC grind, followed by 240-, 320-, 400-, and 600-grit grind; intermediate polishing with a 6-micron diamond compound followed by 1-micron diamond polish, then concluding with a final polish consisting of sub-micron polishing abrasives. This is a total of eight grinding and/or polishing steps.

An automatic polisher may eliminate two or three grinding steps and one intermediate polishing step with more than satisfactory results. This may seem like a relatively minor change, but when multiplied by the many specimens that are prepared each day in a metallographic laboratory, the savings can be dramatic. Not only is sample preparation time shorter, but both consumable costs and labor costs are reduced. The procedures established for ferrous and nonferrous alloys processed through the polisher are basically the same; the deviation being mostly in the final polishing abrasive used.

In some instances—for example, carbon steel alloys—the initial grinding step commenced with a 240-grit SiC grind followed by a 600 grit SiC grind, thus eliminating yet another grinding step. In another case, twelve mounted titanium alloy specimens went from the 600 grit SiC grind directly to 0.05-micron gamma alumina with excellent results. The 600 grit scratches were effectively removed and etching showed the specimens to be virtually free of disturbed metal.

The procedures outlined in the table below have been used as the starting point for successfully preparing a wide variety of samples, including low and medium carbon steels, gray and nodular cast iron, free machining steels, super alloys, heat resistant alloys, carburized steels, titanium alloys, copper alloys, aluminum alloys, and more.

Guidelines for Grinding Specimens Using Automatic Preparation

SiC GRIT SIZE	POLISHING WHEEL TIME (SEC)	SPINDLE SPEED/ SPEED (RPM)	DIRECTION (RPM,CW/CCW)	OSCILLATION (Y/N)	PRESSURE (PSI)
180	60	300	100/CW	Y	45
320	60	300	100/CW	Y	45
600	60	300	100/CW	Y	45

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