LECO® Met-Tips Ideas for Metallographic Procedures No. 11

The Art of Grinding

One of the two major contributions to the art of specimen preparation was the introduction of fixed abrasive grinding papers; the other being diamond polishing compound. These two contributions, more than any other, served to advance metallography to its present state-of-the-art status. Before the introduction of fixed abrasive grinding, grinding was accomplished by making a slurry of abrasive powders (SiC or Al_2O_3) with water and applying the slurry to a flat wheel made of cast iron, lead, or a wax-coated wheel. These wheels had a machined spiral groove (or concentric rings) on the polishing surface and a lip on the outer edge to retain the slurry. The grooves tended to keep the slurry evenly distributed over the surface of the wheel. Specimen surfaces had to be flat to ensure the entire area of the sample came into contact with the grinding abrasive; this usually required a surface grinding operation. Moreover, both surfaces of a specimen needed to be flat and parallel to allow weights to be added that would keep the specimens flat against the grinding wheel. The specimens were held in a rigid position while following the same tracking on a wheel, but the specimens were free to rotate around their own axis. Needless to say, this was a very time consuming operation, not to mention being messy, particularly since several successively finer grits had to be used. However, the end result was very good; edge retention was excellent and minor constituents in the matrix microstructure were flat and intact. This was lapping with externally charged abrasives and was used until the introduction of fixed abrasive papers.

Any metallographic procedure involves three distinct stages: (1) preparation (which consists of sectioning, mounting, and grinding); (2) polishing and etching; and (3) microscopic examination. The three stages actually break down to six steps, and of the six steps involved in the overall process of metallographic examination, the one most overlooked—not the most important because each step is important— is the grinding step. This can be quite disastrous when interpretation is done. Regardless of which brilliant etching techniques are 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. For instance, 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 can be accomplished with several different grinding abrasives: silicon carbide (carborundum); aluminum oxide (corundum); or emery (a composite of ferric oxide and aluminum oxide). Silicon carbide is by far the most widely used for almost all ferrous and nonferrous alloys. Exceptions to this include the grinding of certain alloys containing titanium, tungsten, and molybdenum (where the use of emery paper seems to produce 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. Metal is removed more rapidly and flatness and edge retention are more readily achieved.

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, leaves only a shallow layer that can be removed by the subsequent intermediate and final polishing steps.

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 those 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. 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. 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, and one cannot be said to be superior to the other. Any method preferred by a metallographer is usually the one he has been trained on, or more specifically, what he has inherited in the laboratory.

Water should be used as a coolant to avoid damage to the specimen surface (Met-Tip#10). With vertical or horizontal disc grinding, however, the use of a wax lubricant tends to minimize embedment of loosened abrasive particles into the specimen surface. The wax holds loosened abrasive particles in position rather than allowing them to roll about under the specimen surface. A lubrictating stick wax (i.e. Relton STICK-KUT) or a candle are excellent wax lubricants and are applied by wiping once across the rotating surface of the grinding disc, starting at the center and drawing to the outer periphery. Moderately heavy pressure should be applied. Too little pressure will be ineffective, and just a little more pressure will result in burnishing. Burnishing is where metal is not being removed by abrasive particles, but rather the particles act as a buffing agent. Too much pressure will result in uneven scratches or heavy gouges, or worse yet, a beveled surface. Grinding should continue until all scratches are uniform in size and uni-directional. 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, more often than not the coarse scratches will extend into the specimen edges, but may not be seen until the specimen has been taken through the polishing steps and viewed with a microscope. Only a regrind will remove them, and time has been lost.

Anyone who grinds has a pressure point (i.e. heavier pressure inadvertently applied at one point). It can be at the fingertips or at the thumb, as a sample is held in the hand. The secret to overcoming this and to ensure a flat surface is to look at the surface of the specimen before that particular grinding sequence is completed, and preferably after the first few seconds of specimen-paper contact. The new set of grinding scratches superimposed over the old set will very effectively illustrate where the pressure point is and the operator can concentrate on equalizing the pressure. Once an operator establishes his pressure point and consciously concentrates on overcoming it, it soon becomes second nature.

Each fixed abrasive particle acts as a single point planing tool, and grinding can be considered a microscopic version of a milling machine except there are thousands of "planing" points on a fixed abrasive paper as opposed to one large planing point on a milling machine. Chips are formed that have definite rake angles, and abrasive particles are oriented such that some chips produce a positive rake angle (cutting action) only in one direction as the surface of a specimen is drawn across it, while other particles are oriented such that a cutting action is achieved in either direction. Rake angle is the angle that is formed between the start of a chip and an abrasive particle. Each abrasive particle, regardless of orientation, will cut the material being abraded, some particles producing well-defined chips and others with 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 chips that plough deep troughs.

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.

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, more often than not the specimen will need to be taken back to a grinding step when it is already through the final polishing stages. Good grinding techniques can be developed very easily and the metallographer is urged to cultivate them as soon as possible so they become standard. Good grinding techniques will include the following.

- Use water (or wax) during grinding steps
- Use moderately heavy pressure
- Rotate specimen 45 degrees to 90 degrees between grinding steps
- Visually observe uniformity of scratches in mounting media as well as on the specimen surface
- Do not try to grind too many specimens on the same grinding paper, particularly on the finer grit sizes

For a more comprehensive understanding of grinding characteristics, L.E. Samuels' book, Metallographic Polishing by Mechanical Methods, is recommended (ISBN: 0-87170-779-9, SAN: 204-7586).

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LECO Corporation • 3000 Lakeview Avenue • St. Joseph, MI 49085 • Phone: 800-292-6141 • Fax: 269-982-8977
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