Mechanical Preparation

The basic process of mechanical specimen preparation is material removal using abrasive particles in successively finer steps, to remove material from the surface until the required result is reached. There are three mechanisms of removing material: *grinding, polishing and lapping.* They differ in the tendency to introduce deformation in the specimen surface. In general, the sequence of steps involves; a single plane grinding step, 1 – 2 fine grinding steps, 1 – 2 polishing steps and an optional oxide polishing step.

Contents

Selecting the correct method

In order to select the appropriate method for preparation of your material, you need to have an understanding of these parameters:

- The hardness/ductility of the specimen
- Characteristics of the different abrasives
- Abrasive techniques
- Parameters that influence material removal (time, force, speed etc.)

The latter three are discussed in further topics.

There are three different ways to select the appropriate procedure for plane grinding, fine grinding, diamond polishing and oxide polishing:

1. According to the material name using e-Metalog (in the e-shop).
   Login with email: eng-mat@deakin.edu.au and password: eng-mat
2. According to a specific application using Struers Application notes.
3. According to a materials physical properties using the Metalogram.

Some materials such as composites, coatings or other materials consisting of various phases or components cannot be easily placed in the Metalogram. In these cases, the following rules can be applied when deciding on the preparation method:

- *Predominant component -* Select a method which is suited for the material's predominant component.
- *Artifacts -* Check the samples after each step and, if preparation artifacts do occur, consult troubleshooting for advice. The most common artifacts are edge rounding, relief, pull-outs and porosity.

For composites containing less than 10-20% of hard phases/components (800HV+) in a soft matrix/softer components

- Select method appropriate for the softer phases/components

For composites containing more than 10-20% of hard phases/components (800HV+) in a soft matrix/softer components

- Select the PG step according to the hard phases/components
- Select the FG, DP, OP steps according to the softer phases/components

Lapping

- The abrasive is applied in a suspension on to a hard surface.
- The abrasive rolls and moves freely in all directions, hammering small particles out of the specimen surface and introducing deep deformations.
- Used for very hard, brittle materials eg: ceramics and minerals.

There are three positions of an abrasive grain passing the specimen surface in a rolling fashion (figure 1):

1. The grain enters the specimen surface.
2. The grain rolls over and hammers a piece of the specimen material out, causing severe deformation in the specimen material.
3. The grain rolls on without touching the specimen surface. When it passes the specimen again a smaller or bigger piece is hammered out, depending on the shape of the grain.

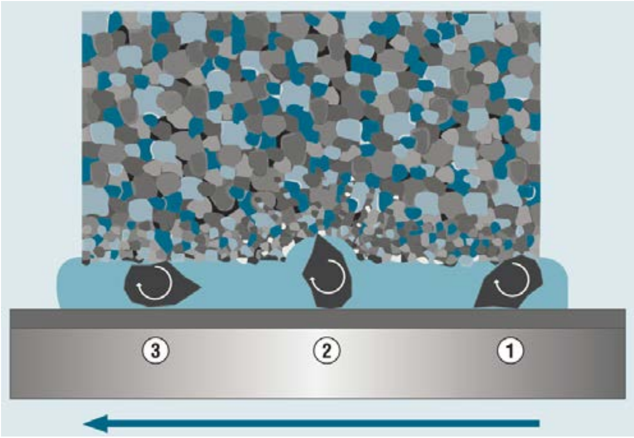


FIGURE 1: THREE POSITIONS OF AN ABRASIVE GRAIN PASSING THE SPECIMEN SURFACE DURING LAPPING.

Grinding

- The abrasive is fixed.
- Fixed abrasive particles produce chips of the specimen material. Sharp abrasive grains produce the lowest amount of deformation in the specimen while giving the highest removal rate.
- Dull abrasives cause ploughing instead of cutting, which produces greater deformation and heat.

The three positions of an abrasive grain passing the specimen surface in a fixed state are (figure 2):

1. The grain is entering the specimen surface. The grain is totally fixed in the X-direction; movement (resilience) in the Y-direction can take place. The chip is started when the grain enters into the specimen material.
2. The grain is halfway through and the chip is growing.
3. The grain passes out of specimen surface, leaving a scratch in the surface with relatively little deformation in the specimen material.

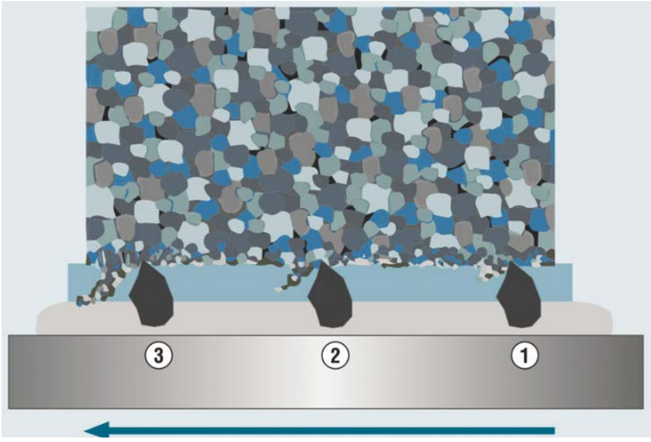


FIGURE 2: THREE POSITIONS OF AN ABRASIVE GRAIN PASSING THE SPECIMEN SURFACE DURING GRINDING.

There are two types of grinding processes in mechanical preparation:

1. Plane Grinding

- Normally the first step in the grinding process.
- Totally fixed grains with a relatively large grain size are preferably used.
- During wear, new abrasive grains are revealed thus ensuring a consistent material removal.
- Removes damage introduced by cutting.
- Ensures that the surfaces of all specimens are similar.
- Keeps multiple specimens in same plane.
- Short grinding times.
- Maximum flatness.

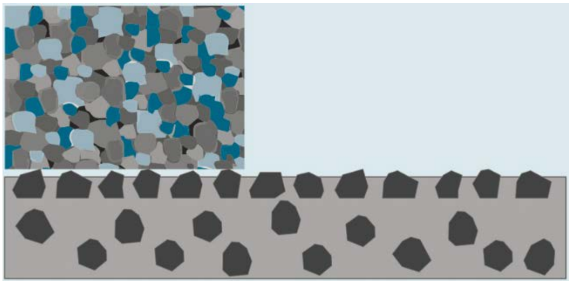


FIGURE 3: ABRASIVE GRAINS EMBEDDED IN THE SURFACE PASSING THE SPECIMEN SURFACE DURING PLANE GRINDING.

2. Fine Grinding

- Abrasives are incorporated into the surface and added to the surface.
- Produces a surface with little deformation that can easily be removed during polishing.
- Ensures that the surfaces of all specimens are similar.
- Keeps multiple specimens in same plane.
- Rigid disc system - ensures edge retention and minimises deformation.

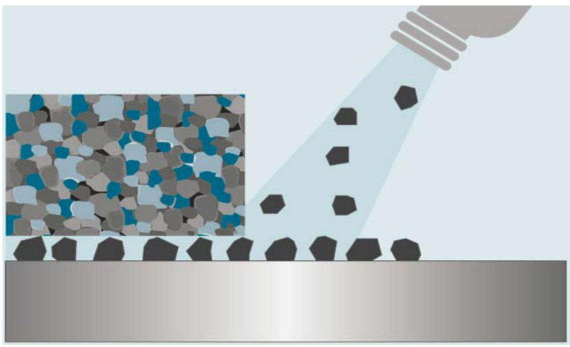


FIGURE 4: ABRASIVE GRAINS EMBEDDED AND ADDED TO THE SURFACE PASSING THE SPECIMEN SURFACE DURING FINE GRINDING.

Abrasives

The abrasives used for grinding must be 2 – 3 times harder than the material being prepared. There are three types of abrasives; Aluminium oxide (Al_2O_3), silicon carbide (SiC), and diamonds. The use of a rigid disc system provides is essential when edge retention is a necessity. The use of a rigid disc reduces fine grinding to one step rather than the normal grinding steps with SiC paper #500, #1000, #2400 and 4000 grits, and can be performed both manually and automatically. However, there are some materials that require the use of SiC paper as its fine grinding step(s).

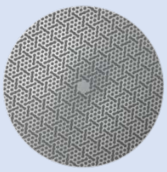
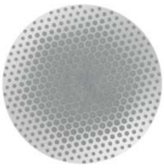
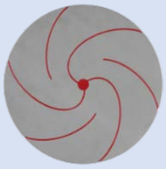
MD-Rigid Disc Selection Guide

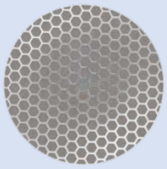
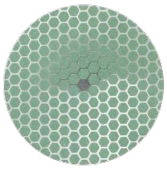
The choice of rigid disc is very important in order to obtain a high, consistent material removal rate, short grinding times, maximum flatness and to minimise post-processing. Table 1 outlines the required disc for grinding and its properties based on sample material.

After determining the method required for your sample material, if you require any MD grinding discs you will need to organise their purchase with the project budget form. The MD-disc size for the LaboPol and Tegramin is 25mm.

MD-System Selection guide

Table 1: Recommended MD-Rigid disc for different sample materials.

Sample Material	Hardness Range	Disc	Abrasive	Bond
Ferrous metals and hard materials	150 – 2000HV	MD-Piano 80, 120, 220, 500, 1200, 2000, 4000 	Diamond	Resin
Non-ferrous metals and soft materials	40 – 250HV	MD-Primo 120 or 220 	Silicon Carbide	Resin
Aluminium alloys & hard materials containing aluminium	50 – 2000HV	MD-Molto 220 	Diamond	Resin
Titanium Alloys	150 – 450HV	MD-Mezzo 220	Diamond	Resin

				
Fine grinding materials harder than 150 HV	>150HV	MD-Allegro 	15 – 6µm added as suspension or spray	
Fine grinding of soft materials, composites with soft matrix	40 – 250HV	MD-Largo 	9 – 3 µm added as suspension or spray	

Polishing

There are two types of polishing processes in mechanical preparation:

1. Diamond Polishing
    - A diamond abrasive is added and incorporated into to a cloth surface.
    - A smaller chip size is desirable to ultimately achieve a specimen surface without scratches and deformation.
    - More resilient cloths are used, along with smaller grain sizes, such as 3 or 1 µm, to obtain a chip size approaching zero.
    - A lower force is used on specimens to reduce the chip size during polishing.

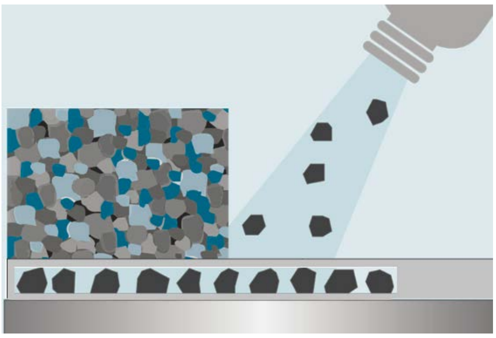


FIGURE 5: ABRASIVE DIAMOND GRAINS ARE ADDED AND INCORPORATED INTO THE CLOTH PASSING THE SPECIMEN SURFACE DURING POLISHING.

2. Oxide Polishing
    - Uses colloidal silica, with a grain size of approximately 0.04 µm and a pH of about 9.8.
    - Combines chemical activity and fine, gentle abrasion to produce scratch-free and deformation-free specimens.
    - Required for certain materials, especially those that are soft and ductile
    - Required when preparing sample for microstructure visualisation.

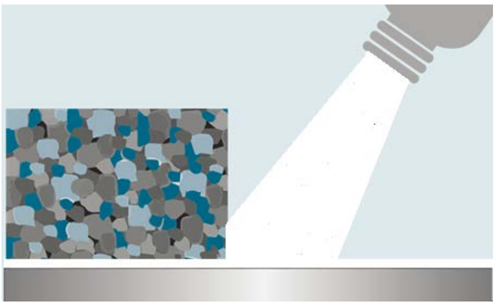


FIGURE 6: COLLOIDAL SILICA IS ADDED AND INCORPORATED INTO THE CLOTH PASSING THE SPECIMEN SURFACE DURING OXIDE POLISHING.

MD-Cloth Selection Guide

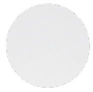
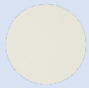
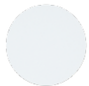
The choice of cloth material vs sample material is very important in order to obtain a high quality result free of scratches, deformation, edge rounding and relief. Hard polishing cloths offer low resilience and Soft polishing cloths offer high resilience. Table 2 outlines the required disc for polishing and its properties based on application.

After determining the method required for your sample material, if you require any MD cloth discs you will need to organise their purchase with the project budget form. The MD-disc size for the LaboPol and Tegramin is 25mm.

MD-Cloth Selection guide.

Table 2: Recommended MD-Cloth disc for different applications.

Application	Resilience	Hardness Range	Disc	Abrasive	Cloth material
Fine grinding of soft material Pre-polishing of hard materials	Very low	Hard	MD-Plan	15 – 3µm	Coated, woven polyester

Fine grinding of soft metals Pre-polishing and polishing of hard and brittle materials	Very low	Hard	MD-Pan 	15 – 1μm	Impregn. Non-woven technical textile
Fine grinding and polishing of ferrous metals, non-ferrous metals, coatings and plastics	Medium	Hard	MD-Sat 	9 – 3μm	Woven acetate
			MD-Dur 	9 – 1μm	Satin woven natural silk
Polishing of all materials	Medium	Hard	MD-Dac 	6 – 3μm	Satin woven acetate
Polishing of ferrous and non-ferrous metals and polymers	High	Soft	MD-Mol 	≤3 μm	Taffeta woven 100% wool
One step polishing for sintered carbides and steels	High	Soft	MD-Plus 	≤3 μm	Synthetic nap
Polishing of all materials	High	Soft	MD-Floc 	≤3 μm	Synthetic nap
Final Polishing of all materials	Very high	Very soft	MD-Nap 	≤1 μm	Synthetic short nap
Final Polishing of all materials	High	Soft	MD-Chem 	<1 μm	Porous neoprene

Use figure 7 when the determined method produces relief, edge rounding, scratches or deformation.

FIGURE 7: TROUBLESHOOTING GUIDE FOR MD-DISCS AND MD-CLOTHS WHEN METHOD DOESN'T PRODUCE HIGH QUALITY SURFACE OF THE SPECIMEN.

Preparation Parameters

There are nine parameters that need to be considered during mechanical preparation; Disc surface, abrasive, grit/grain size, lubricant, rotational direction, rotational speed, force, time and specimen holder positioning. The first four parameters are covered above, the later five are addressed below. The first eight parameters are outlined in the determined method for a given sample material and are dependent on the disc size, specimen size, and number of specimens.

1. Rotational Direction

- Co-direction is recommended.
- Counter-rotation is only used when extreme abrasion is required.
- Counter-rotation can be used during oxide polishing to minimise suspension loss.

2. Rotational Speed

The requirements are outlined in your determined method, however, in general;

- The sample holder is always rotated at a speed of 150rpm
- 300rpm disc speed is used for grinding (higher removal)
- 150rpm disc speed is used for polishing

3. Force

The requirements are outlined in your determined method based on preparing six individual specimens with a diameter of 30mm. However, in general;

- Grinding: 20 – 40 N
- Polishing: 15 – 30 N
- OP-Polishing: 10 – 15 N

These can be adjusted according to the number of samples and their size using table 3.

Table 3: Conversion factors for adjusting the amount of force to apply during mechanical preparation based total sample surface area.

No. of Samples	1	3	6
25mm dia.	5cm^2	15cm^2	29cm^2
30mm dia.	7cm^2	21cm^2	42cm^2
40mm dia.	13cm^2	38cm^2	75cm^2
50mm dia.	20cm^2	59cm^2	118cm^2

3 samples 25mm dia. = 15cm^2 – divide the force by 3
3 samples 30mm dia. = 21cm^2 – divide the force by 2
3 samples 40mm dia. = 38cm^2 – same force as stated
6 samples 25mm dia. = 29cm^2 – divide the force by 1.5
6 samples 30mm dia. = 42cm^2 – same force as standard sample size
6 samples 40mm dia. = 75cm^2 – increase force slightly, extend preparation time

4. Time

The requirements are outlined in your determined method.

5. Specimen Holder Positioning

- The specimen holder should be no more than 1-1.5mm above the surface.
- The specimen holder should be slightly over the edge of the disc and not over the centre line (figure 8).
- Correct positioning of the specimen holder ensures planeness by preventing halfmooning and pencil shaping.

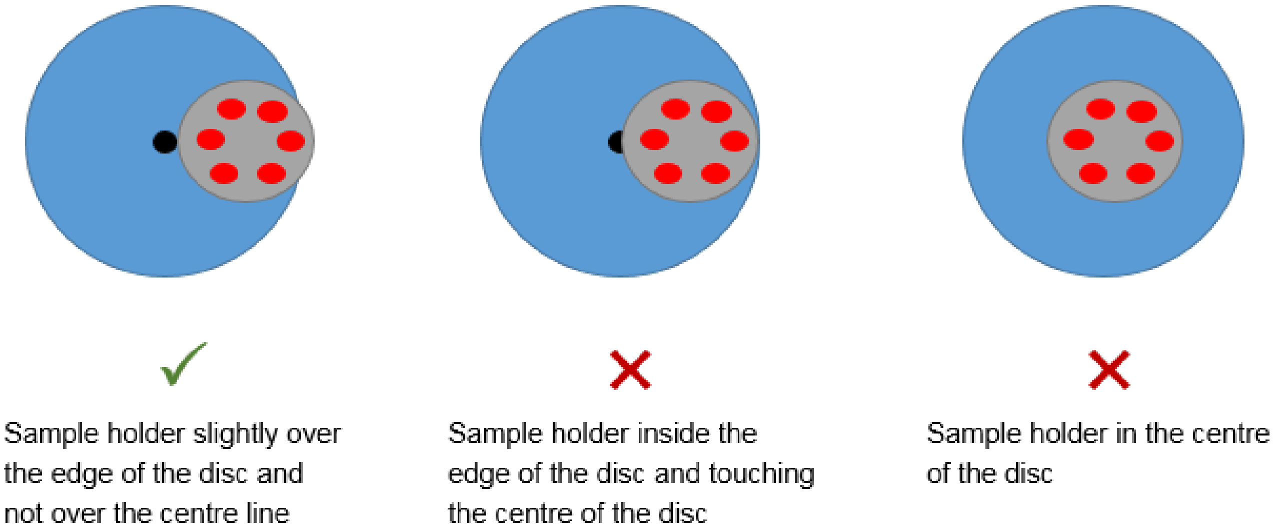


FIGURE 8: CORRECT POSITIONING OF THE SPECIMEN HOLDER.