Sandpaper

The Nitty-Gritty

Art Scott

Who knew that P400 was the same as 320 grit? That's just one of many facts I learned from my research on sandpaper. After thirty-eight years of woodworking, I thought I knew about sandpaper. Turns out I didn't.

When I took up woodturning, I found that there was a lot I did not know. For instance, I was not getting the results I wanted when sanding and if I talked to three different woodturners, I got three different answers.

I decided to undertake a study of sandpaper. I began by emailing questions to my suppliers. One replied, "I don't envy your task. The subject has always confused me."

From Rockler Woodworking I received an email that said, "Sorry that I don't have an answer for this. It looks like you have already done more research on this topic than any information I know. I'd be interested in hearing more, though, on any details your further research digs up." What I learned may astound him. It did me.

We are not using our grandfathers' sandpaper. Today's sandpaper does not contain sand and at times does not include paper. Sandpaper is not properly called sandpaper but should technically be called *coated abrasive* or *abrasive sandpaper* or *abrasive paper*. And, identical grits rated under different standards do not have the same abrasive particle size.

Some artists can work wonders with materials, while individuals with less talent struggle. Perhaps your sanding results are suitable, but if you are like me and see room for improvement, try the progression recommended in the comparing methods section.

The ideal is, of course, to improve tool use and control in order to minimize the amount of sanding that is required. But if sanding is what is called for, additional knowledge and a few hints will improve results.

U.S. and European standards: What's the difference?

There are two different standards used to specify the average abrasive particle size in the abrasive sandpapers we use in the United States. The Coated Abrasives Manufacturers Institute (CAMI) governs grit scaling in the Unites States. The Federation of European Producers of Abrasives (FEPA) provides the standard for the European scale.

The letter *P* in front of the grit number indicates that the abrasive particle size falls under the European classification for coated abrasives.

In this article, when you see a grit number alone, the number is classified under the U.S. standard. If the grit number has a *P* in front of it, its abrasive particle size is classified under the European standard.

Grit refers to the grit number printed on the backing of the abrasive sandpaper.

Simply put, it is the number of abrasive particles that will fit in one square inch. A larger number indicates a finer grit because more of the smaller abrasive particles will fit in one square inch.

Manufacturers determine the grit size by passing the abrasives through a series of sieves for the larger particle sizes. The smaller abrasive particles (from 230/P230 and finer) are selected by sedimentation and measured with a photosedimentometer.

There is a range of abrasive particle sizes that is permitted within each grit size. The European system allows a smaller variation in particle size, so their papers will produce a finer scratch pattern than the U.S. ones.

The future of grading systems

In email and telephone exchanges, both Ted Mullins of Keystone Abrasives and Coleman Fourshee of Klingspor Abrasives agree that the U.S. grading system is gradually going by the wayside and the FEPA (European) grading system will eventually become the only system used.

It was difficult to find all the grits I needed when looking for the CAMI-based abrasive sheets for the evaluations for my study. The hardware stores did have all the grits, although some were in an abrasive material other than aluminum oxide. Some grits were only ▸

% Change in particle size for same grit between CAMI & FEPA				
USA		European		% increase from USA to EUROPEAN standard for the same grit
CAMI-grit	average particle size in microns	FEPA-grit	average particle size in microns	
80	188	P80	201	6.9%
100	148	P100	162	9.5%
120	116	P120	127	9.5%
150	92	P150	100	8.7%
180	78	P180	78	0.0%
220	66	P220	68	3.0%
240	51.8	P240	58.5	12.9%
280	42.3	P280	52.2	23.4%
320	34.3	P320	46.2	34.7%
400	22.1	P400	35	58.4%
600	14.5	P600	25.8	77.9%
800	12.2	P800	21.8	78.7%
1000	9.2	P1000	18.3	98.9%

Table 1 *(Above)*. The difference in average abrasive particle size between the two main standards used in the United States.

Table 2 *(Right)*. Grits for both classifications (U.S. and European). (Grits are listed according to their average abrasive particle size in descending order from the coarsest to the finest. The sizes are in microns. One micron equals one millionth of a meter, or a thousandth of a millimeter.)

Ranking the grits by particle size		
average particle size in microns	CAMI (USA)	FEPA (Europe)
201		P80
188	80	
162		P100
148	100	
127		P120
116	120	
100		P150
92	150	
78	180	P180
68		P220
66	220	
58.5		P240
51.8	240	
52.2		P280
46.2		P320
42.3	280	
34.3	320	
35		P400
25.8		P600
22.1	400	
21.8		P800
18.3		P1000
14.5	600	
15.3		P1200
12.6		P1500
12.2	800	
9.2	1000	
6.5	1200	

offered in garnet, others only in silicon carbide, emery, or even flint. Not all of these materials will give us the results we strive for.

Not so with the European system. All grades are easily available, but the main problem is that the catalogs rarely list any grits with the *P*, even though they are actually European. Klingspor, a German company, only carries the European grades. In major home-improvement stores, the *P* is omitted on some of the packages, but it is present on the back of the sheets. This can lead to the false assumption that the grits from both systems are equal, which they are definitely not, especially in the higher grit numbers (see Table 1).

Selecting based on abrasive particle size instead of grit number

Notice in Table 1 and Table 2 that the abrasive particle sizes classified under the FEPA and the CAMI systems are only identical at grit 180/P180. For all the other grits listed, the particle sizes of the European grits are larger than the U.S. particle size for the same grit number.

For 320 grit (U.S.), the average abrasive particle size is 34.3 microns, while for P400 (European) it is 35 microns. This difference is only 2%. The difference in abrasive particle size between 320 and P320, however, is 34.7%! In U.S. workshops, 320 grit should be thought of as equal to P400.

In my study, I used the endpoint for the CAMI system as 320, while for the European system I used P400. The endpoint for both, then, is a comparable abrasive particle size.

But what about P600? Its equivalent CAMI grit would be 380, which is slightly smaller than the critical 400 grit. The P600 can be used to get a super-smooth finish.

Ted Mullins of Keystone Abrasives noted that when you sand much above 400 grit, there is the danger of burnishing the pores closed during the sanding process, which means that stains and colored finishes may not be evenly absorbed into the wood, resulting in a blotchy look. For wood that will not receive a color or stain, however, sanding to a very fine grit is generally not a problem.

Progressively sanding

One recommended method of progressively sanding through the range of

USA progression with 1.5 factor (Method # 1-US)			European progression with 1.5 factor (Method # 1-EU)		
CAMI-grit (USA)	average particle size in microns	% reduction between grits	FEPA-grit (Europe)	average particle size in microns	% reduction between grits
80	188		P80	201	
		38.3%			36.8%
120	116		P120	127	
		32.8%			38.6%
180	78		P180	78	
		33.6%			25.0%
240	51.8		P240	58.5	
		33.8%			21.0%
320	34.3		P320	46.2	
		35.6%			24.2%
400	22.1		P400	35	
		34.4%			26.3%
600	14.5		P600	25.8	

Table 3. Comparing the U.S. and European systems when increasing the grit number by 50% (increasing each grit by a factor of 1.5)

(This method results in a more uniform change for the U.S. sequence with an average change between each grit of 34.8%. But for the European system, an extra grit is added to achieve a similar abrasive particle size for the endpoint of each system [320 vs. P400)].)

Uniform change with USA standard (Method # 2-US)			Uniform change with European standard (Method # 2-EU)		
CAMI-grit (USA)	average particle size in microns	% reduction between grits	FEPA-grit (Europe)	average particle size in microns	% reduction between grits
80	188		P80	201	
					19.4%
		38.3%	P100	162	
					21.6%
120	116		P120	127	
					21.3%
		32.8%	P150	100	
					22.0%
180	78		P180	78	
		33.6%			25.0%
240	51.8		P240	58.5	
		33.8%			21.0%
320	34.3		P320	46.2	
		35.6%			24.2%
400	22.1		P400	35	
		34.4%			26.3%
600	14.5		P600	25.8	

Table 4. Grit selection based on getting a uniform change in particle size from one grit to the next.

grits is to use each available grit. Some authors, however, recommend an abbreviated version. Most experts recommend not skipping more than one grit in any progression. An article in *AW* (vol 13, no 3, Fall 1998) suggests a sequence of 80, 120, 180, 220, 280, and ending at 320. Which method should you use? Should you use a selection of grit sizes based on a different method?

If you apply the theory of using all available grits, the sequence you use for the CAMI standards (80 through 320) would involve nine different grits. With the European sequence (P80 through P400) you would be using ten grits of abrasive sandpaper. This increase of one grit number is because of the slower progression of the abrasive particle sizes in the European system.

I have found it isn't necessary to use all available grits to achieve superior results. Using fewer grits saves money and time.

You might never sand beyond 220/P220 or 320/P400 grit in your shop. That is okay, but keep in mind that the P400 grit has almost the exact same abrasive particle size as 320 (320 = 34.3 microns while P400 = 35 microns).

Comparing methods

Method 1

Method 1 is based on increasing the grit number by 50%. Here, you are increasing each grit size by 50% (multiply the grit by 1.5) beginning with 80-grit abrasive.

Running through the grits using the 1.5 method will result in the following progression in the U.S. system.

80 × 1.5 = 120 and a 38.3% reduction in particle size
120 × 1.5 = 180 and a 32.8% reduction in particle size
180 × 1.5 = 270

At this point, we must make our first decision since 270 is not an available grit. Should you select 320, 280, 240, or 220? Since 280 is not available in aluminum oxide from the suppliers I most frequently use, the choice is either 220 (15.4% reduction), 240 (33.6% reduction), 280 (45.8% reduction) or 320 (56% reduction).

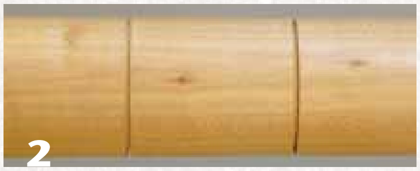
Attempting to keep the percentage change between the grits similar, I selected the 240-grit abrasive.

240 × 1.5 = 360, and I chose the 320 grit for similar reasons.

I applied the same process to the European classification and compared the two systems (see Table 3). A major difference in particle size can be seen between P320 and P400. In the European sequence, this means you use one additional paper. Remember, it is more important to compare particle ▶

1

Mahogany cylinder prepared with an oval skew chisel. As in all cylinders, the first section on the left will be finished to 320 grit with Method 1 & 2-US. (Note: Methods 1 and 2-US are identical and are referred to as Method 1 & 2-US.) The middle section will be finished to P400 grit with Method 1-EU. The section on the right will be finished with Method 2-EU, which has the extra two grits added (P100 and P150).

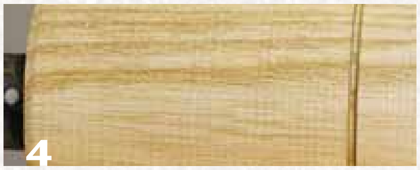


2

Cherry cylinder prepared with an oval skew prior to using any abrasives.

3

Ash cylinder prepared by scraping with a dull bowl gouge to produce torn grain and tool marks.



4

Ash: Close-up view of the first section of the cylinder in *Photo 3*, before applying any abrasives.

5

The various woods used, left to right: Maple, ash, cherry, mahogany, yellow poplar. The top section of each cylinder has been finished with Method 1 & 2-US to 320 grit. The middle sections are all finished with Method 1-EU to P400 grit. The bottom sections are all finished with Method 2-EU to P400 grit. Method 2-EU included grits P100 and P150, which were not used in any of the other sections.

size than grit number to accurately compare grit to grit.

Method 2

Method 2 is based on selecting a uniform change in particle size. The goal is to develop a progression through the grits that comes as close as possible to a uniform percentage change between each of the grits used in the sequence. This is based on the assumption that if there is a consistent percentage change between grits, a superior, smooth, scratch-free finish can be achieved faster.

With the U.S. system (see Table 4, Method 2-US) the average change in particle size is 34.6% (32.8% to 38.3%) and a progression of 80, 120, 180, 240, 320, for a total of five grit numbers. This sequence of grits is identical to Method 1-US where each grit number is increased by 50%.

For the European system (Method 2-EU), you can achieve a change in particle size from grit to grit for an average change of 22% and a progression of P80, P100, P120, P150, P180, P240, P320, and P400 for a total of eight grit numbers (see Table 4). This method results in an increase of two grit numbers over the 1.5 method and a percentage change between grits that is more consistent. The grit sequences for all of the methods are compared in Table 5.

Setting up the evaluation

I used abrasive sheets rather than discs for my study because there are more operator variables using a power sander or a Sandmaster-type tool, and not all grits may be available in the various disc systems. However, the basic principles used will still apply regardless of the system you use in your shop.

In an attempt to keep as many variables as possible out of my evaluations, I made several decisions, the primary one being to use a spindle-turned cylinder for my test studies. I chose not to use bowls in this evaluation because of the variables introduced by the many different designs as well as the occasional need to reverse the lathe in order to smooth stubborn endgrain. Granted, it will take longer to smooth the endgrain encountered in the bowls as compared to the face grain of spindles, but the progression I use should apply to all projects. Here is how I set up the evaluations:

- I turned a cylinder for a consistent, smooth surface. (Bulk reduction with a ¾" [20 mm] roughing gouge and finish with a 1" [25 mm] oval skew.) *(Photos 1, 2)*
- I also compared the progressions on cylinders with a rough finish achieved with a dull ½" (13 mm) bowl gouge held off the bevel resulting in tool marks and torn grain. *(Photos 3, 4)*
- I used abrasive sheets applied by hand to minimize pressure variables.
- I used abrasive paper cut into strips that were 1" (25 mm) wide.
- I used each strip only once on a section before throwing it away.
- I kept the strips in constant motion when touching the wood.
- I applied firm pressure but not enough to result in feeling any warmth in my fingertips.
- I cut each wood sample to be 9" (23 cm) in length, divided it into three 3" (8 cm) sections.
- I sanded each section separately even if two adjacent sections called for the same grit number.
- I used kiln-dried wood.

I used a variety of hardwoods, with pores that went from ring-porous and open to diffuse-porous and small. The hardness range was from the medium-hard maple and ash down to yellow poplar, one of the softer hardwoods *(Photo 5)*.

I kept the lathe's speed consistently at about 500 rpm, as I do when sanding in my shop. There are several reasons for using a slower speed for sanding:

1. The heat produced with pressure and high speeds can result in cracks occurring in the wood.

CAMI progression with 1.5 factor is the same as uniform % change between grits (Method #1-US=Method #2-US)			FEPA progression with 1.5 factor (Method #1-EU)			European progression with uniform change in % reduction between grits (Method #2-EU)		
CAMI-grit (USA)	average particle size in microns	% reduction between grits	FEPA-grit (Europe)	average particle size in microns	% reduction between grits	FEPA-grit (Europe)	average particle size in microns	% reduction between grits
80	188		P80	201		P80	201	
								19.4%
		38.3%			36.8%	P100	162	
								21.6%
120	116		P120	127		P120	127	
								21.3%
		32.8%			38.6%	P150	100	
								22.0%
180	78		P180	78		P180	78	
		33.6%			25.0%			25.0%
240	51.8		P240	58.5		P240	58.5	
		33.8%			21.0%			21.0%
320	34.3		P320	46.2		P320	46.2	
		35.6%			24.2%			24.2%
400	22.1		P400	35		P400	35	
		34.4%			26.3%			26.3%
600	14.5		P600	25.8		P600	25.8	

Table 5. Comparison of selection methods. (U.S. grit choices based on Method 1 and 2 are on the left. The grit sequence is identical for the two U.S. methods.) European grit choices in the middle column are based on the 1.5 method. European progression in right column is based on a uniform percent change between grits.)

2. If there are resins present, they can be brought to the surface by the heat, which causes burns resulting in wood discoloration.
3. High lathe speed, combined with coarser grits, can change the shape of the turning, although not as evenly as with steel tools.
4. Most bowls are slightly out-of-round by the time the sanding process happens—when sanding at a high speed, the abrasive will be primarily hitting the high spots (rather like hydroplaning), leaving the lower areas untouched by the abrasive paper.

When the abrasive paper meets the wood

I always started each sequence with 80/P80 grit *(Photo 6)*. Whichever number you begin with, the goal is a uniform surface before moving to the next grit. The rougher the tool finish, the more time should be spent on the very first grit. The objective of the first grit used is to remove torn grain and tool marks.

For the cylinders with a smooth tool finish, I used the 80/P80 grits for one minute on each section, then all the other grits in the sequence for 30 seconds each. Although I begin with a finer grit for my own turning, for testing purposes I started with 80 grit because in some of the progressions I tested I am comparing several grits that I would have skipped had I begun at 240/P240. I wanted to be consistent and use all of the grits in a progression regardless of the tool finish to ensure more accurate results.

On the cylinders with a rough finish, I used the 80/P80 grits for two minutes on each section, then 30 seconds for the remainder of the grits.

The European abrasive paper was the cloth-backed J-flex from Klingspor. For the U.S. system, I used GatorGrit for 80-120-180. Then I switched to the multipack abrasive rolls for pen finishing from Craft Supplies, USA, for the 240 and 320 grits. I used these rolls because, even after checking catalogs, local hardware stores, and the major home-improvement stores, I could not find all the grits I needed under the U.S. classification from the same manufacturer.

In the photos, the first section on the left is always the U.S.-grit sequences. Method 1-US and Method 2-US have identical grit sequences, so the first section represents both US-methods. The middle section is the same sequence of grits as the first ▸

6 Maple: The first section is finished to 80 grit and the other two sections were finished with P80.

section but with the European-graded papers. The last section on the right is the European graded papers with the extra grits added (P100 and P150).

Comparing results

I found that the sequence of P80, P120, P180, P240, P320, P400 consistently produced the most acceptable finish with all five woods, regardless of whether the initial tool finish was smooth or rough.

Adding two extra grits (P100 and P150) to the sequence did not make any difference in the surface finish at P180 when compared with the sequence that left these two grits out *(Photo 7)*.

Finishing to a P600 grit left an extremely smooth surface.

All methods passed the feel test; they all felt smooth. The *P* grade finishes were a little smoother in all sequences.

The sight test was a little different. After each sequence was completely finished and I looked at the cylinders when they were in a horizontal position while still on the lathe, it appeared as though all three sections of each sample were scratch-free *(Photos 8, 9, 10)*. When I removed the cylinders from the lathe and placed each one at a 45° angle, however, I saw scratch marks in all of the five cylinders in the sections finished with the U.S.-grade paper *(Photos 11, 12, 13)*.

I noticed that for each grit from 80/P80 to 180/P180, the U.S. grit felt smoother than the other two columns where the European grits were used.

At 240/P240 all three sections felt the same. Then at 320/P400 the European grit felt slightly smoother and markedly smoother at the 320/P600 level.

It also appears that having a consistent change in abrasive particle size from one grit to the next is not essential. The best sequence (Method 1-EU) had a change in particle size in the upper 30% range for grits P80, P120, and P180. Then the percentage change dropped to the low to mid 20% range for the remainder of the grits *(Photo 14)*.

Substituting between the European and U.S. systems

If you have abrasive papers from both systems in your shop and run out of one grit number, Table 6 will help you find a replacement grit in the other system with the closest average abrasive particle size.

From 80/P80 to 220/P220, the best replacement is the identical grit. For those numbers higher than 220/P220, the replacement grit will be a different grit number. For P240, you could go either way: 220 = change of 12.8% or 240 = a change of 11.5%.

Choosing abrasive materials

Selection of an abrasive material is based on the friability of the particles—how easily the particles fracture under use.

There are a number of abrasive materials available. The following three are the ones most often used by woodturners.

Aluminum oxide

- the workhorse
- available with paper, cloth, or a synthetic backing

7 Cherry: The left section is finished with Method 1 & 2-US. The middle section is finished with Method 1-EU. The right section is finished with Method 2-EU.

8 The maple cylinder, viewed horizontally. The same section, viewed at an angle in *Photo 11*, reveals some scratches that are not evident in this photograph.

9 Cherry: At this viewing angle, no scratches are visible. Scratches become obvious when viewed at an angle, as in *Photo 12*.

10 Poplar: The apparently smooth finish actually has abrasive scratches, which become noticeable when viewed at an angle, as in *Photo 13*.

11 Maple: The same cylinder in *Photo 8*, but viewed at an angle to reveal scratches.

12 Cherry: The abrasive scratches are revealed when the cylinder in *Photo 9* is viewed at an angle.

Poplar is the softest of the hardwoods used for this article. Scratches are present, but are not as evident as in the other woods.

Ash: This is the same cylinder in *Photos 3* and *4*. The three sections, left/middle/right, have been finished to 320 (Method 1 & 2-US); P400 (Method 1-EU); P400 (Method 2-EU). Two additional grits (P100 and P150) were used in Method 2-EU that were not included in the other sections.

If missing a grit in one system, what is the closest replacement in the other system and at how large a difference in particle size?

USA grit	particle size	European grit	particle size	% change in grit from USA to European
80	188	P80	201	6.5%
100	148	P100	162	8.6%
120	116	P120	127	8.7%
180	78	P180	78	0.0%
220	66	P220	65	1.5%
		P240	58.5	
240	51.8	P280	52.2	0.8%
280	42.3	P320	46.2	8.4%
320	34.3	P400	35	2.0%
		P600	25.8	
400	22.1	P800	21.8	1.4%
		P1000	18.3	
600	14.5	P1200	15.3	5.2%
800	12.2	P1500	12.6	3.2%
1000	9.2	P2500	8.4	8.7%

Table 6. Nearest comparable grit from one system to the next. (From 80/P80 through 220/P220, the nearest grit is the same grit. After 220/P220 the average abrasive particle sizes begin to separate and best choice will be a different grit number.)

- abrasive particles are easily broken down as the paper is used, resulting in the creation of new, sharp edges; in effect, renewing the surface and extending the life of the abrasive
- most common abrasive in woodworking catalogs

Garnet

- softer abrasive than aluminum oxide and wears out more quickly
- produces a finer, softer scratch pattern on wood
- recommended by some as the last few grits because it will result in a much smoother final finish. I have found I do not have to use garnet to achieve a super-smooth finish.

Silicon dioxide

- often called wet/dry sandpaper and usually has a waterproof paper backing
- hard material not easily broken down on wood, is very aggressive
- usually used on metals
- too aggressive to use as a primary abrasive on wood

Reviewing backing material

The *backing* is the material used to hold the abrasive particles. Backings include paper, cloth and synthetic materials like Mylar. Some can be waterproofed.

Waterproof backing allows the paper to be used with water to rinse off dust that tends to clog the abrasive, or to finish sand with oil instead of using steel wool.

Papers are graded from A through F, with A being the most pliable. Coarser grits will have a heavier, stiffer grade of paper. Grade F is the stiffest and is used for sanding belts. The paper grade, if listed, will follow the grit number, for instance 800A or P60C. The paper grade is not always included with the grit number.

In the manufacturing process for coated abrasives, the backing is first coated with a resin that will hold the grit. As the paper is passed over and slightly above the abrasive particles, an electrostatic charge is introduced, resulting in the abrasive particles moving up and into the resin. The larger part of the particle embeds in the soft resin with the smaller, sharper end exposed. The resin with the embedded particles is then dried. A second coat of resin is applied over the exposed particles to extend the life of the abrasive.

This somewhat scientific approach to sandpaper selection has provided me with an understanding of the abrasive particle size used in the various grits, which has greatly improved the finishing portion of my turnings. I hope it will do the same for you. ■

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