Saw Tooth Geometry

Note: The following article applies only to Western handsaws and backsaws. It does not cover two-man cross-cut saws or other saws that are not sharpened with a triangular saw file (e.g., Japanese saws and Disston's Acme 120). The geometry covered in this article does apply to the vast majority of Western saws made or found and used today.

This article remains very much a work in progress as I clarify my thoughts and writing. Please email me with any thoughts or comments, or to correct any errors, technical or otherwise.

We find many good mechanics who frankly acknowledge that they never could file a saw satisfactorily; the probable reason is that they never studied the principle of the action or working of the tool.

-Disston Handbook on Saws, 1907, page 153

Although saw teeth may appear simple at first glance, closer inspection reveals multiple cutting edges in different planes. Each of these cutting edges has a role to play, and a change to any one of them has an effect on the others that must be considered. Although the geometry of saw teeth is more complex than that of planes or chisels, the basic elements are easily understood when they are examined individually. The six elements that we control are:

- Pitch
- Breasting
- Rake
- Fleam
- Point slope
- Set

Before examining these elements, let's begin by defining the relevant parts of a saw. Figure 1 shows a backsaw; the nomenclature used in this article is identical for handsaws.

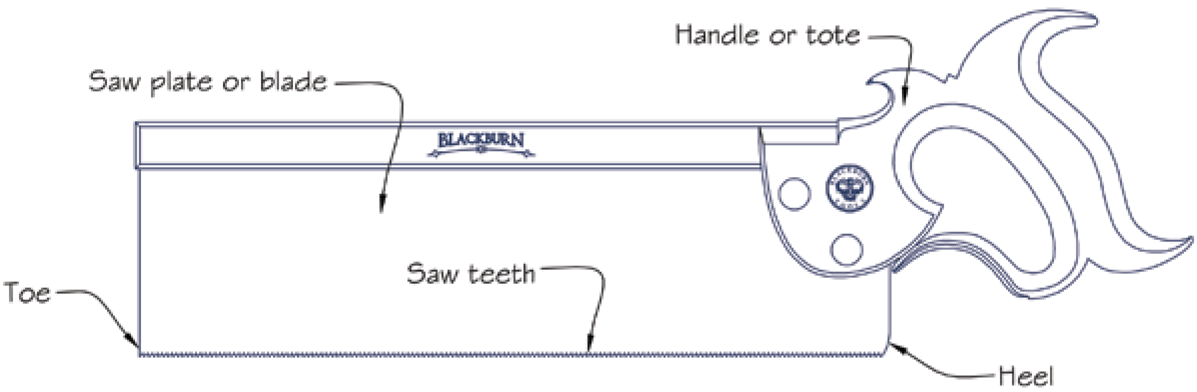


Figure 1. Basic saw nomenclature.

Next, let us flip the saw over so that the teeth are up (as if to put the saw in a vise for filing) and examine them a little more closely. Figure 2 shows what we might see. Notice that the angles formed by the tip of the tooth and the base of the gullet are both 60° (see footnote at bottom of this section). A quick examination of the cross section of a saw file shows that these angles are an inherent product of using a triangular saw file.

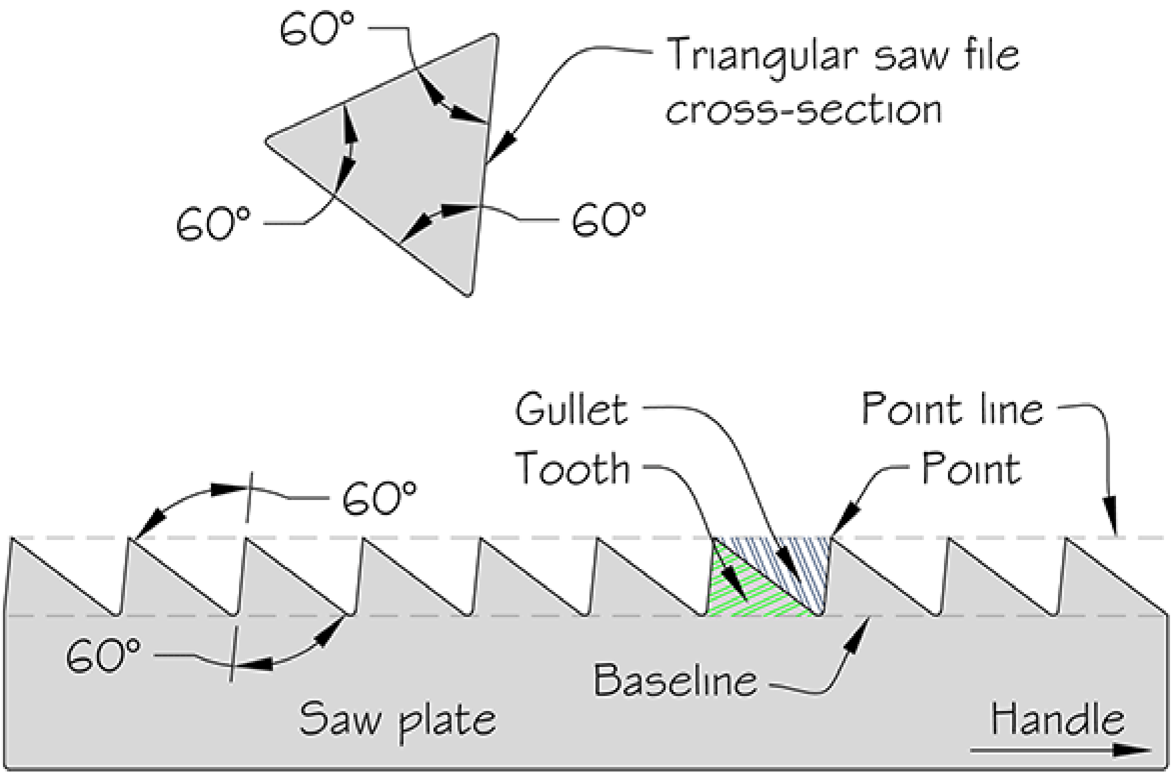


Figure 2. Basic saw tooth nomenclature.

There are two basic categories of saws. Rip saws are meant to cut parallel with the grain of wood, while cross cut saws are used to cut across, or perpendicular, to the grain. Figure 3 shows a typical rip tooth profile as viewed from the side and from the toe of the saw. Figure 4 shows a cross cut profile from the same views. It should be clear from these figures that rip and cross cut saws have teeth with very different profiles. The remainder of this article will show how each tooth is formed.

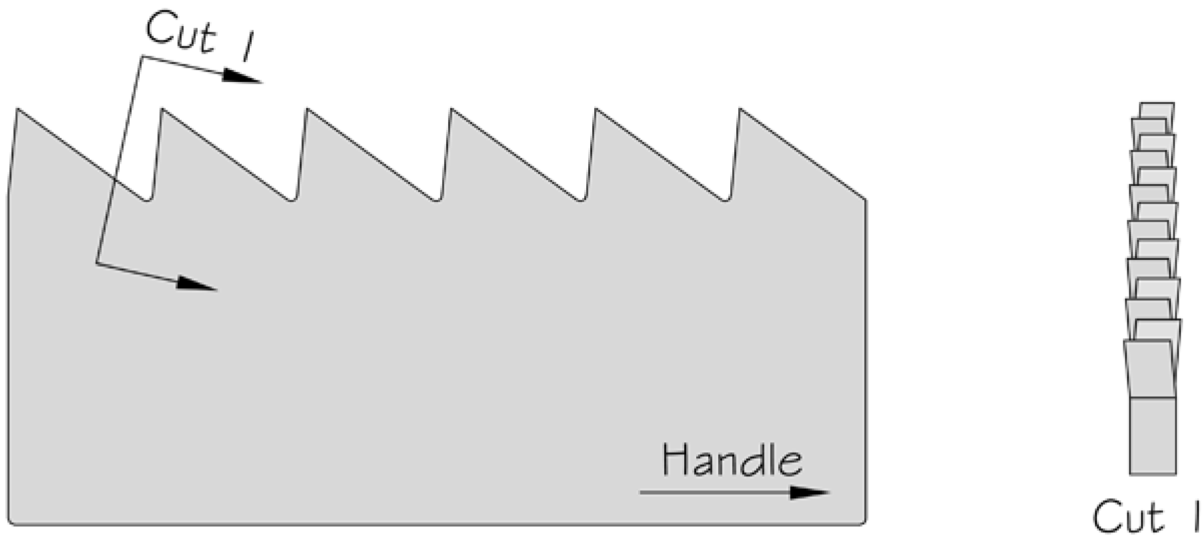


Figure 3. Rip teeth viewed from the side and the toe.

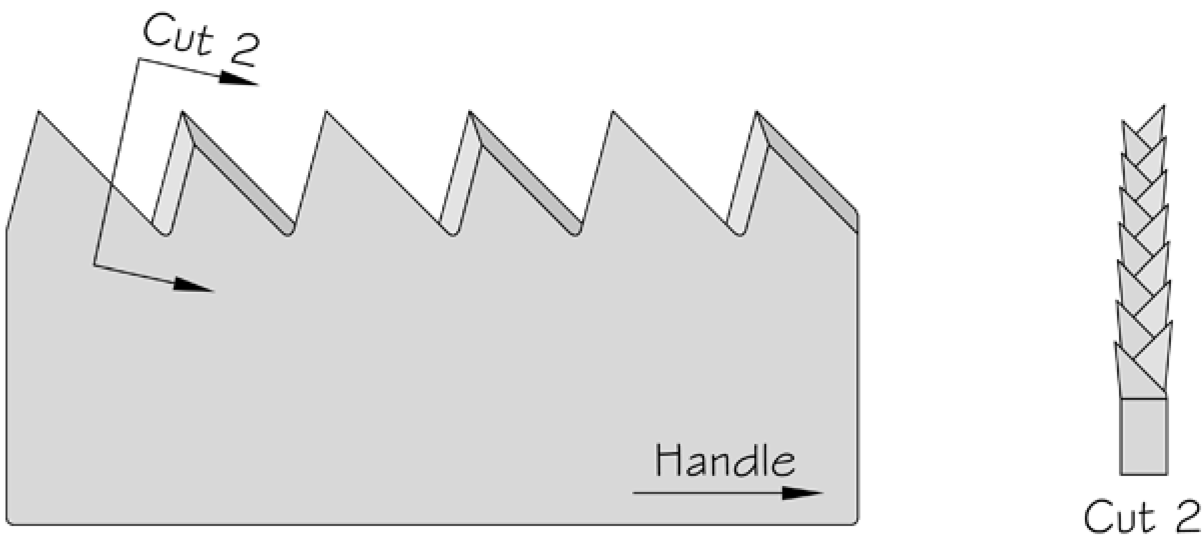


Figure 4. Cross cut teeth viewed from the side and the toe.

Figure 5 shows the three planes or dimensions that the file can be rotated in. All angles involved in saw sharpening are defined by some combination of these three angles.

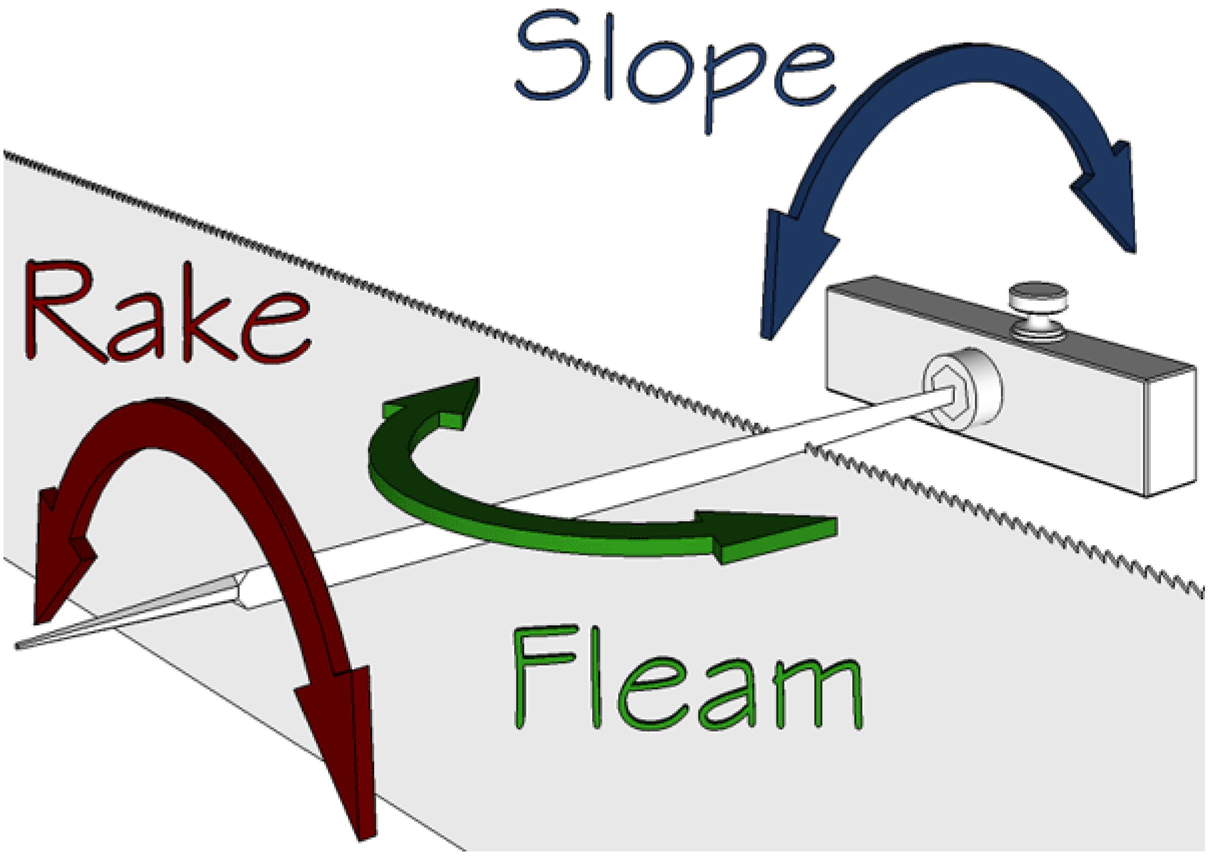


Figure 5. Rotation of file in the rake, fleam, and slope planes.

Finally, the guidelines given below for fleam, rake, and point slope should not be viewed as rigid rules, but as a starting point. With a little experience, you will quickly find the geometry that best meets your needs. Remember that talk and writing are cheap; a treatise that cuts wood will never be written, no matter how sharp the writer's wit. Sharpening and using a single saw can teach you more than a month's worth of reading.

Footnote: Technically, these angles are only 60° when the teeth are filed without fleam or slope. When fleam and slope are introduced, this angle changes. These changes are beyond the scope of this article. For a more detailed analysis of the interrelationship between rake, fleam, and sloped gullets, I recommend reading Brent Beach's Sloping Gullets. For an empirical look at cross cut tooth angles, I have written an article that presents a practical range of rake, fleam, and slope angles.

Pitch

Pitch is a measure of the number of points or teeth that fall within one inch, as measured along the point line. It is expressed as either points per inch (ppi) or teeth per inch (tpi).

While most American saws were (and are) described in ppi, rumor has it that British saws are traditionally described in tpi. Not to worry, though - converting between the two is simple:

ppi = tpi + 1

tpi = ppi - 1

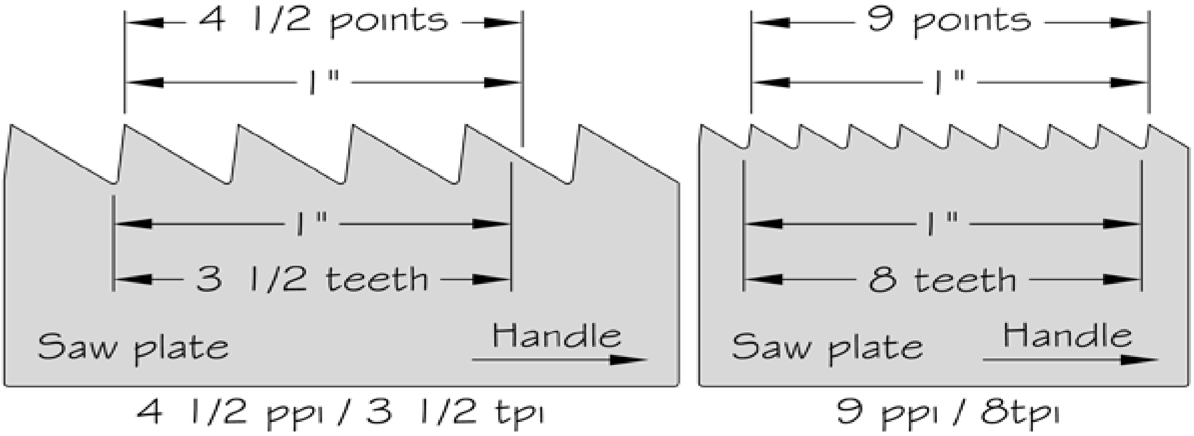


Figure 6. Measuring pitch.

As with all other aspects of saw sharpening, there is no hard and fast rule dictating proper pitch. As a general guideline, you want at least five or six teeth in the cut at any time, lest the saw catch too easily. However, as the fineness of the work increases, so does the number of teeth in the cut, although a limit is reached when the gullets of the teeth become too small to carry out the dust or shavings, and the saw begins to bog down.

A notable exception to the above are miter box saws, which are almost invariably filed with 11 ppi, even though they are frequently used to cut wide boards. In this case, speed is sacrificed for smoothness of cut, on which a premium is placed.

Finally, some saws are filed with progressive pitch, accomplished in one of two ways. The first is to simply file or cut the first few inches at the toe of the saw with finer teeth. The second is to gradually increase the pitch over the entire length of the saw. In either case, the pitch is usually measured at the heel of the saw plate. The goal of either filing method is the same: make the saw easier to start while taking advantage of the momentum and power present towards the middle and end of the stroke.

Figure 7. Effects of changing pitch.

Breasting

Breasting is a measure of the convexity of the point line (Figure 8). Not all saws are breasted; in particular, backsaws never are. In general, the heavier or coarser the work the saw is intended for, the greater the breasting.

Breasting is achieved by jointing the teeth in a gentle arc, then filing to maintain that arc. Breasting may vary from none, up to 3/8" or more, on a long, coarse rip saw.

The main advantage of breasting is in keeping the teeth in better contact with the center of the cut, resulting in smoother cutting. At least, that's my theory.

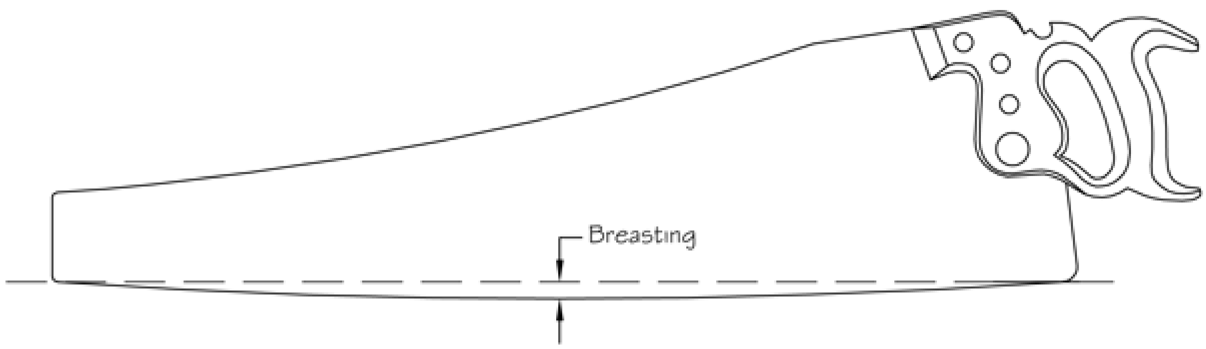


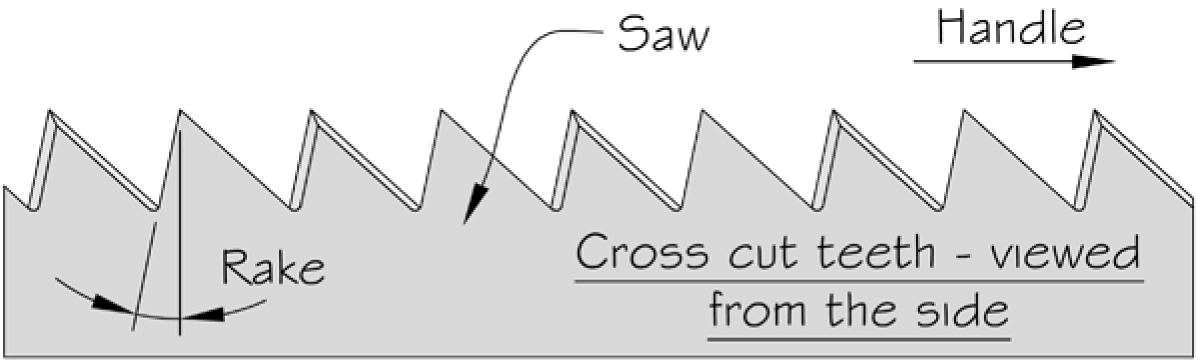
Figure 8. Breasting on a handsaw (slightly exaggerated).

Figure 9. Characteristics of breasting.

Rake

Rake is the angle that the front of the tooth makes with a line drawn perpendicular to the point line, and lying in the plane of the saw plate (Figure 9). It is created by rotating the file about its longitudinal axis (as shown in Figure 5). The main role that rake plays is controlling the aggressiveness of the saw. All other things equal, a saw will cut more aggressively as its rake is decreased.

While most saws are filed with a uniform rake along the length of the blade, some are filed with progressive rake, which is accomplished in one of two ways. The first is to simply file or cut the first few inches at the toe of the saw with greater (more relaxed) rake. The second is to gradually decrease the rake over the entire length of the saw. The goal of either filing method is the same: make the saw easier to start while taking advantage of the momentum and power present towards the middle and end of the stroke.



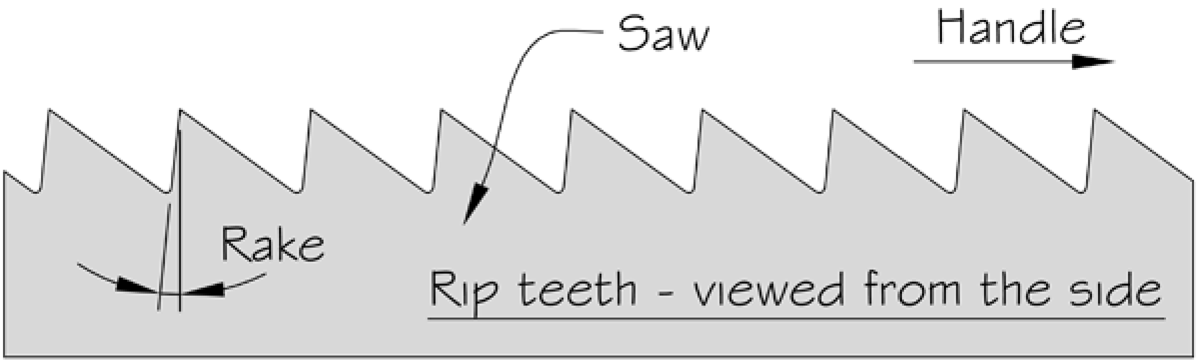


Figure 10. Rake on rip and cross cut saws.

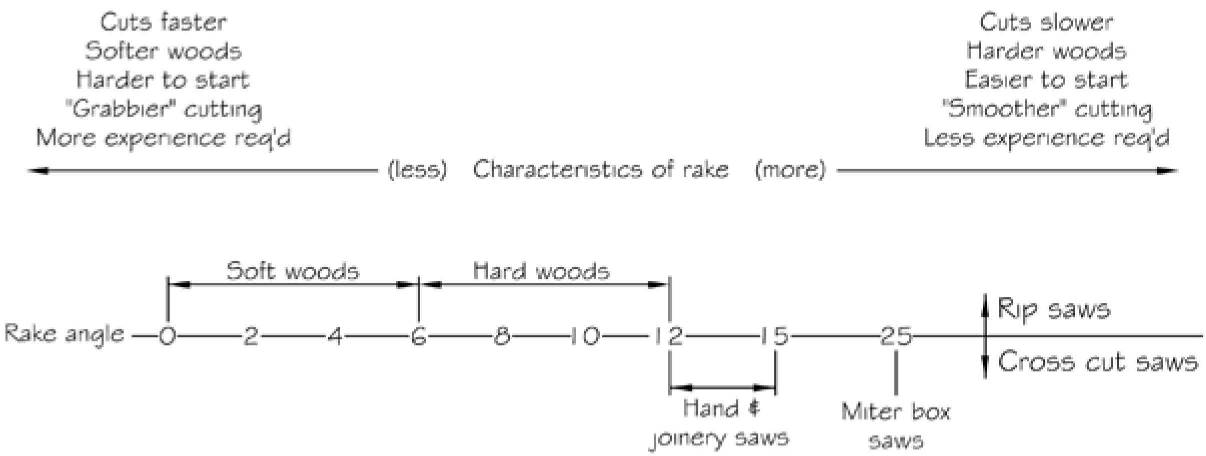


Figure 11. Rake guidelines and characteristics.

Fleam

Fleam (sometimes called bevel) is the angle that the front of the tooth makes with a line drawn perpendicular to the plane of the saw plate (Figure 12). Although fleam can be created by filing sloped gullets (see the section on point slope), the most direct method of controlling fleam is to swing the file from one side to the other so that the angle alternates from tooth to tooth (Figures 5 and 13). The main effect of fleam is on the smoothness of the cut. All other things equal, a saw will cut more cleanly as its fleam is increased.

In theory, a rip saw is filed with no fleam; in practice, a few degrees of fleam is often introduced so as to leave a smoother cut, especially on saws that may deviate from pure ripping (e.g., dovetail saws).

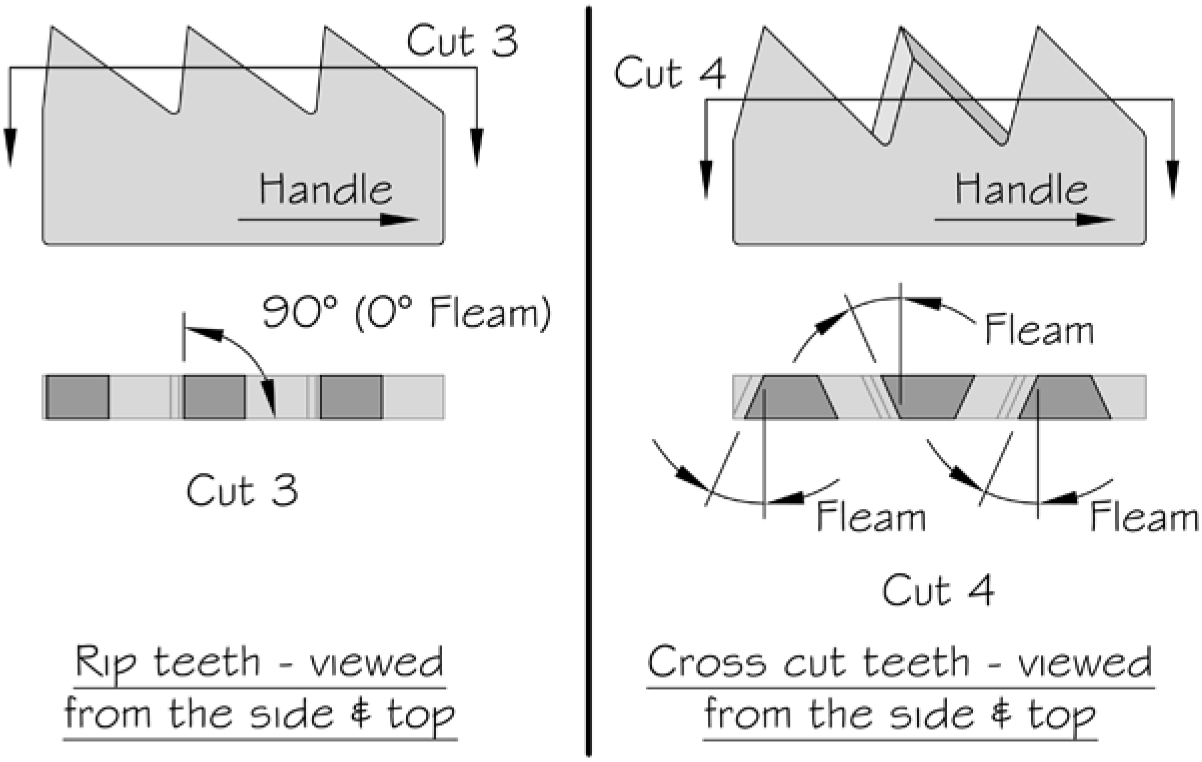


Figure 12. Fleam on rip and cross cut saws (no set shown).

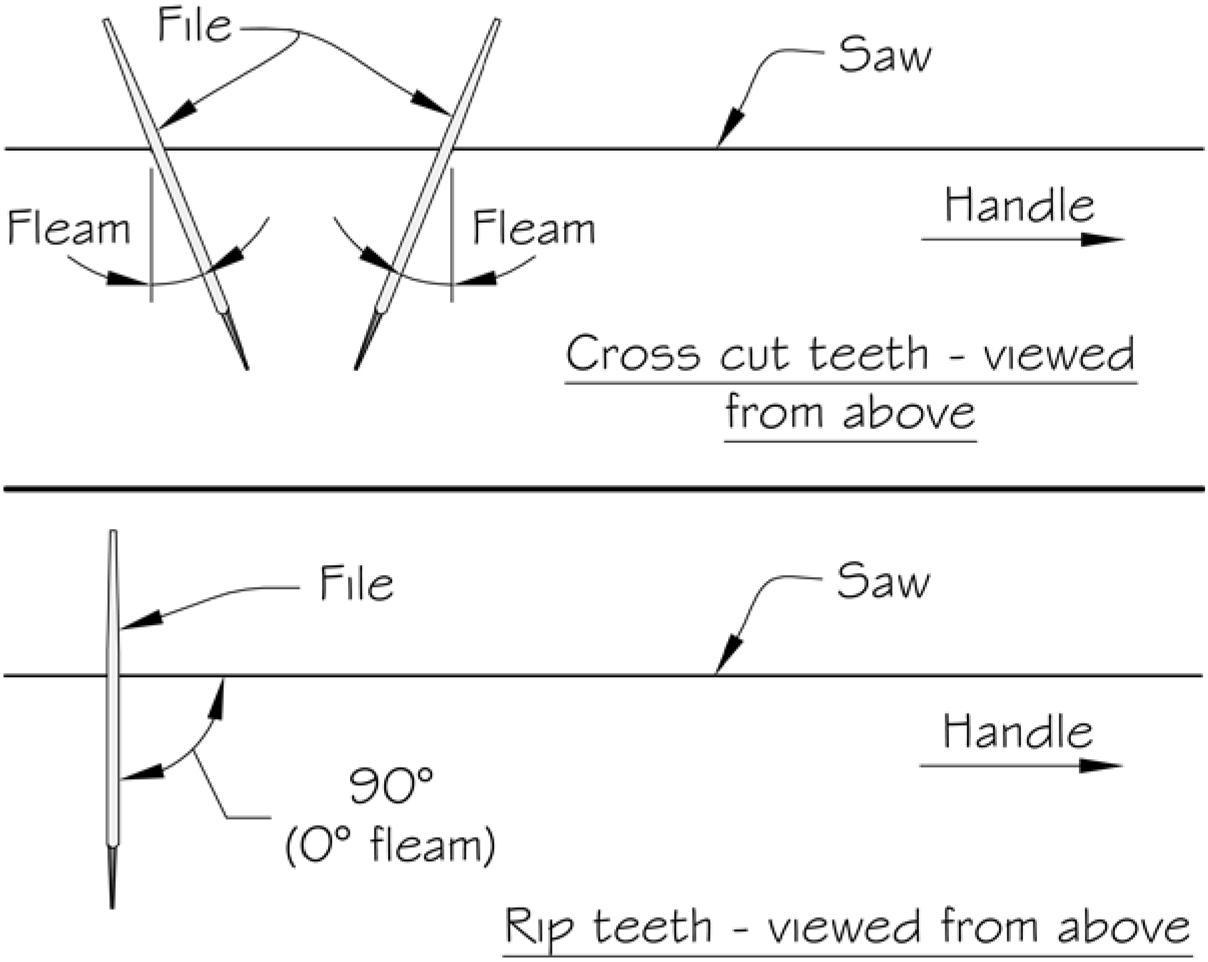


Figure 13. Filing fleam on rip and cross cut saws.

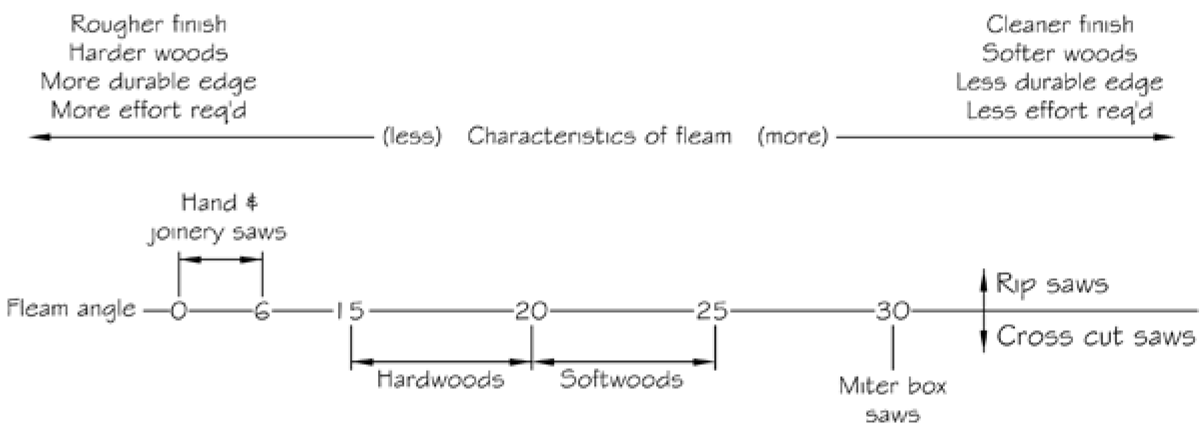


Figure 14. Fleam guidelines and characteristics.

Point Slope

Point slope is the angle that the tip of the tooth creates with the side of the saw plate. Looking back to Figure 12, it is apparent that point slope is a byproduct of filing fleam into a tooth. To complicate matters, this slope may be altered by filing teeth with sloped gullets. And this is perhaps the most important role that sloped gullets (see the next paragraph for more on sloped gullets) play in saw sharpening: by adding slope, we can strengthen the points of the teeth while maintaining the desired fleam angle, optimizing the saw for cutting harder woods. Figures 15-18 show point slopes for various tooth configurations. Notice especially the acuteness of the point of the cross cut tooth filed for soft woods (Figure 17) when compared to that filed for hard woods (Figure 18).

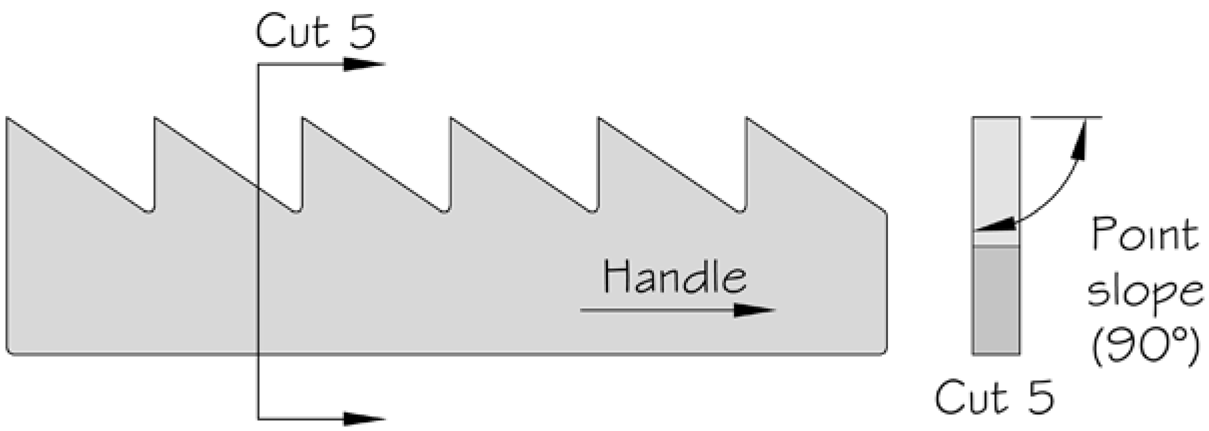


Figure 15. Rip teeth with unsloped gullets, viewed from the side and toe (no set shown).

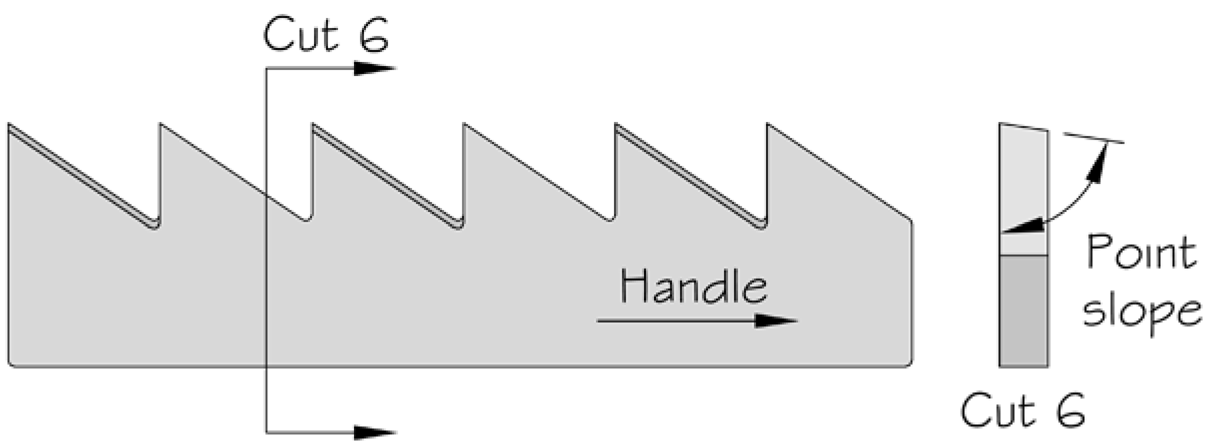


Figure 16. Rip teeth with sloped gullets, viewed from the side and toe (no set shown).

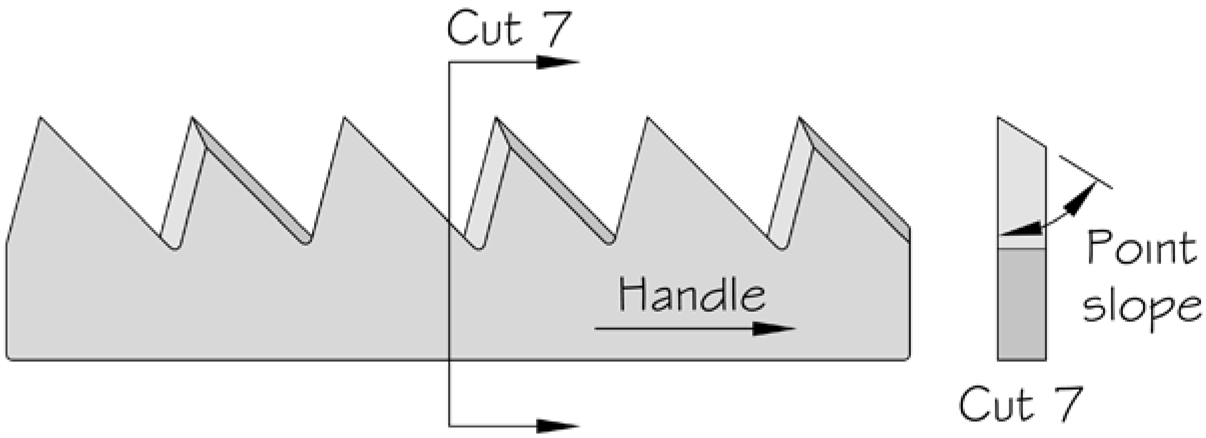


Figure 17. Cross cut teeth filed for soft woods, viewed from the side and toe (no set shown).

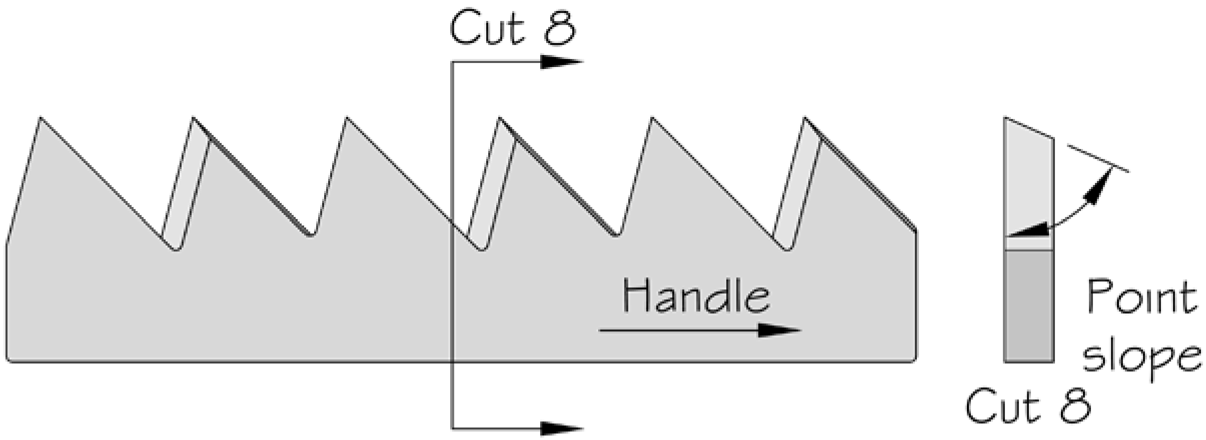


Figure 18. Cross cut teeth filed for hard woods, viewed from the side and toe (no set shown).

Sloped gullets are created by lowering the handle of the file vertically (Figures 5 and 19). Alternate gullets are sloped in opposite directions. In practice, the saw vise is often tilted so that the file remains horizontal, making it easier to maintain a consistent slope. In either case, the effect is the same. The telltale sign of sloped gullets is visible at the baseline. From the side, the bottom of every other gullet is lower than its neighbors' (Figure 20). If the saw is flipped end for end, the bottoms of these gullets are now higher than their neighbors'.

A secondary benefit of sloped gullets is the increased volume of the gullet, which allows more sawdust to be cleared on each stroke. This can be advantageous when cutting wetter wood or when cutting across wide boards (as in a miter box).

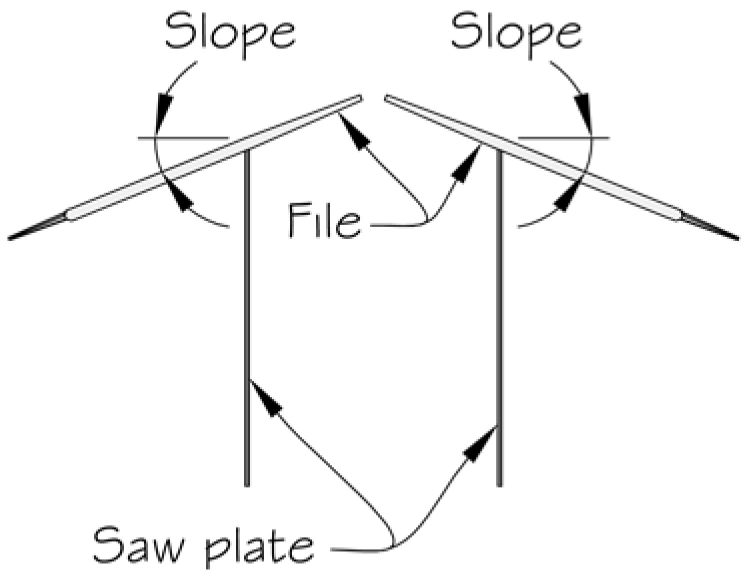


Figure 19. Filing slope on rip and cross cut saws, viewed from the heel or toe.

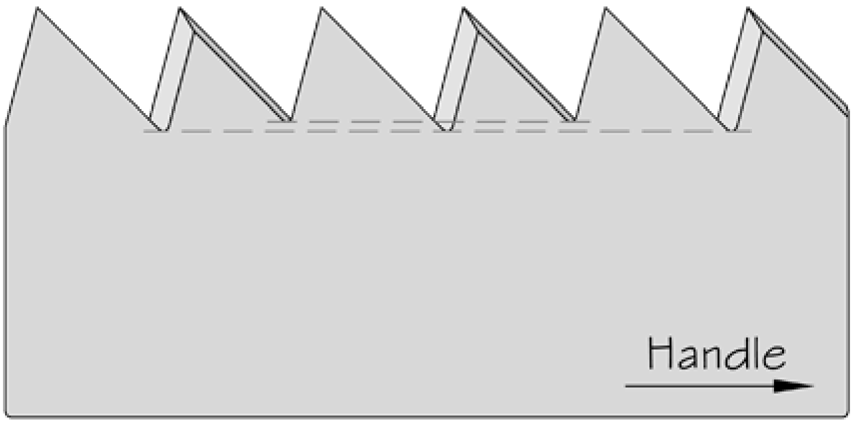


Figure 20. Side view of sloped gullets, showing alternating baseline.

While sloped gullets are found primarily on cross cut saws, they can also be used on rip saws. In the special case where the rake angle is 0°, the fleam on the front of the tooth remains 0° (Figure 16). I believe this makes the saw easier to start and less prone to grabbing. Others disagree, while others claim this turns the teeth into a cross cut profile. Figure 16 shows how this creates a tooth that has no fleam on the front, yet has an acute point. Figure 21 shows the tooth profile from the side and toe of a rip saw filed with sloped gullets. Comparing this profile with Figures 3 and 4, it is seen that the teeth resemble those on a cross cut saw when viewed from the toe. Those who believe that cross cut saws are defined by point slope use this image to support their view that this is a cross cut saw, while the absence of fleam lends credence to the theory that it is still a rip saw. As with so many other topics, the truth is not easily defined.

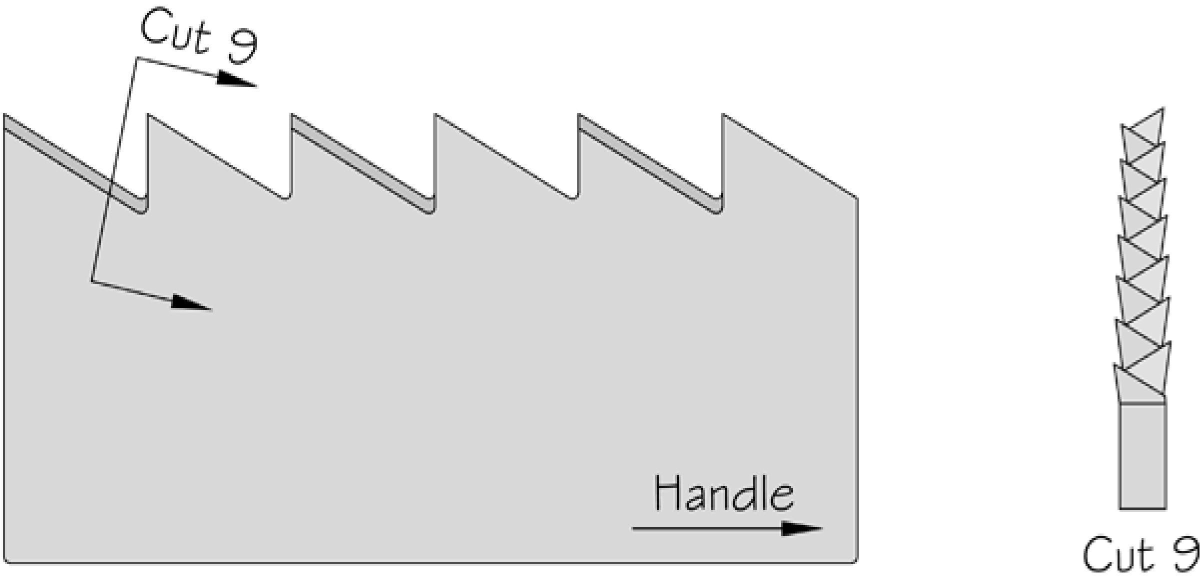


Figure 21. Sloped gullets on rip saw, viewed from the side and toe.

Cross cut teeth will always have some point slope, generally becoming more acute as the saw is filed for softer woods (Figure 17 and 18). Just as a chisel sharpened to a lower angle will penetrate wood with less effort than one sharpened with a higher bevel, so too will a saw tooth filed more acutely. And as with a chisel, an acutely filed saw tooth will be less durable.

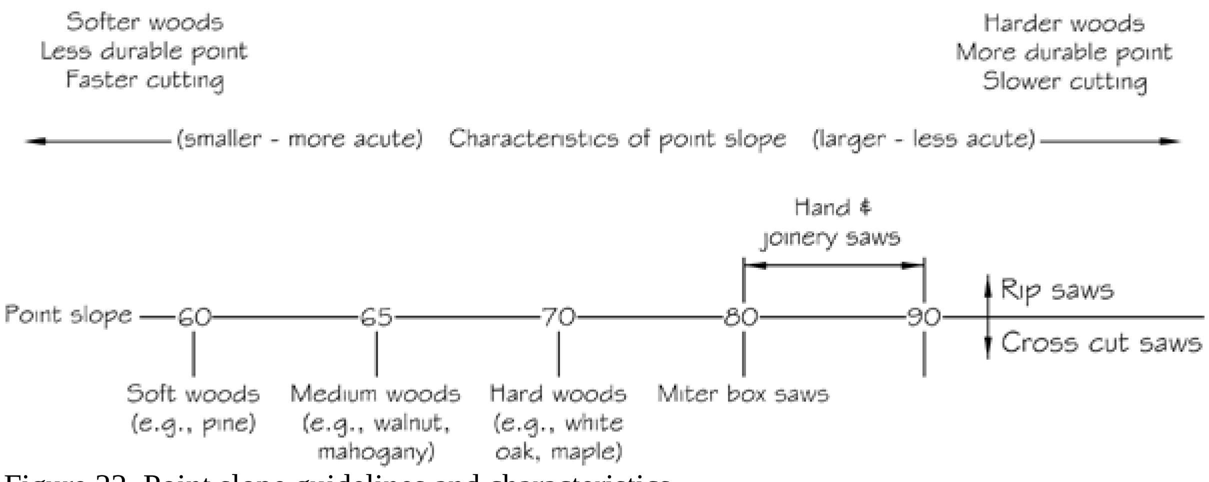


Figure 22. Point slope guidelines and characteristics.

For more detailed analyses of sloped gullets, I recommend reading Brent Beach's Sloping Gullets and Leif Hanson's Sloped Gullets. For an empirical look at cross cut tooth angles, I have written an article that presents a practical range of rake, fleam, and slope angles.

Set

Set is created by bending the tips of the teeth in alternating directions. This creates clearance in the cut for the saw plate, reducing friction and binding. Figures 23 and 24 show this in rip and cross cut saws, respectively.

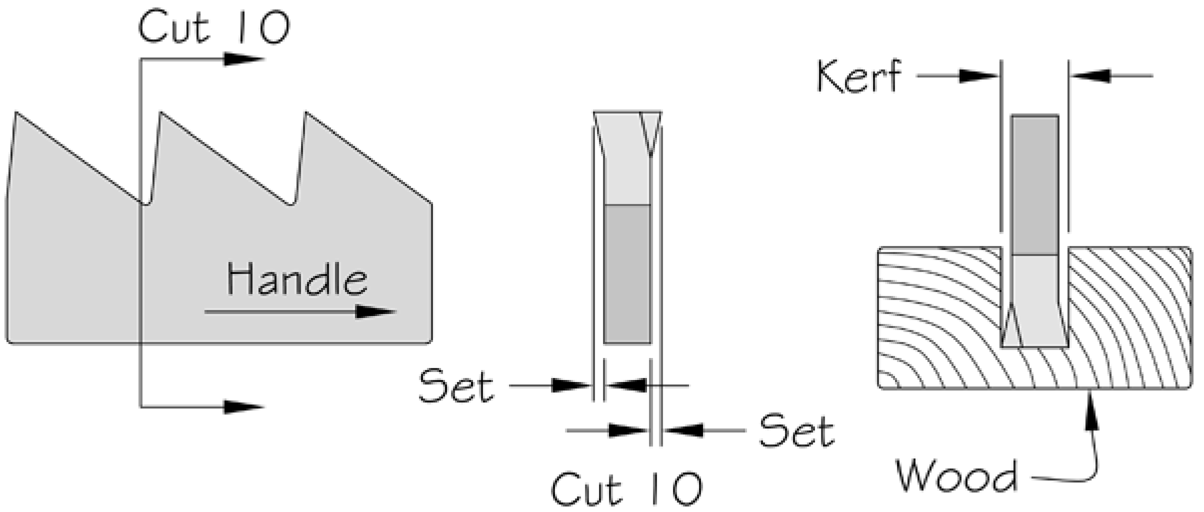


Figure 23. Set on rip teeth, viewed from the side and toe.

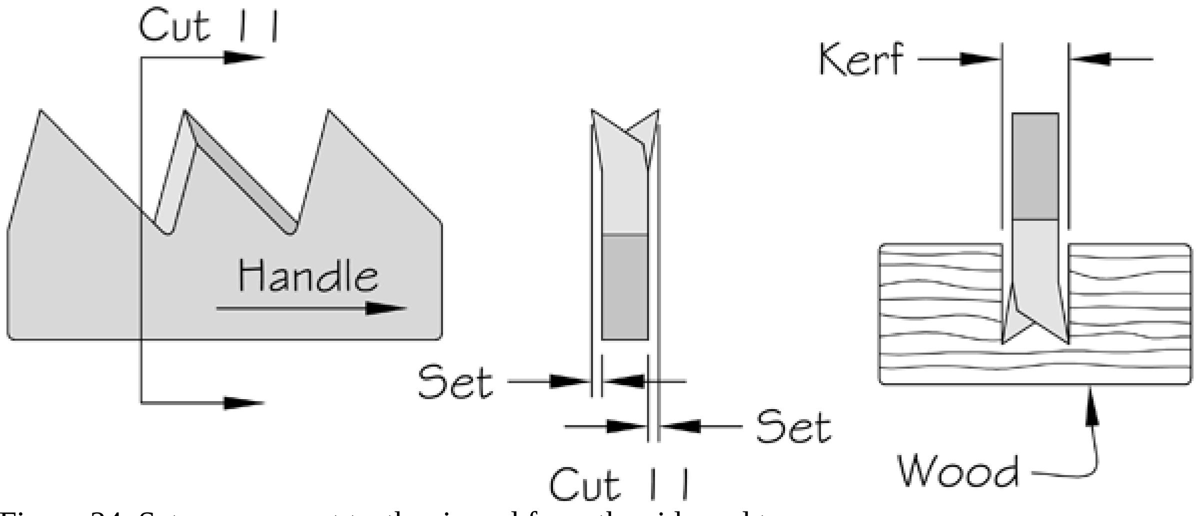


Figure 24. Set on cross cut teeth, viewed from the side and toe.

Set varies from none in saws that are heavily taper ground and used in dry hardwoods, to a hundredth of an inch or more in coarse saws used in wet woods. The optimal amount of set varies, but in general, the least amount needed to prevent binding in the wood being cut will work best. Additional set creates more work (by increasing the amount of wood being removed) and decreases the quality of the cut.

Figure 25. Characteristics of set.

There are numerous devices designed to impart set to saw teeth, ranging from the simplest saw wrests to wonderfully complex mechanical saw sets. The sheer variations of these tools are testament to the importance of handsaws in the past. They were surely one of the most patented woodworking tools in American history. For a sampling of this variety, visit Mark Conley's The Saw Set Collector's Resource.