Materials for CNC Knives (Die Cutters, Vinyl Cutters)

Bates-Green, K.
kyle.bates_green@edcc.edu

Abstract

The lesson includes lecture materials and demonstrations/activities for illustrating concepts related to material properties for materials suitable for use with CNC knives. The properties are considered with respect to how they affect the way they may be used, how those properties are connected to the material structure or composition of the material, and how that information might allow the user to predict the usability of other candidate materials.

Learning Objectives

- Identify the parts of a CNC knife and demonstrate its basic use
- Define the physical properties that influence decisions about whether and how to use a CNC knife on a given material
- Identify common materials suitable for CNC knife use
- Identify any preparation procedures necessary for the use of the materials chosen
- Select the appropriate tool end and method to use with different materials
- Plan and construct a 3D object starting from 2D components made with a CNC knife

MatEdU Core Competencies

0Cc1: Demonstrate workplace safety methods

0Dd1: Recall key job-related information (processes, references, terminology, acronyms)

1Cc1: Demonstrate familiarity with safe laboratory practice

6Aa3: Interpret the proper tool selection for a given task

8Aa2: Explain and illustrate the various additive manufacturing processes

11Aa1: Fabricate a part or an assembly using additive manufacturing equipment

11Aa3: Compare the differing properties and characteristics of common materials used for additive manufacturing models

11Aa9: Describe the different hardware systems used in the production of prototypes, with emphasis on the specific additive manufacturing machines

Key Words - CNC knife, vinyl cutter, sign cutter, die cutter, in-plane, out-of-plane, toughness, stiffness, tension, bending, shear

Type of Module - In-class activity and/or demonstration

Time required to complete - One class period for background information and discussion. Additional time variable depending on the depth of activities chosen and class' previous experience.

Prerequisite knowledge and skills - Basic safety around edged tools and power tools. Introductory CAD use for some activities.

Target grade levels - 9th grade and up

Table of Contents

Curriculum Overview and Notes to Instructor

A CNC knife is a cutting tool that moves a blade across a surface according to digitally programmed tool paths. This can be done by moving just the knife, or moving both the knife and the material. Also known as a vinyl cutter or sign cutter, the CNC knife's distinguishing characteristic is that it cuts by pressing a tool into the material to split it, and is therefore best suited to cutting material sheets (fig 1). This means that, unlike other tools that cut with spinning tools, laser heat, or water jets, almost no material is removed and almost no heat is delivered to the cutting surface. As a result, CNC knives are clean, simple, and comparatively safe to use in a wide variety of environments. Consumer-grade CNC knives are inexpensive, easy to use, and easy to maintain. Materials in CNC knives can be held down (fixtured) with physical clamps, adhesive backings, or a vacuum table. Though CNC knives are inherently a subtractive 2D manufacturing tool, 3D modeling software allows their use to rapidly produce many layers for assembly into 3D shapes, as a 3D additive manufacturing process.

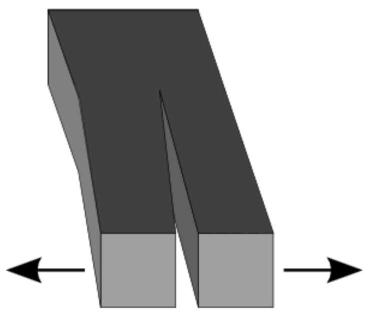


Figure 1: Material is split apart rather than being removed, in the "crack opening failure mode" (adapted from wikimedia commons)

This document will refer to stresses experienced by materials in the "in-plane" and "out-of-plane" directions (fig 2). An in-plane stress is one applied in the flat direction of the material, like if you were to grab one end and stretch the material by pulling. An out-of-plane stress is one applied perpendicular to the material, like if you were to tear the material by pulling part of it upward while holding the rest down.

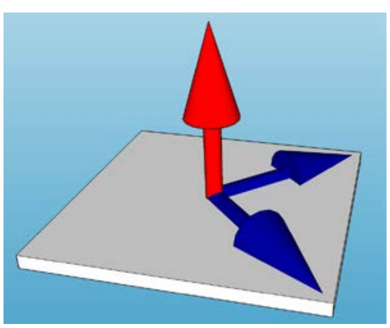


Figure 2: Out-of-plane direction (upward red arrow) and In-Plane directions (blue arrows)

A CNC knife can be identified by its arrangement to grip sheet material against a backing surface, and method of positioning a cutting tool against that material. This usually takes the form of a gantry holding a tool and moving in the XY plane, and either a bed or rollers used to restrain the material to be cut. Some cutters may move the blade only in one axis, and use rollers to pull the material in the other. You should also expect to see some mechanism on the gantry for lifting the blade so that it can be moved while not cutting.

Figure 3: Industrial CNC knife with 160cm wide bed (left, stylecnc.com), and consumer die cutter with 30cm wide rollers (right, silhouetteamerica.com). Both show a drag knife on a gantry.

Cutting Tools

CNC knives most commonly use a “drag knife” tool - a blade simply pushed by the machine. The knife may be anything from a boxcutter blade in a holder to a hardened alloy of a custom-engineered shape. Drag knives are easy to use and easy to replace, but may have trouble with very tough or abrasive materials. If the material is very thick, the cut material will be in contact with the sides of the blade and produce increased friction. This friction will put stress on the blade and also tend to push the material out of place.

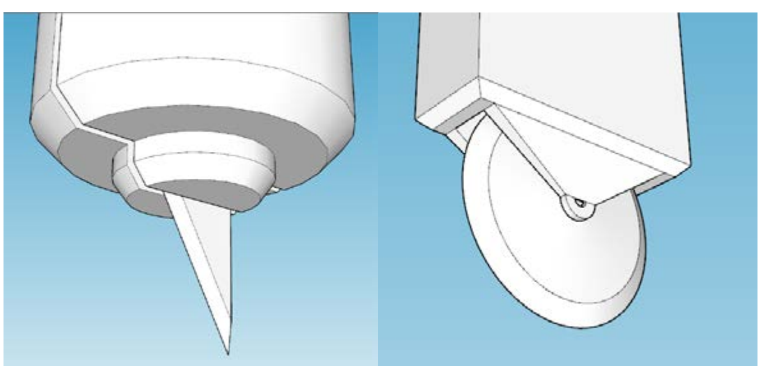


Figure 4: Basic geometry of one type of drag knife (left), and a rotary blade (right).

An “oscillating tangential knife” may be used for tough or thick materials. This kind of blade cuts part way into the material, retracts upwards, and then returns quickly. By doing this, strain on the material is repeatedly released instead of building up around the blade, reducing the chances of tearing the material or breaking the blade. Oscillating tangential knives may just be drag knives mounted to move up and down, or may be more specialized for downward penetration, like a chisel.

A rotary blade, often called a “creasing wheel”, may be used for cutting abrasive or hard materials, or for making indentations in any material. A rotary tool turns freely as it is pushed, and has one continuous edge. Very abrasive materials will quickly dull the pushed edge of a drag or oscillating knife, but a rotary edge doesn’t drag through the material. In many cases a hardened (titanium nitride) oscillating blade is tough enough and can cut quickly, but a wheel blade can be the ideal solution especially for thin, abrasive composites. The downside of a rotary blade tool is that the curve of the blade can push into the material in more than just one point, so where a drag knife might cut at just one point as it cuts a curve, a rotary blade might scrape the surface on the convex side of the cut.

Drag knives are the most susceptible to dulling by abrasion, and a duller blade will experience more stress as it is dragged, making it more likely to break. For this reason, drag knives are often cheap and easily replaced rather than re-sharpened. Oscillating tangential knives are more likely to fail in fatigue due to vibration than the other tools. Rotary blades tend to be much harder and tougher than what they’re cutting, and experience less friction, and so are the least likely to fail. A tool which is not sharp enough adds stress to the region it is cutting, which can result in jagged edges as the material bunches and releases, deformations like stretches or tears around the cut, or even shoving the material out of its fixturing.

Cutting Surface and Fixturing

Your CNC knife setup will have some sort of work surface, possibly one shared with milling or routing tools. If your CNC is a small purpose-specific machine like a vinyl cutter, the work surface may be the backing attached to your material, or a hard support strip underneath the axis the knife moves in. In each case, the role of the cutting surface is to support the work material so that it remains engaged with the cutting tool. If the material is not sufficiently fixtured in place it may move, tear, or stretch instead of cutting, ruining the piece.

Since CNC knives often work with thin and flexible materials, and the knife end is susceptible to bending stresses, your work surface should be flat and smooth. It should also be tough and have a low coefficient of friction with the knife end. A hard plastic “cutting mat” material is recommended. If your cutting surface is also used for other CNC ends like a router, then the surface may have uneven parts where a tool has previously accidentally removed material (fig 5). In this case, it is recommended to secure a temporary new surface over top and to re-zero the Z axis for CNC knife use.

Figure 5: This CNC machine work surface, in the middle of the image, is level but uneven due to use of other cutting tools on it. The bar across the top of the image is the gantry, and the dark object it is holding on the right is a router, which is ready to be removed and replaced with a knife. To perform as a CNC knife, the work surface of this setup needs to be routed smooth or fully replaced.

Fixturing methods, the ways of making sure that your work material stays in place and oriented during cutting, depend on how much force will be transmitted in the plane of the work material. A thick, tough material will tend to be pushed by the knife rather than sliding easily, and will have to be held down more firmly. Thin and flexible materials may curl or wrinkle while being cut, and will have to be attached uniformly to the work surface. Some materials, like adhesive-backed vinyl, may cut easily and come with their own backing already, and need almost no fixturing. Others, like cardboard sheeting, can be held down with a CNC vacuum table. Weak adhesives may also be used to attach the cutting material either to the work surface or to a temporary backing. Many purpose-made vinyl cutters use a temporary adhered backing rather than a large work bed. When using this method, ensure that your material can be released from the adhesive without being damaged.

Basic Makerspace Effectiveness and Safety

When you are working with your CNC knife:

- Always wear the correct PPE, especially eye protection
- Never wear dangling clothing or loose hair where it could possibly be caught by any machinery
- Keep your wires and cords bundled and organized where they cannot trip people or ever interfere with the operation of the machines
- Leave space around your machine for maneuvering
- A person must always be present while machinery is running, unless automated safety shutoffs are in place <u>and</u> you accept the risk of a machine damaging itself
- Keep tools maintained at all times and remember that a dull blade is more likely to build up stress and break instead of cutting, possibly throwing shards

These rules apply whether you are using a 30m^2 industrial CNC with an oscillating blade on a factory floor, or a 30cm wide consumer die cutter in the corner of your classroom.

Activities

Vinyl Decal Production

Purpose:

- Create a physical product with a CNC knife using a material it is optimized for
- Practice basic use of design software
- Get first-hand experience with the advantages and limitations of the machine
- Use the engineering design process by testing and redesigning
- Consider the manufacturing use of the CNC knife

Materials:

- Adhesive-backed vinyl sheet (buy vinyl adhesive by the roll for craft and die cutters)
- Transfer tape (masking tape bought on a large roll)

Equipment:

- CNC drag knife
- Design and control software of your choice

Procedure:

CNC knives are remarkably good at cutting vinyl sheet. As a group, create a set of designs of differing complexity to cut out. Use vector drawing tools to do this, as well as contrast tracing (high- or low-pass filter, for example) to make your designs. Cut out your designs on vinyl with your CNC knife, and don't correct any errors the machine makes. Analyze and share what types of cutting paths work best, and where the greatest risk for flaws or defects appears.

Using this information, have each participant design a sticker, decal, or label they would like to produce. Make sure that your design fits within the size of the material from which you are cutting it. Use your cutter to cut each design in adhesive-backed vinyl, and instead of removing the backing, cover the top side of your design with transfer tape. After doing this, remove the original backing from your vinyl so that the adhesive is exposed, but the orientation of the vinyl is preserved by the transfer tape. This will allow you to place the design exactly where desired.

Discussion:

What did you learn about how the knife is programmed and how it operates? What surprised you? What is your software good at and bad at? What is the hardware good at and bad at? Pick another method for manufacturing or making things, and compare and contrast the vinyl cutter to it.

Paint Mask Production

Purpose:

- Get first-hand experience with the interaction of design software with CNC knife hardware
- Use the engineering design process to test and redesign
- Create a useful object from commonly available and reuseable material
- Find the correct settings to use with a given material

Materials:

- Cardstock or corrugated cardboard
- Spraypaint

Equipment:

- CNC knife, suitable for corrugate cardboard thickness if chosen
- Design and control software

Procedure:

A paint mask, or stencil, is a type of simple tooling that can be produced by a CNC knife. Its role is to protect part of a surface, while allowing other parts to be affected. In this case, spray paint will be used to mark a surface, and your pattern will protect some of the surface from the paint, leaving behind the image you choose.

Begin by choosing words and a symbol for the stencil you want to design. Use your design software to place your text and symbols as cut paths. Then fixture and cut your material. Does it cut correctly, and does it turn out exactly how you expected? However it has turned out, take your stencil and place it on the surface you wish to label. Hold it in place with masking tape if necessary, and paint over it with even passes of spray paint, creating a result that may or may not match your original intention.

What is the result? Can all symbols and letters be used in a stencil? Did every cut fully penetrate the material? Are there problems with the durability or reuseability of your stencil? Return to your design software and evaluate what is required to make a paint mask functional. What tools can you use in your software to eliminate the problems you discovered? Designers call the isolated portions of letters “islands”, which will detach from the rest of the stencil if all edges of letters are cut. Furthermore, even portions that are not islands may be structurally unsound if not given additional supports. Plan ahead before cutting!

Discussion:

As a group, write a short guide for first-time users doing the activity you have just completed. What information will they need to ensure that they have the best success on their first attempt?

What properties of your material determine if supports are needed for non-island portions of designs? Research to see what precise term an engineer would use for this property.

(The term for this type of stiffness is “elastic modulus in bending”)

Acid Etch Mask Production

Purpose:

- Use a CNC knife product in a process to modify another object
- Take advantage of differing material properties to perform a task
- Use the engineering design process to test and redesign
- Gain experience predicting the behavior of a process based on choices made in the design phase

Materials:

- Glass material (vases, cups, or test squares)
- Masking Tape
- Previously-cut vinyl pattern
- Glass etching “cream” (ammonium biflouride acid)
- Glass cleaner

Equipment:

- Personal protective equipment: Rubber or latex gloves
- Natural fiber paintbrush
- Large acid-resistant plastic bucket (painter’s polypropylene bucket)
- Water supply and eye-wash station
- Magnifying glass or suitable optical microscope

If your skin, eyes, or other membrane are exposed to acid:

- Rinse immediately and continuously with running water
- Remove any material holding acid against yourself or the affected individual and continue rinsing
- Do NOT scrub or abraid the affected area
- Seek medical attention
- Do NOT add basic chemicals to neutralize the acid, use only water

Procedure:

The concept of using a mask for glass etching is that the mask protects the glass in some places from attack by acid, and not in other places. You make use multiple masks at different times, allowing the acid to work for longer or shorter amounts of time, to etch different depths. However, only one etching step is necessary to show the concept.

During this activity, make sure you are also complying with any safety or use instructions supplied with your etching cream.

From sticky-backed vinyl, use your CNC knife to cut out a pattern that you would like to etch into your glass material. Follow the instructions in the Paint Mask Production activity for this, but keep in mind that the mask will not need to be self-supporting since it will be adhered to your glass and only used once. Clean and wipe dry your glass object, and then adhere your mask to the surface where desired. If necessary, use transfer tape to keep your mask correctly aligned while removing the backing to apply it to your glass. Masking tape may also be used to create a border around your vinyl mask and further restrict the area that is exposed to the acidic “etching cream”.

After applying your mask to your cleaned glass, put on your protective gloves and then use a chemically resistant paint brush to apply a thin coating of your etching chemical to the exposed areas of the glass. Allow the etch to sit as directed. Most etching should reach its full effect within one to ten minutes, depending on the concentration of your mixture and the amount that is built up on the surface. Once etching is complete, rinse the acid off into your large bucket rapidly with warm water, keeping the acid from contacting yourself or other exposed parts of the glass. Dilute the rinse water with large amounts of additional water before washing down any drain in order to prevent damage to plumbing or the environment. Once clean, remove your vinyl mask and inspect the edges of the etched glass with a magnifying glass. Note the quality of the edge formed in different areas.

Discussion:

How well does your cut vinyl mask protect the glass? Is there a difference between the quality of etching along curves and sharp corners in your results? As a class you may consider experiment with different patterns and times of exposure to see what features and variables achieve the best results, and if the recommended time of exposure given for your glass etching solution actually produces the best results under your conditions.

3D Layered Objects

Purpose:

- Create an object through an additive process, from layers made by a subtractive process
- Engage in the engineering process by designing, prototyping, and iterating
- Use different types of design software with the CNC knife
- Select the correct CNC knife settings to use for a given material

Materials:

- Corrugated cardboard, foam core board, or chipboard

Equipment:

- CNC knife
- CAD software
- “123D Make” free software
- CNC knife design and control software

Procedure:

With your CAD software, design a simple 3D object. This may be as simple as a sphere or a cube, but a curved shape with a cylindrical cross section (“vase” shape) is recommended. Export your simple design as an STL, and import it into the slicer program 123D Make, or one with similar functionality. Choose an assembly method like stacked layers or slotted layers, set your layer thickness to the thickness of the material you will be cutting, examine your options in the program, and view the flat layers it creates. Note that these are vectors - the format your CNC knife uses. Export the vector files and import them into your CNC knife’s design software.

Inspect the vector paths created by 123D Make in your CNC knife’s design software and modify them if necessary. Cut your layers and assemble them to show that you can produce a 3D object from a 2D process.

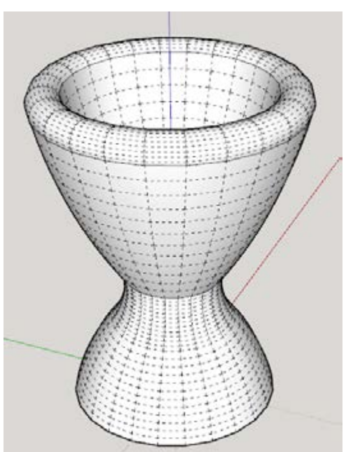



Figure 6: Model, made in CAD (left), assembled as different interlocking thin slices in parallel and then radially, and assembled as many stacked slices (right)

Discussion:

Were the objects you made final products, or prototypes? Consider the results of different slicing options and determine whether the each object made might be improved by being sliced in a different way – in a different orientation or with a different algorithm. What are the constraints and criteria that must be considered to make this decision? As a group debate the question of whether creating layers in this way and then assembling them is a type of 3D printing, and whether it is a type of additive manufacturing.

3D Folded Objects

Purpose:

- Use a CNC knife to create a 2D sheet designed to be folded into a 3D manifold
- Engage in the engineering process by designing, prototyping, and iterating
- Use different types of design software with the CNC knife
- Select the correct CNC knife settings to use for a given material
- Complete a task in workgroups contributing to a common goal

Materials:

- Paper stock for folding into rigid structures

Equipment:

- CNC knife (consumer-grade die cutter)
- 2D to 3D drawing software (preferably design software such as Fab@School)

Procedure:

In this activity, our goal is to create a 3D assembly as a team from cut, creased, and folded paper. We will start from either a 3D plan or a 2D layout, depending on the method your classroom uses. In this example, we suggest Fab@School, though many other ways of planning your objects will work. The assembly your class makes could be as precise as a moving-parts model internal combustion engine, or could be freeform such as your class' ideas for structures to put in a public park.

Start by planning as a group how you will work in teams. For example, one group or person may be in charge of trying different ideas until they can produce free-standing trees for all over your park model, while another might be in charge of planning and building the ranger's station, and another might be in charge of designing a few types of park benches and deciding where they should go, and another takes the project planner role of determining the purpose of different spaces and placement of pathways. In this way, subdivide your project into components.

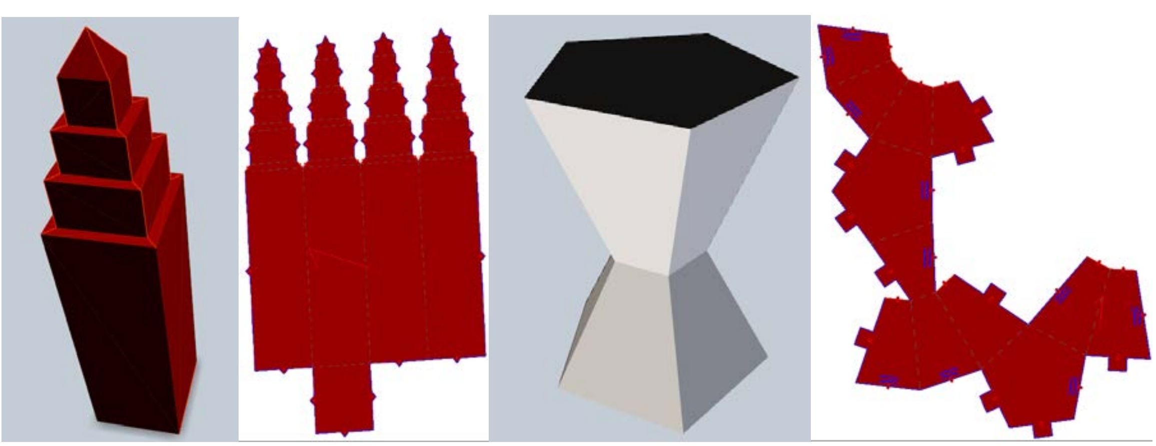


Figure 7: Two 3D objects with their corresponding folded-sheet-and-tab patterns.

As you work, try test-folding with lightweight printer paper before using cardstock. Experiment with joining edges in different ways, both using tape on edges and glued or fitted tabs. This process should intentionally allow for students to discover many good and bad ways to make their shapes, and zero in on the ones that work best for their intentions.

Discussion:

What settings in your software affected the quality of the objects you made? Did some settings work well for one type of object but not for another? Which properties of your construction material were helpful and which created problems? How were those problems handled? Discuss what lessons were learned during the process of completing the project, and how those lessons were shared both intentionally and unintentionally. Did groups always understand each other's intentions and work towards the same goal perfectly? What approaches and methods could have improved the final results?

Materials

For a material to work well as stock for a CNC knife, it must be strong enough in in-plane shear that it does not “shred” around the stresses caused by cutting, and not be so brittle that it spreads cracks away from the knife’s cut. The sharper and slimmer the cutting tool, the lower the stresses that tool will create, and so the more delicate the material can be. If the material is very flexible and would stretch or wrinkle instead of cutting accurately, it may need to be attached to a rigid backing during cutting. Any material that needs to be fixtured with a backing must also be strong enough in out-of-plane shear to resist tearing when it is later peeled off of its backing, or other methods will have to be used to remove it. The more abrasive the material (the rougher and harder the surface it forms when cracked), the faster the cutting tool will dull, and a dull tool will create more compressive and shear stresses that are likely to tear the material instead of cutting. Issues like chemical and thermal stability of the material are not major considerations for use with a CNC knife, since only physical pressure is used to cut the material, and the amount of heat generated by abrasion is usually very small. Extremely tough materials will spread the force of the cutting tool and tend to slide out of place rather than being cut, and so may require slow cutting, very sharp tools, or robust fixturing.

Paper Products

Including standard bond paper, cardstock/cardboard, chipboard, wax paper, and corrugated cardboard, these cellulose/lignin organic composites have low shear strength in all directions and are easy to cut with a drag knife. A dull rotary blade may also be used to crease paper products accurately without cutting them. Though paper products are generally easy to cut, fixturing them properly can be a challenge, and in some cases corrugated or sandwich cardboard may be too thick for a standard drag knife to cut through. In all cases, care should be taken to adhere paper to a backing strongly enough to accurately cut the smallest detail your design requires, but also not to adhere it so strongly that layers of the paper separate when removing it from fixturing. This is especially an issue with short-fiber papers like chipboard. For low-quality papers it may be difficult to find a method that accurately fixtures the material but does not damage the material during release. Expect that shorter fibers in a paper product will result in lower tensile and shear strengths.

Foamcore

This simple composite combines the compressive strength and low density of polymer foam with the tensile strength of paper. Foamcore board has low resistance to crack tip opening, but is generally too thick to cut with consumer grade CNC knives (die cutters). However, it will cut very well with an oscillating blade of the right length, or a long and thin drag knife. Additionally, foamcore is stiff enough in bending stress to be fixtured by a vacuum table, or in some cases just by physically fixturing the edges, so it isn’t necessary to damage the paper surface with adhesives. Sharp corners can be cut by plunging the knife at different locations, but smooth curves will be very difficult to cut cleanly through any thick material, since the concave side will be scraped by the back side of the blade.

Vinyl sheet

Vinyl is in many ways the ideal material for accurate cutting with a CNC knife. Because vinyl is flexible, elastic, and has a low resistance to crack tip propagation, a dull knife will cause it to bunch up and deform or tear. However, a sharp knife will cut smoothly, and will cut clean curves because of the elasticity and thinness of vinyl sheet. Because it is flexible, it must be well fixtured. It is fairly strong in shear, and, as long as it has no sharp nicks to initiate tears, it is easy to remove from adhesive fixturing. It is often manufactured with an adhesive backing attached to transfer paper, providing a convenient cutting support which is easily removed when desired.

Rubber

Elastomers like rubber can be expected to cut well, similar to vinyl, when in a thin sheet. The high coefficient of friction of rubber, however, will rapidly become an issue the thicker the sheet is. A thicker sheet will have more surface area for friction in contact with the sides of the blade as it cuts. This friction will convert energy intended to be delivered at the blade tip into compressive stress in front of the blade and tensile stress behind the blade, with bending stress being applied to the blade in its axis, peaking at its tip. The thicker the rubber, the higher these forces will be, and the higher the risk of shoving the rubber out of place, breaking fixturing, or breaking the blade. Use of an oscillating or vibrating blade may relieve these stresses by rapidly releasing and re-engaging with the rubber.

Corrugated plastic

Usually made of polypropylene, corrugated plastic is inelastic and relatively inflexible, but weak in resistance to sharp crack opening, making it both easy to cut and easy to fixture. However, it is much too thick for common consumer die cutters to handle. Keep in mind that its corrugations may compress and release in the out-of-plane direction as it is put under pressure during cutting, so cut edges may have a slight vertical ripple to them. The direction of the corrugation gives the material a variable yield stress in bending, and makes it easier to cut in some in-plane directions than others. Be aware of the orientation of your material when you are working with it.

Fabrics

Including cotton and synthetic cloth, burlap, felt, and carpet, fabrics can be cut with drag knives of the appropriate size. With fabrics, the fixturing of the material is the challenge. Even fabric with its own relatively stiff backing, like carpet, is made to intentionally flex in bending stress and even stretch somewhat in tension, so bunching-and-tearing behavior is a threat. Additionally, if small parts of the fabric can come out of place, it will be very difficult to accurately cut any detail. An adhesive backing is often helpful, but keep in mind that removing the fabric from adhesive can tear the material. Fabrics with low cohesion or low thread count, especially thin cottons or loose weaves, will cut best with a sheet of low-adhesive transfer tape applied on both the top and the bottom of the cloth, preventing fibers from curling out of place while cutting.

Fiberglass and Carbon Fiber weave

Woven stiff abrasive fibers, often cut to shape before being added to a composite matrix, can be cut well with the right tools. In this case, a hardened rotary blade is recommended to cut the fibers by primarily applying “downward” force towards the plane of the material. Stiff, abrasive fibers like these will quickly dull oscillating or drag knives, but are less of a problem for rotary blades that “crush” them apart. A very resilient cutting surface will be required.

Safety note: Clean and ventilate well any time you are cutting carbon fiber, or any other material that releases small conductive particles. <u>Carbon fibers or carbon dust that settles on electronics, or is sucked into an electronics case by a ventilation fan, can cause shorts, sparks, and fires. All short, stiff fibers are skin and eye irritants, including broken fiberglass and carbon fiber.</u>

Vellum, Leather

Flexible, tough, medium elasticity, low-friction materials like leather and vellum can be cut well with some challenges. They may be cut with a sharp rotary tool against a tough pliable surface, allowing the blade to cut without applying enough force to slide the material out of place. For detailed cutting paths, they may have to be adhered or even vacuumed into place and cut with a thin blade instead. Keep in mind that these materials are complex organic composites made of layers of chemically treated animal epithelial cells. This means they can have a unique blend of properties that is hard to achieve in other ways, but also that there will be variations between different samples.

Polymer Foams

Foams made from polymers are made by gas bubbles inside of a cooling liquid made up of molecular chains. Imagine the way the chains will stretch and shift on the surface of an expanding gas bubble, and you will realize that the chains are oriented in the plane of the curved bubble surfaces. This means that foams may flex elastically by compressing or elongating the bubble-shaped structures, but the chains may already be too well-aligned to shift around each other and engage in plastic deformation. In other words, foams will either stretch by shifting the shape of their bubbles and then return to their original shape or they will fail by tearing, but will almost never deform plastically.

A closed-cell polymer foam is a foam where each bubble is fully enclosed, so fluids will not pass through the material unless doing so by chemical diffusion. Styrofoam is a good example. Because the gas trapped inside a closed-cell foam resists compression, they tend to be stiffer and firmer. Cut closed-cell foams by plunging with an oscillating blade, and expect the surface to not deform much during cutting.

Open-cell foams are made when bubbles formed in the melt share open sides rather than sharing walls, leaving a structure where fluids can pass through. Ethylene vinyl acetate (EVA) foam is a common example of a soft open-cell foam padding. The open-cell foam structure tends to be more flexible and compressible, since the bubble structures can compress and recover without breaking any bonds or rupturing any walls. Very flexible foams should be cut with an oscillating blade, or they will stretch and tear rather than cutting. Open-cell foams made of more rigid plastics can still be cut with a drag knife.

Metal Foils and Sheets

Thin metal materials like aluminum or copper foil, or tin sheet, may be easily creased with a slightly dull rotary tool called a “creasing wheel”. This essentially allows custom stamping or patterning to be done, and can create folds where desired. These metals are tough, hard, and malleable compared to most of the other materials used with a CNC knife. When the material is thin enough to be cut or creased with these tools though, it will be very flexible. Depending on the grain structure of the metal used, the metal may cold-work to different degrees. This means that the metal will stiffen as it deforms, so cutting or creasing an area that has already been deformed by a rotary tool will have different results than the initial operation. A hardened creasing wheel, with fixturing on a resilient surface, may be used to cut metal sheet of different thicknesses . . . but a water jet may be a better tool for accomplishing this task.

Common Classroom Materials

More than any others on this list, adhesive-backed vinyl and cardstock paper are highly accessible and will produce great results. Consumer grade digital die cutters and vinyl cutters are made specifically with these materials in mind. Vinyl sheet can be bought in hobby or craft stores. Since it can be rolled up for storage and transport, it can also be shipped at a reasonable price. Cardstock, cardboard, and chipboard of different qualities and thicknesses can be purchased in bulk from office supply stores, and unusual variations can be found at crafting and art supply sources.

With CNC drag knives capable of cutting thicker materials, the next set of basic materials that become accessible include foamcore board, rubber sheet, and corrugated plastic, and corrugated cardboard. Foamcore can be purchased or ordered through office and craft supply stores, and is usually cheaper to pick up from a store than to order direct, due to the price of shipping. Rubber sheet can be bought or ordered at hardware stores and retail craft stores. For bulk amounts, order from industrial supply companies. Corrugated plastic is sold under names such as Coroplast, and can be obtained from office supplies, signmakers, and home improvement stores.

Student Evaluation Questions

1. What material properties make a material difficult for a CNC knife to cut?
2. What tool would you use to cut a very abrasive sheet material with high toughness and low ductility? Why?
3. What tool would you use to cut a sheet material with low toughness, high elasticity, and high tensile strength? Why?
4. What tool would you use to cut a thick sheet material with low strength in tension and shear and high strength in compression? Why?
5. What part of a drag knife contacts the material? What part of a rotary blade contacts the material? Draw a three-perspective close-up diagram showing the geometry of a cut from both tools, clearly showing their differences. Think about the shape of the blade and how it touches the material.
6. When a rotary blade cuts a 90 degree corner pointing inwards to a shape, it can produce a quality control concern that it does not create when cutting a 90 degree corner pointing outwards from the shape. Why is this?
7. What methods can be used to hold a material in place while it's being cut with a CNC knife?
8. What products would a manufacturer make from rubber sheet cut with a CNC knife? Which of these products are finished goods, and which are used in the process of making other products? Answer this same question for metal foils and carbon fiber weave. Search online and see if you can find examples of these types of products for sale.

Instructor Evaluation Questions

1\. At what grade level was this module used?

2\. Was the level and rigor of the module what you expected? If not, how can it be improved?

3\. How did the module work as presented? How did activities add to student learning? Please note any suggestions. Were there any problems?

4\. Was the background on material properties sufficient for your background? Sufficient for your discussion with the students?

5\. Did the module generate interest among the students? Explain.

6\. What challenges did your class face in obtaining equipment for lessons?

8\. How did you modify this module or these activities for your students?

7\. Please provide your input on how this module can be improved, including comments or suggestions concerning the approach, focus, and effectiveness of this activity in your context.

(Please send feedback to **matedu@edcc.edu**)

Suggested Answers to Student Evaluation Questions

1. *What material properties make a material difficult for a CNC knife to cut?*

High toughness, high hardness, high elasticity, especially when combined with low in-plane shear strength.

2. *What tool would you use to cut a very abrasive sheet material with high toughness and low ductility? Why?*

A hardened rotary blade. Low ductility means it will take force to create a crease or cut, but high toughness and abrasiveness mean that plunge or oscillating blades will be dulled and damaged quickly.

3. *What tool would you use to cut a sheet material with low toughness, high elasticity, and high tensile strength? Why?*

A very sharp drag knife. An oscillating blade will pull this elastic material out of place easily, and similarly a rotary blade will stretch it without cutting it. The low toughness means that a sharp crack made by a knife will spread quickly regardless of the tensile strength, but using a duller blade risks catching and stretching instead.

4. *What tool would you use to cut a thick sheet material with low strength in tension and shear, but high strength in compression? Why?*

A long oscillating blade will be best here. Compressive resistance and thick geometry will result in bad cuts from a rotary tool, especially on curves. Thickness means that a drag knife will create lots of friction, and low shear strength means friction will create tearing in the material. An oscillating blade will circumvent these problems by cutting downward repeatedly.

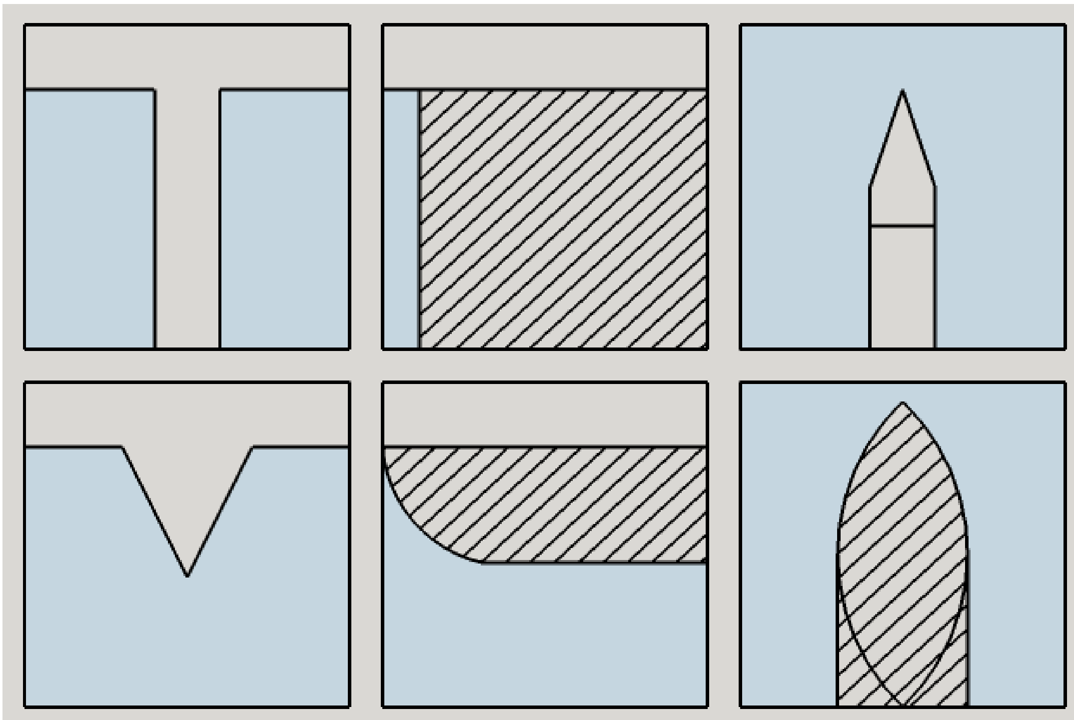
5. *What part of a drag knife contacts the material? What part of a rotary blade contacts the material? Draw a three-perspective close-up diagram showing the geometry of a cut from both tools, clearly showing their differences. Think about the shape of the blade and how it touches the material.*

From in front / behind: A drag cut is a gap the width of the blade or less, down to the surface. A rotary cut is a V-shaped indentation of a variable depth.

From the side: The path of the drag cut is simply a rectangle section from the top to the bottom of the material. A rotary cut or crease is a rectangle section of variable depth from the top, with a shallow mark at the front where the wheel has only contacted at the beginning of its curve.

From above: A drag cut should look like a line, hopefully with no tears, and a very small notch at the front if the blade stopped within the material. A rotary cut is a sharp ellipse of fixed length for any given depth, meaning that on corners it will scrape with both the front and back of the wheel above where the lowest part of the wheel contacts.

See diagram:



6. *When a rotary blade cuts a 90 degree corner pointing inwards to a shape, it can produce a quality control concern that it does not create when cutting a 90 degree corner pointing outwards from the shape. Why is this?*

Since the curved blade of the tool reaches maximum depth in the material only in the center of the rotary blade, any inward-pointing angle will have scrape marks on the obtuse side of the angle where the front or back of the blade scraped over the surface as the blade rotated in place. If the angle is pointing outward from the shape, the obtuse side will be on the outside and only scrape the extra material that's being removed anyways.

7. *What methods can be used to hold a material in place while it's being cut with a CNC knife?*

Many! The material could be held down by its own weight and friction, or it could be clamped at the edges with or without tension or compression applied across the surface, or it could be screwed or pinned or held down by weights in place at places where the tool is programmed not to go, or adhered to the surface, or held down uniformly by suction applied to a porous bed on which it sits, or even pressed down into place by a rolling or sliding jig that always moves with the blade.

8. *What products would a manufacturer make from rubber sheet cut with a CNC knife? Which of these products are finished goods, and which are used in the process of*

making other products? Answer this same question for metal foils and carbon fiber weave. Search online and see if you can find examples of these types of products for sale.

There are many answers to this, and it should be used as an opportunity for students to show their ability to think about the world around them and do some simple research. Rubber sheet is used most often to make gaskets and tough anti-slide surfaces, but students may identify products like flip-flops where rubber sheet has been cut and layered with other things. Sheet may even be cut to size and then heat-pressed into a non-flat shape, but things like tires and curved shoe soles are usually injection molded.

Metal sheet is stamped into many shapes, but not frequently CNC cut. A good example would be shrouds for protecting equipment from particulate while also reflecting infrared heat. Metal foil strips are also cut and layered in some composite materials.

Carbon fiber weave is CNC cut into custom shapes for composite layup on unique things like racing car bodies, and mass products like quadcopter bodies. Students may come up with interesting product examples for this that they can reasonably assume would be done a CNC knife.