Formech
Perfectly formed

Vacuum Forming Guide for the Classroom

August 2024 v1

Introduction

Thermoforming has been around for a very long time, and has transformed the world that we live in. It is a process that has helped to make items from the simplest of food packaging trays and car interior parts, to sets and costumes in Hollywood blockbuster movies, life saving medical equipment, and even components for space exploration.

The possibilities of this production method are endless, with applications seen in almost every industry you can think of. Despite seeing and using thermoformed plastics every day, not everyone has even heard about thermoforming before, let alone had the chance to use it to design and manufacture something fresh out of their own imagination.

The simplest description of the process is that of a sheet of plastic having heat applied to it until it softens, before being draped over a mold tool. A strong suction of air, or 'vacuum', is applied from below, attracting the soft plastic over the mold tool to adopt its shape. Once cooled, the mold tool can be removed, leaving just a perfectly formed plastic component.

The early 1900s saw the development of the first thermoforming machines but they were big, and took up a huge amount of space. Things have changed a bit since then, and thermoforming equipment today can be so small it can fit on a school desk.

In this guide we will be exploring the potential of Formech vacuum forming machines, covering all aspects of how to use them, what to use them for, how to produce your mold tools to form over, and all the tricks of the trade that go along with it.

This document will be your one stop guide, which you can refer back to at any point during a project to find all the answers, hints and tips you might be looking for.

Once you've got to grips with the contents of this guide, there will be just one question left unanswered: *what are you going to make?*

The Vacuum Forming Process

Vacuum forming machines are simple to use. They need just three things to produce high quality and consistent plastic products: a mold tool, a sheet of suitable plastic material, and an operator.

Let's walk through the basics of the machine, and how to carry out a successful vacuum form.

Warming up

Fristly, the Formech machine will need to be switched on 15 minutes before it is to be used, with the heater in its back position. This is to allow the heater elements to heat up and deliver a consistent and even temperature.

The table can be raised by simply pulling the lever towards you until it locks. The mold tool to be vacuum formed over can be placed on the table and positioned centrally; then the table can be slowly lowered, descending the mold tool inside the vacuum forming machine.

Clamping the plastic sheet

A sheet of plastic material can be placed over the opening, as if putting a lid on the space containing the mold tool. The clamp frame can be lowered and secured in place. The tight clamp will create an airtight seal between the aperture window and the plastic sheet, creating perfect conditions for the vacuum forming process.

Heating the plastic

The heater can now be pulled forward to cover the clamped plastic, and be given the appropriate length of time to heat the material - depending upon both its thickness, and the type of plastic material used. The heater can be moved back and forth to check on the material as needed.

Having had ample time to heat the plastic, the heater can be pushed back all the way. The sheet material should have a visible slight sag, indicating that it is ready to be vacuum formed.

Forming the mold tool

Raise the table completely using the lever, which will push the mold tool into the heated plastic sheet from below. The vacuum pump can be switched on, which will draw air out from under the mold tool, sucking the soft plastic over it. The vacuum pump might be applied for 15 seconds or more, to ensure a high definition form, and to allow some time for the plastic to cool.

Releasing the mold tool

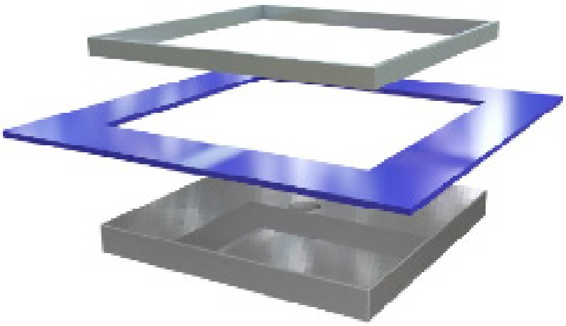
The vacuum pump can now be switched off, and then the exhaust/release pump is pulsed once or twice. Rather than removing air like the vacuum pump, the exhaust/release pump does the opposite, pushing air in from below. This pushes the plastic material up very slightly and separates it from the mold tool.

The table can be lowered slightly and by tapping gently on the plastic material, the mold tool will be released from the formed shape, and sit back on the table. The table can now be slowly lowered completely.

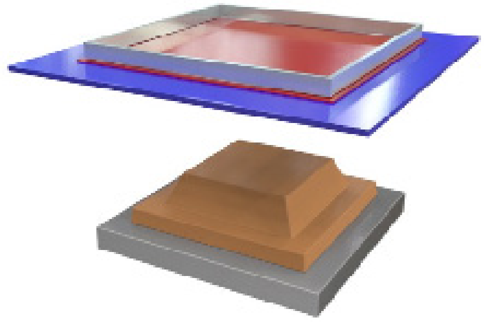
The clamps can now be unclipped, and the clamp frame raised.

You will now have your completed vacuum formed product, ready to have excess plastic material trimmed off.

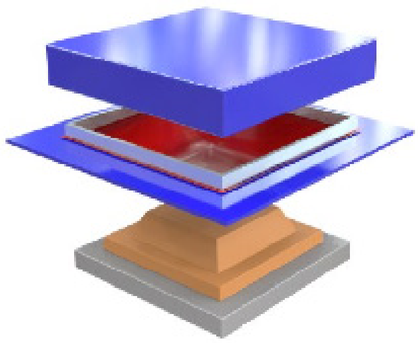
Basic principles of vacuum forming



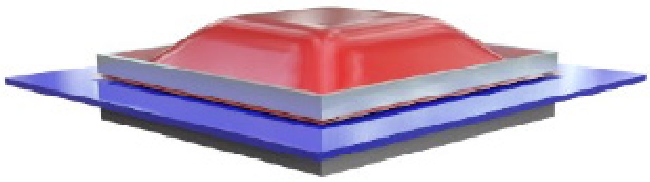
1. Clamping frame, aperture plate & table



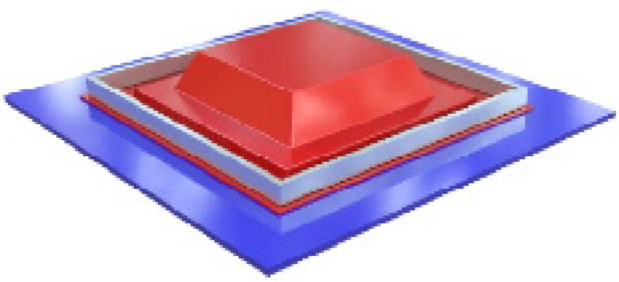
2. Material clamped and tool (mold tool) mounted on table



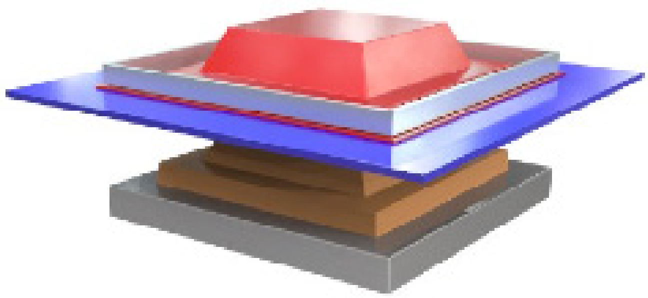
3. Heating the clamped material



4. Material pre-stretched & table up



5. Vacuum applied



6. Cooling, release & table down

Heating the plastic correctly

It is important to heat the plastic material appropriately to gain the perfect vacuum form. This comes with the experience of just a few forming cycles, although a good general rule is to apply 20 seconds of heat for every 0.5mm of thickness of the plastic material.

For example, 1.5mm thick plastic requires approximately 60 seconds of heat. This varies between type of plastic material used, but these timings can be a good place to start (see page 21).

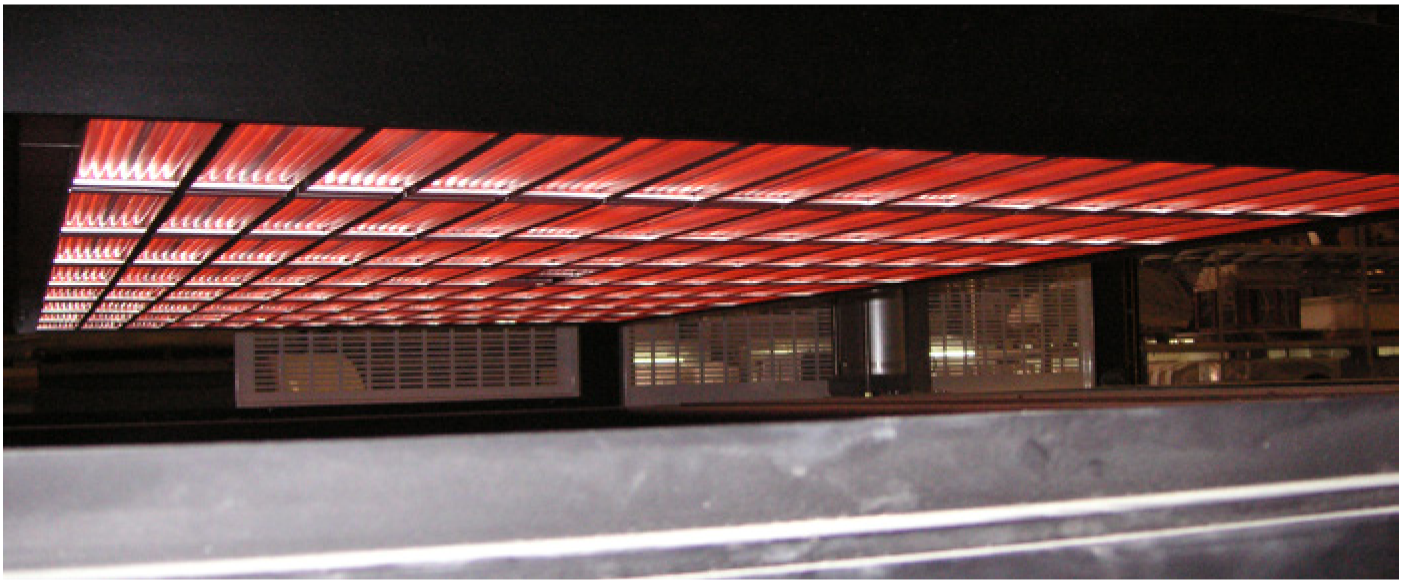
Be Careful

Do not touch the heated plastic material with your hand or any other object during the heating cycle. This may cause harm or damage the material itself. Rely on the visible slight sag as the indicator for the optimum temperature to perform the vacuum form, or use a temperature gun to aid you.

Do not attempt to raise the table of the vacuum forming machine when the heaters are in the forward position. This may damage the lever mechanism, or the heating elements. Most vacuum forming machines have a safety mechanism that will not allow the table to be raised unless the heaters are in their fully back position, or for the heaters to be pulled forwards if the table is raised.

When lowering the table, be sure to make this a smooth and steady motion rather than dropping it. This will prevent any damage or movement of the mold tool within the forming area, and reduce stress on the machine.

Always remember, this machine produces heat that reaches very high temperatures. Do not touch or put anything on top of the heating draw of the machine, or put your hand under the heating drawer itself.



Mold tool design is, for most people, the most exciting and rewarding part of the vacuum forming process. It is here that you can draw upon everything that is in your imagination as a designer, an artist, or an engineer, and realise it in a physical object.

The mold tool, sometimes called the 'tool', is the object placed on the table of the vacuum forming machine over which heated plastic will be formed. This mold tool is the most important part of the vacuum forming process, as without its considered and purposeful design, there would be limited success in the forming process.

There are a few considerations to make when designing your mold tool, from its shape, to the material used, to airflow, to size, and spacing, but don't worry; in this section of the guide we will take you through each consideration, and have you making perfect custom mold tools which produce perfect vacuum formed products.

Mold Tool Materials

There are a wide variety of mold tool materials available, from clay and wood, to MDF, resin and more. Which you select depends on a list of requirements for the designer and the final vacuum formed product.

- How many times will the mold tool need to be vacuum formed?
- How much detailing will the mold tool involve?
- How are you going to shape or tool the mold tool?
- How much does the mold tool need to cost?
- Is there a budget?
- How much time do you have to produce the mold tool?

Here we will go through each material one by one, covering its benefits and drawbacks, which should help you make the correct choice in your mold tool material choices.

Modelling Clay and Plaster

Modelling clay is widely used as a mold tool material due to its incredible ease of shaping and very low cost. For simple mold tool designs the designer might even use just their hands to shape and mold tool the material to their desired shape. This makes it an ideal material for producing a one-off item, or to prototype a product quickly.

One big disadvantage of clay is its fragility, or lack of strength. It performs well for a limited number of forming cycles before becoming brittle, at which point cracks will begin to appear and shape will be lost. This makes it ideal for only a very short production run.

Clay mold tools will need to be dried completely before being vacuum formed to ensure that they hold their shape during the vacuum forming process. The heat and pressure applied during a forming cycle will most likely deform any clay mold tool that has not been allowed to dry thoroughly. Dried clay mold tools will also likely require few or no venting holes applied, as the material is relatively porous and will allow air to flow through it. It should be possible to push a wire through the clay before it has dried to create vacuum holes.

Shaping and smoothing the sculpted clay

Sculpting ready to be vacuum formed

Vacuum formed mold tool

Wood and Medium Density Fibreboard (MDF)

Wood and MDF are very popular mold tool materials due to their low cost and ease of tooling. Using a range of simple woodworking tools and techniques, the designer is able to produce a mold tool with relative ease, which is capable of withstanding hundreds of vacuum forming cycles.

MDF is especially easy to work with, and even though it is not as strong as wood, it certainly performs well in the vacuum forming process, providing a fast and effective mold tool making material. One advantage of MDF is that it is a porous material so vacuum vent holes are not always required.

This material is a favoured material in education and small factories due to its cost, time, and ease of tooling benefits.

Wooden tool

Cast Epoxy Resin

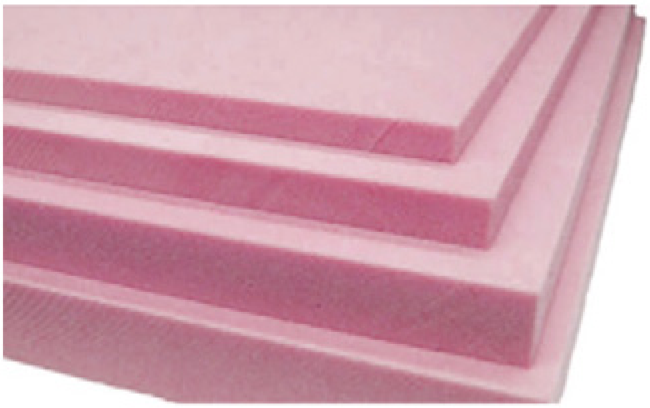
Epoxy resin begins life in liquid form, most often two separate liquids: the resin, and a hardener agent. When combined and mixed thoroughly, they can be poured into a prepared mold tool and allowed to set, creating a very hard and very durable mold tool to be vacuum formed. These resins are available in many different varieties, and can take anything between 30 minutes and 12 hours to set completely.

The main benefit of resin as a mold tool material is its long life and durability. Unlike clay, a well-made resin mold tool will be fit to withstand hundreds of forming cycles with little or no visible sign of aging, or decrease in quality of the vacuum formed product.

The only real drawbacks of casting mold tools from resin are the relatively high expense, length of time required, and the need to source or make an original mold tool within which to pour the resin in its liquid form. Resin is also a non-porous material, which means that no air can pass through it, therefore venting holes will need to be applied for most mold tools made from this material.

Foam

Foam material can be one of the cheapest, and easiest materials to shape. When we talk about foam, we mean large sheets of building insulation foam that can be cut to the desired shape very quickly, using a machine or hand saw, or a hot wire cutter.



Using a variety of both hand and machine tools, detail can be added and some very impressive mold tools produced. Due to this ease of working, it is a popular material for prototyping or single run vacuum forms.

We recommend you use a foam with a small bubble structure so that you get a good quality end result, which is less likely to crumble.

It may be quick and easy to work with, but be warned: foam material has a very low level of heat resistance, and its shape will be affected by the heat produced during a forming cycle. This means a foam mold tool may only be suitable for a handful of vacuum forms.

To increase its cycle life and to encourage ease of mold tool release, a foam mold tool might have a layer of aluminium tape, or simple aluminium kitchen foil applied to any surface that will come into contact with heated plastic material.

3D Printing/Rapid prototyping/Additive manufacturing

This is where vacuum forming and computer technology meet in the middle.

3D printers have become increasingly cheaper and much more common in recent years, and can be found in most schools and workshops.

They allow an object to be designed using Computer Aided Design (CAD), which can then be printed as a 3D physical object using a wide variety of materials. This allows the designer complete control over the size, dimensions, and specifics of the object to be printed, which can be produced sitting in front of a computer rather than in a workshop using traditional tools and materials.

Alternatively, 3D printing files can be downloaded from online sources, and scaled up or down as desired. Either way, they can be printed with the single click of a mouse.

The types of materials and processes used to 3D print objects vary widely in both characteristics and cost, but two processes which are commonly used are FDM and PolyJet.

3D printed mold tool

Vacuum formed mold tool

Final part

Aluminium Cast

Aluminium is a favoured material for mold tools used in mass production lines using vacuum forming.

It is incredibly strong whilst remaining incredibly light, and allows heat to dissipate quickly following the forming cycle, reducing the need to cool it down between cycles on lengthy production lines where temperatures can get very high.

It can be machined by human control or CNC, or can be cast to the desired shape.

Just like CNC, it is unlikely to be found in High School workshops, but certainly helps give context to the range of mold tool materials available to designers and engineers within the mold tool making process.

Cast aluminium

Computer Numerical Control (CNC) machined tooling board or model board

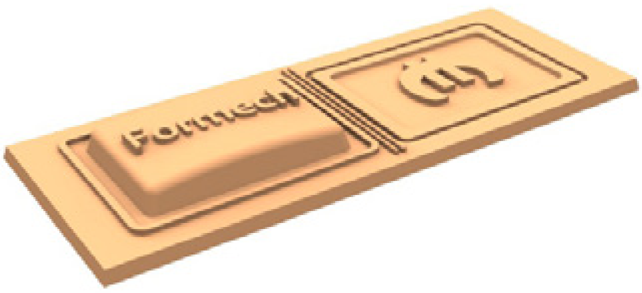
CNC is a method used widely in industry to cut materials to shape, using a rotary cutting tool whose path is controlled by a computer.

With the mold tool material laid stationary on a machine's table, the tool then works its way around above it, changing its height and direction, cutting away material as it goes.

This is a method of tooling which is unlikely to be readily available for High School students, but because it is so widely used in industry, it is important it receives a mention.

Materials for which CNC is widely used might include MDF, tooling/model board, aluminium or Alwapor porous board. All of these cut relatively easily and produce mold tools perfectly suited to vacuum forming, whilst providing a high level of control and detail.

Just like 3D printing, all the hard work takes place behind a computer, with the physical shaping of the materials being done by an automated machine. Tooling paths can be produced on a computer using specialist software, or downloaded from online sources.



Any suitable existing object

One of the most enjoyable parts of design and engineering is being inspired by the world around you, and using 'organic' objects to aid the design process. This can be true of the designs that you draw on paper, and also of the materials you use, and mold tool materials are no different.

In addition to mold tool materials, any designer must also think about design requirements when designing their tool. In this section we will explore just a few brief, but absolutely essential requirements for mold tool design.

Draft Angles

When designing a mold tool it is important to think about working draft angles into the design.

These are very slight tapers which are applied to the outer edges of the mold tool, and any substantial angles within. They aid both the distribution of plastic material during the vacuum forming process, and mold tool release.

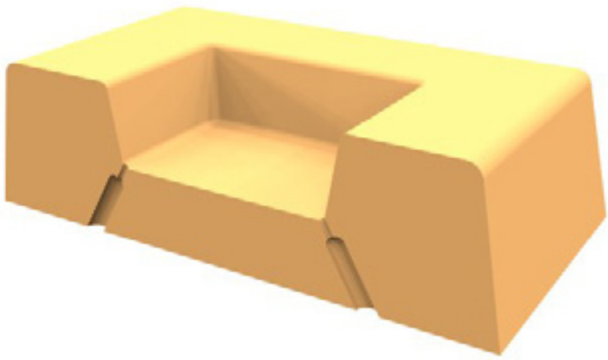
These inward tapers do not need to be dramatic or hugely visible, although the bigger the draft angle, the more successful the vacuum forming process and mold tool release will be. It is recommended that draft angles should be a minimum of 3˚ - 5˚.

Venting

We know that vacuum forming relies heavily on airflow to attract heated plastic over a mold tool. It’s quite simple; the greater the amount of airflow, the more successful the vacuum forming process will be.

With this in mind, every mold tool produced should have venting holes considered. These are holes from the top of the mold tool, right the way through the material and out of the base, creating a channel for air to flow completely through. They can be as small as just 1.5mm wide, and drilled using a simple pillar or hand drill. These small holes will not be visible on the final vacuum formed product.

Knowing where to apply them is easy. Any place on a mold tool where there is a recess or notable groove will need a venting hole or two. This will create an air channel which. when the vacuum pump is applied, will attract the heated plastic into that specific area of the mold tool. Think of any part of a mold tool where plastic will need to be formed within it rather than over it. These are the key spots where venting holes will be essential.

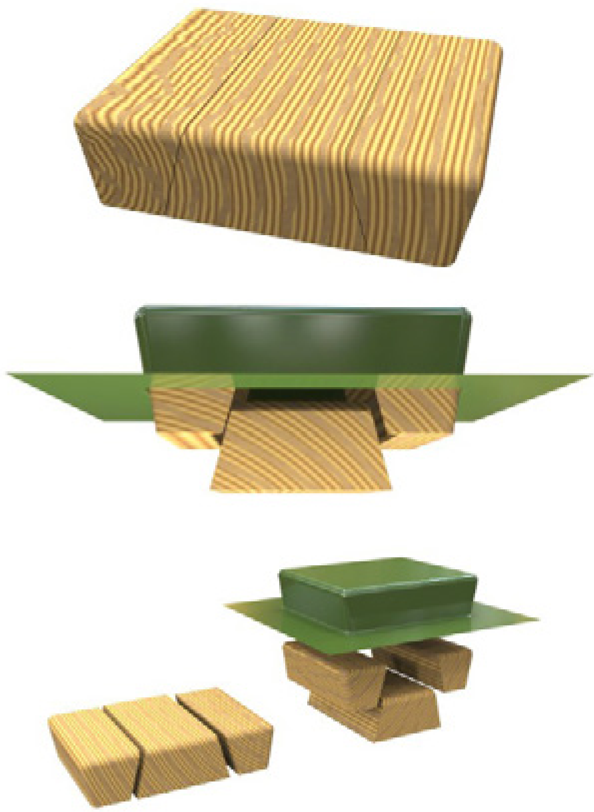


Undercuts

Undercuts are very rarely seen in any vacuum forming mold tool and 99% of mold tools will have no undercuts at all - and there is very good reason for this. Imagine vacuum forming over a dining plate, which has a very visible undercut all the way around its outer edge. During the forming cycle, plastic material would be formed over, and indeed under the plate itself. This would make it impossible to remove the dining plate from the formed plastic material. This simple consideration should be applied to all mold tool designs, with every effort made to avoid undercuts.

If undercuts are an unavoidable element of mold tool design, then there are some methods which may assist you in a successful form and mold tool release:

- Use putty or clay to fill in the spaces within the undercut during the forming process
- Complete the vacuum forming process with flexible material, like Polyethylene foam
- Us a tool which is made up of multiple intersecting pieces, which once vacuum formed can be dismantled and removed



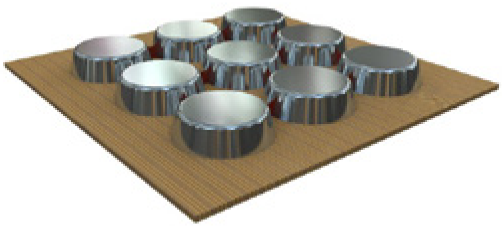
Male and Female Mold Tools

Male and female mold tools are the two categories that mold tools fall into, sometimes referred to as 'positive and negative' mold tools.

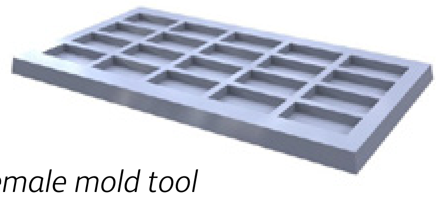
Put very simply, the difference between the two is whether heated plastic material will be formed *over* or *within* the mold tool. This simple illustration clearly demonstrates what this means:

The female mold tool illustration also demonstrates when venting holes would be an absolutely essential part of mold tool design, in that it relies on heated plastic material being attracted into the six deep recesses.

Each individual recess would likely need several venting holes applied at their base, all the way around their outer edge.



Male mold tool



Female mold tool

Webbing

Webbing is used to describe any unwanted folds of plastic that gather around or in between the mold tool or mold tools being vacuum formed.

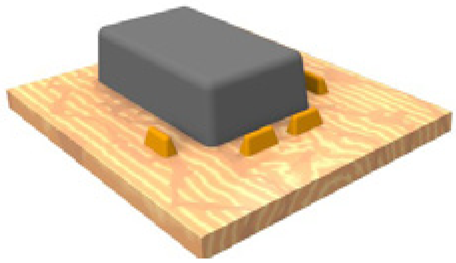
These are most likely as a result of heated plastic material being distributed inappropriately when the mold tool is raised to make contact with it. When the vacuum pump is applied, the plastic material is pulled down unevenly, rather than forming perfectly over the mold tool. Some plastic material adheres to itself and creates these unwanted folds around the edges of the formed piece.

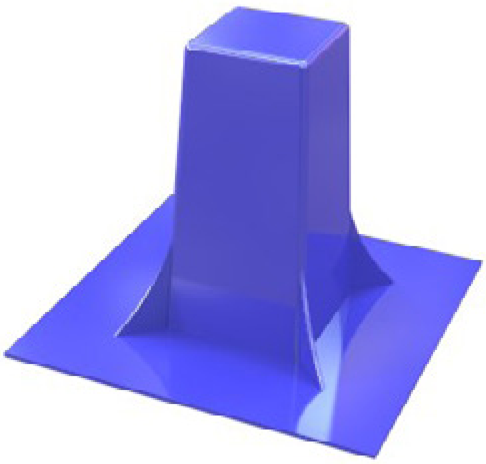
There are four main causes for this:

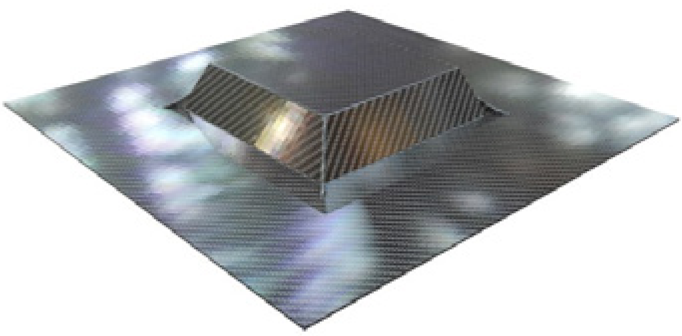
• The mold tool is too tall
• The mold tool does not have enough draft angles applied
• There is too much heated plastic material for a small mold tool
• Multiple mold tools are too close together

The reduce the chance of webbing, try these suggestions to see which applies to your mold tool and the forming process:

• Use a smaller sheet size so that the mold tool/tool stretches the material more
• Place angled blocks around the corners to use up the excess material
• Add draft angles and soften corners to allow the material to flow over the mold tool
• Try using a female mold tool instead of a male mold tool







Thinning

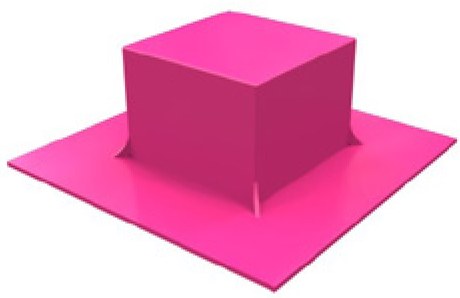
When heated plastic material is overly stretched during the forming process, it causes the material to become thin and weak in certain places. Solutions to this are straight forward:

• Increase draft angles around the sides of the mold tool
• Decrease the height of the mold tool
• Use thicker material

Difficult Mold Tool Release

Sometimes the mold tool may become difficult to remove from the formed plastic sheet, which can be very frustrating. Here are some of the possible reasons why your mold tool and your plastic may not want to part company:

• The mold tool has become too hot after more than
one vacuum forming cycle
• The plastic was allowed to cool a little too long over the mold tool before being removed
• There is an undercut somewhere on the mold tool
• The reverse pump was not used at the end of the forming cycle



This graphic displays a sharp cornered rendering with zero draft angles and sharp corners, which is difficult to form and release.

Lack of Definition

This is when the formed plastic piece doesn't look quite as impressive as it should do, and without as much detail as the mold tool should create. It could be caused by any of the following reasons:

• There are not enough venting holes in the mold tool
• The plastic material was not heated enough
• The seal between the plastic and the aperture window is not airtight and you are losing vacuum – check the vacuum gauge

Finishing and Trimming

Once you have done all of the hard work, made your mold tool and vacuum formed it perfectly, you need to trim off the excess material, leaving you with just the vacuum formed piece you require.

To do so there are a few different techniques that can be used in the classroom or in a small workshop.

Whatever method you choose, be sure to approach the process with great care, and only use equipment with the correct training and supervision.

By hand - scissors, tinsnips, or sharp blade

This is method will work well with many items, especially those with straight edges.

By placing the vacuum formed plastic flat on a work bench, and placing one hand directly on top of it, the mold tool can be gently pushed down to prevent it moving around.

With the other hand, take a strong sharp blade such as a Stanley knife, and run it along the desired cutting line. It will not cut directly through the material, but after one or two passes it will make the material weak enough that it can be bent along the cutting line and the material will separate nicely.

Always break the plastic away from the knife line you have just cut to give you a cleaner break. This works well with HIPS and ABS.

The edges may be a little rough, but these can be scraped to remove excess, and sanded with sandpaper to a smooth finish.

For very thin plastic material (less than 1mm thick) a strong pair of scissors might be used to trim off excess material. Again, a light sanding will remove any rough edges created.

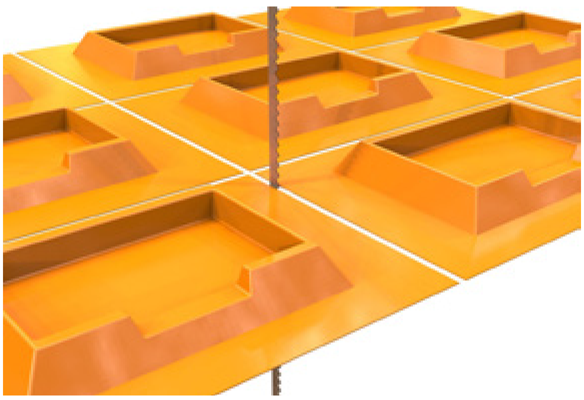
Vertical band saw

Trimming using a band saw is quick and easy, although getting very close to the desired cutting line can be difficult if the line is not a straight edge.

Curved edges rely greatly on the skill of the operator, and so a little practice may be necessary.

This method can produce a rough edge, but this can be neatened up with a small amount of scraping and some light sanding.

If you choose a different trimming method, the band saw can still come in handy to trim off the majority of excess plastic material, before trimming neatly by hand for example.



Rotary slitting saw

A rotary slitting saw can be fitted into a pillar drill, and the table adjusted to a height where the blade is almost touching it. The vacuum formed part canbe placed flat on the table and moved around so the rotating blade cuts around the desired line separating the desired piece from the excess material. It is advisable to roughly trim away most of the excess before using this method.

Please proceed with caution, as the rotary slitting saw is a very effective cutting tool and will certainly cause harm if a hand comes into contact with it.

With this in mind, consider turning the slitting saw over on the spindle end so that the rotary slitting saw rotates with the teeth in reverse. This means that the saw will grind plastic material away rather than cut it, and in the event that the saw is mis-takenly touched it will not cause serious harm.

Table mounted router (15,000 – 25,000 RPM)

Not dissimilar to the rotary slitting saw method, a table mounted router also involves a rotating slitting saw, only this one is mounted below the table.

A vacuum formed plastic part can be placed over the rotating cutting tool. The formed plastic can be moved around, allowing the cutting tool to trim away excess material from the inside.

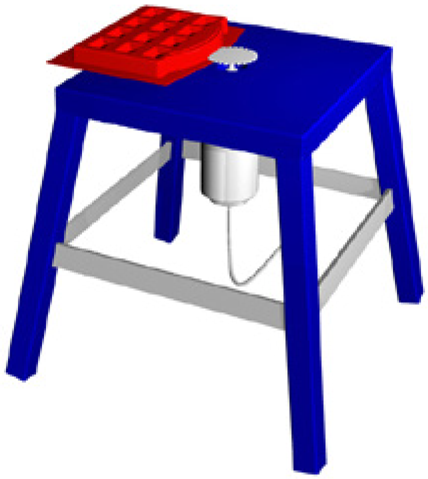
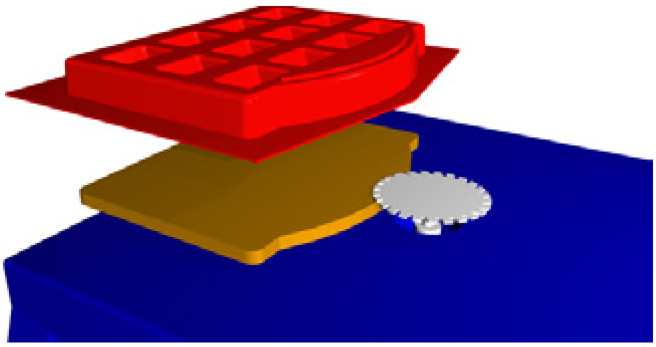


Table mounted trimmer (FT10 and FT20 trimmers –1,250 RPM approx)

A rotary slitting saw can be used on a table mounted router, although a small sanding disc might also be suitable. This will grind the plastic material rather than cut it and reduce any risk of harm during the trimming process.



Final Thoughts

This brings us to the end of our guide for vacuum forming in the classroom, but certainly not to the end of your learning about the vacuum forming process. These are the very basics to get you started creating some incredible vacuum formed products, drawing upon all of your existing skills in the workshop and applying them to the process. The vacuum forming process will never just be about heating and shaping plastic, rather it is going to draw upon all of your skills as a designer, your problem solving skills, material selection choices, tooling methods selections, and most importantly, your imagination.

This is a technology which can truly change the way you see the world as a designer or artist, and open up new and interesting doors for you as you complete any project you take on.

Be creative. Be innovative. And most importantly, have fun.

Formech has a content-rich website bursting with video and written materials, such as How To guides and Case Studies, which showcase vacuum forming being used in the most incredible of ways. Check them out at formech.com/case-studies and formech.com/blog.

Plastics and Approximate Heating Times

Plastic	Thickness	Approx. Heating Time (seconds)
ABS	1mm / 0.04”	40
	1.5mm / 0.06”	60
	2mm / 0.08”	80
	3mm / 0.12”	120
	4mm / 0.14”	140
HIPS	1mm / 0.04”	30
	1.5mm / 0.06”	45
	2mm / 0.08”	60
	3mm / 0.12”	90
	4mm / 0.14”	120
PC	1mm / 0.04”	60
	1.5mm / 0.06”	90
	2mm / 0.08”	120
	3mm / 0.12”	180
	4mm / 0.14”	240
PE	1mm / 0.04”	50
	1.5mm / 0.06”	75
	2mm / 0.08”	100
	3mm / 0.12”	150
	4mm / 0.14”	200
PETG	1mm / 0.04”	30
	1.5mm / 0.06”	45
	2mm / 0.08”	60
	3mm / 0.12”	90
	4mm / 0.14”	120
PMMA	1mm / 0.04”	40
	1.5mm / 0.06”	60
	2mm / 0.08”	80
	3mm / 0.12”	120
	4mm / 0.14”	160
PP	1mm / 0.04”	50
	1.5mm / 0.06”	75
	2mm / 0.08”	100
	3mm / 0.12”	150
	4mm / 0.14”	200

Plastic	Thickness	Approx. Heating Time (seconds)
PS	1mm / 0.04”	30
	1.5mm / 0.06”	45
	2mm / 0.08”	60
	3mm / 0.12”	90
	4mm / 0.14”	120
PVC	1mm / 0.04”	30
	1.5mm / 0.06”	45
	2mm / 0.08”	60
	3mm / 0.12”	90
	4mm / 0.14”	120