VACUUM FORMING & THERMOFORMING MACHINES

From flat thermoplastic sheet to finished part — the process, machines, moulds, materials, parameters, defects and design rules, all on one sheet

~6 mm	max sheet thickness
~200 °C	forming temp ceiling
20–180 s	typical cycle time
low	mould tooling cost
±0.5–1 mm	dimensional tolerance

THE BASICS

WHAT IS VACUUM FORMING?

Vacuum forming is the simplest and most widely used branch of **thermoforming**. A flat sheet of thermoplastic is heated until it is soft and sagging, draped over or into a mould, and then a **vacuum** sucks the air out beneath it. **Atmospheric pressure** (roughly 1 bar / 101 kPa outside against ~0.1–0.3 bar inside) then presses the soft sheet tightly onto the mould so it copies every detail of the surface.

The sheet never fully melts — it only softens — so it is a low-cost way to make large, thin, light parts. Because the tooling is cheap and quick to make, it shines for **prototypes and short runs** as well as mass-produced packaging.

- The vacuum removes the air — the **atmosphere does the pressing**
- Only **thermoplastics** form (they re-soften on reheating)
- Low-cost thermoforming method — cheapest tooling in plastics

THE PROCESS

HOW IT WORKS — STEP BY STEP

- **1. Clamp** — sheet gripped in a clamp frame, overhanging all edges so the seal holds
- **2. Heat** — radiant heaters warm the sheet until it sags ~10–25 mm (softens at ~140–200 °C)
- **3. Lower** — heater swings away / platen rises so the mould meets the sagging sheet
- **4. Vacuum** — pump pulls ~28 inHg (0.7–0.9 bar); air evacuates beneath the sheet
- **5. Form** — atmosphere presses the soft sheet into every detail of the mould (10–30 s)
- **6. Cool** — fans chill the part while vacuum holds it so it sets without distorting
- **7. Trim** — cut away the clamped waste web; sand, drill and finish the edge

Cycle timing (1 mm HIPS, bench machine): clamp ~15 s · heat 60–120 s · form 10–30 s · cool 30–60 s · trim ~60 s = 3–5 min per part. Heating is the bottleneck.

MACHINE ANATOMY

THE MACHINE'S PARTS

- **Heater bank** — quartz/ceramic radiant elements, zoned, ~300–400 °C, above the sheet
- **Clamp / frame** — hinged frame that grips the sheet edges all round
- **Mould platen / table** — the table (often rising) the mould sits on
- **Vacuum holes + plenum** — drilled holes connect each detail to a sealed chamber below
- **Vacuum pump** — oil or dry pump pulling ~28 inHg (0.7–0.9 bar)
- **Cooling fans** — speed the set of the hot part (some platens are water-cooled)
- **Trimming station** — knife, laser or router cut the finished profile
- **Controller** — CNC / thermoform timer runs heater zones, platen and vacuum valve

MOULDS

MALE vs FEMALE MOULDS

MALE (positive / plug) — the sheet drapes **over** the mould. Detail lands on the **inside** face; the outside stays smooth. Cheaper and easier to make; allows deeper draws, but walls thin at the top corners. Used for trays, covers and model-car bodies.

FEMALE (negative / cavity) — the sheet is pulled **into** a hollow cavity. Detail lands on the **outside** face; the inside stays smooth. Gives the best exterior finish, so it is chosen for packaging, blisters and cases.

Which detail? Male moulds give better inner detail; female moulds give better outer detail — pick by the face the customer sees.

Draft: 3–5° minimum on vertical faces so the part releases. **Corner radii** ≥ 1 × sheet thickness (2–3 mm) — sharp corners go thin and tear. Avoid undercuts, or the part locks onto the mould.

MOULD MATERIALS

MOULD MATERIAL BY BATCH SIZE

Material	Best for
Wood / MDF / plywood	Prototypes & one-offs — cheap, easy, naturally porous (aids vacuum); seal the surface for glossy parts
Phenolic board	Short–medium runs — stiff, heat-stable, machinable

Material	Best for
Aluminium	Production / long runs — best finish, precise, water-coolable
PU / cast resin	Short–medium runs — fine detail, fast to cast, paintable
3D printed	Prototypes & fast iteration — complex shapes easy (PLA deforms >60 °C, use PETG/ABS)
Plaster / foam	Sculptable one-offs — porous for vacuum; seal foam or it melts

Every mould needs: **draft** ✓ · **vent holes** ✓ · **radiused edges** ✓ · **sealed surface** ✓ · **secured to the platen** ✓. Drill 0.5–1 mm vents at the deepest / lowest points so trapped air can escape.

TYPES

THERMOFORMING FAMILY

VACUUM FORMING — one mould, low pressure; the default, cheapest thermoforming. Sheet pulled against a single mould face.

PRESSURE FORMING — a second platen adds compressed air (up to ~20–200 psi) on top of the sheet as well as vacuum below. Two-side pressure gives **sharper detail, deeper draws, crisper corners and mild undercuts** — near injection-moulding look at a fraction of the tooling cost.

TWIN-SHEET — two heated sheets are clamped together around the mould and formed at once, welding into a **hollow sealed part** (pallets, tanks, kayaks, ducting).

NOT thermoforming — distinguish: **blow moulding** inflates a hot tube (parison) with air inside a closed die to make hollow bottles; **rotational moulding** tumbles powdered plastic in a heated rotating mould so it fuses to the walls of hollow tanks, kayaks and toys.

ADVANTAGES

WHY VACUUM FORM

- **Cheap tooling** — hours–days, not weeks–months, for a mould
- **Fast setup** — low-volume and prototype runs are economic
- **Large parts** — big sheets make bath trays, boat hulls, guards
- **Thin, light walls** — minimal material use
- **Low cost per unit** at low volume — no huge die investment
- Colour & texture built into the sheet
- Smooth, seamless surfaces — no parting lines
- One machine makes prototypes **and** production parts

Sweet spot: POS displays, custom packaging, jigs, trays, sign faces — where injection moulding tooling could never pay for itself.

LIMITATIONS

WHERE IT STRUGGLES

- **Uniform wall thickness is hard** — forming stretches the sheet, so corners and vertical faces go thin (use thicker stock)
- **Limited detail** — no sharp corners, no fine features, no true undercuts
- **Thermoplastics only** — thermosets, rubber, paper and foil won't form
- **Post-trimming needed** — the clamped waste web has to be cut away
- Detail on **one side** only — the mould side
- **Not for high volume** — per-part cost stays higher than injection moulding at scale
- Low dimensional accuracy (±0.5–1 mm)
- Deep draws need plug assist or go paper-thin

vs injection moulding: cheaper tooling and faster to market, but thicker / uneven walls, lower detail, and higher per-part cost at volume.

PARAMETERS

KEY PROCESS PARAMETERS

Parameter	Effect
Sheet thickness	Thicker = stiffer part, less detail; thin = crisp detail but fragile walls
Heater temperature	Higher softens faster; too high burns, webs or sags the sheet
Heating time	Too short = poor detail; too long = sag / blistering — watch for 10–25 mm sag
Vacuum pressure	Stronger pull = sharper detail; leaks or blocked vents = blurry features
Cooling time	Too short = part distorts on release; full set = clean, stable part
Sheet moisture	Damp acrylic/PETG/nylon traps steam → cloudy blisters; dry first

SHEET MATERIALS

THERMOPLASTIC SHEET — WHAT TO FORM

Only thermoplastics work — the sheet must soften repeatedly and set when cool. Match material to temperature, toughness, clarity and fumes.

Material	Form temp	Properties & typical uses
HIPS (high-impact polystyrene)	140–165 °C	Cheap, easy, good detail — the default. Blister packs, trays, food punnets, model parts, packaging inserts.
ABS	150–180 °C	Tough, impact-resistant, nice surface. Casings, RC / model-car bodies, luggage, instrument trays.
PET / PETG	150–170 °C	Clear, tough, food-safe. Clear packaging, display blisters, point-of-sale stands, drink trays.
PVC	130–160 °C	Cheap and forms easily, but releases HCl fumes when hot — avoid in school, never on laser cutters.
HDPE	130–170 °C	Opaque, tough, chemical-resistant; harder to form — warps and shrinks unevenly. Troughs, liners.
Polycarbonate	170–190 °C	Very tough, impact- & heat-resistant. Machine guards, safety shields, aircraft interior panels.
Acrylic (PMMA)	150–180 °C	Clear and rigid but brittle. Signs, displays, machine covers. Must be dried before heating.

QUALITY CONTROL

DEFECTS & FIXES — RECOGNISE, CAUSE, CORRECT

Golden rule: ~90% of faults trace back to heat (too hot / cold / uneven), draft (missing) or vacuum (leaks / blocked vents). Fix those three first.

Defect	What it looks like	Main cause	Fix
Thin / cracked corners	Paper-thin or torn plastic at corners	Sharp mould edges; draw too deep; sheet too hot	Radius corners; thicker sheet; less heat
Webbing (folds)	Excess-sheet folds in concave corners	Sheet too hot; too much vacuum; concave detail	Cool sheet; reduce heat; add draft; plug assist
Sagging	Sheet droops / distorts before forming	Overheated, or left too long under the heater	Shorten heat; zone the heater; watch the sag
Blistering	Cloudy bubbles / blisters on surface	Moisture or trapped steam in damp sheet; overheating	Dry the sheet; lower temp; shorten heat time
Poor detail / unwetting	Blurry features, mould not copying	Not hot enough; weak vacuum; blocked vent holes	More heat; check pump & seal; clear vents
Part sticking	Part won't release from mould	No draft; rough or hot mould; vacuum not released	Add draft; smooth & seal mould; reverse-air valve
Uneven thickness	Thin walls one side, thick the other	Uneven heating (frame heat-sink); sheet off-centre	Zone the heater; centre sheet; wait for even sag

COMPARE

VACUUM vs INJECTION vs BLOW MOULDING

Three very different ways to shape plastic — pick by volume, budget, detail and part shape.

Attribute	Vacuum forming	Injection moulding	Blow moulding
Tooling cost	Low (hours–days)	Very high (weeks, steel die)	Medium–high
Dimensional tolerance	±0.5–1 mm	±0.05–0.1 mm	±0.1–0.5 mm
Detail / sharpness	Limited (no sharp corners)	Excellent, crisp, undercuts	Moderate
Wall thickness	Uneven — thins at corners	Uniform & precise	Even, seamless
Part type	Open, thin shell shapes	Any solid / complex shape	Hollow bottles & containers
Typical volume	Low–medium (short runs)	Mass production	Mass production
Cycle time	20–180 s (minutes by hand)	Seconds (fully automated)	Seconds
Typical parts	Blister packs, trays, guards	Housings, gears, toys	Bottles, jerry cans, tanks

APPLICATIONS

WHERE YOU SEE IT

- **Packaging** — blister packs, clamshells, trays, chocolate inserts, egg & fruit punnets
- **Food** — punnet trays, fresh-produce packaging, disposable catering trays
- **Signage** — sign faces, display trays, point-of-sale stands, protective covers
- **Automotive** — dashboards, door panels, liners, truck fairings, bumpers (big machines)
- **White goods** — fridge liners, washing-machine tubs, bath & shower trays
- **Transport** — aircraft cabin panels, seat backs, train interior trim (fire-retardant sheet)
- **Boat hulls** — translucent & opaque hull panels, kayak and canoe shells
- **Medical** — sterile blister trays, instrument organisers, dental models
- **Machine guards** — strong clear polycarbonate safety shields & enclosures
- **Prototyping** — quick visual / ergonomic models before committing to injection moulding

APPLICATIONS 2

MORE REAL-WORLD USES

- **Retail display** — branded POS stands, shelf trays, hooks & holders
- **LE toys & hobby** — model-car bodies, F1-in-Schools shells, kites, masks
- **Building** — cladding panels, ceiling panels, skylight domes (free / drape forming)
- **Agriculture** — seed trays, plant pots, poultry drinkers, equipment guards
- **Luggage** — camera & equipment cases, carry handles, shell cases
- **Electronics** — equipment housings, vent covers, keyboard & bezel trim
- **Sports** — helmet liners, visor shields, sled & board covers
- **Packaging inserts** — fitted trays that hold tools, chocolates or cosmetics
- **Furniture** — chair shells, drawer liners, back panels, decorative cladding
- **Scale models** — architectural / product mock-ups formed over a 3D-printed master

SCALE

FROM ONE-OFF TO MILLIONS

One-off / prototype — school projects, product development; MDF or 3D-printed mould, one sheet at a time.

Short run (100s–1000s) — POS displays, custom packaging, jigs & trays — the economic sweet spot where tooling cost is tiny.

Mass production (millions) — roll-fed automatic machines pull sheet from a reel, form, and trim inline — blister packs by the million.

Why it's everywhere: tooling costs almost nothing next to injection moulding, so short runs and prototypes pay — yet the same machines scale to millions of blister packs a year.

GLOSSARY — 16 KEY TERMS

Sheet — flat thermoplastic stock that is heated & formed
Clamp frame — hinged frame that grips the sheet edges for sealing
Plenum — sealed vacuum chamber beneath the drilled plate
Male mould — positive plug — sheet drapes over it; detail inside
Draft — taper on walls so the part releases (3–5°)
Thermoforming — shaping heated thermoplastic sheet by pressure/vacuum
Blister pack — package formed around a product on a vacuum machine
Twin-sheet — two sheets formed & welded into one hollow part
Heater bank — radiant quartz/ceramic elements that soften the sheet
Platen — the table the mould sits on (often rises to the sheet)
Vacuum pump — machine that removes air to create the pressure drop
Female mould — negative cavity — sheet pulled in; detail outside
Webbing — excess-sheet folds in concave corners
HIPS — high-impact polystyrene — the default forming sheet
Plug assist — mechanical pusher that evens wall thickness on deep parts
Pressure forming — adds compressed air for sharper detail than vacuum