Chapter Four – Material Removal Processes

Introduction:

- The m.r.p are a family of shaping operations such as solidification processes, forming processes and particulate processing.
- The m.r.p. in which excess material is removed from the starting w.p. so that what remains is the desired final geometry.
- Figure (4-1) shows the family tree of the m.r.p.

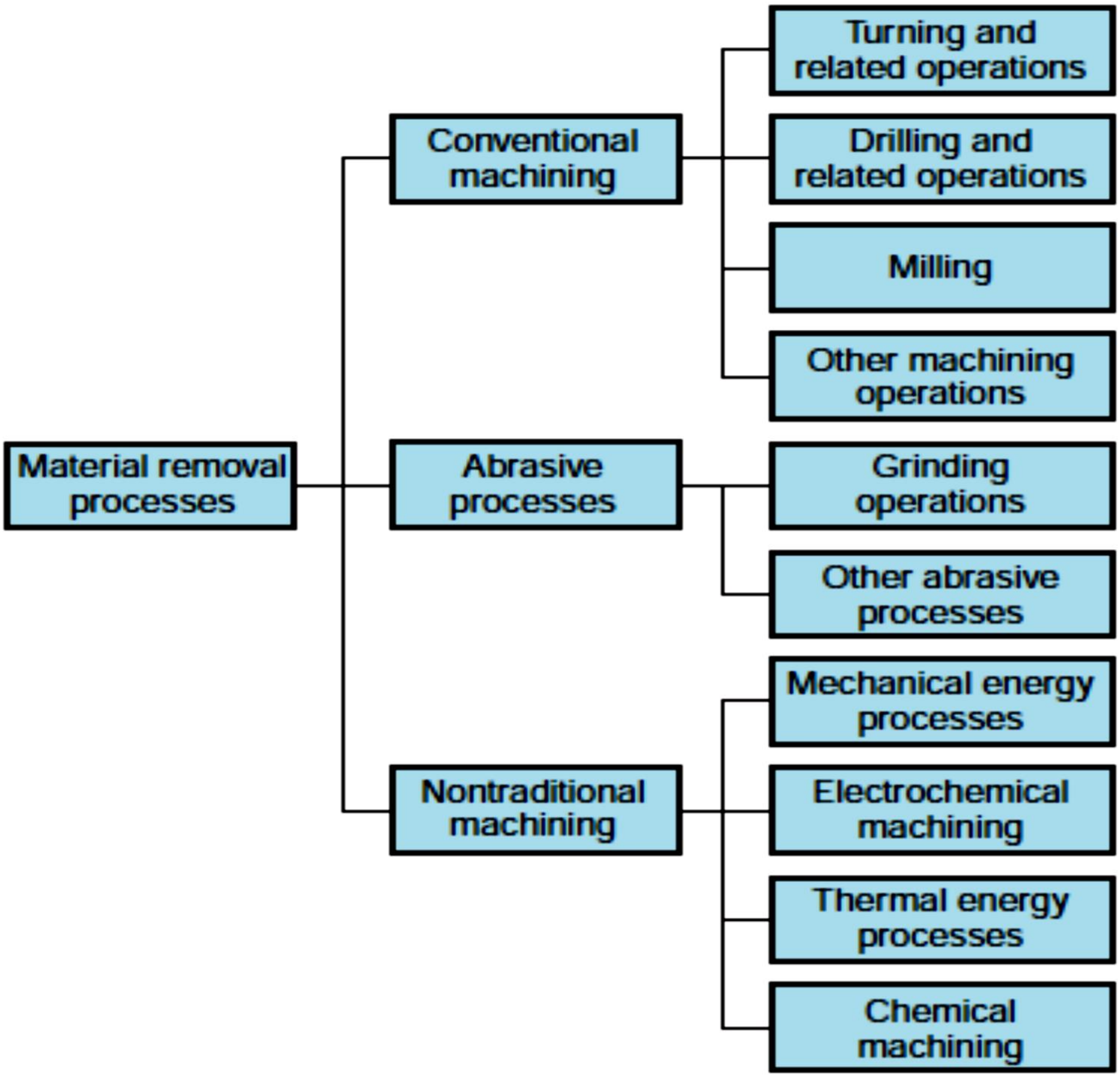


Figure (4-1) Classification of Material Removal Processes

- The three principal conventional machining processes (sharp cutting tool is used to mechanically remove the material) are: turning, drilling and milling.
- The other conventional machining operations include: shaping, planing, broaching and sawing.
- Figure (4-2), (4-3) and (4-4) show the conventional machining processes.

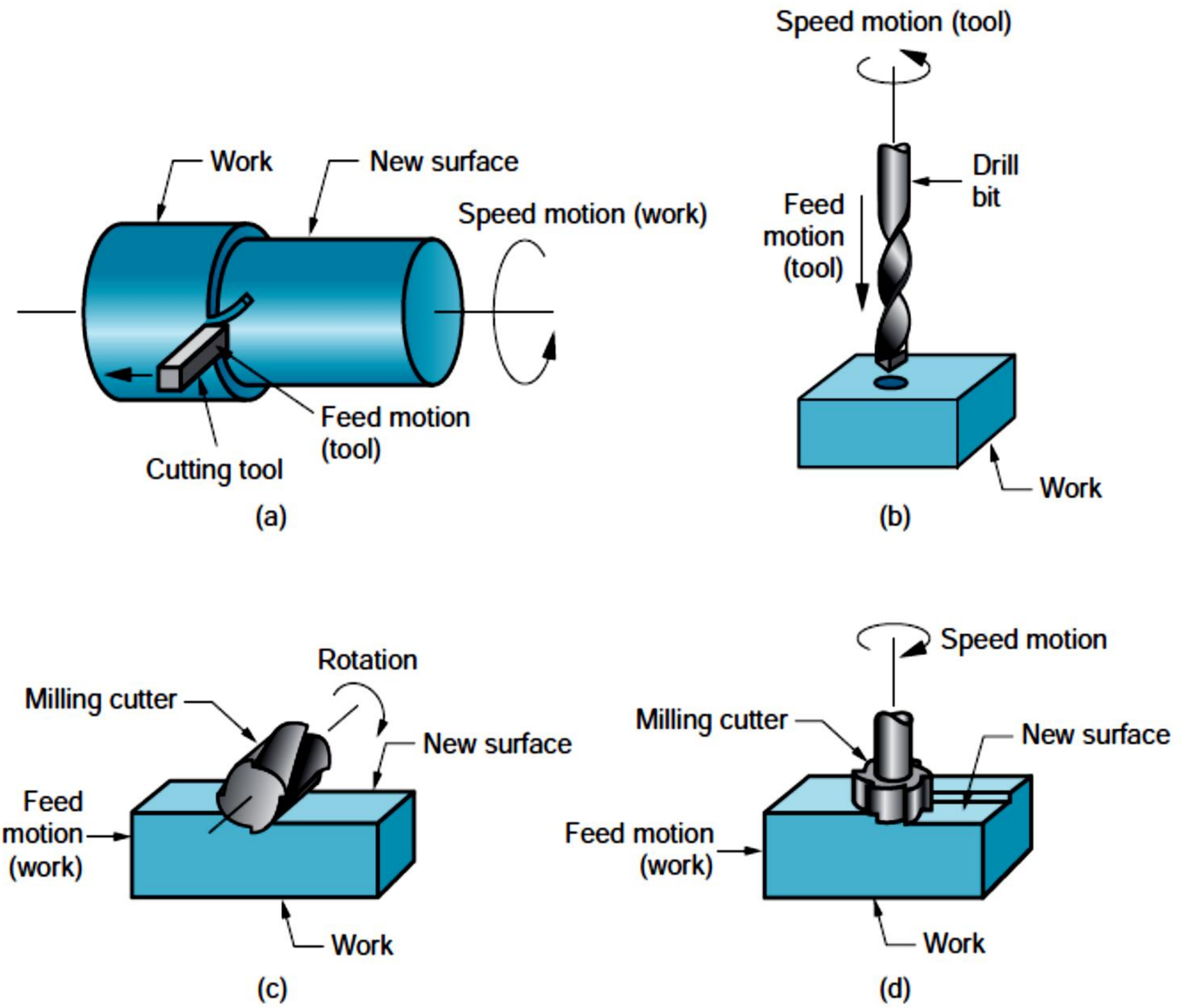
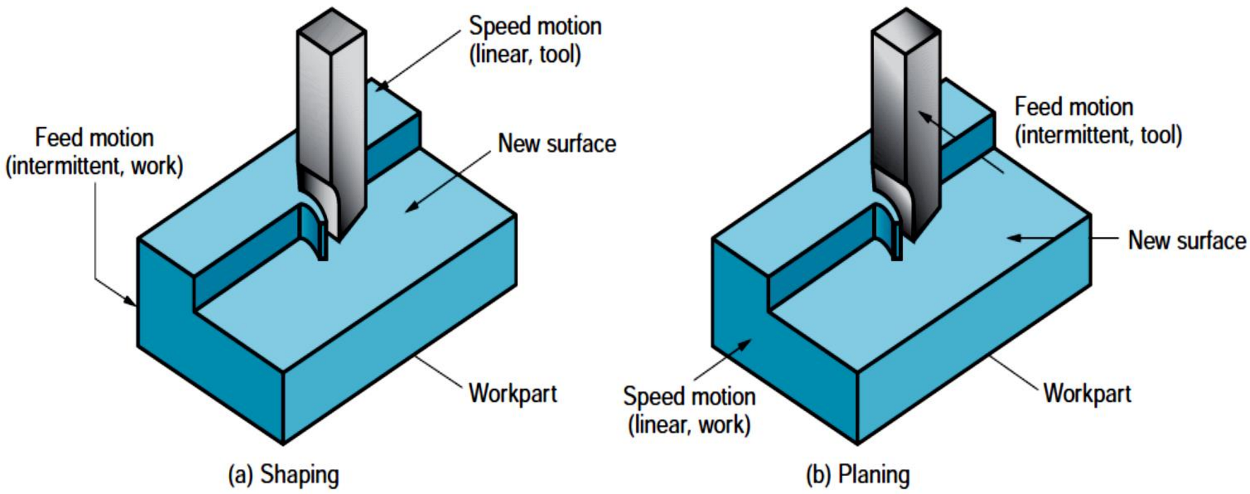
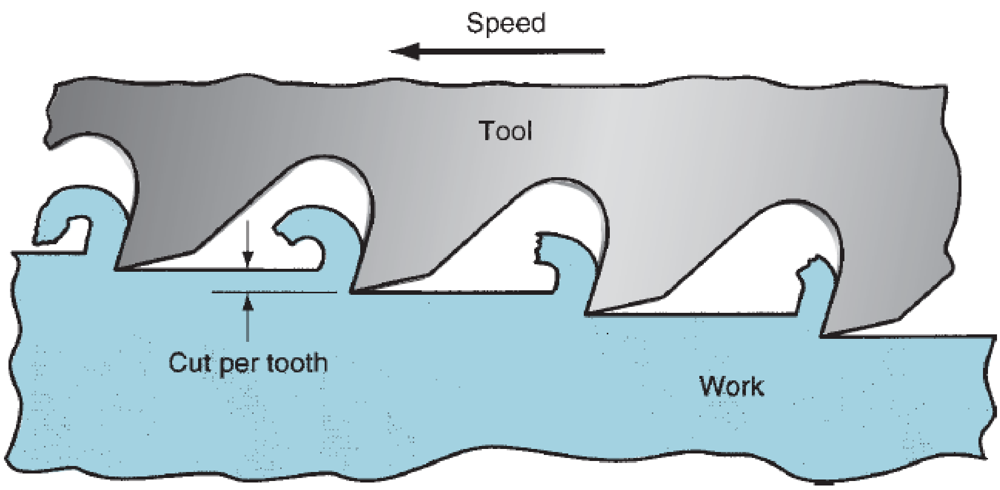
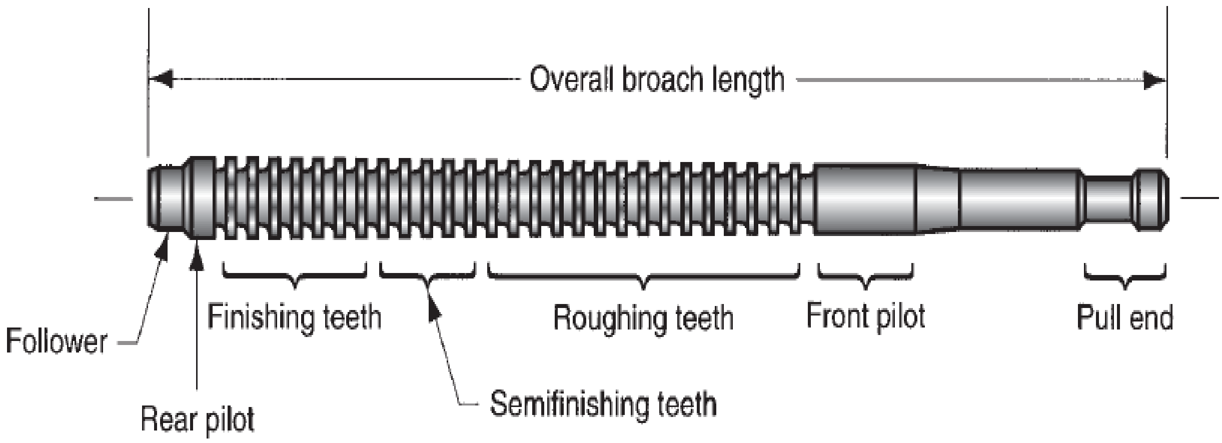


Figure (4-2) three principal conventional machining operations: (a) turning (b) drilling and two forms of milling, (c) peripheral milling (d) face milling





(c-1)



(c-2)

Figure (4-3): (a) shaping, (b) planing, (c-1) external broaching, (c-2) internal broaching

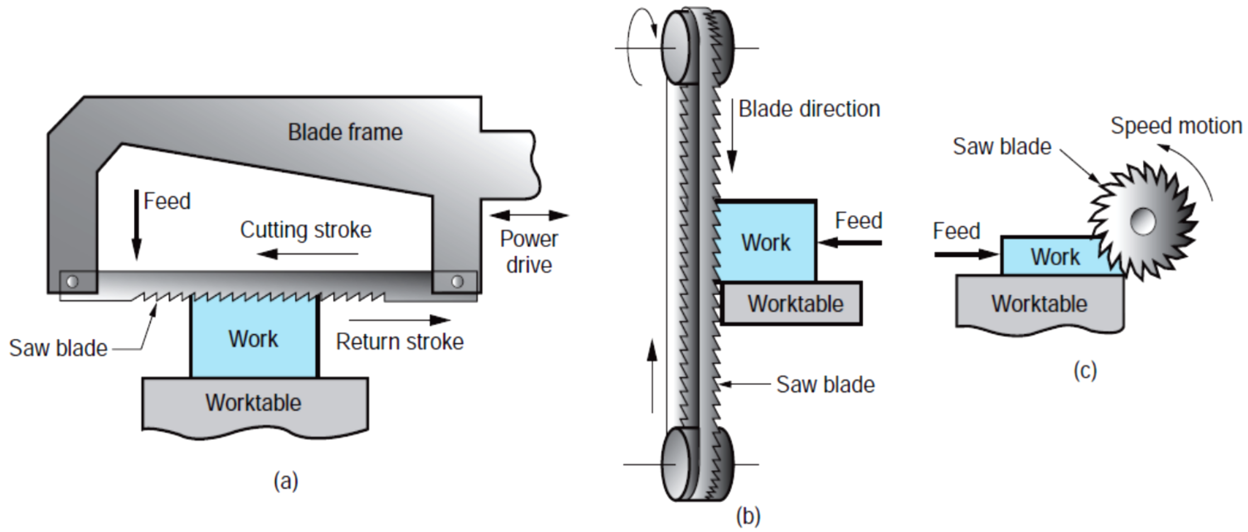


Figure (4-4): sawing operations: (a) power hacksaw (b) bandsaw (vertical) (c) circular saw

- Another group of m.r.p. is the abrasive processes (which mechanically remove material by the action of hard abrasive particles) such as grinding.
- The other abrasive processes include honing, lapping and superfinishing.
- The abrasive processes are shown in figures (4-5) to (4-8).

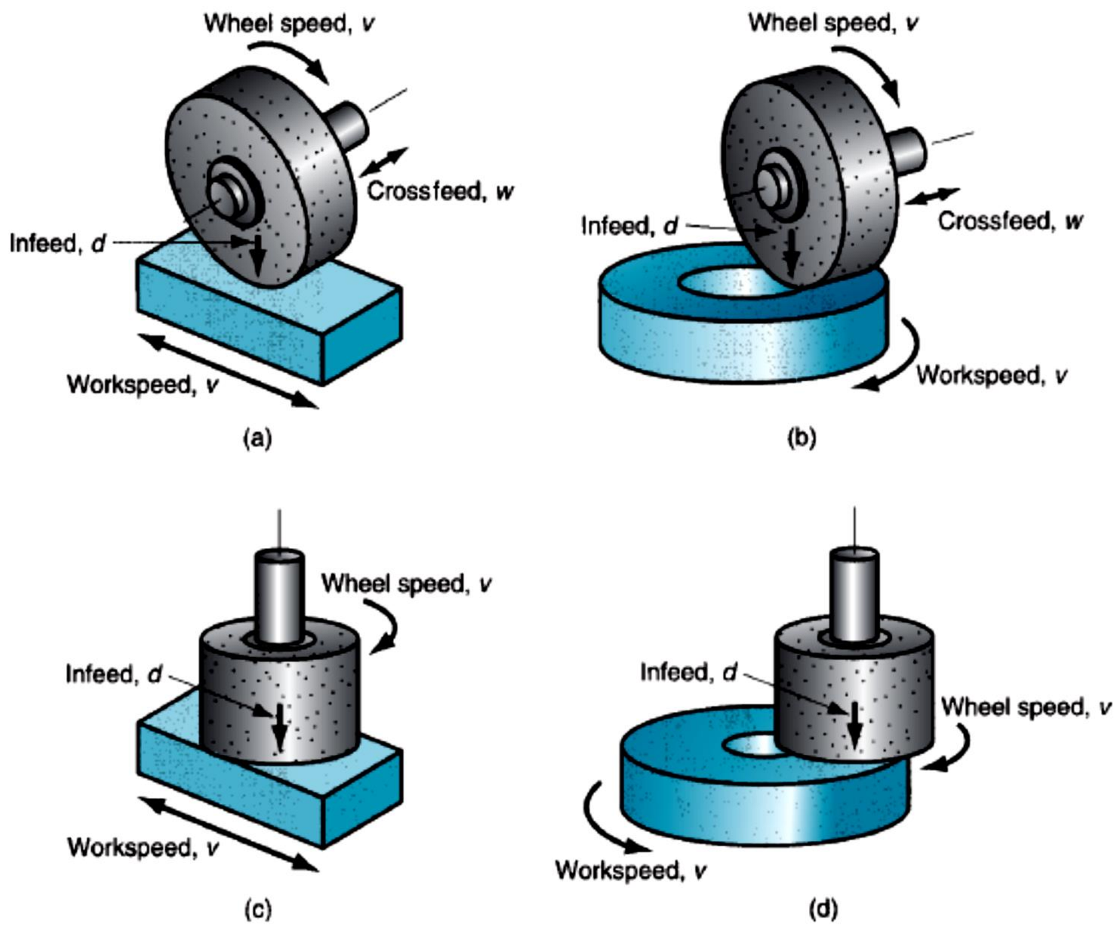


Figure (4-5) four types of surface grinding: (a) horizontal spindle with reciprocating worktable (b) horizontal spindle with rotating worktable (c) vertical spindle with reciprocating worktable (d) vertical spindle with rotating worktable

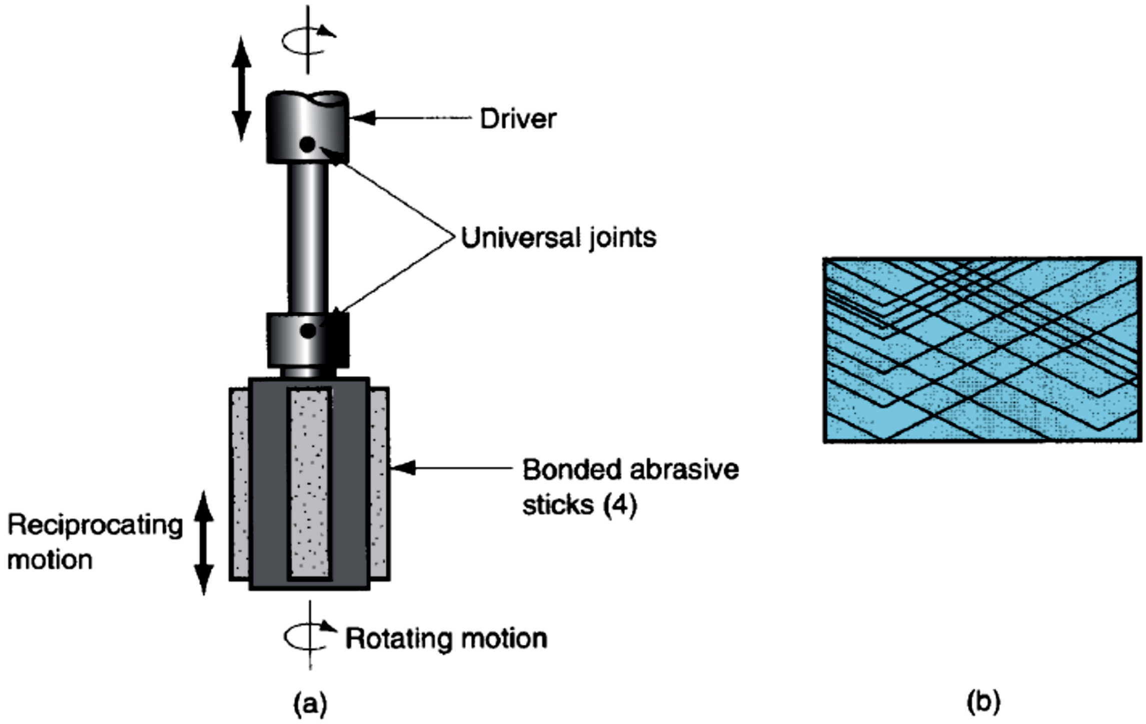


Figure (4-6) the honing process: (a) the honing tool used for internal bore surface (b) cross-hatched surface pattern created by action of honing

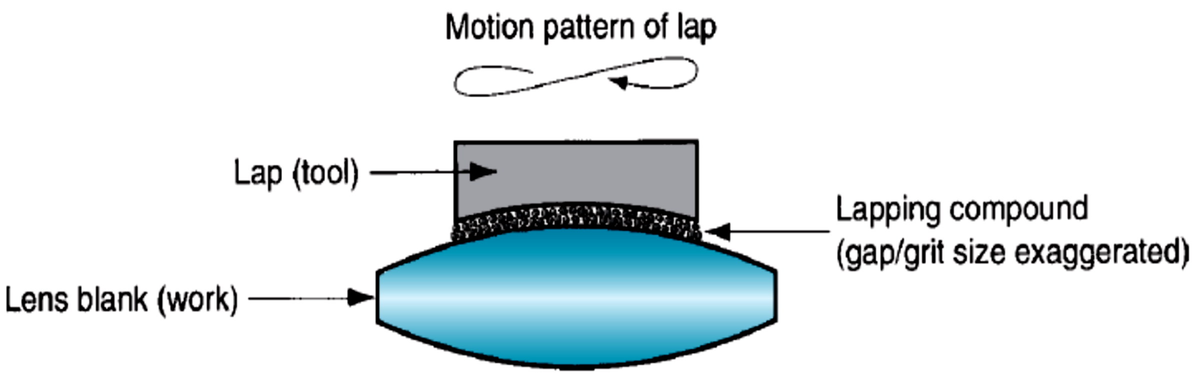


Figure (4-7) the lapping process in lens-making

- Superfinishing differs from honing in the following respects: (1) the strokes are shorter 5mm; (2) higher frequencies are used up to 1500 strokes per minute; (3) lower pressures are applied between the tool and the surface below 0.28MPa; (4) workpiece speeds are lower 15 m/min or less; (5) grit sizes are generally smaller.

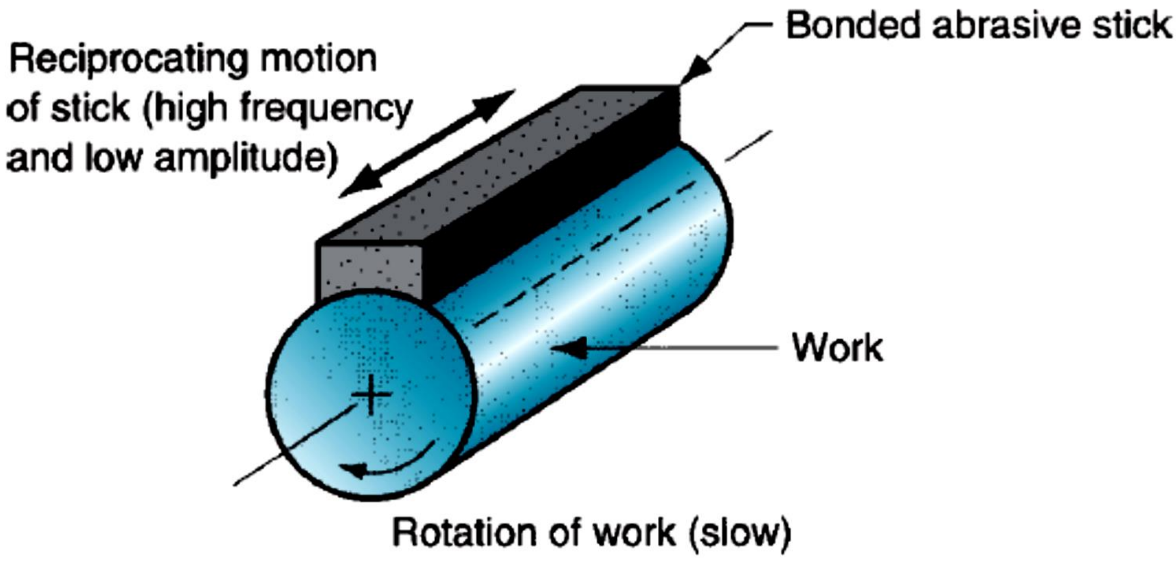


Figure (4-8) superfinishing on an external cylindrical surface

- Finally, there are the nontraditional m.r.p. which use various energy forms other than a sharp cutting tool or abrasive particles to remove material.
- The energy forms used in nontraditional m.r.p. include: mechanical, electrochemical, thermal and chemical.
- **Mechanical Energy:** includes erosion of the w.p. by a high velocity stream of abrasives or fluid (or both). Like ultrasonic machining (USM), water jet cutting (WJC) and abrasive water jet cutting (AWJC) processes. Figure (4-9) and (4-10) explain these processes.

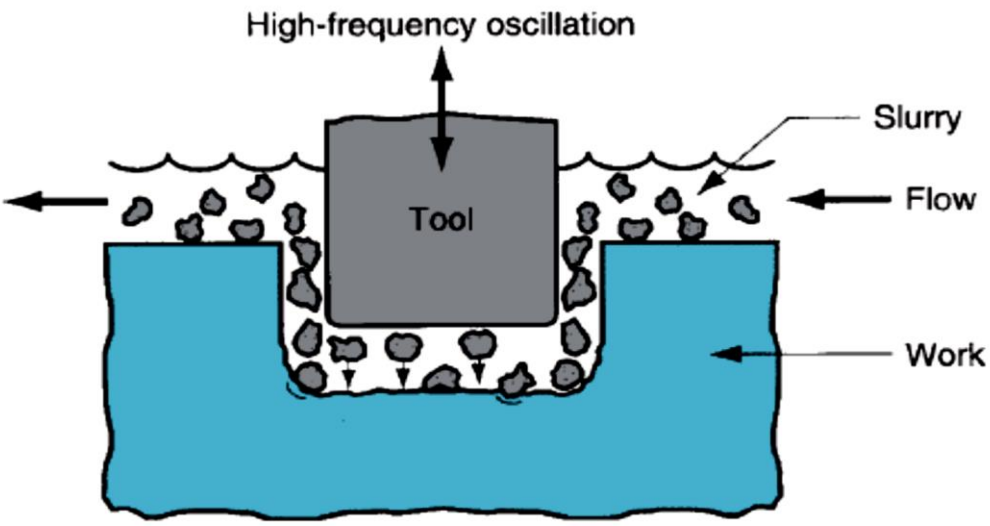


Figure (4-9) USM: uses abrasives (silicon carbide, diamond) contained in slurry, are driven at high velocity against w.p. by a tool vibrating at low amplitude (0.075mm) and high frequency (20 kHz).

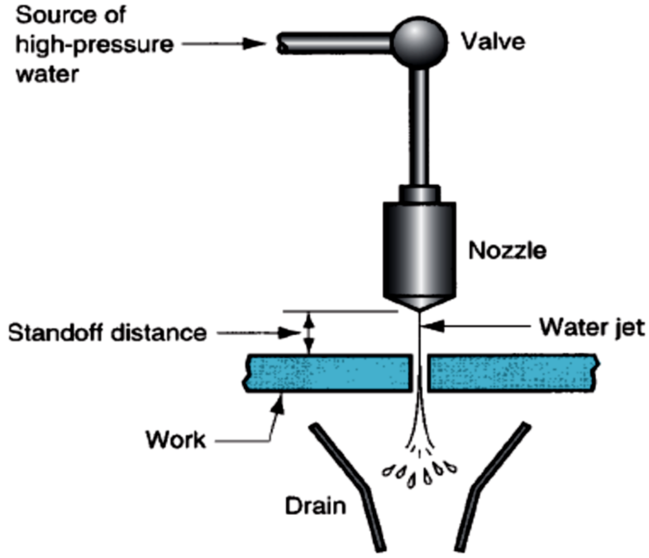


Figure (4-10) WJC: uses a fine water jet with polymer solutions (small nozzle opening 0.1-0.4mm), high-pressure (400MPa), high-velocity stream of water (900m/s). WJC is used to cut narrow slits in plastics, composites, floor tile, leather and carpet.

AWJC: when used on metallic w.p., abrasive particles (like aluminum oxide) be added to the jet stream to facilitate cutting.

- **Electrochemical Energy:** it is used to remove the material by mechanism the reverse of electroplating (de-plating operation). Electrical energy is used in combination with chemical reactions to remove material. Figure (4-11) shows the electrochemical machining (ECM).

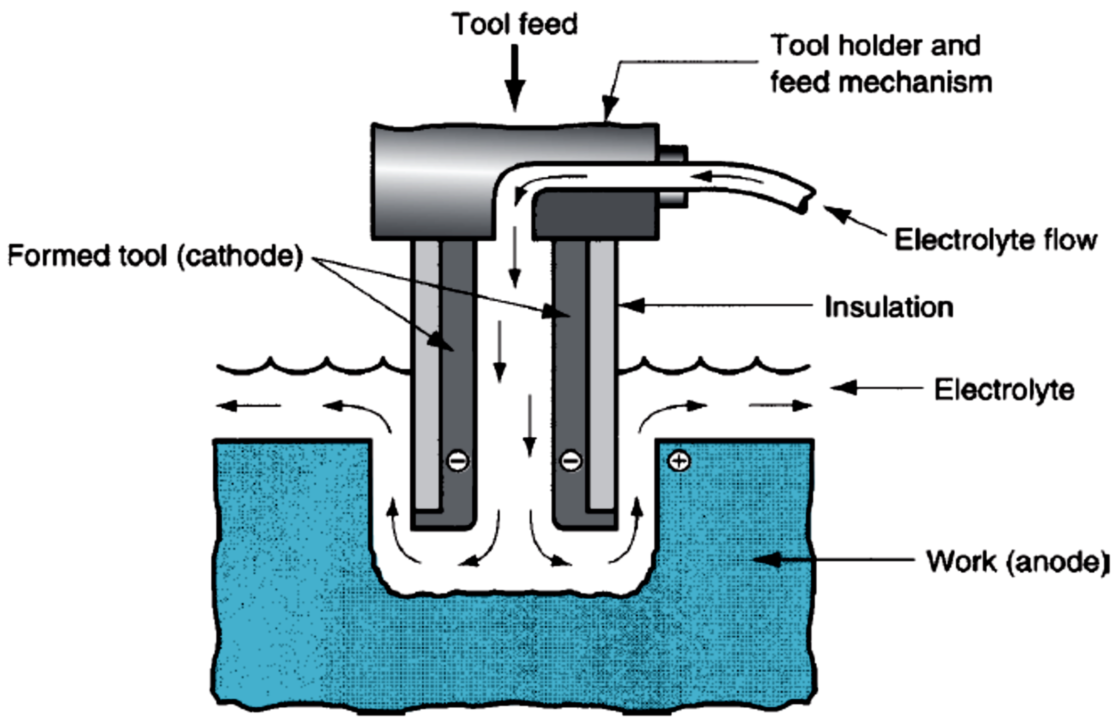


Figure (4-11) ECM process: the principle underlying the process is that material is deplated from the anode (+ pole) and deposited onto the cathode (- pole) in the presence of an electrolyte ~~path~~. This ~~path~~ flow rapidly to carry off deplated material, so that it does not become plated onto the tool. Bath

Electrolyte: a liquid or gel that contains ions and can be decomposed by electrolysis.

Electrolysis: chemical decomposition produced by passing an electric current through a liquid or solution containing ions.

- **Thermal Energy:** these processes use thermal energy to cut or shape w.p. It is applied to a very small portion of w.p. surface to remove that portion by fusion and/or vaporization of material. The thermal energy is generated by conversion of electrical energy. The common thermal energy processes are: **(1) electric discharge machining (2) electric discharge wire cutting (3) electron beam machining (4) laser beam machining (5) arc cutting processes (6) oxyfuel cutting processes.**
- The following figures illustrate the thermal energy processes.

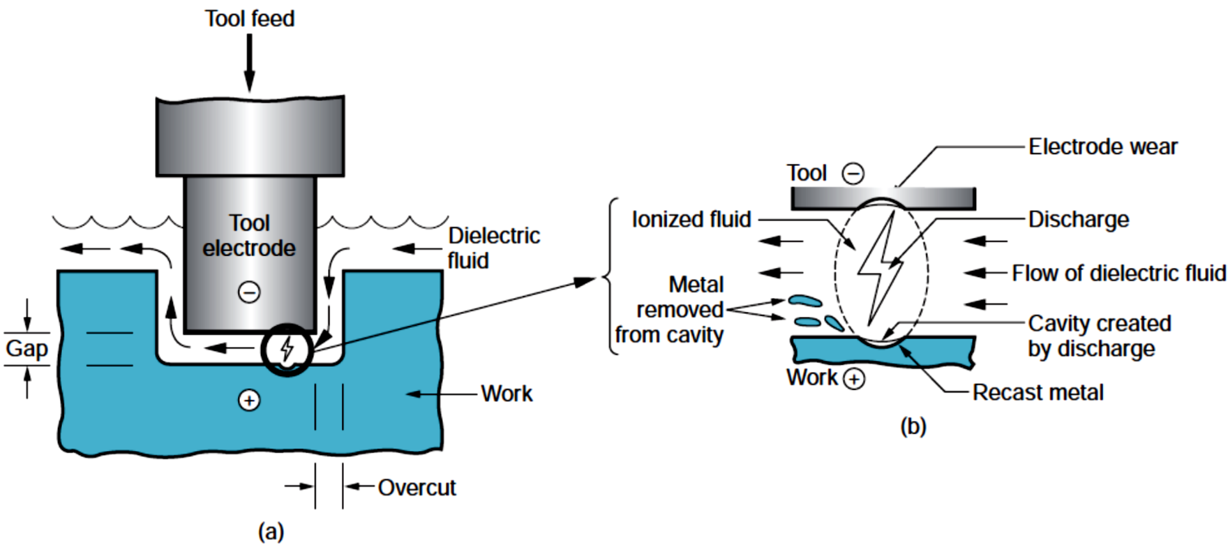


Figure (4-12) electric discharge machining (EDM): (a) overall setup, (b) close-up view of gap. EDM removes metal by a series of discrete electrical discharges (sparks) that cause localized temperature high enough to melt or vaporize metal in the immediate vicinity of the discharge.

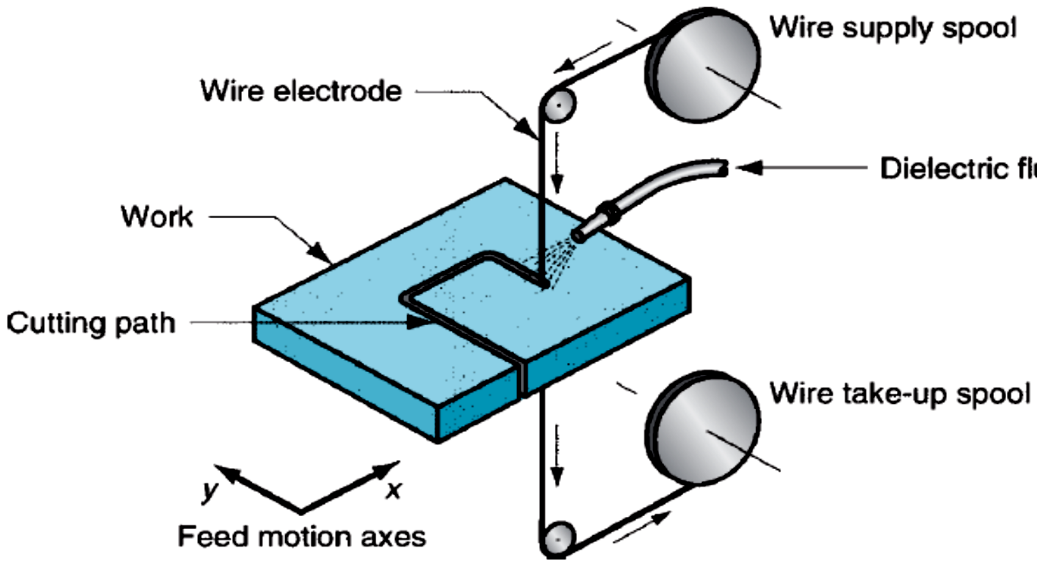


Figure (4-13) electric discharge wire cutting (EDWC): commonly called wire EDM that uses a small wire (0.076 – 3 mm, brass, copper, tungsten) as the electrode to cut a narrow kerf in the w.p. The cutting action is achieved by thermal energy from electric discharges between wire and w.p. The w.p. is fed past the wire.

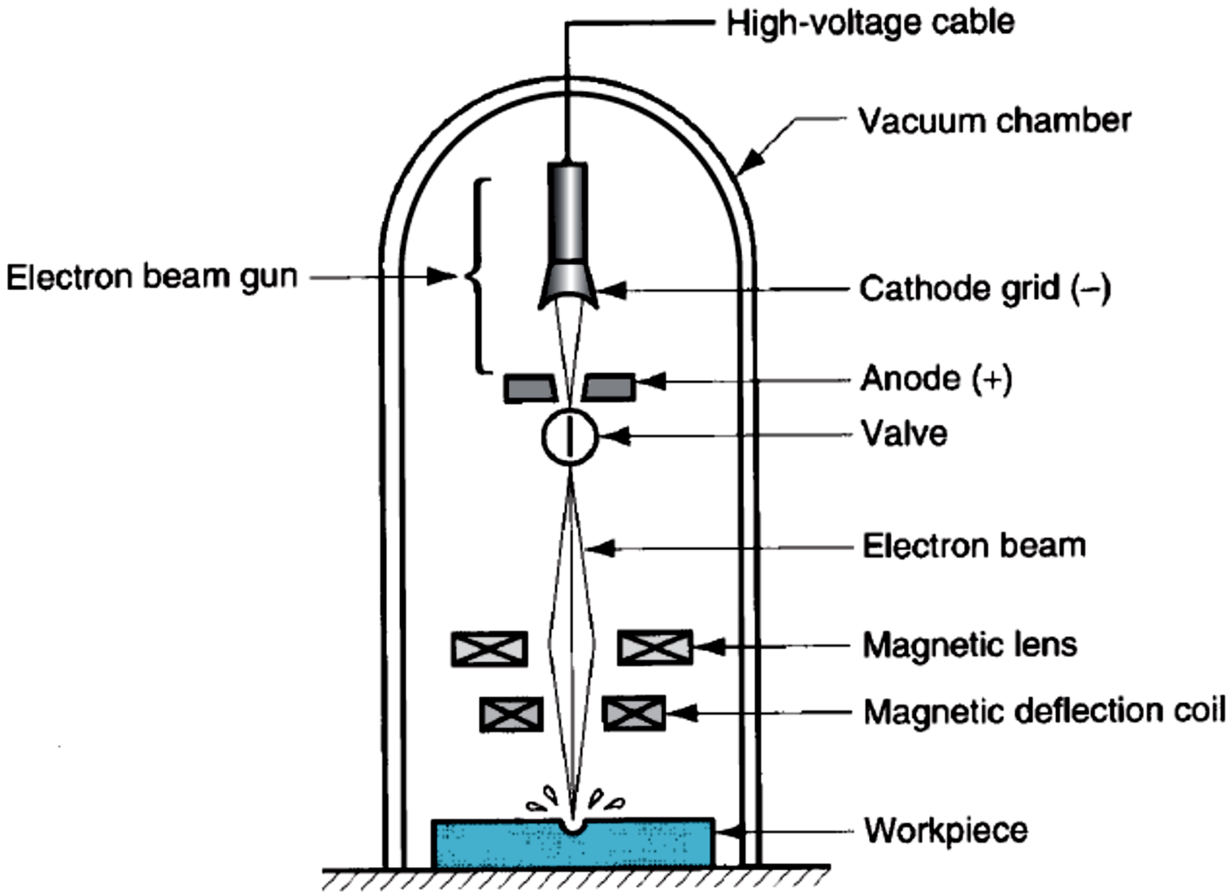


Figure (4-14) electron beam machining (EBM): uses a high velocity stream of electrons focused on w.p. surface to remove material by melting and vaporization. An electron beam gun generates a continuous stream of electrons that is accelerated to approximately 75% of light speed. The lens reduce the area of beam to a diameter of 0.025mm. On impinging the w.p., kinetic energy of electrons is converted into thermal energy.

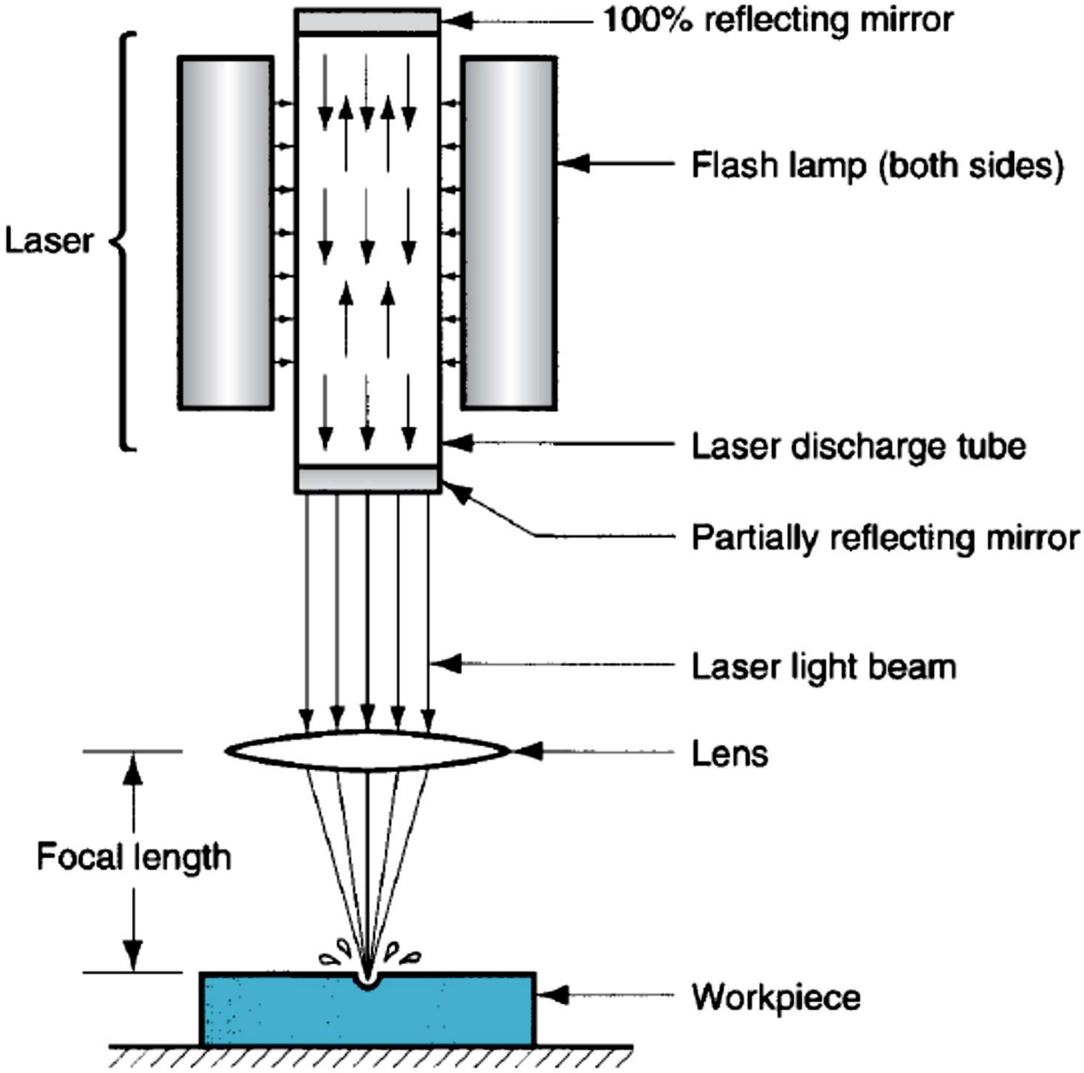


Figure (4-15) laser beam machining (LBM): A laser is an optical transducer that converts electrical energy into a highly coherent light beam. LBM uses light energy from a laser to remove material by vaporization and ablation. The light beam is pulsed so that the released energy results in an impulse against the work surface that produces a combination of evaporation and melting, with the melted material evacuating the surface at high velocity. LBM is used to perform drilling, slitting, slotting, scribing, and marking operations.

Arc Cutting Processes (ACP): use heat generated by an electric arc between electrode and a metallic w.p. (plate, sheet) to melt a kerf. Common ACP are: **(1) plasma arc cutting (PAC), (2) air carbon arc cutting (ACAC)**

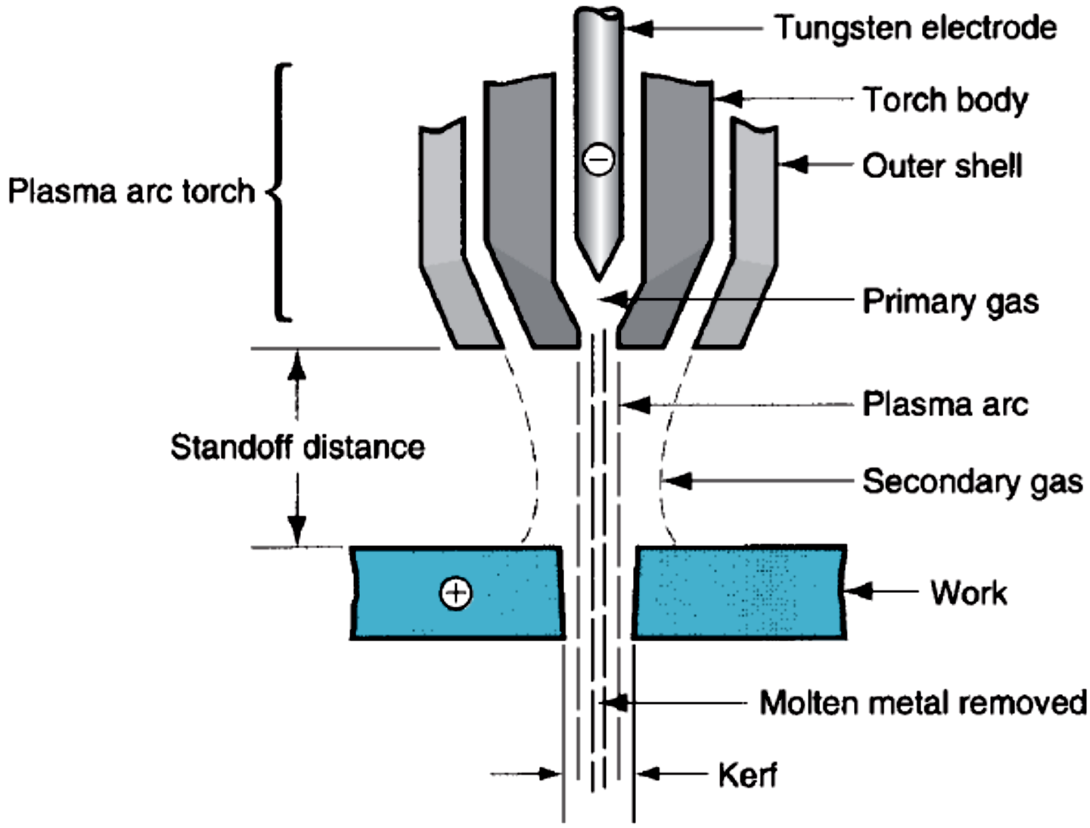


Figure (4-16) plasma arc cutting (PAC): plasma is defined as a superheated, electrically ionized gas. PAC uses a plasma stream at (10000 – 14000° C) to cut metal by melting. Gases used to create plasma (nitrogen, argon, hydrogen or mixtures of them). The plasma arc is generated between an electrode inside the torch and anode w.p. The cutting action operates by directing high-velocity plasma stream at w.p. thus melting it. W.p. having 150mm thick can be cut by plasma arc.

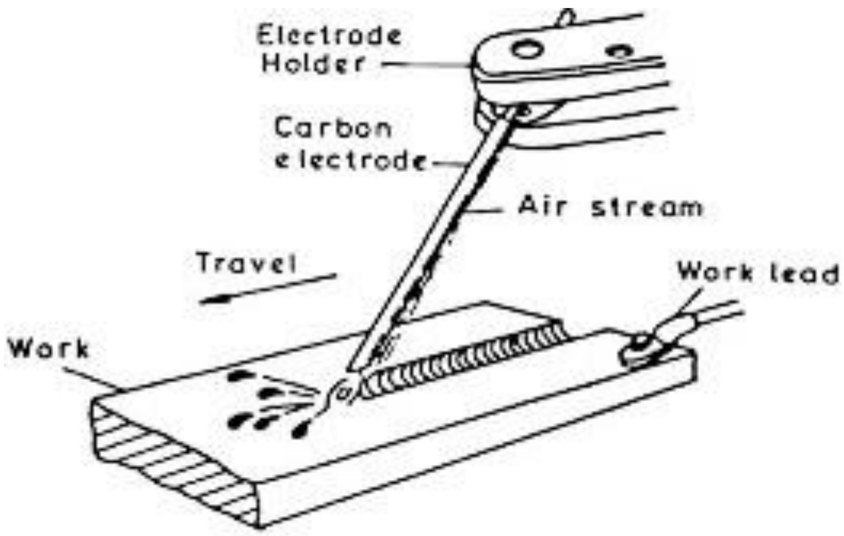


Figure (4-17) Air Carbon Arc Cutting (ACAC): the arc is generated between a carbon electrode and metallic w.p. (such as cast iron, carbon steel, stainless steel and nonferrous alloys) and a high-velocity air jet is used to blow away melted portion of metal. This process can be used to form a kerf for severing the w.p. or to gouge cavity in w.p.

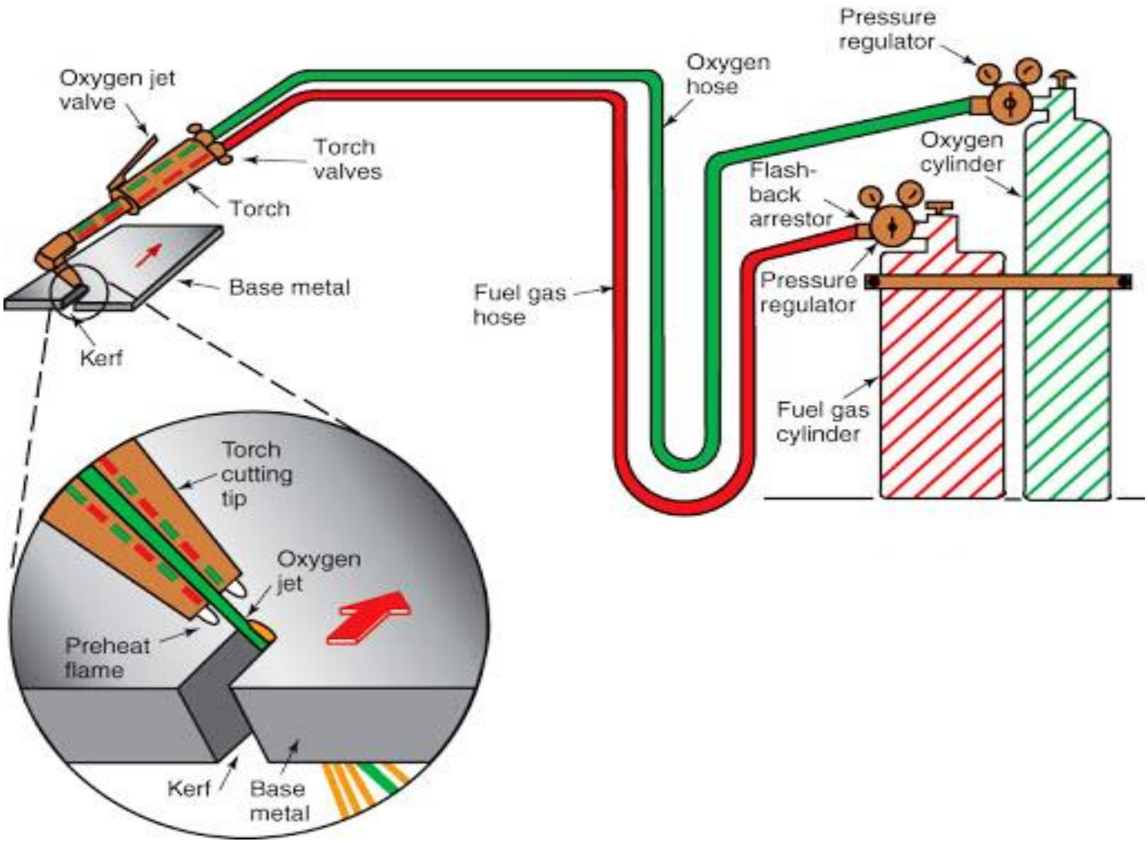


Figure (4-18) Oxyfuel-Cutting Processes (OFC): also known as **flame cutting,** use heat of combustion of fuel gases combined with exothermic chemical reaction of metal (w.p.) with oxygen. Thus oxyfuel combustion raises temperature in cutting region to support w.p.-oxygen reaction. The cutting torch is used to deliver a mixture of fuel gas and oxygen in proper amounts, and to direct a stream of oxygen to the cutting region.

Fuel gases in OFC include acetylene, methylacetylene-propadiene (MAPP), propylene and propane.

For cutting nonferrous metals (having low melting point and more oxidation resistance than ferrous metals), a chemical fluxes or metallic powders are added to oxygen stream in order to promote metal oxidation reaction.

- **Chemical Energy:** most materials (metals particularly) are susceptible to chemical attack by certain acids or other etchants. In chemical machining, chemicals selectively remove material from portions of w.p., while other portions of w.p. surface are protected by mask.

The chemical machining includes: chemical milling, chemical blanking, chemical engraving and photochemical machining. Following figures will explain these processes.

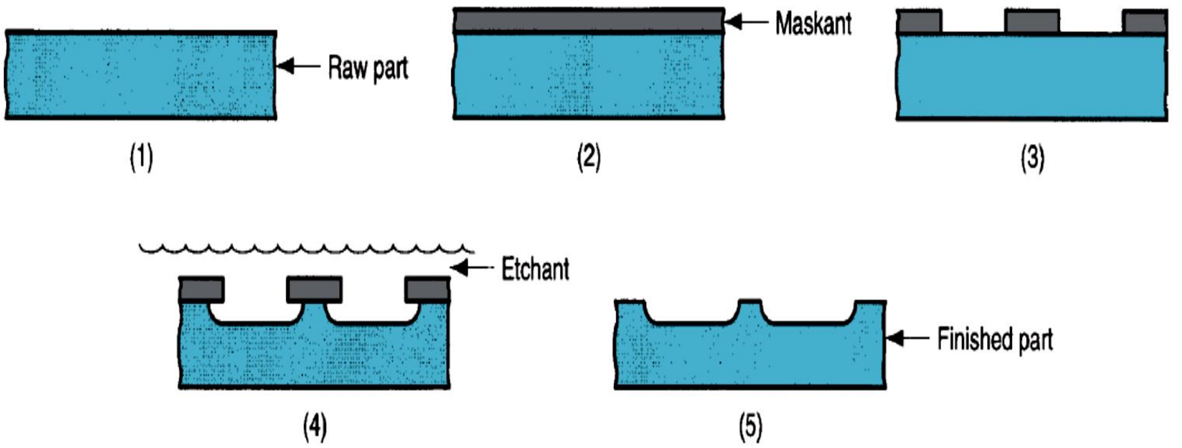


Figure (4-19) chemical milling (CM): it is used to remove a substantial amount of metal. CM is used largely in aircraft industry, to remove material from wings and fuselage for weight reduction. Steps in CM: (1) clean raw w.p., (2) apply maskant (protective coating which chemically resistant to the etchant), (3) scribe, cut and peel the maskant from zones to be etched, (4) etch, (5) remove maskant and clean to yield finished w.p.

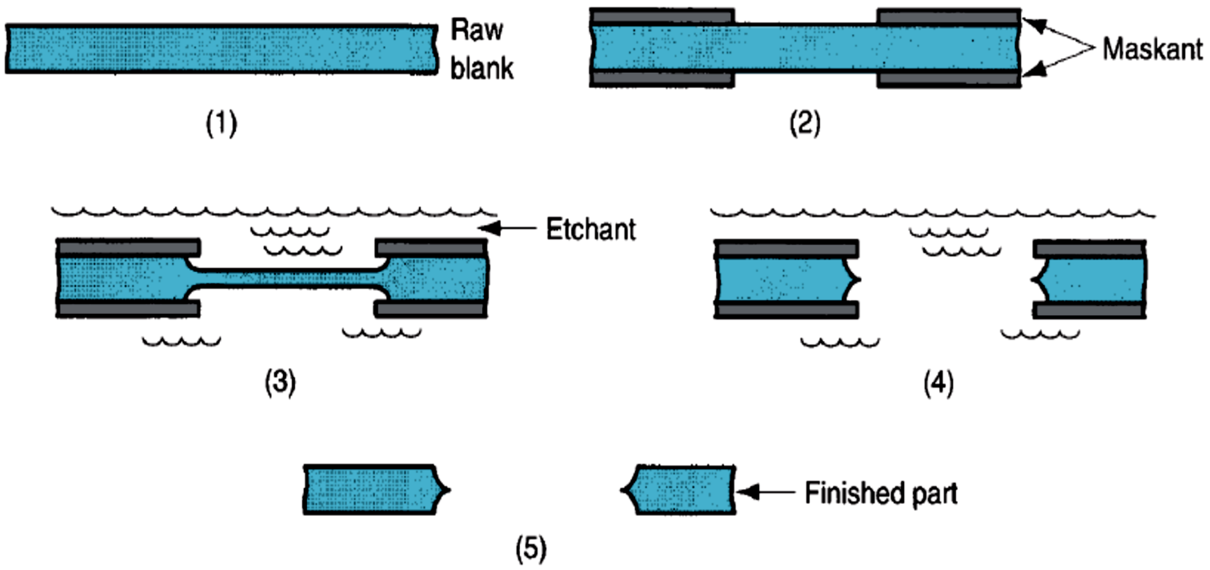


Figure (4-20) chemical blanking (CB): it uses chemical erosion to cut very thin sheetmetal parts (0.75mm down to 0.025mm) for intricate cutting patterns. Punch and die methods do not work here because the stamping forces damage the sheetmetal or the costly tooling. CB produces parts that are burr free. Hardened and brittle materials can be processed by CB where mechanical methods will damage the w.p. Steps in CB: (1) clean raw w.p., (2) apply maskant, scribe, cut and peel the maskant from zones to be etched, (3) erosion, (4) complete erosion and cut w.p. (5) remove maskant and clean to yield finished w.p.

Chemical Engraving (CE): it used to make name plates and other flat panels that having lettering and/or artwork on one side. CE can be used with either recessed lettering or raised lettering, simply be reversing the portions of the panel to be etched.

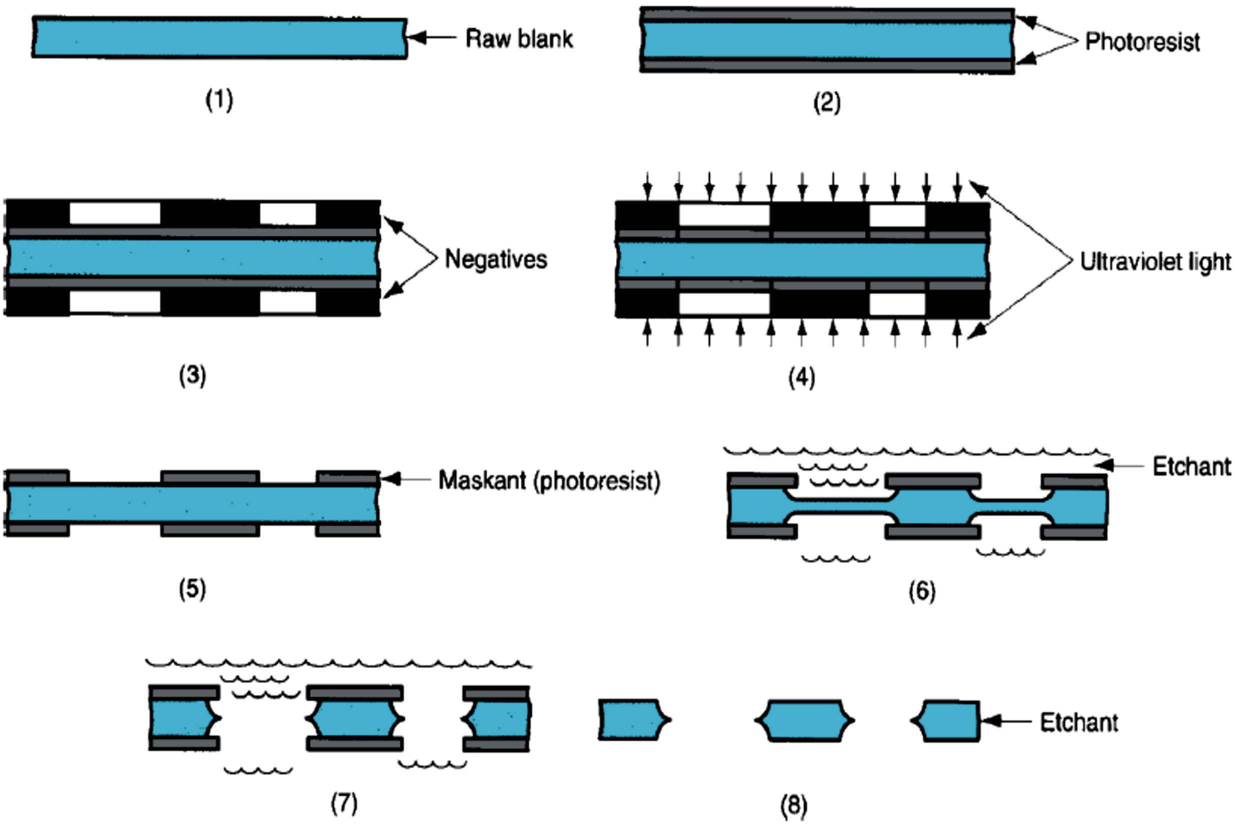


Figure (4-21) photochemical machining (PCM): it is employed in metalworking when close tolerances and/or intricate patterns are required on flat w.p. PCM are also used extensively in electronics industry to produce circuit designs on semiconductor wafers.

Steps in ~~CB~~ PCM: (1) clean raw w.p., (2) apply photoresist (maskant- which is sensitive to ultraviolet light but not to light of other wavelengths) by dipping, spraying or painting, (3) place negative on photoresist, (4) expose to ultraviolet light, (5) develop to remove photoresist from areas to be etched, (6) etch (partially etched), (7) etch completed, (8) remove resist and clean to yield finished part.