



## Advanced Processes and Materials M3X7198

## **AIM(S)**

To enable the student to gain a critical understanding of the principles and potential applications of a range of advanced engineering processes and materials.

## **LEARNING OUTCOMES**

Upon the successful completion of this module, the student should be able to :

1. demonstrate an ability to analyse the structure-property relationships and behaviour of a range of advanced engineering materials and manufacturing processes (component A)
2. demonstrate a critical awareness and appraise the potential for application of a range of advanced materials and processes in typical engineering applications, gaining an understanding of the development of new sustainable materials for specific applications (components A and B)
3. demonstrate key transferable skills in problem formulation and decision making, and the interpretation of experimental results (component B)
4. demonstrate the ability to progress to independent learning (component B)

## **ASSESSMENT**

### **Assessment Component A – 70%**

Written / Exam (2 hours)

The exam will assess the understanding of the structure-property relationships and behaviour of a range of advanced engineering materials and manufacturing processes.

### **Assessment Component B – 30%**

This will be assessed individually via one coursework assignment. Students will be encouraged to critically analyse an advanced technology and to produce an investigative report that addresses the scientific principles of the technology, analysis of its application and its potential strategic impact on the market or industry sector. The results will be in the form of a -1800-word written essay and presentation to the peer-group and lecturing team.

## **Reading List**

**Analysis of Machining and Machine Tools**  
**by Steven Y Liang and Albert J Shi**



**Additive Manufacturing Technologies: 3D Printing, Rapid Prototyping, and Direct Digital Manufacturing**  
**By Ian Gibson, David Rosen, Brent Stucker**



**Rapid prototyping : principles and applications C. K. Chua Kah Fai Leong; C. S Lim**



**Principles of modern manufacturing**  
**By M. Groover**



**Library section 670**

# Traditional vs Non-traditional

## Traditional machining processes

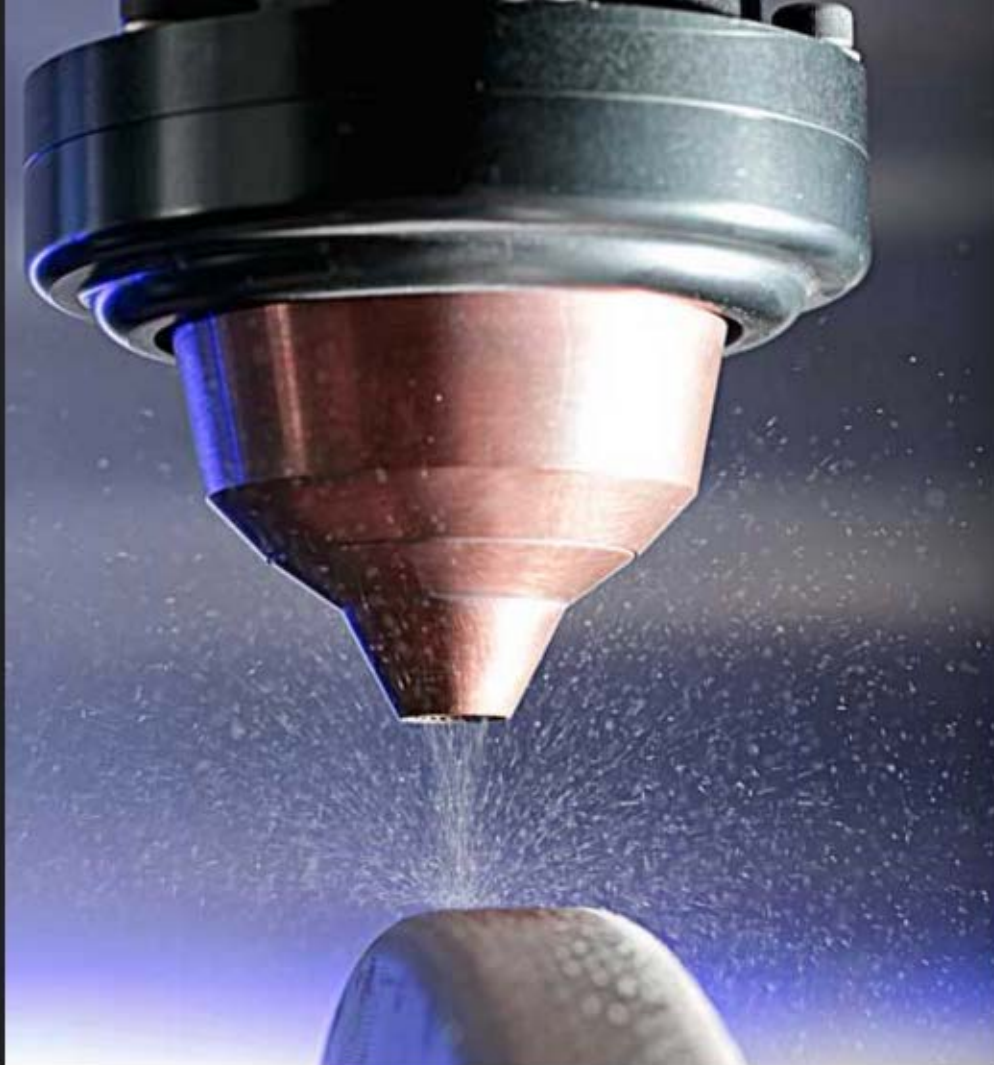
- ▶ Example: turning, drilling, milling
- ▶ Removes material from workpiece by shear deformation
- ▶ Uses a sharp cutting tool

## Non-traditional machining tools

- ▶ Water jet, laser beam, electrochemical
- ▶ Removes material by mechanical, thermal, electrical or chemical energy
- ▶ Do not use sharp cutting tools

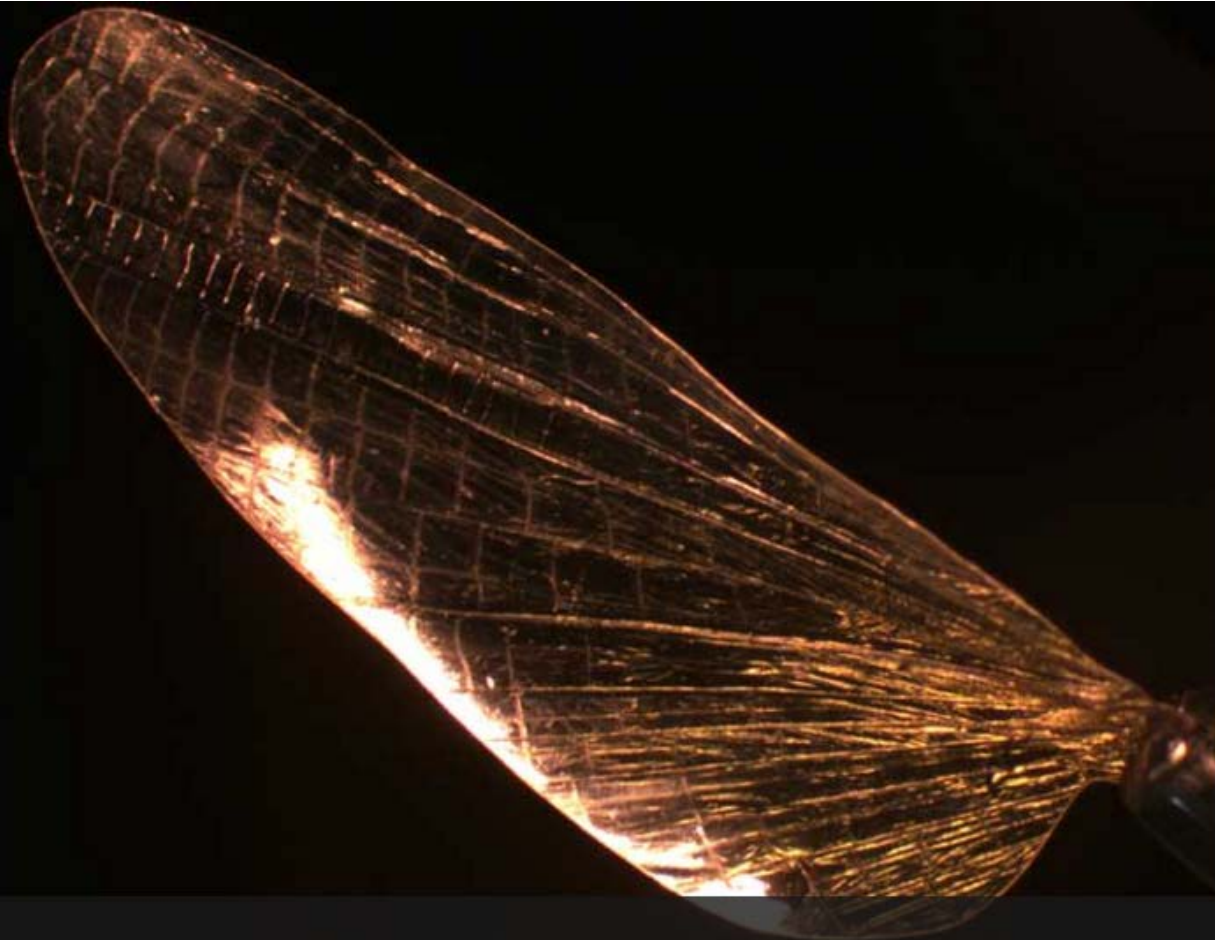
# Graphene aerogel



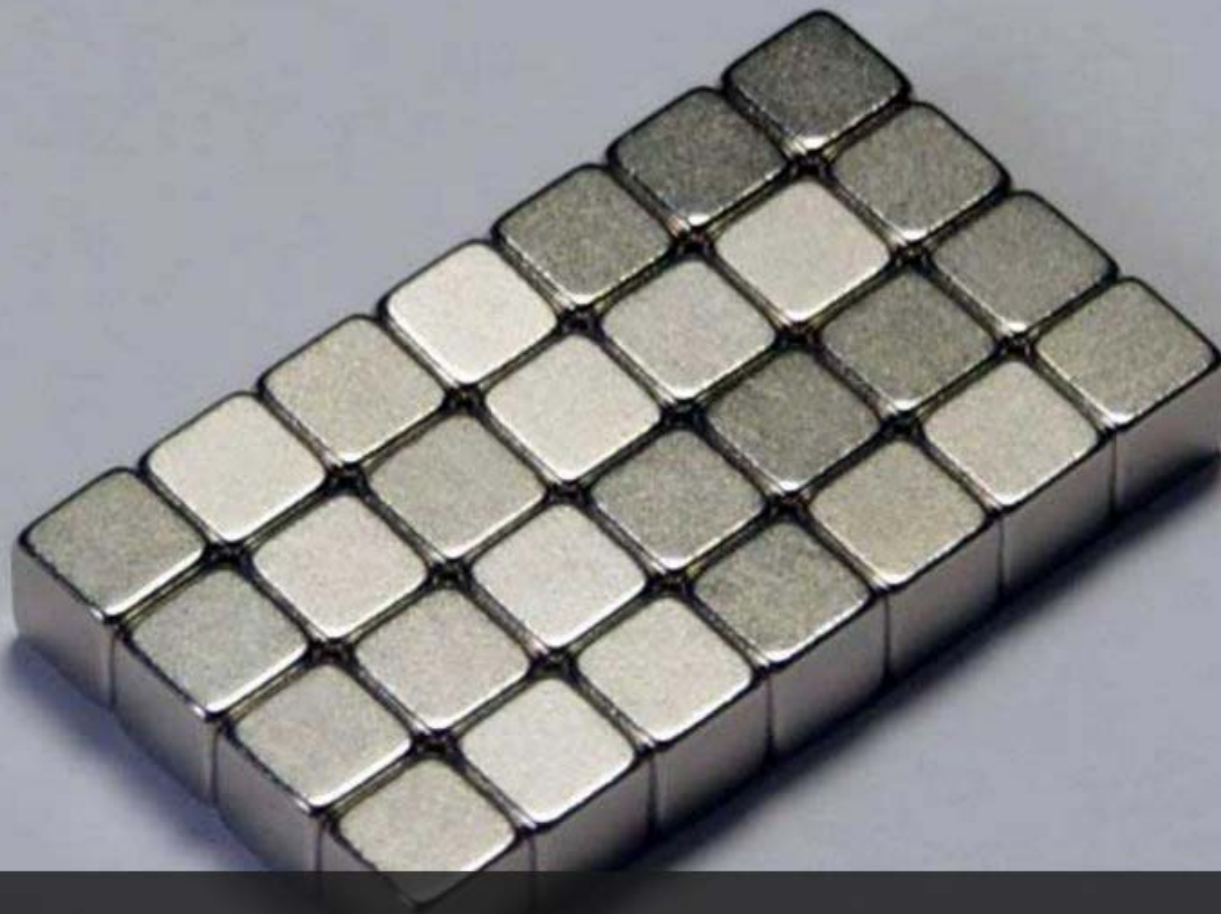


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**ROCK-SOLID COATING:** Engineers from the Oak Ridge and Lawrence Livermore national laboratories, the Colorado School of Mines and elsewhere have designed extreme-duty, iron-based, glassy alloy coatings for industrial drill bits, bores and cutters to make this equipment more resistant to breaking even under heavy loads. NanoSHIELD Coatings—short for Nano Super Hard Inexpensive Laser Deposited Coatings—require a laser to fuse alloy powder to the surface of cutters and other tunnel-boring tools. The coatings cost far less than conventional materials such as tungsten carbide cobalt, and their longer operating life improves the efficiency of the tunnel-boring process. COURTESY OF OAK RIDGE NATIONAL LABORATORY



**BIO-INSPIRED PLASTIC:** Light enough to permit flight and thin enough to accommodate flexibility and strong enough to protect its host, natural insect cuticle—found in the rigid exoskeletons of houseflies and grasshoppers—provides its host protection without adding weight or bulk. Researchers at Harvard University's Wyss Institute for Biologically Inspired Engineering have developed a new material called Shrilk to replicate insect cuticle's strength, durability and versatility. Shrilk—so called because it is composed of chitin commonly extracted from discarded shrimp shells and fibroin protein from silk—could be used to make trash bags, packaging and diapers that degrade quickly. As an exceptionally strong, biocompatible material, it might also be used to suture wounds that bear high loads, such as in hernia repair or as a scaffold for tissue regeneration. COURTESY OF WYSS INSTITUTE, HARVARD UNIVERSITY



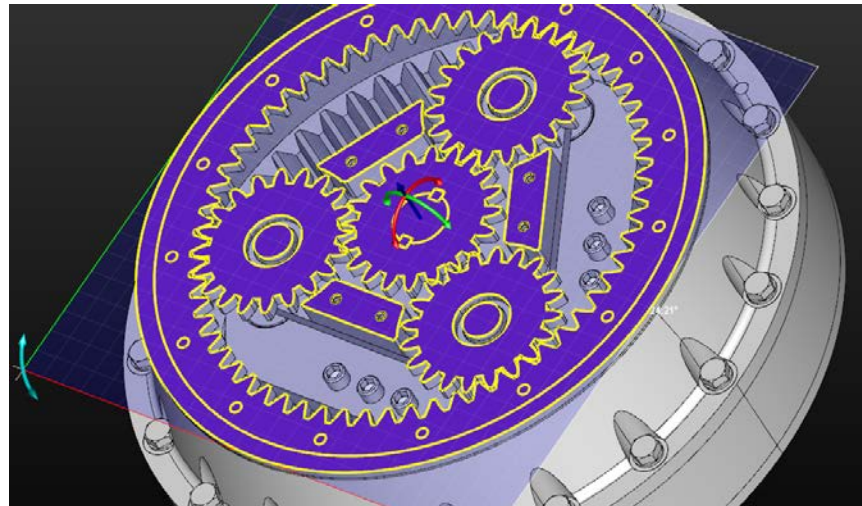
**MEGA MAGNETS:** Rare earth materials are vital to the manufacture of wind turbines, electric and hybrid cars, and consumer electronics due to their powerful magnetic properties. Yet they are also expensive and come almost entirely from one source—China. Whereas electric motors use magnets to transform electrical energy into mechanical energy, sintered rare earth magnets produce incredibly strong magnetic fields at small sizes, allowing manufacturers to build smaller, lighter motors, according to Electron Energy Corp. The firm has teamed up with University of Delaware researchers to develop a manufacturing process that increases sintered rare earth magnets' electrical resistivity by at least 30 percent. Their goal is to make magnets with increased electrical resistivity that can reduce motor efficiency losses even when motors operate at high speeds. Shown here are blocks of nickel-plated neodymium magnet, one of the most widely used types of rare-earth magnet. COURTESY OF IMAGES-OF-ELEMENTS.COM, VIA WIKIMEDIA COMMONS



CHEAPER, LIGHTER CARBON FIBER: Autos of the future will require strong, lightweight carbon-fiber composite structures to enhance efficiency and driving range, but low-cost fibers will be needed for market success. A consortium of national labs, industry and academia working at Oak Ridge National Laboratory's Carbon Fiber Technology Facility are working to overcome the challenges of making cheaper carbon fiber. The U.S. Department of Energy gave Oak Ridge a \$35-million award to build and operate the lab, which will include a pilot plant capable of producing up to 25 tons a year of new carbon-fiber materials. Pictured here is a polymer resin used to make carbon fiber. COURTESY OF OAK RIDGE NATIONAL LABORATORY

# Why use non-traditional methods?

- ▶ New materials developed, both metal and non-metal, difficult/impossible to cut.
- ▶ New products requiring complex geometries
- ▶ New requirements for higher quality surfaces mean traditional processes that damage the surface cannot be used



# Types of non-traditional methods

- ▶ Mechanical – erosion by abrasives/fluid
- ▶ Electrical – electroplating in reverse
- ▶ Thermal- fusion or vaporization
- ▶ Chemical – acids/chemical attack

# Mechanical processes

- ▶ Examples :-
- ▶ Ultrasonic machining
- ▶ Abrasive jet machining
- ▶ Abrasive Flow Machining
- ▶ Water jet cutting
- ▶ Abrasive waterjet cutting

# Video Waterjet

- ▶ [https://www.youtube.com/watch?v=2jm4\\_HikMqk](https://www.youtube.com/watch?v=2jm4_HikMqk)

# Manufacturing Technology

## Water Jet Cutting

- ▶ Fastest growing machining process
- ▶ One of the most versatile machining processes
- ▶ Complements other technologies such as milling, laser, EDM, plasma and routers
- ▶ True cold cutting process – no HAZ, mechanical stresses or operator and environmental hazards
- ▶ Not limited to machining – food industry applications

# Manufacturing Technology

## Water Jet Cutting

- ▶ Dr. Franz in 1950's first studied UHP water cutting for forestry and wood cutting (pure WJ)
- ▶ 1979 Dr. Mohamed Hashish added abrasive particles to increase cutting force and ability to cut hard materials including steel, glass and concrete to develop Abrasive Water Jet Cutting.
- ▶ First commercial use was in automotive industry to cut glass in 1983
- ▶ Soon after, adopted by aerospace industry for cutting high-strength materials like stainless steel and titanium as well as composites like carbon fibre.

# Manufacturing Technology

## Water Jet Cutting

- ▶ 2 Types, pure **Water Jet** and **Abrasive Water Jet**
- ▶ Pure cuts soft materials – corrugated cardboard, disposable diapers, tissue papers, automotive interiors
- ▶ Very thin cutting stream (0.18mm to 0.5mm diameter)
- ▶ Extremely detailed geometry
- ▶ Very little material loss due to cutting
- ▶ Can cut thick, soft, light materials like fiberglass insulation up to 24” thick or thin, fragile materials
- ▶ Very low cutting forces
- ▶ Water jet erodes work at kerf line into small particles

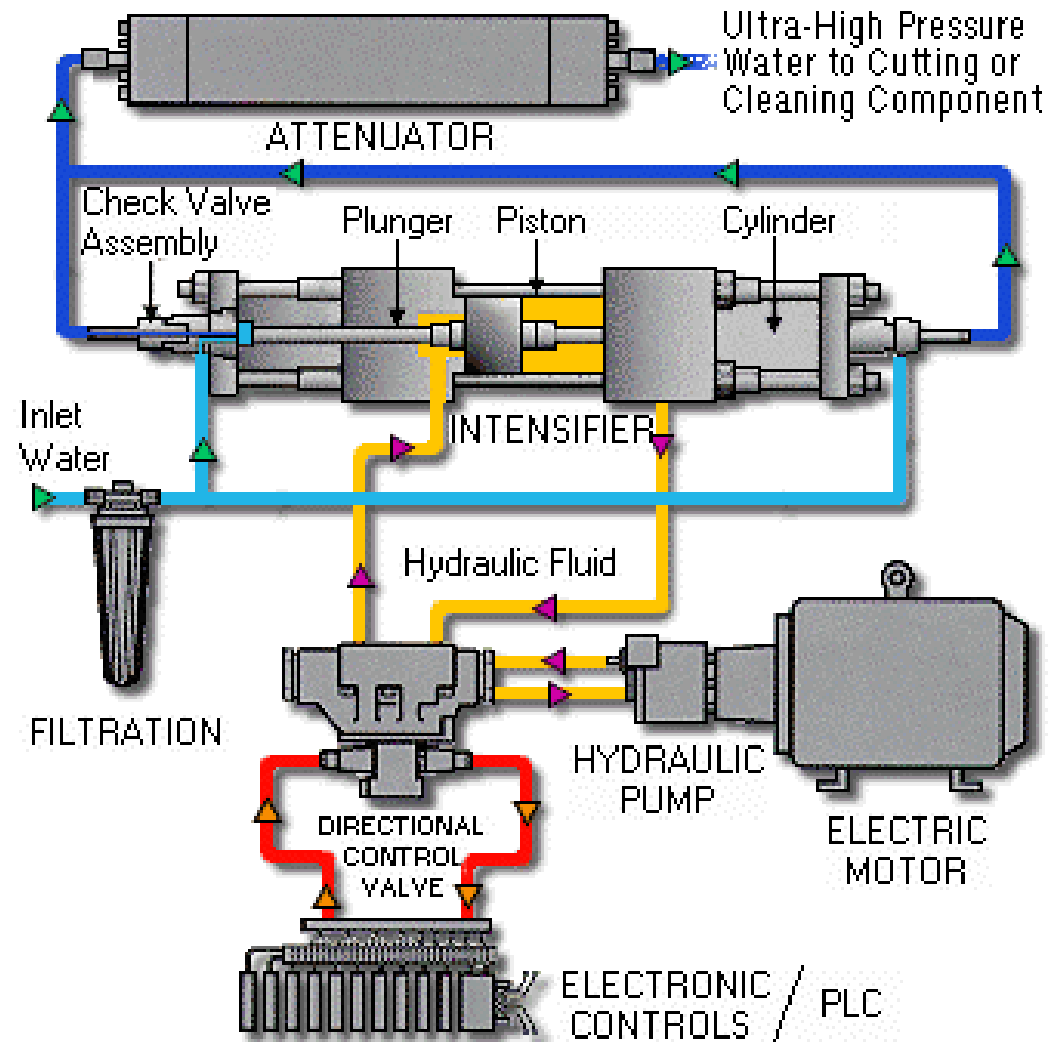
# Manufacturing Technology

## Water Jet Cutting

- ▶ Water inlet pressure between 20k-60k psi (1400 bar to 4100 bar)
- ▶ Forced through hole in jewel 0.18mm to 0.5mm diameter.
- ▶ Three common types of orifice materials.
  - ▶ Sapphire, Ruby, Diamond
- ▶ Sapphire is the most common orifice material used today. It is a man- made, single crystal jewel. It has a fairly good quality stream, and has a life, with good water quality, of approximately 50 to 100 cutting hours.
- ▶ In Abrasive Waterjet applications the Sapphire's life is half that of Pure Waterjet applications.
- ▶ Rubies with 50 to 100 hour life
- ▶ Diamond with 800-2,000 hour life, but 10x to 20x more cost.

# Manufacturing Technology

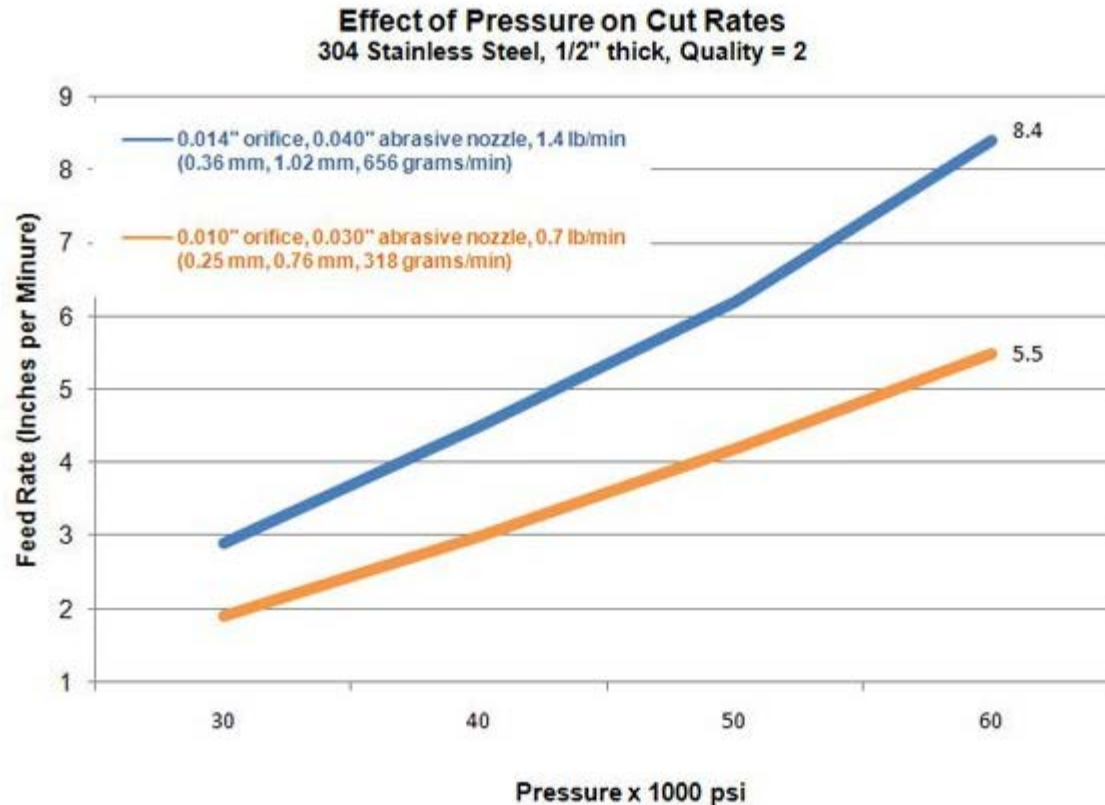
# Intensifier



Water jet video

[https://www.youtube.com/watch?v=7\\_UA8kSC5MU](https://www.youtube.com/watch?v=7_UA8kSC5MU)

Question: The following graph shows the cutting speeds for ½" (12 mm) stainless steel for a Quality 2 edge finish. What happens to the linear cutting speed when doubling the pressure from 30,000 psi (2068 bar) to 60,000 psi (4137 bar)

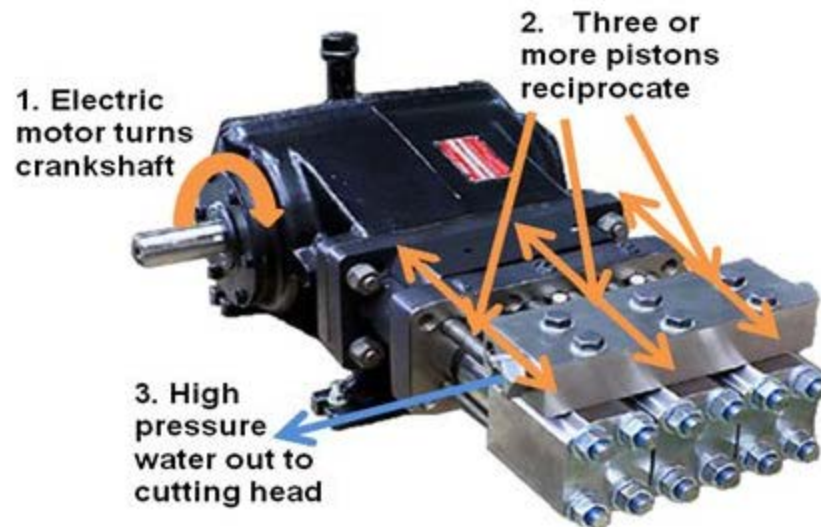
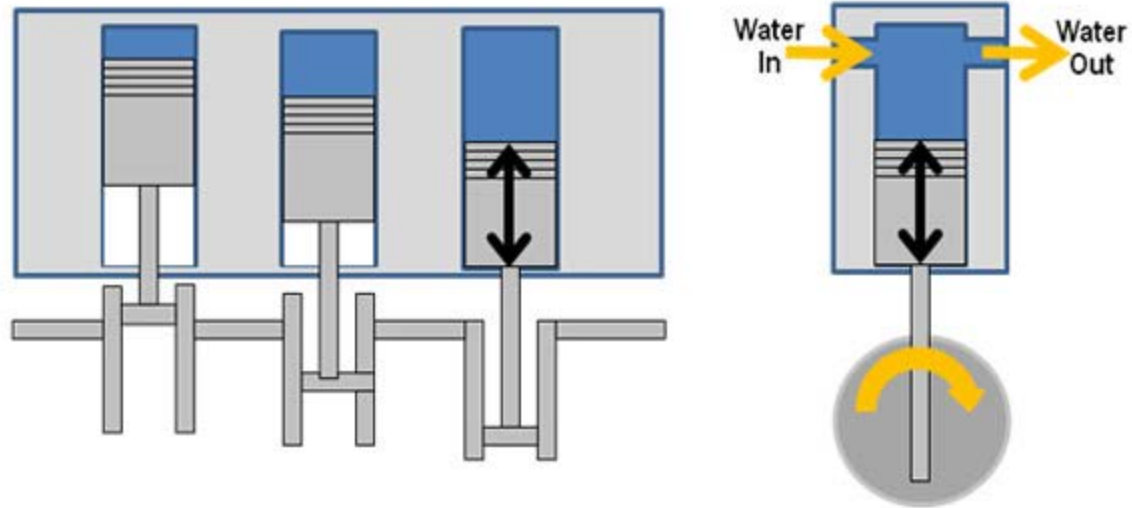


In groups of 2/3 write an abstract for the paper you have been given.

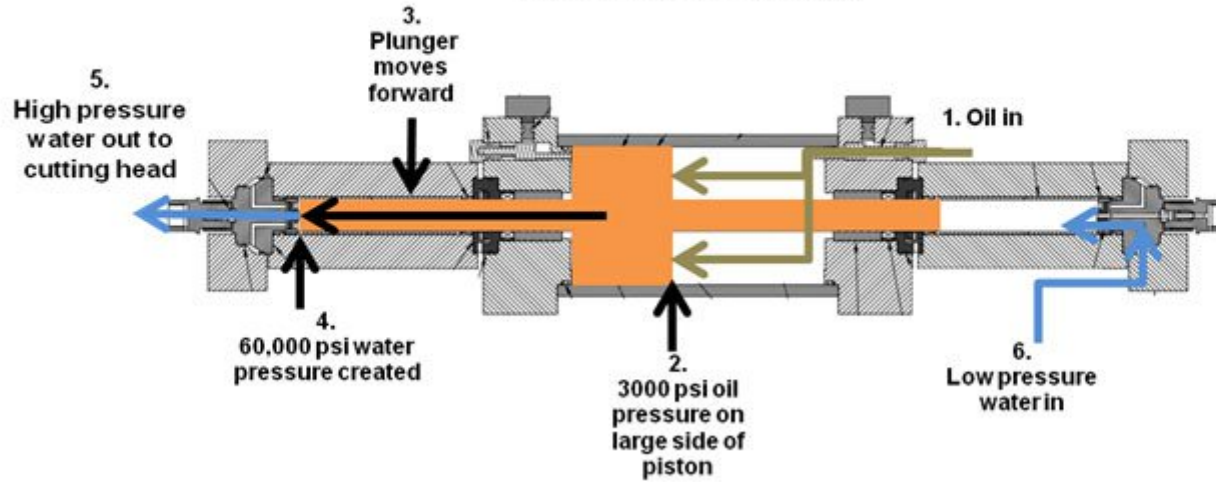
You should include:

1. The main objectives of the paper
2. advantages
3. disadvantages
4. applications of the technology
5. The main results of the paper

## Direct Drive Pump Concept



## Intensifier Concept



<https://wardjet.com/waterjet/university/nozzle-orifice>

The question frequently comes up as to which is better, a direct drive or an intensifier pump. Of course depending upon which manufacturer with which you are talking, you will get different answers. The best way to answer this is to ask the following questions and do your own research:

- What percentage of pumps in use today are intensifier as opposed to direct drive?
- What percentage of new machines being sold today have intensifier pumps versus direct drive?
- How many businesses have been created to swap out a direct drive pump with a retrofit kit to change over to an intensifier – basically dispose of the direct drive?
- How many businesses have been created to swap out an intensifier pump for a direct drive – in other words dispose of an intensifier pump?
- What are the maintenance costs associated with each style pump for the first 1500 hours, including replacement of consumable and spare parts?
- How much downtime is involved to replace consumable and spare parts on each style pump?

# Manufacturing Technology

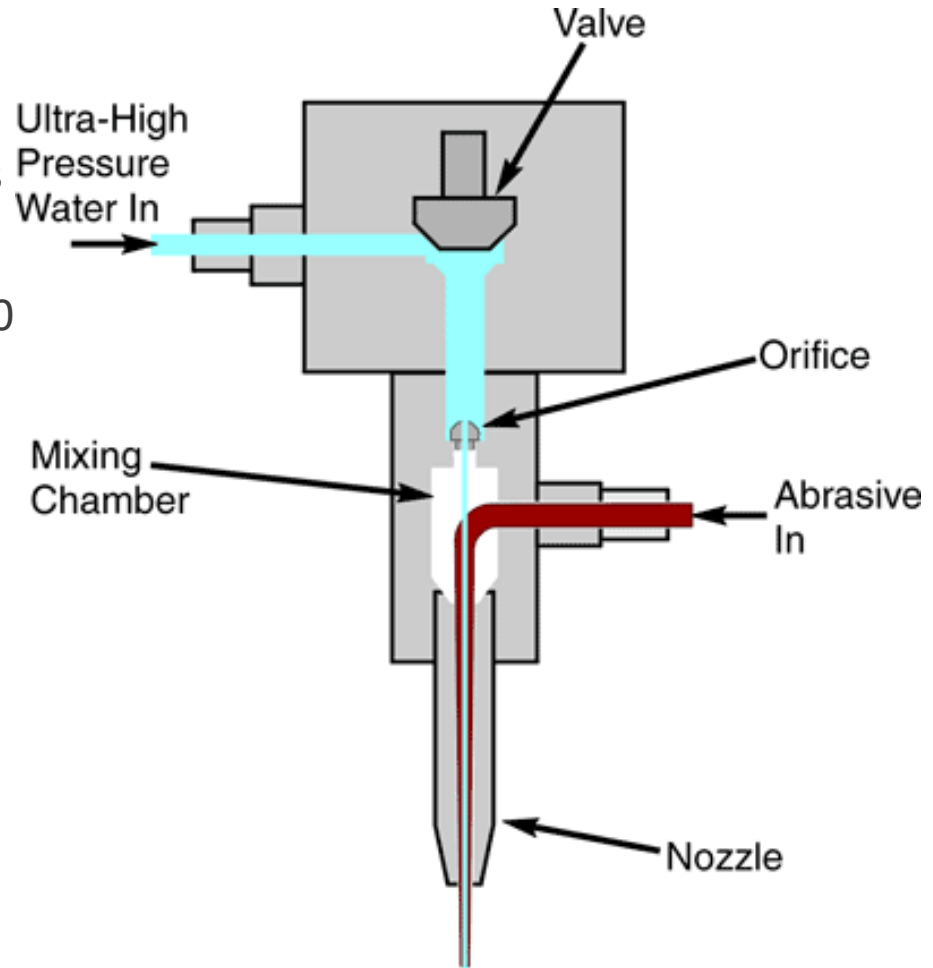
## Abrasive Water Jet Cutting

- ▶ Used to cut much harder materials
- ▶ Water is not used directly to cut material as in pure water jet cutting, instead water is used to accelerate abrasive particles which do the cutting.
- ▶ 80-mesh garnet (sandpaper) is typically used though 50 and 120-mesh is also used.
- ▶ Standoff distance between mixing tube and workpart is typically 0.25mm to 5mm – important to keep to a minimum to keep a good surface finish.

# Manufacturing Technology

## Abrasive Water Jet Cutting

- ▶ Evolution of mixing tube technology
- ▶ Standard Tungsten Carbide lasts 4-6 hours (not used much anymore)
- ▶ Premium Composite Carbide lasts 100-150 hours
- ▶ Consumables include water, abrasive, orifice and mixing tube



# Manufacturing Technology

## Tolerances

- ▶ Typically +/- 0.127mm
- ▶ Machines usually have repeatability of 0.0254mm
- ▶ Comparatively traditional machining centers can hold tolerances of 0.0254mm with similar repeatability
- ▶ Water Jet tolerance range is good for many applications where critical tolerances are not crucial to workpart design

# Manufacturing Technology

## When is it a practical process solution?

- ▶ The cutter is commonly connected to a high-pressure water pump, where the water is then ejected from the nozzle, cutting through the material by spraying it with the jet of high-speed water.
- ▶ It's practical to use it to cut any kind of material.
- ▶ In waterjet cutting, there is no heat generated. This is especially useful for cutting tool steel and other metals where excessive heat may change the properties of the material.
- ▶ Waterjet cutting does not leave a burr or a rough edge, and eliminates other machining operations such as finish sanding and grinding. It can be easily automated for production use.

# Manufacturing Technology

## Water Jet Cutting

- ▶ Cheaper than other processes.
- ▶ Cut virtually any material. (pre hardened steel, mild steel, copper, brass, aluminum; brittle materials like glass, ceramic, quartz, stone)
- ▶ Cut thin stuff, or thick stuff.
- ▶ Make all sorts of shapes with only one tool.
- ▶ No heat generated.
- ▶ Leaves a satin smooth finish, thus reducing secondary operations.
- ▶ Clean cutting process without gases or oils.
- ▶ Modern systems are now very easy to learn and are very safe.
- ▶ Machine stacks of thin parts all at once.

# Manufacturing Technology

## Advantages of Water Jet Cutting

- ▶ Unlike machining or grinding, waterjet cutting does not produce any dust or particles that are harmful if inhaled.
- ▶ The kerf width in waterjet cutting is very small, and very little material is wasted.
- ▶ Waterjet cutting can be easily used to produce prototype parts very efficiently.
- ▶ An operator can program the dimensions of the part into the control station, and the waterjet will cut the part out exactly as programmed.
- ▶ This is much faster and cheaper than drawing detailed prints of a part and then having a machinist cut the part out.

# Manufacturing Technology

## Advantages of Water Jet Cutting

- ▶ Waterjets are much lighter than equivalent laser cutters, and when mounted on an automated robot.
- ▶ This reduces the problems of accelerating and decelerating the robot head, as well as taking less energy.



9.25" Aluminum Water Jet Cut

# Manufacturing Technology

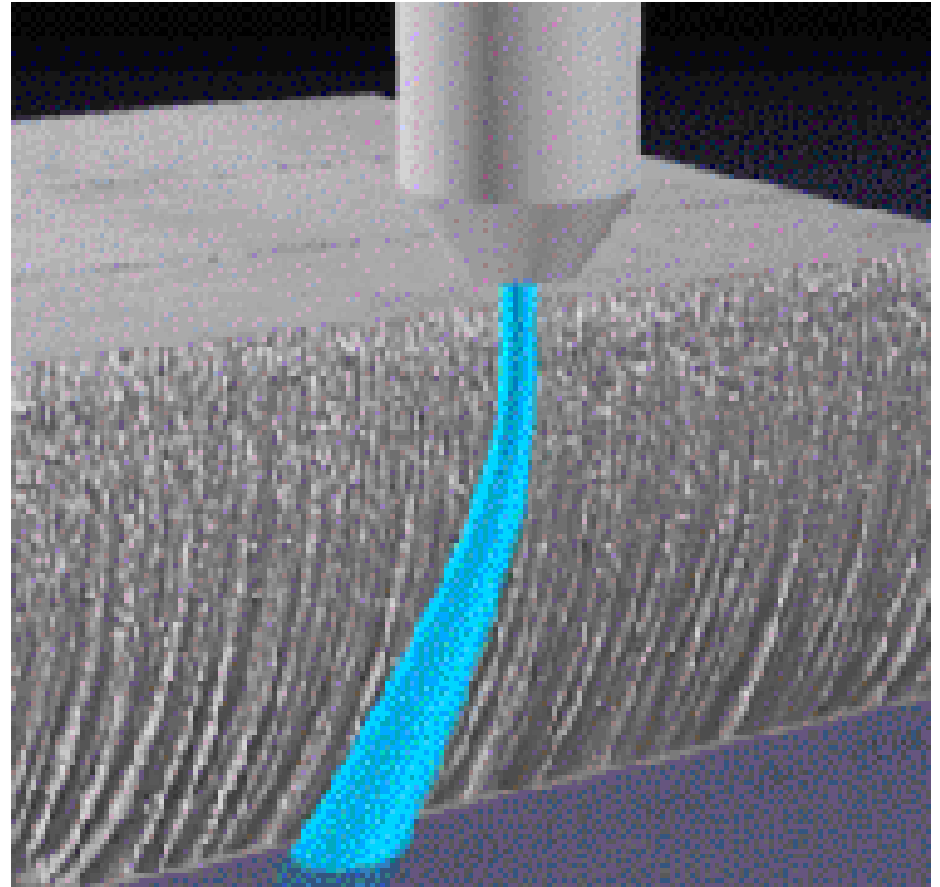
## Disadvantages of Water Jet Cutting

- ▶ One of the main disadvantages of waterjet cutting is that a limited number of materials can be cut economically.
- ▶ While it is possible to cut tool steels, and other hard materials, the cutting rate has to be greatly reduced, and the time to cut a part can be very long. Because of this, waterjet cutting can be very costly and outweigh the advantages.

# Manufacturing Technology

## Disadvantages of Water Jet Cutting

- ▶ Very thick parts can not be cut with waterjet cutting & hold dimensional accuracy.
- ▶ If the part is too thick, the jet may dissipate some, and cause it to cut on a diagonal, or to have a wider cut at the bottom of the part than the top.
- ▶ It can also cause a rough wave pattern on the cut surface.



# Manufacturing Technology

## Disadvantages of Water Jet Cutting



- ▶ Taper is also a problem with waterjet cutting in very thick materials.
- ▶ Taper is when the jet exits the part at a different angle than it enters the part, and can cause dimensional inaccuracy.
- ▶ Decreasing the speed of the head may reduce this, although it can still be a problem.

# Manufacturing Technology

## Water Jet Cutting vs. Laser Cutting

- ▶ Abrasive waterjets can machine many materials that lasers cannot. Reflective materials in particular, such as Aluminum and Copper.
- ▶ Uniformity of material is not very important to a waterjet.
- ▶ Waterjets do not heat your part. Thus there is no thermal distortion or hardening of the material.
- ▶ Precision abrasive jet machines can obtain about the same or higher tolerances than lasers (especially as thickness increases).
- ▶ Waterjets are safer.
- ▶ Maintenance on the abrasive jet nozzle is simpler than that of a laser, though probably just as frequent.

# Manufacturing Technology

## Water Jet Cutting vs. Laser Cutting



*After laser cutting*



*After waterjet cutting*

# Manufacturing Technology

## Water Jet Cutting vs. EDM

- ▶ Water Jets are much faster than EDM.
- ▶ Water Jets machine a wider variety of materials
- ▶ Uniformity of material is not very important to a water jet.
- ▶ Water Jets make their own pierce holes.
- ▶ Water Jets are capable of ignoring material aberrations that would cause wire EDM to lose flushing.
- ▶ Water Jets do not heat the surface of what they machine.
- ▶ Water Jets require less setup.
- ▶ Many EDM shops are also buying water jets. Water jets can be considered to be like super-fast EDM machines with less precision.

# Manufacturing Technology

## Water Jet Cutting vs. Plasma Cutting

- ▶ Waterjets provide a nicer edge finish.
- ▶ Waterjets don't heat the part.
- ▶ Waterjets can cut virtually any material.
- ▶ Waterjets are more precise.
- ▶ Plasma is typically faster.
- ▶ Waterjets would make a great compliment to a plasma shop where more precision or higher quality is required, or for parts where heating is not good, or where there is a need to cut a wider range of materials.



*After plasma cutting*



*After waterjet cutting*

# Manufacturing Technology

## Water Jet Cutting vs. Other Cutting Processes

### ▶ Flame Cutting

- ▶ Waterjets would make a great compliment to a flame cutting where more precision or higher quality is required, or for parts where heating is not good, or where there is a need to cut a wider range of materials.

### ▶ Milling

- ▶ Waterjets are used a lot for complementing or replacing milling operations. They are used for roughing out parts prior to milling, for replacing milling entirely, or for providing secondary machining on parts that just came off the mill.

### ▶ Punch Press

- ▶ Some stamping houses are using waterjets for fast turn-around, or for low quantity or prototyping work. Waterjets make a great complementary tool for punch presses and the like because they offer a wider range of capability for similar parts.

# Manufacturing Technology

## Machine types

- ▶ The simplest of machines is the stationary Waterjet. Looking much like a band saw, it is usually used in the Aerospace industry to trim composites. The operator feeds the material through the stream much like a band saw.
- ▶ XY tables, sometimes called “Flatstock machines,” are the most common forms of Waterjet motion equipment.
- ▶ These are used with pure waterjets to cut gaskets and plastics, rubber and foam.
- ▶ Abrasive waterjets utilize these tables to cut metals, composites, glass stone and ceramics.
- ▶ This is what we can see operating at SMU.

# Manufacturing Technology

## XY Tables

- ▶ Controlled by either CNC or PC
- ▶ Servo motors, usually with closed-loop feedback to ensure position and velocity integrity.
- ▶ Base unit with linear ways, bearing blocks and ball screw drive
- ▶ Bridge unit also with ways, blocks and ball screw
- ▶ Catcher tank with material support

# Manufacturing Technology

## 5+ axis machines for 3-Dimension cutting

- ▶ Advances in complex 3D composites and metal forming technologies suggest fewer flat parts will be designed.
- ▶ The lightweight heads and low kickback forces during cutting give machine design engineers freedom not found when designing for the high loads found in milling and routing.

# Manufacturing Technology

## Future applications of Water Jet Cutting

- ▶ Drilling wells
- ▶ Drilling for oil
- ▶ Radial tunnels

# Manufacturing Technology

## Conclusion

- ▶ Relatively new technology has caught on quickly and is replacing century-old methods for manufacturing
- ▶ Used not only in typical machining applications, but food and soft-goods industries
- ▶ As material and pump technology advances faster cutting rates, longer component life and tighter tolerances will be achievable
- ▶ Paves the way for new machining processes that embrace simplicity and have a small environmental impact

# Manufacturing Technology

## Water Jet Cutting @ UWTSD

- ▶ Waterjet Sweden machine
- ▶ Model NC3015E
- ▶ 3000 x 1500mm cutting bed
- ▶ Maximum cutting depth on the bed of 160mm
- ▶ Operational cutting pressure of 3600bar
- ▶ Abrasive is 80 or 120 grit



# EDM

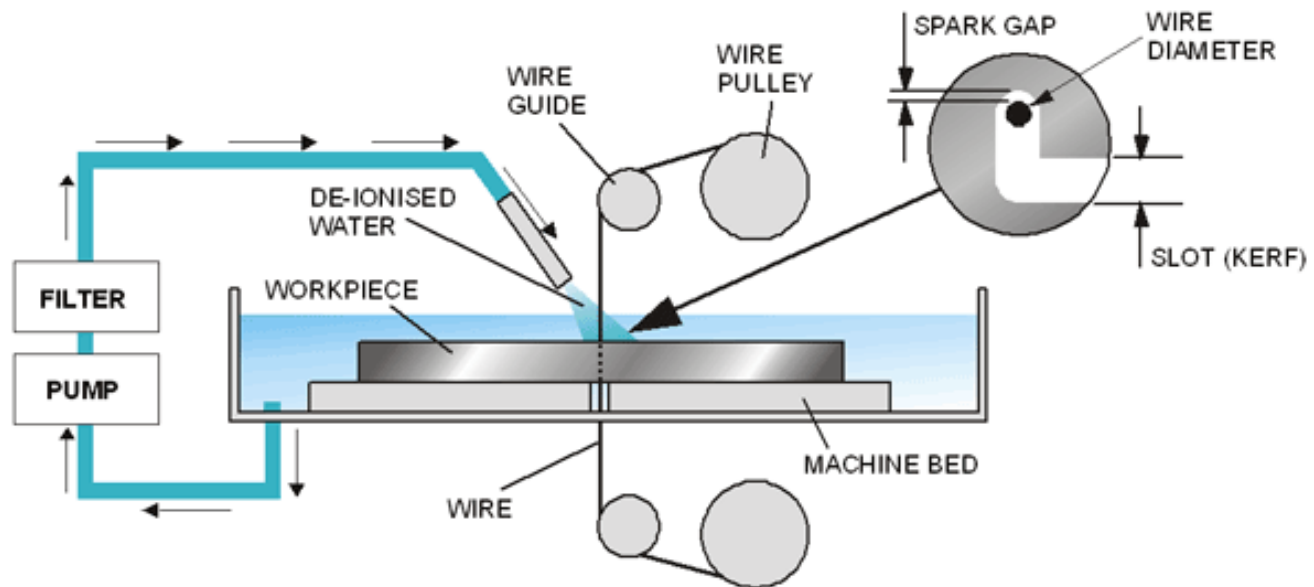
<https://www.engineeringclicks.com/electro-discharge-machining-edm/>

|                                 | Tolerance<br>(mm); |       | Surface roughness<br>( $\mu\text{m}$ ) |      |
|---------------------------------|--------------------|-------|----------------------------------------|------|
|                                 | min                | max   | min                                    | max  |
| Electro- discharge wire cutting | 0.01               | 0.125 | 0.1                                    | 30   |
| Band sawing                     | 0.8                | 3     | 0.8                                    | 45   |
| Circular sawing                 | 0.2                | 3     | 0.8                                    | 45   |
| Cropping/guillotining           | 0.2                | 2     | 0,1                                    | 12.5 |
| Sheet metal                     | 0.01               | 1     | 0,1                                    | 12.5 |
| Sheet metal (non-tooled)        | 0.01               | 1     | 0,1                                    | 12.5 |
| Water jet cutting               | 0.1                | 0.25  | 3.2                                    | 27   |
| Oxyfuel gas cutting             | 0.8                | 2     | 6.3                                    | 71   |
| Plasma arc cutting              | 0.5                | 2.54  | 12                                     | 128  |
| Chemical machining              | 0.004              | 0.3   | 0.8                                    | 12.5 |
| Chemical polishing              |                    |       | 0.0001                                 | 1.3  |
| Electro-Chemical Machining      | 0.013              | 0.5   | 0.2                                    | 12.5 |
| Electro-Discharge Machining     | 0.05               | 0.1   | 0.1                                    | 30   |
| Electron beam machining         | 0.005              | 0.05  | 0.2                                    | 6.3  |

|                               | Tolerance<br>(mm); |       | Surface roughness<br>( $\mu\text{m}$ ) |      |
|-------------------------------|--------------------|-------|----------------------------------------|------|
| Process name                  | min                | max   | min                                    | max  |
| Electropolishing              |                    |       | 0.012                                  | 1.3  |
| Abrasive jet machining        | 0.05               | 0.125 | 0.1                                    | 1.6  |
| Abrasive grinding / polishing | 0.0006             | 0.1   | 0.025                                  | 6.3  |
| Broaching                     | 0.0015             | 0.02  | 0.4                                    | 6.3  |
| Drilling                      | 0.2                | 0.5   | 0.4                                    | 12.5 |
| Honing                        | 0.00055            | 0.04  | 0.025                                  | 1.6  |
| Lapping                       | 0.00055            | 0.04  | 0.012                                  | 0.8  |
| Milling (CNC)                 | 0.01               | 1     | 0.2                                    | 25   |
| Milling (manual)              | 0.01               | 1     | 0.2                                    | 25   |
| Planing/shaping               | 0.02               | 1     | 0.4                                    | 25   |
| Reaming                       | 0.002              | 0.07  | 0.4                                    | 6.3  |
| Turning/boring (CNC)          | 0.003              | 0.2   | 0.05                                   | 25   |
| Turning/boring (manual)       | 0.003              | 0.2   | 0.05                                   | 25   |
| Ultrasonic machining          | 0.005              | 0.05  | 0.2                                    | 1.6  |
| Laser beam machining          | 0.013              | 0.13  | 0.2                                    | 6.3  |

## Process Description:

- Electrical Discharge Wire Cutting (EDWC) involves a continuously spooling conductive wire (the most widely used is brass).
- A power supply generates rapid electric pulses that create a discharge between the workpiece and electrode (the wire).
- The discharge causes the melting, and probably the vaporisation, of a minute piece of material, slowly eating into the work piece.
- Any electrical conductive material can be machined irrespective of hardness.
- The position of the wire with respect to the workpiece is controlled in the x and y planes usually by CNC.
- On some machines the wire can be tilted to create tapered parts.
- An advantage of this process is that no mechanical stresses are created in the workpiece because the wire does not make contact with it.



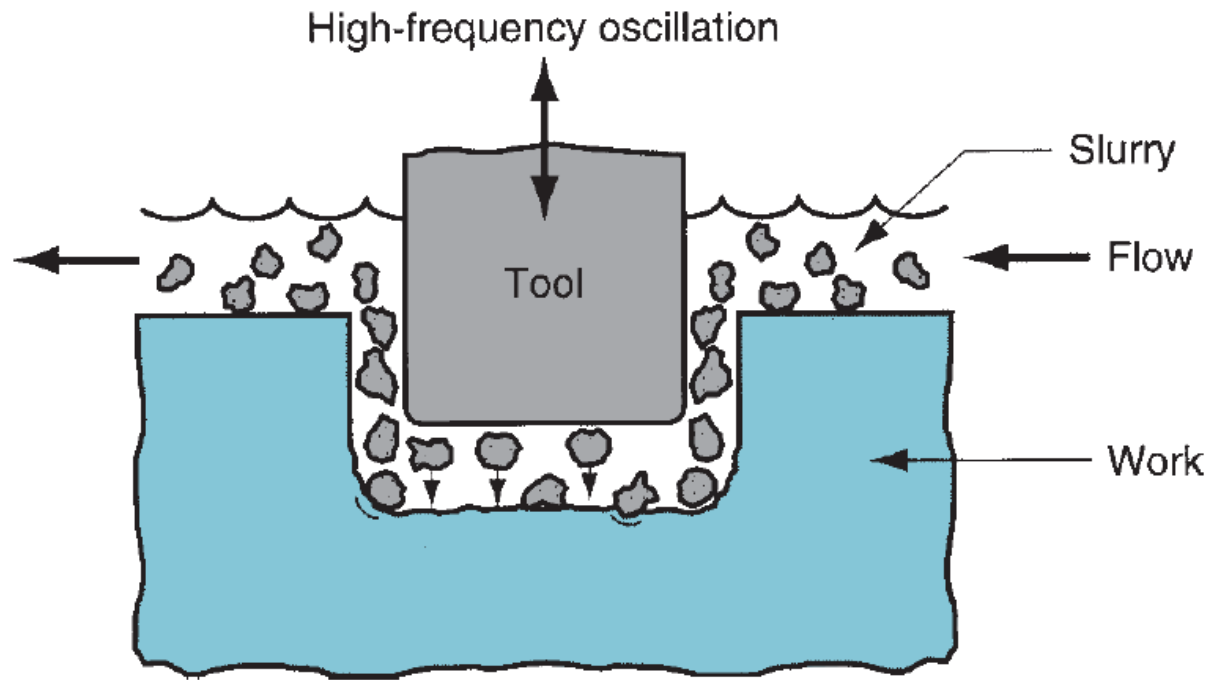
EDWC process schematic

<https://www.engineeringclicks.com/electro-discharge-wire-cutting-edwc/>

# Ultrasonic machining (USM)

- ▶ is a non-traditional machining process in which abrasives contained in a slurry are driven at high velocity against the work by a tool vibrating at low amplitude and high frequency.
- ▶ The amplitudes are around 0.075 mm (0.003 in), and the frequencies are approximately 20,000 Hz.
- ▶ The tool oscillates in a direction perpendicular to the work surface, and is fed slowly into the work, so that the shape of the tool is formed in the part.
- ▶ However, it is the action of the abrasives, impinging against the work surface, that performs the cutting.

# Ultrasonic Machining



Groover: Non traditional  
machining

# USM

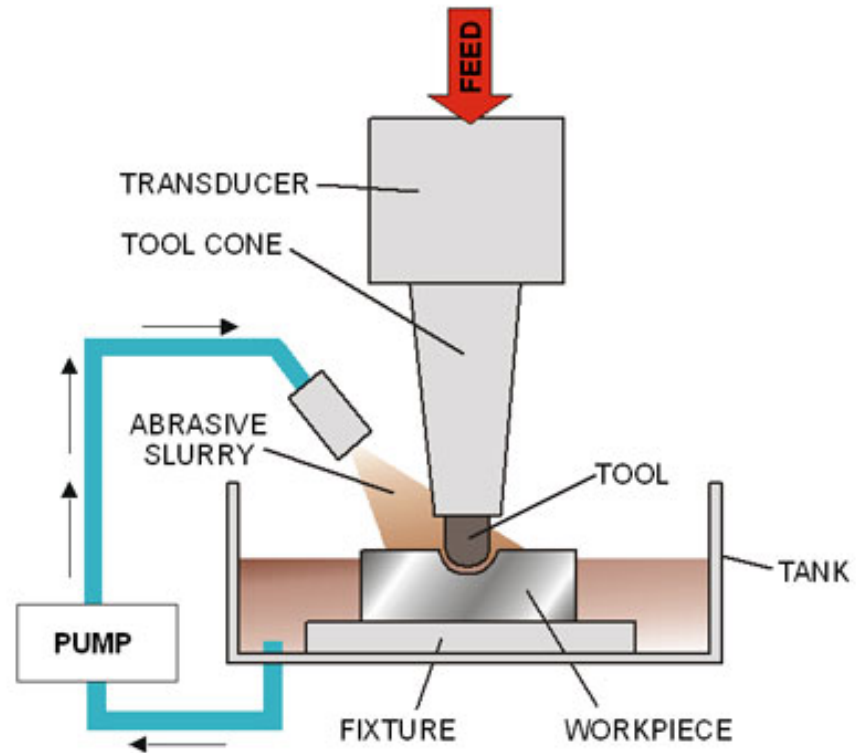


Fig.1: Ultrasonic machining.

# USM

- ▶ Common tool materials :soft steel, stainless steel.
- ▶ Abrasive materials in USM include boron nitride, boron carbide, aluminum oxide, silicon carbide, diamond
- ▶ Vibration amplitude should equal grit size
- ▶ Surface finish depends on grit size
- ▶ Material removal rate is an important performance variable (MRR)
- ▶ The abrasive particles wear the tool
- ▶ Grinding ratio – Material removed/tool wear
- ▶ Abrasive concentration 20-60%

## Process Description:

The tool, which is a negative of the workpiece, is vibrated at around 20KHz with an amplitude of between 0.013mm and 0.1mm in abrasive slurry at the workpiece surface.

Material removal is by 3 mechanisms:

1. Hammering of grit against the surface by the tool.
2. Impact of free abrasive grit particles (erosion).
3. Micro-cavitation.

- Parts are burr-free with no residual stresses, distortion or thermal effects. There are no changes to the metallurgical, chemical or physical properties of the workpiece.
- The tool is gradually moved down and a constant gap is maintained between the workpiece surface and the tool.
- Good for machining very brittle materials.
- Slicing, coining, dicing, lapping, engraving, deburring, broaching, boring and trepanning operations are also practical.

### Typical Uses:

- Burr free holes and slots in hard, brittle materials.
- Complex cavities.
- Coining operations.

### Design guidelines:

- Can be used for any material, however, brittle hard materials (eg. ceramics, precious stones, tool steels, glass, titanium) are preferable to ductile materials.
- Finer surface roughness available with finer grit grades.
- Limited to shape of tool and control in 2-dimensions.
- Sharp corners difficult as they are eroded by abrasive slurry.
- Good for small diameter holes with 3:1 to 4:1 length to diameter ratios, although tapering occurs.

### **Process variations:**

- RUM (Rotary Ultrasonic Machining). A rotating diamond coated tool allows drilling, threading and end-milling functionality.
- It is common to use an ultrasonic assist in other material removal processes (e.g. drilling).
- Rotary Ultrasonic Machining.
- Ultrasonic cleaning.

### **The environment:**

- Scrap material cannot be recycled.

### **The economics:**

- Suitable for low production rates only.
- Special tooling required for each job. High tooling costs.
- Multiple cuts required for progressively better finish. Tool wear is a problem requiring frequent changes.

### Technical notes:

- A high frequency electrical signal is converted into a oscillatory mechanical motion. This motion is acoustically transmitted through a metal tool holder and cutting tool assembly. This linear oscillation is typically at a rate of 20,000 times per second, and, when used with an abrasive slurry flowing around the cutting tool, microscopic grinding occurs.
- The process is very difficult to control due the large number of variables involved. These include the type, size and concentration of the abrasive powder, the fluid, the flux intensity, the vibration amplitude and frequency and the tool geometry and material. The optimisation of the process regarding to these parameters is not well established in literature.

<https://www.youtube.com/watch?v=-fLz4B8vg20>

Industry 4.0

<http://bullentech.com/contract-machining-services/ultrasonic-machining/animation/>