ABSTRACT:
The abrasive water jet machine is a non-conventional type of machine which uses abrasives embedded in a high kinetic energy jet of water, to machine the surface. It has a very good process capability and is more than capable of producing intricate surfaces with a good surface finish. For much of the 20th century, conventional machines had been used to manufacture products. Majority of these processes, though useful they are, are economically wasteful in nature. With the commencement of the 21st century there was a considerable interest towards developing non-conventional processes, such as Abrasive water jet machining. These processes or techniques were much advantageous when it came to efficient machining, optimization of cost and material wastage. Machining is the process of removal of material from the work piece by means of certain processes in order to get the desired size and shape as per the specifications. Machining can be generally classified in to two categories namely [1-3].

1) Conventional machining
2) Non-conventional machining

1. Conventional Machining

Conventional machining processes are those processes which involve cutting action by physical contact between tool and work piece having relative motion between the same. They are (i) turning, (ii) milling, (iii) shaping, (iv) drilling, (v) grinding, etc

2. Non- Conventional machining

Known scientific principles have been intensively developed and applied to material removal processes of unconventional nature in manufacturing industry. They are (i) Chemical, (ii) Electrochemical (iii) Thermoelectric (iv) Electro-discharge machining (v) Laser Beam Machining (vi) Ultrasonic Machining (vii) Water Jet Machining (viii) Abrasive Water Jet Machining, etc

ABRASIVE WATER JET MACHINING:

Water jet cutting uses high pressure water to cut softer material like rubber and add abrasive to add
water to cut harder materials like steel, glass, and titanium. The high pressure water is forced through a tiny area to cut.

Water jet machining is the removal of material from a work piece by the application of a high speed stream of abrasive particles carried in a water medium from a nozzle. The process is used chiefly to cut intricate shapes in hard and brittle materials which are sensitive to heat and have a tendency to chip easily. The process is also used for deburring and cleaning operations. It is used to cut materials very quickly, accurately and economically. Few advanced ceramics are so hard that it’s not economical to cut them. Some composite materials (layers of different materials sandwiched together) can't be cut because the water can seep between the layers and "delaminate" the material. AWJM is inherently free from chatter and vibration problems. The cutting action is cool and overheating free. The water itself acts as the coolant and the medium through which the abrasive flows.

Water jet cut with a supersonic stream of water that is so powerful it can cut through materials in one pass without shredding or crushing them. The Jet Edge water jet is created by pressurizing water up to 4200 bar with a Jet Edge water jet intensifier pump. The water jet cutting action takes place as a result of the ultra-high pressure (UHP) water being forced through a pre-mounted orifice as small as 1.1 mm. In many applications, an abrasive material such as garnet is added to the water jet to create an abrasive water jet that can cut cleanly through virtually any material. The abrasive water jet system is given in Figure 1

**The Machining System:**
The system comprises of table, Siemens CNC controller, a nozzle, abrasives, pumps and pressurized water.

1. Table: It has multiple utility. It does the function of providing datum to the controller. It provides a base to hold the work piece. The water filled base acts as both energy absorber and heat dissipation media.
2. CNC control: It controls all the process parameters such as pressure, standoff distance, cutting speed, nozzle movement, work-piece coordinate control.

![Fig. 1: Schematic of Abrasive Water jet System [4]](image)
3. Nozzle: It converts highly pressurized water into high velocity concentrated jet. Abrasive particles are directed into work piece through nozzles, at very high velocities. It is subjected to very high wear and tear. Material used: tungsten carbide, synthetic sapphire

Tungsten carbide (WC) is used for circular cross sections in the range of 0.5-1.1mm diameter. Rectangular cross-sections of sizes commonly used are 0.08 by 0.5 to 0.18 by 4.0mm². For square sections 0.7*0.7 mm² cross-sectional area is generally used. Sapphire nozzles of 0.2 to 0.7 mm diameter are used for circular cross-sections only. Average life span of a nozzle: 1) WC nozzle: 40-60 hours and 2) Sapphire nozzle: 300 hours

Rate of material removal and size of machined area depends on the standoff distance. The abrasive particles from the nozzle follow a parallel path only for a short distance and then the jet flares resulting in an oversized hole. The MRR initially increases with the increase in the distance of nozzle from the work piece because of the momentum of the abrasive which it carries while leaving the nozzle. This happens up to a distance of ~4-5 mm. Then it steadily drops off because of increase in machining area and decrease in velocity of abrasive particle stream due to drag.

4. Abrasives: They enhance the cutting action and makes cutting of harder materials easier. Major abrasive particles used in WJM: (i) Alumina (ii) Silicon carbide. Size of sand used is 80 grit. Dolomite, up to 200 grit size, is used for light cleaning and etching, if required. Sodium bicarbonate is used for extra fine cleaning operations. Glass beads of diameter 0.30 to 0.60 mm are used for light cleaning and deburring operations. Abrasives cannot be reused because of the reduced cutting action after the operation. Abrasive flow influences the M.R.R and Maximum theoretical MRR ranges from 8-18 g/min. Increasing flow rate above normal range for a particular nozzle design results in a lower Stream velocity and hence, a slower MRR. It is desirable to use optimum flow rate to regulate velocity of flow and increase nozzle life.

5. Pressurized water: Provides cutting force. It acts as carrier media for abrasives. It also performs cooling function. High pressure water is forced through a small hole (typically called the "orifice" or "jewel") to concentrate an extreme amount of energy in a small area. The restriction of the tiny orifice creates high pressure and a high-velocity beam. Pure water jets use the beam of water exiting the orifice to cut soft material like candy bars, and thin soft wood, but are not effective for cutting harder materials. The inlet water for a pure water jet is pressurized between 2000 to 4200 bar. This is forced through a tiny hole in the jewel, which is typically 0.18 to 0.4 mm in diameter. This creates a very high velocity, very thin beam of water travelling as close to the speed of sound (about 600 mph or 960 km/hr).

An abrasive jet starts out the same time as a pure water jet. As the thin stream of water leaves the jewel, however, abrasive is added to the stream and mixed. The high-velocity water exiting the jewel creates a vacuum which pulls abrasive from the abrasive line, which then mixes with the water in the mixing tube. The beam of water accelerates abrasive particles to speeds fast enough to cut through much harder materials.
6. Pump: Performs the function of pressurizing the inlet water to around 4000 bar. The water jet intensifier pump acts as an amplifier as it converts the energy from the low-pressure hydraulic fluid into ultra-high pressure water. The hydraulic system provides fluid power to a reciprocating piston in the intensifier centre section. A limit switch, located at each end of the piston travel, signals the electronic controls to shift the directional control valve and reverse the piston direction. The intensifier assembly, with a plunger on each side of the piston, generates pressure in both directions. As one side of the intensifier is in the inlet stroke, the opposite side is generating ultra-high pressure output. During the plunger inlet stroke, filtered water enters the high pressure cylinder through the check value assembly. After the plunger reverses direction, the water is compressed and exits as ultra-high pressure water and then enters the pressure vessel (attenuator). The attenuator smoothes pressure fluctuations from the intensifier and delivers a constant and steady stream of ultra-high pressure water to the cutting or cleaning tool. The pump used in the machine is given in Figure 2. The KMT pump is used for pressurizing the inlet water to an acceptable working pressure. The KMT pump is divided into 2 stages. The low pressure pump and the high pressure pump. Initially, R.O Water is fed into the prime motor and delivered at 6 bar. This water enters the low pressure KMT pump. The water pressure increases to 800 bar (Figure 2). Then it is raised to 4186 bar in the high pressure KMT pump.

Fig. 2: **KMT PUMP (IDMC)**

![Water jet Intensifier Pump Diagram](image)

**Fig. 3:** Water jet Intensifier Pump[4]
Process Characteristics:

1. MATERIAL REMOVAL RATE: Major factors influencing MRR: (i) Abrasive flow rate: The rate with which the abrasive flows the nozzle is known as abrasive flow rate. It affects the surface finish of work piece. Abrasive flow rate varies with variations in cutting speed, thickness of work piece material of work piece and hence material removal rate. (ii) Water jet velocity: The velocity with which water flows from the nozzle varies with material of work piece, thickness to be cut and intricacy of the profile to be cut. (iii) Working pressure: It is the pressure at which the cutting operation is performed. The material removal rate increases with the increase in working pressure. (iv) Standoff distance: It is the distance between the nozzle tip and work piece surface. With increase in distance, the MRR increases initially and then decreases. (v) Abrasives: Fine particles used in cutting. Finer the abrasive particles i.e. higher the grit number higher the MRR.

2. ACCURACY AND SURFACE FINISH: High surface finish can be obtained by close control of various parameters and a close tolerance (+/- 0.05 mm). Normal production implies an accuracy of +/- 0.1 mm. Masking is done to prevent stray cutting by defining the machining area. Copper, glass and rubber are used for masking. Glass: excellent definition but poor life. Rubber: good life poor definition. SURFACE FINISH ranges from 0.4 μm to 0.12 μm.

Experimental Investigation:

The investigation of surface finish and taper on the AJM machine has been carried out and the results are given below in Table 1 and Graph 1

<table>
<thead>
<tr>
<th>Sr. No</th>
<th>Pressure Bar</th>
<th>Surface Finish (Ra) μm</th>
<th>Taper Degree</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2500</td>
<td>3</td>
<td>1.308</td>
</tr>
<tr>
<td>2</td>
<td>3000</td>
<td>3.03</td>
<td>1.005</td>
</tr>
</tbody>
</table>

Table 1: Effect of Pressure on SF and Taper

Graph 1: Pressure vs Surface Finish and Taper

Advantages Of AWJM:

The advantages are: It has the ability to cut intricate shapes in materials of any hardness. It can cut fragile and heat sensitive materials which are very difficult to be machined with conventional machining processes. Compared to conventional CNC machines setup is faster and programming is convenient. Very less mechanical stresses are developed in AWJM with minimal work piece distortion. Work pieces of very high thickness can be easily machined at very high cutting speeds with a good surface finish. Little or no fixtures are required in abrasive water jet machining (AWJM). Heat affected zone is not that significant due to rapid heat dissipation.

Disadvantages Of AWJM:

Slow in cutting thick jobs of high thickness. Stray cutting is possible and so we need mask the surface with materials like copper. Abrasives get embedded in work piece surface while machining soft materials, thus adversely affecting the material. Cannot cut some materials like tempered glass. High wear of nozzle calls for frequent replacement of nozzle. Operating cost is high so its operation has to be justified with the end product machined.

Applications:

In general purpose machine shops. Water jets are good all-around machine tools, as it is fast and easy
to go from idea to finished part. Water jets can also minimal fixtures and setup. Artists use water jets because they can create intricate designs in materials that have traditionally been difficult to work with, such as stained glass, marble and stone. Similar to the art market, there are many machines out there making custom flooring from stone, as well as making architectural details from metal. Companies that makes parts for the aerospace industry, machines a lots of aluminium, which is easily machined on an AWJM machine. Exotic metals such as Inconel, titanium, and Hastalloy can also be machined by water jets. Water jets are used for making many of the parts used to make the machines on the assembly lines. Prototyping and production parts for automobiles, and the tooling for making automobiles can be easily made by AWJM. Also there are a lot of custom race car parts made on water jets. Lasers and water jets are highly complementary tools. They both pick up where the other leaves off. Some of the small size and higher precision water jet machining centres are great complementary tools to EDM because they allow for higher speed machining of similar shapes, and can provide other services for the EDM such as pre-drilling start holes or stress relieving the part prior to skim cutting on the EDM.

**Defects:**

1. Tapered cutting action: The energy of jet is maximum at the starting point it diminishes gradually. Jet starts getting dispersed and forms a tapering section resulting into tapered surface (Fig. 4). It is minor in work piece with lower thickness work with many different types of materials with but increases and becomes prominent with increase in thickness.

2. Marred surface: During the cutting operation the abrasive jet penetrating through the work piece tries to follow the path of minimum resistance. The jet after travelling for a certain distance spreads out. Now the jet has less energy, so it deviates from the original path and results into kerfs which mares the surface (Fig. 5).

![Photograph of marred surface](image)

3. Lead- in-lead-out error: While machining any curved profile the nozzle does not begins exactly at the desired start point but a bit earlier and similarly ends after the desired point resulting into such an error. This is inevitable (Figure 6).
CONCLUSION:
1. It has the ability to cut intricate shapes in materials of any hardness. It can cut fragile and heat sensitive materials which are very difficult to be machined.
2. Compared to conventional CNC machines setup is faster and programming is convenient.
3. Very less mechanical stresses are developed in AWJM with minimal work piece distortion.
4. Work pieces of very high thickness can be easily machined at very high cutting speeds with a good surface finish.
5. Little or no fixtures are required in abrasive water jet machining
6. The cutting pressure increase in the range of experimentation has little effect on Surface roughness
7. The cutting pressure increase in the range of experimentation results in decrease of taper angle

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