CHAPTER 2

ABRASIVE WATER JET MACHINING

2.1 INTRODUCTION

Abrasive water jet machining (AWJM) is a mechanical material removal process used to erode holes and cavities by the impact of abrasive particles of the slurry on hard and brittle materials. Since the process is non-thermal, non-chemical and non-electrical it creates no change in the metallurgical and physical properties of the work piece.

2.2 BASIC PRINCIPLE

Abrasive Water Jet Machining is a non-traditional machining process, which makes use of the principles of Abrasive Jet Machining (AJM) and Water Jet Machining (WJM).

The Abrasive Jet Machining process involves the application of a high-speed stream of abrasive particles assisted by the pressurized air on to the work surface through a nozzle of small diameter. Material removal takes place by abrading action of abrasive particles [67].

Water jet machining is an erosion process technique in which water under high pressure and velocity precisely cuts through and grinds away minuscule amounts of material. The addition of an abrasive substance greatly increases the ability to cut through harder materials such as steel and titanium. Water jet Machining is a cold cutting process that involves the removal of material without heat. This revolutionary technology is an addition to non-traditional cutting processes like laser and plasma, and is
able to cut through virtually any material. The water jet process is combined with CNC to precisely cut machine parts and etch designs [63].

Since water jet machining is done with abrasives, it is often synonymous with abrasive jet cutting. The combination of compressor, plumbing and cutting heads accomplishes the pressure and velocity to attain the cutting ability. High-pressure compressors create a jet of water under extreme pressure that exceeds the speed of sound. This slim jet of water produced from a small nozzle creates a clean cut. Before cutting, the materials are carefully laid on top of slates over or submerged in the catch tank.

Abrasive water jet uses the technology of high-pressure water typically between 2069 and 4137 bar, to create extremely concentrated force to cut stuff. A water cutter pressurizes a stream of pure water flow (without abrasive) to cut materials such as foam, rubber, plastic, cloth, carpet and wood. Abrasive jet cutters mix abrasive garnet to a pressurized water stream to cut harder materials. Examples are stainless steel, titanium, glass, ceramic tile, marble and granite. Water jet metal cutting machine yields very little heat and therefore there is no Heat Affected Zone (HAZ). Water jet machining is also considered as “cold cut” process and therefore is safe for cutting flammable materials such as plastic and polymers. With a reasonable cutting speed setting, the edges resulting are often satisfactory.

In Abrasive Water Jet Machining, the abrasive particles are mixed with water and forced through the small nozzle at high pressure so that the abrasive slurry impinges on the work surface at high velocity. Each of the two components of the jet, i.e., the water and the abrasive materials have both separate purpose and a supportive purpose. The primary purpose of the abrasive material in the jet stream is to provide the erosive forces. The water in the jet acts as the coolant and carries both the abrasive material and eroded material to clear of the work.
2.3 ESSENTIALS OF THE PROCESS

A schematic diagram of abrasive water jet machining is shown in Figure 2.1. It consists of:

- Compressor
- Air filter cum drier
- Relief valve
- Pressure gauge
- Opening valve
- Mixing chamber
- Nozzle holder
- Nozzle
- Work piece

Figure 2.1 Schematic diagram of Abrasive Water Jet Machining Set-up [59]
The compressed air from the compressor enters the mixing chamber partly prefilled with fine grain abrasive particles and chemical. The vortex motion of the air created in the mixing chamber carries the abrasive slurry to the nozzle through which it is directed on to the work piece.

2.4 ABRASIVE SLURRY

The slurry used in this process is a mixture of abrasive particles and a liquid component, mainly water. The ratio of abrasive to liquid can vary from 1: 6 to 1: 14 (by volume). Slurry is to be fed through the nozzle, which directs the abrasive slurry centrally to the work piece. The slurry serves several purposes. It carries and distributes the abrasive grains on the work surface thus, removes the waste material and cools the work piece avoiding thermal stresses. The abrasives normally used in the process are boron carbide(cubic boron nitride), silicon carbide, aluminum oxide, garnet, tin oxide etc.,

2.5 WORKPIECE

The work piece material may be of any size and shape. It is held by means of a fixture. Many of the difficult to work materials may be machined by abrasive water jet machining. The abrasive water jet machining technique is especially suited for hard materials like tungsten carbide, titanium carbide and ceramics. Materials which exhibit high hardness and which have high impact brittleness can be successfully machined by this technique. Such materials are germanium, ferrites, glass and quartz. These materials often cannot withstand the forces needed for ordinary mechanical working.

2.6 MECHANISMS OF MATERIAL REMOVAL

Though the process is commercially used for many years, the details of the material removal mechanism are yet to be fully understood. However, the past works done to understand the process parameters, have thrown light on the
possible mechanism of material removal in abrasive water jet machining. The main mechanisms responsible for the material removal in abrasive water jet machining are listed below.

- Direct impact of the abrasive particles on the work piece.
- Impact of the free moving abrasive particles on the work piece.
- Erosion of the work surface due to cavitations effect of the abrasive slurry.
- Chemical action associated with the fluid used.

It has been reported that among the above-mentioned mechanisms, the first two are primarily responsible for major stock removal. The part played by erosion has been reported as insignificant for normal materials machined by this process [61].

2.6.1 Abrasive Water Jet Erosive Wear Mechanism

High-pressure abrasive water jet cutting is essentially an erosion process, which involves two distinct mechanisms depending upon whether the eroded material is brittle or ductile in nature. Ductile erosion is defined as a cutting process in which the abrasive particles progressively cut the eroded materials, eventually causing volume removal [9]. Brittle erosion is described as a cracking process in which material is removed by the propagation and intersection of cracks ahead of and around the abrasive particle [61]. In fact, abrasive water jet cutting of any material takes place as a combination of brittle and ductile erosion wear mechanisms. But, one or the other may dominate the cutting process [2].

The mechanism of material removal also depends on the type of jet employed and the type of material to be cut. Unlike water jets that operate on a macroscopic level, abrasive water jets operate on a microscopic level [71].

In case of cutting ductile materials with pure water jets, the material is removed by the hydrodynamic loading which in turn causes a water hammer
effect on the surfaces of the a material. However, in cutting brittle materials, macro cracking and hydro-wedging induced crack propagation are the causes of material removal.

Pre-cracked materials and certain materials like concrete, having a certain degree of in-homogeneities, such as micro-cracks and pores, can be effectively cut with pure water jets [40]. It was indicated that, the stresses on the crack walls are generated due to high velocity water entering the crack. Further, the crack can grow only if the intensity of the applied stress exceeds the critical load material resistance parameters such as the fracture toughness. A micro-crack network thus formed due to the intersection of several other previously formed cracks thus removing the material.

In case of processing materials with abrasive water jets each of the abrasive particles entered in high-pressure fluid acts as a random single point cutting tool impacting the target material. In general, material removal takes place due to the continuous bombardment and invasive penetration of the abrasive particles on the material surface. In case of ductile materials cut with abrasive water jets, the material removal takes place by displacing the target material into the crater lip where it becomes weak to further erosion or detaches material from the surface [52].

The mechanism of material removal is influenced by the shape of particles impacting the material. When abrasive particle strikes a brittle material it produces cone shaped cracks and these cracks are known as Hertzian cracks. These cracks initiate from pre-existing flaws that lie just outside the area of contact between the particle and the target material. As the loading increases, plastic deformation under the impact site initiates the second set of cracks normal to the impact surface. These cracks are known as radial cracks.

Even an impact by sharp particle results in the formation of two different types of cracks, one perpendicular to the surface of impact, known as radial cracks. While the other parallel to the surface of impact, known as lateral cracks.
Figure 2.2 shows the schematic diagram of crack growth for sharp particles impinging onto the material.

Radial cracks are responsible for degrading the strength of the material while the lateral cracks are responsible for erosive wear, initiation of radial cracks occur during the loading portion of the impact, whereas the lateral cracks are formed during the unloading phase. Lateral cracks take a curve and propagate to the top surface of the target this result in the chip formation and subsequent loss of material. Brittle materials cannot deform plastically as in the case of ductile materials. They crack and fracture when subjected to tensile stresses. Thus for these materials the maximum tensile stress failure criterion applies for fracture to occur.

Figure 2.2 Schematic diagram of crack growth during sharp particle impact [52].
In addition to the above mechanisms responsible for material removal for ductile and brittle material, various other mechanisms of material removal have been found to be responsible for material removal when different types of materials are cut with abrasive water jet. Further the mechanism of material removal can be identified in two different ways such as microscopic and macroscopic level.

2.6.1.1 Macro-Mechanism & Micro-Mechanism of Material Removal

The macroscopic character of material removal can be obtained by analyzing the topography of surface generated with abrasive water jets. It is well known that the formation of striations is a unique aspect of the surface generated. However, the researches explain this phenomenon in different ways.

Hashish M [26] carried out systematic experimental studies to observe the microscopic features of the abrasive water jet cutting process. Based on high-speed photographic studies in cutting transparent material like glass, a two-dimensional structure of the cutting process was assumed. The cutting process was divided into three different stages, an entry stage, cutting stage and exit stage. During the entry stage, the jet just enters the material without its penetration to the maximum depth. However, the cutting stage starts when the jet of certain energy penetrates to the maximum depth of cut. The exit stage occurs at the end of cutting stage, due to the reflection of jet against the traverse direction. This results in the formation of an uncut triangle. This indicates that the cutting process is a study state cutting process in the region just above the start of the uncut triangle. This particular region is known as the cutting wear zone. In this zone the abrasive particles impact at shallow angles of attack and the rate of material removal is equal to the rate of material displacement. However in this mode the mechanism of material removal is not only due to erosion, as in case of cutting wear zone, but is also associated with multiple particle bombardment, surface hardening due to plastic deformation and crack formation. From this it is clear that, material removal occurs due to a change in the micro-cutting
mechanism, but this does not give any reasons for the existence of two different regimes of cutting with abrasive water jets.

2.7 PARAMETERS

Basically abrasive water jet machining process works under slurry systems, besides the geometry and material properties of the product. It thus becomes difficult to predict definite values for performance of the abrasive water jet machining. But still the performance of abrasive water jet machining is decided by the obtainable rate of material removal, accuracy and surface finish [75]. The different parameters, which influence the performance of abrasive water jet machining, are:

2.7.1 Machining Parameters

- The type and size of the nozzle.
- Stand-off-distance greatly influences the performance of abrasive water jet machining.

2.7.2 Abrasive Slurry Characteristics

The type and size of the abrasive, its hardness and fracture tendency, type of the fluid used for forming the abrasive slurry and the concentration of the abrasive particles in the slurry influences the material removal rate along with the accuracy and surface finish.

- High Pressure Slurry
- Low Pressure Slurry
2.7.3 Work Piece Properties

Hardness, brittle fracture characteristics, strength and fatigue properties of the work piece material determine to a great extent, the machining rates. The other properties such as toughness, young’s modulus also play some role.

2.8 LIMITATIONS

Abrasive water jet cutting is a very useful machining process that can be readily substituted for many other cutting methods; however, it has some limitations to what it can cut. Listed below are these limitations, and a brief description of each.

- The jet may tend to dissipate when the target material thickness is too high, thus results in rough wave pattern on the surface.
- In abrasive water jet machine cutting through a thicker specimen is a problem. When the abrasive slurry jet comes out with different angle than it enters the specimen, thus causing dimensional inaccuracy.
- Relatively low cutting rates when compared to laser (when HAZ is not critical) [24].

2.9 APPLICATIONS

Due to the uniqueness of abrasive water jet cutting, there are many applications where it is more useful and economical than standard machining processes. In this section, some of the major applications and uses of abrasive water jet cutting are given.

Abrasive water jet machining is used mostly to cut stronger materials such as steel, and even some tool steels can be cut. Though the applications are somewhat limited listed below are some of the applications.
2.9.1 Machining Tool Steel

Abrasive water jet cutting can be effectively used for cutting tool steels. Tool steel is generally very difficult to cut with conventional machining methods and may result in heat that could alter the metallurgical structure of the material. Abrasive water jet cutting, however, do not produce appreciable amount of heat and the metallurgical structure of the material is not altered thus the strength of the tool is retained.

2.9.2 Manufacturing Industry

The abrasive water jet machining is used to cut any profile required by Automobiles, Ships and Aircrafts. The glass industry calls for artistic work on different glass materials.

2.9.3 Construction Industry

To cut ceramic tile, mosaic and marble or granite for home/ commercial building or even pavement decoration the abrasive water jet cutting often referred as marble cutter or graphite cutting machine or granite cutter, can be effectively used.