6.4. Non-Conventional Machining

Introduction and Abrasive Jet Machining

9.1 Introduction:

Manufacturing processes can be broadly divided into two groups and they are primary manufacturing processes and secondary manufacturing processes. The former ones provide basic shape and size to the material as per designer's requirement. Casting, forming, powder metallurgy are such processes to name a few. Secondary manufacturing processes provide the final shape and size with tighter control on dimension, surface characteristics etc. Material removal processes are mainly the secondary manufacturing processes.

Material removal processes once again can be divided into mainly two groups and they are "Conventional Machining Processes" and "Non-Traditional Manufacturing Processes".

Examples of conventional machining processes are turning, boring, milling, shaping, broaching, slotting, grinding etc. Similarly, Abrasive Jet Machining (AJM), Ultrasonic Machining (USM), Water Jet and Abrasive Jet Machining (WJM and AWJM), Electro Discharge Machining (EDM) are some of the Non Traditional Machining (NTM) Processes.

9.2 Classification of Non Traditional Machining Processes

To classify Non Traditional Machining Processes (NTM), one needs to understand and analyse the differences and similar characteristics between conventional machining processes and NTM processes.

Conventional Machining Processes mostly remove material in the form of chips by applying forces on the work material with a wedge shaped cutting tool that is harder than the work material under machining condition. Such forces induce plastic deformation within the work piece leading to shear deformation along the shear plane and chip formation. Fig. 9.1 depicts such chip formation by shear deformation in conventional machining.

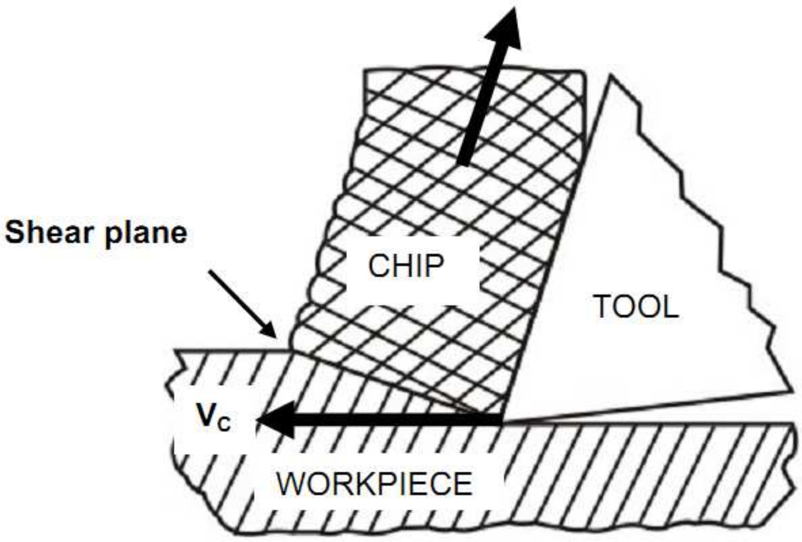


Fig 9.1 Shear deformation in conventional machining leading to chip formation

Thus the major characteristics of conventional machining are:

- Generally macroscopic chip formation by shear deformation
- Material removal takes place due to application of cutting forces – energy domain can be classified as mechanical
- Cutting tool is harder than work piece at room temperature as well as under machining conditions

Non Traditional Machining (NTM) Processes on the other hand are characterized as follows:

Material removal may occur with chip formation or even no chip formation may take place. For example in AJM, chips are of microscopic size and in case of Electrochemical machining material removal occurs due to electrochemical dissolution at atomic level

In NTM, there may not be a physical tool present. For example in laser Jet machining, machining is carried out by laser beam. However in Electrochemical Machining there is a physical tool that is very much required for machining

In NTM, the tool need not be harder than the work piece material. For example, in EDM, copper is used as the tool material to machine hardened steels.

Mostly NTM processes do not necessarily use mechanical energy to provide material removal. They use different energy domains to provide machining. For example, in USM, AJM, WJM mechanical energy is used to machine material, whereas in ECM electrochemical dissolution constitutes material removal.

Thus classification of NTM processes is carried out depending on the nature of energy used for material removal. The broad classification is given as follows:

- Mechanical Processes
    - Abrasive Jet Machining (AJM)
    - Ultrasonic Machining (USM)
    - Water Jet Machining (WJM)
    - Abrasive Water Jet Machining (AWJM)
- Electrochemical Processes
    - Electro Chemical Machining (ECM)
    - Electro Chemical Grinding (ECG)
    - Electro Jet Drilling (EJD)
- Electro – Thermal Processes
    - Electro-discharge Machining (EDM)
    - Laser Jet Machining (LJM)
    - Electron Beam Machining (EBM)
- Chemical Processes
    - Chemical Milling (CHM)
    - Photochemical Milling (PCM) etc.

Fig: 9.2 schematically depict some of the NTM processes:

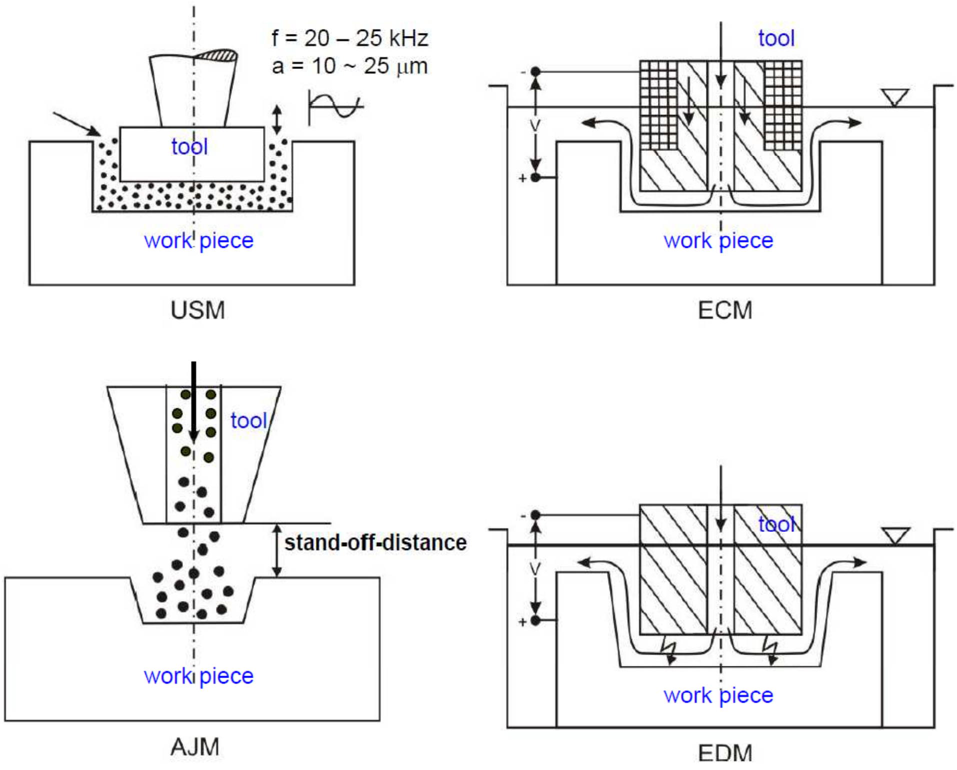


Fig: 9.2 Schematic representations of various metal cutting

9.3 Need for Non Traditional Machining

Conventional machining sufficed the requirement of the industries over the decades. But new exotic work materials as well as innovative geometric design of products and components were putting lot of pressure on capabilities of conventional machining processes to manufacture the components with desired tolerances economically. This led to the development and establishment of NTM processes in the industry as efficient and economic alternatives to conventional ones. With development in the NTM processes, currently there are often the first choice and not an alternative to conventional processes for certain technical requirements. The following examples are provided where NTM processes are preferred over the conventional machining process:

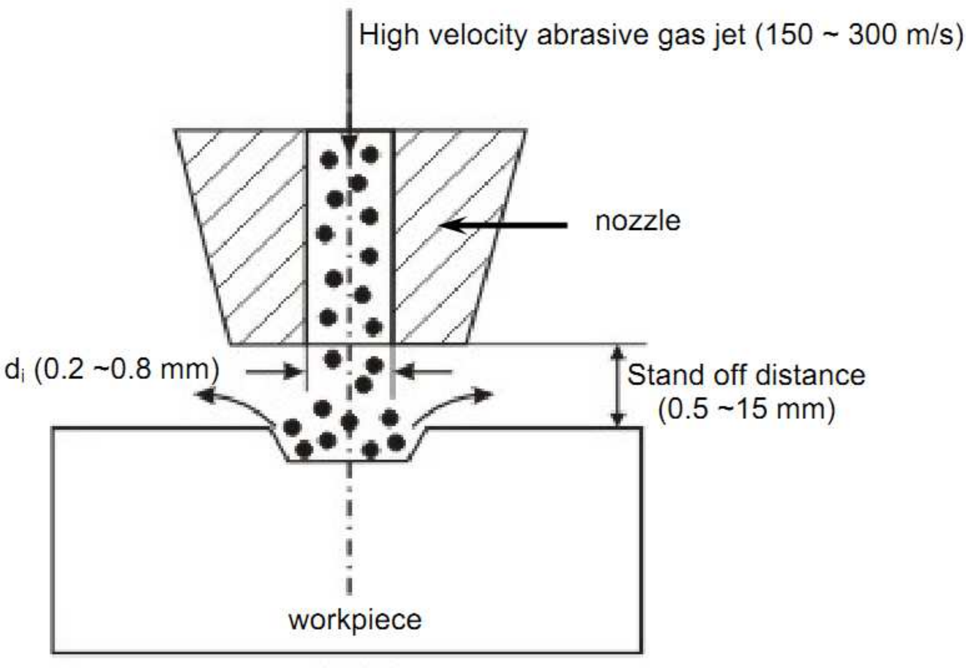
- Intricate shaped blind hole – e.g. square hole of 15mm x 15 mm with a depth of 30 mm
- Difficult to machine material – e.g. same example as above in Inconel, Ti-alloys or carbides
- Low Stress Grinding – Electrochemical Grinding is preferred as compared to conventional grinding
- Deep hole with small hole diameter – e.g. ϕ 1.5 mm hole with L/d = 20
- Machining of composites.

9.4 Abrasive Jet Machining

In Abrasive Jet Machining (AJM), abrasive particles are made to impinge on the work material at a high velocity. The jet of abrasive particles is carried by carrier gas or air. The high velocity stream of abrasive is generated by converting the pressure energy of the carrier gas or air to its kinetic energy and hence high velocity jet. The nozzle directs the abrasive jet in a controlled manner onto the work material, so that the distance between the nozzle and the work piece and the impingement angle can be set desirably. The high velocity abrasive particles remove the material by micro-cutting action as well as brittle fracture of the work material. Fig. 9.3 schematically shows the material removal process.

AJM is different from standard shot or sand blasting, as in AJM, finer abrasive grits are used and the parameters can be controlled more effectively providing better control over product quality.

In AJM, generally, the abrasive particles of around 50 µm grit size would impinge on the work material at velocity of 200 m/s from a nozzle of I.D. of 0.5 mm with a stand off distance of around 2 mm. The kinetic energy of the abrasive particles would be sufficient to provide material removal due to brittle fracture of the work piece or even micro cutting by the abrasives.



AJM

9.3 Schematic representation of AJM

9.4.1 Equipment

In AJM, air is compressed in an air compressor and compressed air at a pressure of around 5 bar is used as the carrier gas as shown in Fig. 9.4. Fig. 9.4 also shows the other major parts of the AJM system. Gases like CO_2, N_2 can also be used as carrier gas which may directly be issued from a gas cylinder. Generally oxygen is not used as a carrier gas. The carrier gas is first passed through a pressure regulator to obtain the desired working pressure. The gas is then passed through an air dryer to remove any residual water vapour. To remove any oil vapour or particulate contaminant the same is passed through a series of filters. Then the carrier gas enters a closed chamber known as the mixing chamber. The abrasive particles enter the chamber from a hopper through a metallic sieve. The sieve is constantly vibrated by an electromagnetic shaker. The mass flow rate of abrasive (15 gm/min) entering the chamber depends on the amplitude of vibration of the sieve and its frequency. The abrasive particles are then carried by the carrier gas to the machining chamber via an electromagnetic on-off valve. The machining enclosure is essential to contain the abrasive and machined particles in a sage and eco-friendly manner. The machining is carried out as high velocity (200 m/s) abrasive particles are issued from the nozzle onto a work piece traversing under the jet.

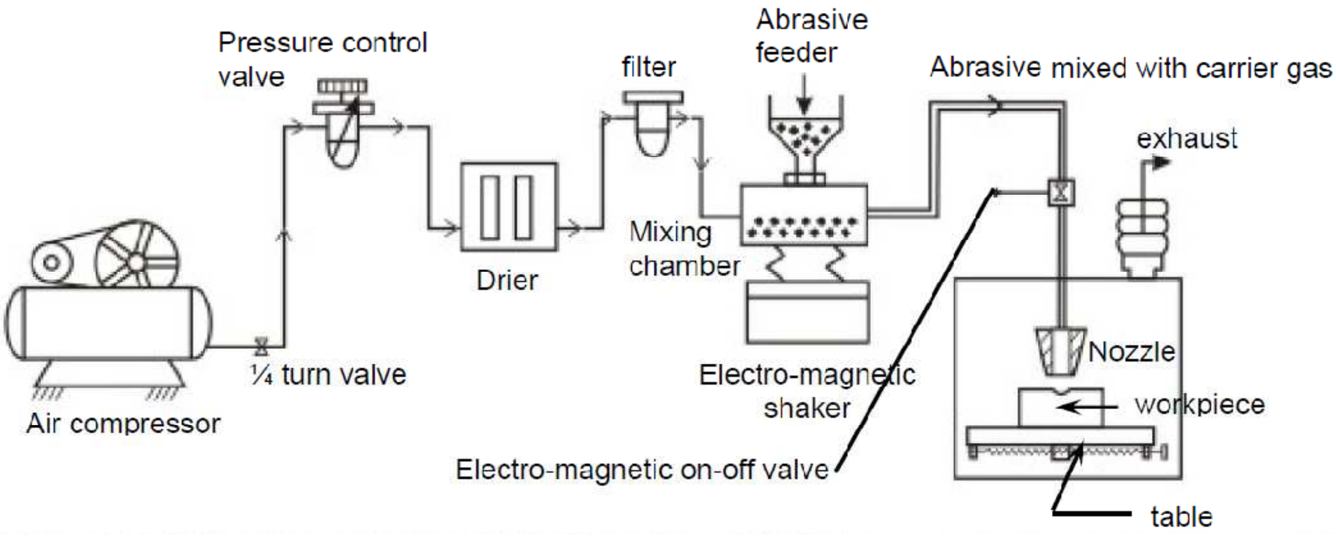


Fig: 9.4 AJM Set-up

9.4.2 Process Parameters and Machining Characteristics

The process parameters are listed below:

- Abrasive
  — Material – Al_2O_3/SiC/glass beads

— Shape – irregular/spherical
— Size – 10 ~ 50 μm
— Mass flow rate – 2 ~ 20 gm/min

- Carrier gas

— Composition – Air, CO_2, N_2
— Density – Air ~1.3 kg/m^3
— Velocity – 500 ~700 m/s
— Pressure – 2 ~ 10 bar
— Flow rate – 5 ~30 lpm

- Abrasive Jet

— Velocity – 100 ~300 m/s
— Mixing ratio – mass flow ratio of abrasive to gas – $\left(\frac{M_{abr}}{M_{gas}}\right)$
— Stand – off distance – 0.5 ~ 5mm
— Impingement Angle – 60^0 ~ 90^0

- Nozzle

— Material – WC / sapphire
— Diameter – (Internal) 0.2 ~ 0.8 mm
— Life – 10 ~ 300 hours

The important machining characteristics in AJM are

- The material removal rate (MRR) mm^3/min or gm/min
- The machining accuracy
- The life of the nozzle

9.4.3 Applications

- For drilling holes of intricate shapes in hard and brittle materials
- For machining fragile, brittle and heat sensitive materials
- AJM can be used for drilling, cutting, deburring, cleaning and etching
- Micro – machining of brittle materials

9.4.4 Limitations

- MRR is rather low (around ~15 mm^3/min for machining glass)
- Abrasive particles tend to get embedded particularly if the work material is ductile

- Tapering occurs due to flaring of the jet
- Environment load is rather high