# ABRASIVE WATER JET MACHINING OF METAL LAMINATES AND CHARACTERIZATION OF METAL REMOVAL PROCEDURE

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## Introduction:

Among the non-conventional machining processes Abrasive Water Jet Machining (AWJM) already have taken an important role. Now-a-days it is used for precision machining processes (e.g. precision drilling, milling). Like conventional machining in AWJM material from workpiece is not removed by shearing process, but by erosion due to velocity water stream and abrasive particle mixture impinging on a small area. The pressure exceeds the flow pressure of the material being cut. The energy flow through an abrasive water jet cutting system from hydraulic power to the cutting action can be divided into following three subsequent steps.

The transformation of the potential energy of an amount of water under high pressure into kinetic energy of a high speed pure water jet.

Transfer of a part of the kinetic energy of the high speed water jet to kinetic energy of the abrasive particles by using the pure water jet and focusing the resulting abrasive water jet.

Utilization of the kinetic energy of the abrasive particles to remove small chips of the work material where the abrasive particles hit the work material.

In AWJM the abrasive particles are either entrained in high velocity water jet or premixed abrasive water jet is issued from a nozzle to form high velocity jet of abrasive and water. One of the major advantages of AWJM over other jet cutting processes (specially when machining laminated structure like GFML and MPL) is that AWJM being heatless process, does not lead to any thermal damages on the workpiece as may be the case of laser jet or plasmas jet cutting .The main area of application of GFML and MPL are respectively in the automobile and aerospace industries. Conventional machining of both the types of laminates may be carried out with diamond coated milling cutters. But uncoated milling cutters often results in poor tool life and poor quality of the cut. A worn out cutter yields increased cutting forces, temperature and thus de-lamination in MPL and GFML.Cutting in guillotine type presses have been successful, but in thicker laminates edge de-lamination takes place.

- **Metal Polymer Laminates (MPL):**

Metal polymer laminates (MPL) have a sandwiched structure with two aluminium layers at the top and bottom with a polymer (Polypropylene or ABS) layer in between. The bonding is achieved by epoxy resin. The aluminium layers can further be covered with a coat to prevent accidental scratches during handling. Depending on applications the thicknesses of the aluminium and polymer layers are tailored.

- **Glass Fibre Metal Laminates (GFML):**

Glass Fibre Metal Laminates (GFML) consists of alternating high strength aluminium layers and fibre/ epoxy prepeg layers. The epoxy resin provides the bonding between the fibre layers and the aluminium. GFMLs are designed to replace fatigue critical components in aircraft structures. Because of the crack bridging effects, preventing cracks from opening, GFMLs show superior fatigue properties. This, in combination with a high specific tensile strength, good damage tolerance and superior impact and fire resistance properties, make them serious candidates for both primary and secondary aircraft structures.

### Experimental Parameters:

AWJM encompasses quite a lot of parameters like the diameter of orifice, the diameter of the insert, the pressure of the water, the mass flow rate of the abrasive particles, the traverse speed, the stand off distance, the angle of impact between the jet and the workpiece, the shape, the size and the materials of the abrasive particles, the presence of additives in the water, the abrasive delivery method within the mixing chamber, the design of the mixing chamber and moreover the characteristics of the work materials which often results in very large size of the experiment even after the application of the concepts of design of experiments.

### Quality parameters of the kerf:

AWJM or any other jet cutting processes like laser jet machining produces a cut in the work material which is often known as the "Kerf". The geometrical and the surface characteristics of such kerfs provide the information about different quality parameters. They are:

- The top width ($b_t$)
- The variation in the top width along the length of the kerf
- The bottom width ($b_b$)
- The variation in the bottom width along the length of the kerf
- De-lamination , its size and its location
- Burr formation
- Surface roughness, waviness etc.
- Taper etc.

A combined quality parameter, taper quality parameter ($T_q$) has been defined as:

$$T_q = (b_b / b_t)$$

For very good quality cut, there would be very less taper and $T_q$ would be around 1.

### Observation of quality of kerf:

After machining of GFML and MPL the common features of the finished products are:

- Burr formation of the exit side of the kerf
- Variation in the bottom width of the kerf
- Less burr formation and less variation of the bottom width of the kerf at the higher $C_P^{\Theta}$ values.

Cutting ability parameter $C_P$ incorporates the effect of geometrical size, process, abrasive material and work material parameters in a single non-dimensional number. Higher $C_P$ indicates better cutting ability of the chosen abrasive water jet parameters with respect to a particular work material being machined.

In AWJM, two types of burr formations are observed and they are:

- The large roll over burr due to plastic deformation
- Small micro machined burr.

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$^{\Theta}$ $C_P$ is the cutting ability parameter at a particular location is defined as the ratio of the predicted depth of penetration to the distance of the point in question from the top of the kerf .

From different experiment it is evident that as $C_P$ increases the size of the burr substantially diminishes. This further indicates that at lower $C_P$ burr formation is by plastic deformation for both MPL and GFML, the exit layer is made of ductile aluminium, which is similarly provided roll over burr at low $C_P$ and as $C_P$ increases the size becomes very small indicating micro machining as the mode of material removal.

**Finite Element Approach to determine the Metal Removal Procedure:**

A nonlinear dynamic finite element model has been developed in order to explain the behaviour of the process. The new model takes into account the precise representation of the constitute behaviour of the workpiece material under abrasive water jet dynamic loading conditions. In this model forces acting on the abrasive particle need not to be initially determined. The interaction of the abrasive particle with the work piece material is traced at small time increments. The new model considers the elastic-plastic behaviour of the work piece material .The failure of the work piece material is examined analytically by means of a virtual finite element abrasive water jet experiment and experimentally by means of surface topographies, surface profiles and scanning electron microscopy. This approach consists of tracing the abrasive particles from its early exit from the mixing tube nozzle until it is reflected from the surface after interaction with the work piece at small time intervals, e.g. 0.01μs. This method has proved to be very rewarding in explaining the mechanism of material removal and the overall behaviour of the process.

Using this model the depth of abrasive water jet kerf is now obtainable. Additionally, deformations and stresses occurring in the workpiece material in the vicinity of the cutting interface, as a result of the erosion impact by abrasive water jet, could be obtained. The finite element results show that the work piece material fails due to highly localized plastic deformation caused by compressive stresses, especially at the abrasive water jet cutting interface. As a result, small overlapping craters are generated. These results indicate a good agreement with experimented results. A mechanism of material removal in abrasive water jet machining as a result of abrasive particle impact through step by step tracing of the abrasive particle as it is interacting with the workpiece material, is described in the present work. This mechanism was verified by experimentation.

The effect of the working conditions, e.g. water jet pressure, traverse rate, stand off distance, abrasive particle size, abrasive low rate, abrasive material and mixing tube diameter, on the depth of cut and kerf topography is investigated in detail. An experimental programme, comprising an extensive series of abrasive water jet machining experiments was designed and implemented. In this programme, working conditions were changed in a large range and the corresponding kerf shapes were recorded. A two dimensional abrasive water jet machine is used in the experimental work. The machine has a maximum pressure of 380 MPa. The work piece kerf profile, three dimensional topographies and kerf depth were measured by a form measuring machine. Each kerf was then photographed by a scanning electron microscope.

The experimental results confirmed the capability of the finite element method in predicting the depth of cut precisely. The model accurately predicts the depth of cut as a result of abrasive water jet impact and the finite element results are in good agreement with the experimental results.

## Conclusion:

Abrasive water jet machining is a recent promising machining process, whose advantages include: low cutting temperature, less heat damage to the material being cut, minimal dust , low cutting forces, deep kerfing capability and no heavy workpiece clamping is needed. Due to the complex interaction of several abrasive water jet machining parameters, combined with the nonlinear dynamic high speed impact of several thousands of small abrasive particles on the workpiece surface, , the mechanism of material removal has not yet been fixedly understood. Mathematical and experimental modeling of abrasive water jet machining has been finding widespread interest for the past twenty years. However there has been a few simple finite element models developed so far. It is believed that, analysis of deformations and stresses generated at the cutting interface could provide deeper insight in order to explain erosion behaviour of the process. This work presents an attempt to model the abrasive water jet machining process using the powerful tool of the finite element method in order to explain the abrasive particle-workpiece interaction. The main objective is to develop a model which would enable to predict the depth of cut without any cutting experiments. In this way, it will be economical to optimize the process parameters.