CHAPTER 2

LITERATURE REVIEW

2.1 MACHINABILITY

Machinability is defined as the easiness with which a given material can be machined under a given set of cutting conditions. The most machinable is the one, which permits easy removal of material with satisfactory finish at a low cost (Trent 2000).

The term 'Machinability' chiefly refers to the evaluation of work material with reference to machining. A material is said to be having good machinability, if the tool wear is low or tool life is long, the surface finish produced is good and the cutting forces are low.

Etheridge (1970) defined machinability is the one which will permit the fastest removal of the largest amount of the material per grind of the tool with satisfactory finish.

2.2 FACTORS OF THE WORKPIECE AFFECTING MACHINABILITY

Al-(SiC)$_p$ metal matrix composites are distinct from the existing material in terms of composition, structure and properties. Hence machining has
to be adapted especially to the specific characteristics of this base material. The properties of the work piece material which affects the machinability are discussed in this section.

2.2.1 Hardness

Hardness of materials have been generally considered as the index for machinability. In Al-(SiC)p composites introduction of SiC ceramic reinforcements increases the hardness of the Al composites. Higher the hardness of the material lower will be the machinability.

2.2.2 Elevated temperature

During metal removal, the heat generated in the shear zone makes the work piece material lose its original strength and excess material flows in the form of chips (Cook, 1973).

If the work piece material is such that it does not lose its strength at elevated temperatures, tremendous cutting force will be encountered to remove such material. Increase in cutting force results in increase in the power required to the machine the materials. Higher the power involved in machining, and then lower will be the machinability of the materials.

2.2.3 Coefficient of thermal conductivity

A major portion of the heat generated in the shear zone is carried away by the chips. The left over heat is conducted away by the work piece. If
this does not happen the residual heat will adversely affect the cutting edge. If the material is having a good thermal expansion, then the machinability will be more.

2.2.4 Built up edge formation

If the alloy has relatively low yield strength and tensile strength i.e. good ductility it will be difficult to machine. It tends to form a BUE at low cutting speed. BUE formation in the tool decreases the machinability by reducing the surface finish of the machined component and as well as it chips off the cutting edge. Aluminium the base alloy of Al-(SiC)ₚ composites is a ductile material which is prone to formation of a BUE.

2.2.5 Work hardening

Certain materials get work hardened when machined. Subsequent working becomes difficult unless they are annealed in-between operations. However, work hardening improves the machinability of soft materials, for example low carbon steel. The presence of SiC particle in the Al matrix hardens the material during the cutting operation. The work hardening is resulted due to the formation of more slip lines by the SiC particle.

2.3 FACTORS OTHER THAN WORK PIECE PROPERTIES AFFECTING MACHINABILITY

Other than the work piece material, a number of parameters decides the machinability. Depending upon the conditions which are used and operation employed the machinability of a material may be affected. They are
i. Type of tool material (H.S.S, Carbide tips, Coated tools)
ii. Tool parameters (Rake angle, Relief angle)
iii. Type of machining operation (Milling, Drilling, Turning)
iv. Cutting parameters (Depth of cut, Feed, Cutting speed)
v. Type and quality of machine used.

2.4 MACHINABILITY CRITERIA.

The ease of machining of different materials can be compared in terms of the values of tool life, cutting forces or surface finish under similar cutting conditions. The following criteria were used to assess machinability:

(i) Cutting power criteria
(ii) Surface finish criteria
(iii) Tool Life Criteria.

2.4.1 Cutting power criteria

This criterion is used when the cutting forces are necessary enough to limit. The specific cutting energy of a material, which is defined as the cutting power required for removing unit volume of material in unit cut time, is often considered as the index of machinability. The longer the specific cutting energy, the lower is its machinability (Trent 1959).

2.4.2 Surface finish criteria

According to this criterion, a material would be easily machinable than the other under given cutting conditions, if it produces a better finish. This criterion may be used in a situation where poor surface finish is the case of rejection of machined parts (Trent 2000).
2.4.3 Tool life criteria

Tool life criterion is the most important criterion used to assess the machinability. If work material produces rapid tool wear, the tool has to be changed often. Machinability criteria based on the tool life is the specific cutting speed, which is defined as the cutting speed corresponding to a predefined tool life (Venkatesh 1969).

To assess the machinability of any new material, any one criteria or in combination may be used. Surface finish and tool life criterions are widely used methods to assess the machinability.

2.5 TOOL LIFE

The performance of any cutting tool is usually evaluated in terms of tool life. Tool life is defined as the usable time that has elapsed before cutting tool has failed to produce acceptable work pieces (Dragos 2001 and Cook 1973). When the wear reaches a certain value, the tool is not capable for further cutting. Tool life is the most important criteria for assessing the performance of a tool material, machinbility of work material and for determining cutting conditions.

Tool life is specified in any one of the following ways:

- Machine time
- Actual cutting time of tool
- Volume of metal removed
- Number of jobs machined
- Equivalent cutter’s speed.
2.6 TOOL FAILURE

A tool is considered ‘Failed’ when it either will not cut or cut in a manner sharply different from a sharp tool. The tool life and the performance of a cutting tool are limited by its wear. The desired surface quality, dimensional accuracy and economy of machining are influenced by tool failure. A study of failure of cutting tools helps to find a suitable tool-work piece combination to improve the machinability.

The wear pattern of a cutting edge can be spotted by magnifying the cutting edge and are given in Figure 2.1. By analyzing the wear patterns of the cutting tools, machinability of a material can be improved. The types of tool failures can be classified as

- Flank wear
- Crater wear
- Notch wear
- Nose radius wear
- Comb or Thermal cracks
- Parallel or Mechanical cracks
- Built up edge (BUE)
- Gross plastic deformation
- Edge chipping of Frittering
- Chip hammering
- Gross fracture

Some of the important tool failures are discussed in this section
Figure 2.1 Types of Wear on Cutting Tools (Stephenson and Agapiou 1996)

(a) flank wear; (b) crater wear; (c) notch wear; (d) nose radius wear; (e) comb or thermal cracks; (f) parallel or mechanical cracks; (g) Built Up Edge (BUE); (h) gross plastic deformation; (i) edge chipping or frittering; (j) chip hammering; (k) gross fracture
2.6.1 Flank wear

This wear produces wear lands on the side of the flanks of the tool on account of the rubbing action of the machined surface (Kalpakjian and Schmid 2000). This wear usually occurs on relief face of the cutting tools Figure 2.1(a). The main reason for the flank wear to occur on a cutting tool is the abrasive wear mechanism. Abrasive wear is usually characterized by forming grooves and ridges in the direction of tool sliding against the machined surface of the work piece material. Flank wear is usually a normal type of wear. The ideal flank wear is the one which maintains a safe progressive flank wear as shown in Figure 2.2. The wear land is not of uniform width. This is due to the fact that the material cut by this part of the cutting edge had been work hardened during the previous cut. The frictional stress and maximum temperature at flanks also goes on increasing with time. After a critical wear land has formed, further wear takes place at an accelerated rate. During the steady wear phase, the flank wear is caused mainly through abrasion, whereas during the rapid wear phase, it is caused by diffusion.

2.6.2 Crater Wear

Crater wear occurs mainly on the rake face of cutting tool Figure 2.1(b). Diffusion wear mechanism is the main mechanism for the crater wear to occur. The crater wear involves chemical reaction between the elements in the work piece and the cutting tool. The above process is getting activated at high temperatures mainly at the chip-tool interface (Gwidon et al, 1994). The increase in temperature at high cutting speeds increases the chemical diffusivity between work piece and tool. A portion of the rake face of the cutting tool is
removed which form as a crater wear. The crater of a cutting tool can be minimized by increasing the hot hardness and minimum affinity between materials.

### 2.6.3 Notch wear

This type of wear is caused due to rubbing of the machined surface at the depth of cut line and also due to cutting of the part of the tool wear over the depth of cut line Figure 2.1(c). Adhesion is the main mechanism involved in notch wear, in which individual grains or their small aggregates are pulled out of the tool surfaces and are carried away by the under side of the chip or tear away by the adherent work piece.

![Figure 2.2 Description of tool wear rate (Boothroyd and Knight 1989)](image-url)
2.6.4 Comb or Thermal Cracks

The frequent change of temperature during machining can lead to fatigue wear. Figure 2.1(e). The crack formation at the site perpendicular to the cutting edge and pieces of tool material between the cracks can be pulled out of the cutting edge and leads to rapid break down of the cutting edge.

2.6.5 Built Up Edge (BUE)

Under some conditions, the friction between the chip and the cutting tool is so great that the chip material welds itself to the tool face Figure 2.1(g). The generation of this welded material further increases the friction, and this friction leads to the building up of the localized layer upon layer of chip material. The resulting localized pile up of material is referred as buildup edge (Sawai Sukvittayawong and Ichiro Inasaki, 1994).

Temperature (Nakayama 1956 and Chandramani, 1964), plastic strain (Usui 1964), work hardening and strain rate (Loewen 1954) have been observed to be the major factor affecting the BUE and disappearance. Takeyama (1968) observed that adhesion between tool and work material was also one of the major factor for the formation of BUE.

The generation of BUE on the cutting tool edge during cutting affects the tool wear in various ways, sometimes decreasing tool life and sometimes increasing. The BUE is of considerable importance in practical cutting operation because of the effect on the surface roughness produced. When surface roughness is an important requirement, the cutting conditions should be selected to avoid this phenomenon.
Hovinga (1971) described a method for evaluating the influence of the BUE on the surface profile in the cutting direction. Influence of various cutting on BUE was analyzed and concluded that cutting speed and work material are the two main factors affecting the finishability of a product.

2.6.6 Plastic deformation

This type of wear (Figure 2.1h) takes place on the cutting tool due to combined effect of high pressure and high temperature on the cutting tool. The heat is generated due to high speed, high feed while machining hard to machine materials. If the tool material does not have high hot hardness, then it deforms. The bulging of the cutting edge will further increase the temperature and makes to loose its shape.

2.6.7 Chipping

Breaking away of a small piece from the cutting edge of the tool is described as chipping Figure 2.1(i). The chipping of the cutting edge when the edge line breaks rather than wears (Kalpak Jian, Schimid 2000) unlike wear. Which is a gradual process, chipping results in a sudden lots of tool material and a corresponding change in shape and dimensional accuracy of the work piece.

2.7 FACTORS AFFECTING TOOL LIFE.

The life of a tool is determined by the amount of wear developed on the tool. The different wear mechanisms are influenced by the hardness and
strength of the different constituents of the work material and friction between work and tool material. The various factors affecting tool life are

1. Cutting materials and tools
2. Work material
3. Cutting speed
4. Feed and depth of cut
5. Tool geometry
6. Cutting fluid
7. Interruption in the cut

2.8 CUTTING MATERIALS AND TOOLS

The productivity enhancement of manufacturing processes imposes the acceleration of the design and evolution of imposed cutting tools with respect to the achievement of a superior tribological attainment and wear resistance. In order to meet these requirements the cutting tool should meet certain basic properties dictated by the process. Li and Low (1994) defined certain basic boundary characteristic for the cutting tool to perform satisfactorily. They are

(i). High indentation hardness of the cutting tool is required. Usually, it has to be three times higher than the work piece hardness (Nakayama, et al. 1959). In machining metal matrix composites, this is important in order to prevent deformations of the tool tip in the contact area of the tool and workpiece. Therefore, a high resistance of the contact area against strong impact and stress is necessary.
(ii). A high hardness and high elastic modulus are required in order to minimize the quantity of local plastic deformation after the cutting tool has passed over.

(iii). Due to the heat generated in the cutting process, the thermal conductivity of the cutting material influences the expansion of the tool and workpiece. Materials with high thermal conductivity reduce the probability that deviations in the geometric of the accuracy of the workpiece occur.

(iv). The high specific forces cause stress on the contact area between tool and workpiece. For this reason, cutting tool materials must have high resistance to mechanical stress combined with a high wear resistance.

(v). High stability against abrasive particles in the microstructure of the workpiece material is required to prevent that grooves in the cutting edge develop as well as to promote that even in case of progressing wear the tool tip keeps its original geometrical shape. (Tonshoff 2000)

(vi). High thermal stability of the cutting tool material has to be guaranteed reliably because the energy resulting high specific cutting forces is almost completely transformed into heat so that extremely high process temperatures are produced in the area of the contact zone.

2.9 APPLICABLE CUTTING TOOL MATERIALS AND THEIR PROPERTIES

As to hard cutting processes, the cutting tool materials require especially high resistant properties against specific cutting forces in connection
with process temperatures, which are caused by the high deformation resistance of workpiece material. Table 2.1 gives the overview of the mechanical and thermal properties of different cutting tool materials (Koneig and Komanduri, 1984)

Table 2.1 Properties of various cutting tools

<table>
<thead>
<tr>
<th>Mechanical Properties</th>
<th>Cemented carbide K10</th>
<th>Ceramic Al₂O₃</th>
<th>PCBN</th>
<th>PCD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (g/cu.cm)</td>
<td>14.0-15.0</td>
<td>3.8-5.0</td>
<td>3.4-4.3</td>
<td>3.5-4.2</td>
</tr>
<tr>
<td>Hardness (GPa)</td>
<td>1500-1700</td>
<td>1800-2500</td>
<td>3000-4500</td>
<td>4000-5000</td>
</tr>
<tr>
<td>Young's modulus (GPa)</td>
<td>590-630</td>
<td>300-400</td>
<td>580-680</td>
<td>680-810</td>
</tr>
<tr>
<td>Fracture toughness (MPa)</td>
<td>10.8</td>
<td>2.0-3.0</td>
<td>3.7-6.3</td>
<td>6.8-8.8</td>
</tr>
<tr>
<td>Thermal Properties</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature stability</td>
<td>800-1200</td>
<td>1300-1800</td>
<td>1500</td>
<td>600</td>
</tr>
<tr>
<td>Thermal conductivity (W/(K-m))</td>
<td>100</td>
<td>30-40</td>
<td>40-100</td>
<td>560</td>
</tr>
<tr>
<td>Thermal expansion coefficient</td>
<td>5.4</td>
<td>7.5-8.0</td>
<td>3.6-4.9</td>
<td>4.2-4.9</td>
</tr>
</tbody>
</table>
2.9.1 Cemented carbides

Cemented carbides are available in variations with different characteristic properties. The most interesting properties are high tensile strength and high fracture toughness. Due to their high hardness, only fine and ultra fine-grained cemented carbides are of interest for hard cutting operations like MMC machining. These cutting tool materials are applied in kinematically more difficult processes demanding complex tool geometry. Apart from this the hardness of cemented carbides is insufficient for hard turning or face milling. The application of cemented carbide tools is also limited by their comparatively low temperature stability (Opitz and Gappisch 1962).

Coated tools are another class of tool materials to enhance the performance of a cutting tool and productivity. Coating layers are selected based on the work tool combination and the primary mechanism involved in machining in order to reduce the wear.

2.9.2 Ceramic, PCBN and PCD tools

The most often applied cutting tool materials for hard turning and face milling operations are Al₂O₃ / TiC ceramics and PCBN (Tonshoff et al 2000). Their high hardness combined with high temperature stability enables these materials to resist the thermal and mechanical loads in the hard cutting processes. A most important difference between ceramics and PCBN is the value of fracture toughness. Compared to ceramics, PCBN tools are favorable in interrupted cutting operations. Considering the effect on dimensional and form accuracy of the workpiece, a high thermal conductivity and a low thermal
expansion coefficient is of importance. Both characteristics favor PCBN as the more adopted tool material for hard cutting processes.

The hardness of PCBN is surpassed by PCD. Even at low temperatures, the diffusion ability of carbon is too high so that it cannot be applied in hard cutting of steel.

### 2.10 TOOL WEAR MECHANISMS

The wear of a cutting tool is a complex phenomenon which is due to several wear mechanism. The factors are the type of cutting tool material, type of work material and cutting parameters decides the dominance of any one or combined mechanisms.

Al-SiC composite is a different class of material in machining point of view. The base alloy is a ductile and easy to machine material where as the SiC is hard and brittle material which cannot be easily machined. Hence the tool wear mechanism involved in machining may be the combination or any of the following mechanism. The tool wear mechanisms are

- Abrasive wear
- Adhesive wear
- Diffusion wear
- Plastic deformation
- Fatigue failure
- Microspalling
Proper understanding of the tool wear mechanisms helps to evaluate the performance of different cutting tools in machining of Al-(SiC)$_p$ composites.

In certain cases one of these wears may be dominating, while in other cases the wear may be determined by simultaneous presence of a few of these. In view of the existence of individual characteristics for each type of wear, wear resistivity of tool material should be defined by different mechanical and physio-chemical properties of tool material under cutting conditions.

2.10.1 Characteristics of Adhesive Fatigue Wear

Adhesive wear occurs when two surfaces are brought into intimate contact under loads and subjected to friction, adhesion phenomena intensifies at high temperature generated by plastic deformation and friction. During this contact bonds are established which are the local strength of the material. During cutting separate adhesive patches are periodically sheared off and reappear again, traces of which can be seen at the tool-work interface contact after short time machining.

In view of such a process any point on the contact surface undergoes cyclic action of shear and normal stresses which eventually lead to the fracture
of the adhesive spot and the damage of the surface layers of the tool. Separation of surface particle of tool material shearing and stripping resulting from adhesion is termed as adhesive wear. If the particles so removed are very small, they are referred as attritious wear. If the particles are visible under the microscope, the process is referred as galling. The adhesive wear mechanism is shown in the Figure 2.2.

During machining, adhesive patches are periodically sheared off which can be seen at the tool work interface. If the adhesion occurs at low temperatures on the rake face of the tool it is often known as Built Up Edge. BUE is a dynamic structure, with successive layers from the chip being welded to the tool. Locke (2000) observed that machining Al-Si alloys at low temperature forms a BUE at low cutting speeds. Weinert (1993) and Tomac (1992) observed that coating tools have a greater susceptibility to BUE in machining hard to machine materials.

The nature of adhesive wear in tools is obviously connected with fatigue phenomena and therefore it is often mentioned as adhesive fatigue. All the factors that go into making the actual materials behave anisotropic, such as cracks, pores, inclusions, residual stresses, thermal stresses etc. These anisotropic properties have a great effect on the fatigue failure and, hence on the adhesive fatigue wear intensity. From the nature of adhesive wear it is evident that wear resistivity of tool material depends upon the micro strength of the surface layers of the tool material.
2.10.2 Characteristics of Abrasive Wear

The abrasive wear occurs when hard inclusions of work material or separated small particles of tool material penetrate into the contact region, scratch the contact surface and / or acting like a micro cutting tip. The surrounding media, in which the machining is done have appreciable effect on the intensity of abrasive wear. While machining in chemically active media the surface area of tool material is weakened and shows low resistance to scratching. Hence the hard inclusions penetrating in the contact zone easily leave ploughing traces on the surface layers of tool and intensify tool wear.

Abrasive wear involves the sliding of the hard particles between the tool and the work piece along the tool surface as shown in the Figure 2.3.
Depending on the location of these hard inclusions in the Tool-Work region, it is termed as two body and three body wear mechanism. To have such wear, it is necessary that one material be harder (or having harder inclusions) than the other member of the sliding pair. Backer (1952) has shown that for one material to scratch another it must be at least 20% harder.

Abrasive wear is usually a dominant wear mechanism on the flank face and it is also observed on the rake surface. Abrasion is characterized by the development of grooves and ridges in the direction of tool. These grooves are caused by the sliding of the chips against a newly machined surface of the work piece or chip sliding against the rake face. The severity of abrasion increases in cases where the work piece material contains hard inclusions. This wear can also occur when hard debris from the work piece or tool is trapped at the interface. Locasto (1996) had related the abrasive wear of a cutting tool to the fracture toughness (K_{IC}) and hardness(H) of a cutting tool. The abrasive wear resistance related K_{IC}^{3/4} H^{1/2} helps to predict the wear resistance of a cutting tool material where abrasion is the dominant wear mechanism. Abrasive wear usually initiate a crack and intersection caused by hard asperities or wear particles acting as small intenders on the cutting face. The abrasive action is attributed to the special features of the flowing chip which is characterized by a serrated profile along its edges. Broken chips of irregular shapes trapped in between the tool and work piece. At high cutting speeds, these serrated chips and broken chips abrade the tool. Most of the high strength materials form a plastically deformed grooves and ridges account for most of the rake and flank face wear.
Figure 2.4 Abrasive wear mechanism in the machining operation
(a) Two body abrasion
(b) Three body abrasion
2.10.3 Characteristics of Diffusion Wear

The factor which probably causes this type of wear is the solubility of tool material in the work piece material at the tool-chip machine surface. Figure 2.4 shows the diffusion wear mechanism in which the tool atoms diffuse into the work material. Brandt (1986) has stated that in some cases interfacial bond formed by tribochemical reaction form stable layers on the rake faces and this point is also stressed by Silva et al (1991). Tribochemical wear is a serious limitation to the performance of a cutting tool. These layers display a glassy appearance on the surface of the tool material. Thus chemical affinity between the elements of the cutting tool and work piece in the cutting zone plays a dominant role in the progressive wear of the cutting tools.

The mechanism of diffusion wear of the cutting tool can proceed through:

a) A mutual dissolution of atom components of tool material.

b) The destruction of the surface layers of the tool material softened due to diffusion.

Investigations says that during machining of carbon steels, nickel and some other materials with carbide tools at high cutting speeds when cutting temperature exceeds certain value, the effect of carbide tools is mostly diffusive. The wear of a diamond tool when machining of low carbon steel at high cutting speed (cutting temperature exceeds 850-900°C) leads to fast dissolution of carbon in γ iron (Gwidon et al., 1994 and Cook 1973). Resistance to the diffusive wear of tool material is controlled by rate of mutual dissolution.
of the components of work materials and the degree of surface layer softening of tool due to diffusion. The former depends on the solubility of the reacting components, which is regulated by alloy equilibrium diagram and temperature equilibrium of diffusion coefficient.

![Diffusion mechanism in the machining operation](image)

**Figure 2.5** Diffusion mechanism in the machining operation

### 2.11 MACHINING STUDIES ON METAL MATRIX COMPOSITES

Metal matrix composites form one group of the new engineered materials that have received considerable research since the trials carried out by Toyato in the early 1980’s (Rohatgi 1990). The density of the most MMC’s is approximately one third of the steel, resulting in high specific strength and stiffness (Monaghan 1994). Aluminium, titanium and magnesium alloys are commonly used as the matrix phase. The most popular reinforcements are silicon carbide and alumina which are in the form of either particulate or fiber.

Particulate metal matrix composites are of particular interest in the industrial point of view since they exhibit higher ductility and lower anisotropy than fiber reinforced MMC’s (Monaghan 1994). While many engineering
Machinability studies using different cutting tools were carried on different metal composites. Bowdon (1993) investigated the machinability of Ti alloy in different composites with silicon carbide fibres. Conventional and unconventional methods were used to machine these composites and unconventional method was recommended for precise machining than conventional method. Machining test of A359/SiC in drilling and tapping was carried out by Lane (1993). The quality of the holes produced with PCD drills was observed to be sufficiently good and also it eliminated the reaming operations.

Burkes and Lesher (1993) further investigated the advanced tooling and technology for drilling metal matrix composites. The effect of new cutting tools and coatings on PCD tools were tested in machining Al metal matrix composites. Cutting tools for different metal matrix composites were selected by measuring the thermal environment in the tool work interface. Infra red thermograph method was used to evaluate the temperature distribution at the tool-work interface. Sullivan (1993) presented techniques for cutting, trimming and drilling of titanium matrix composite for structural applications. The feasibility of using water jet, EDM process to cut, drill and trim the titanium matrix was analyzed.
Hung et al (1997) studied the machining of Al-SiC composites in grinding operation. Grinding of Al-SiC composites with diamond, CBN and SiC wheels revealed that SiC particles are fractured along cleavage planes rather than being machined by grinding grains. Among the grinding wheels, diamond wheels are recommended for both rough and finish grinding of composites.

2.12 CONVENTIONAL MACHINING OF Al-SiC COMPOSITES

The Al-SiC MMC’s are made up of hard abrasive non-metallic SiC inclusions in a soft Al matrix. The machining of these materials presents a significant challenge, since the reinforcements are significantly harder than the commonly used conventional tools like H.S.S and carbide tools (Ramrattan, 1996). The hard abrasive reinforcement phase causes rapid tool wear during machining and consequently high machining costs. The machining of Al-SiC was carried out by many researchers in different machining processes using different cutting tools.

2.12.1 Turning

Looney et al (1992) performed a series of turning tests in which different tool materials were used to machine Al-SiC MMC. The carbide tools either plain or coated, sustained significant levels of tool wear after a very short period of machining. Similarly, other than diamond, different cutting tools were used to turn MMC’s. It was concluded that the best overall performance was achieved with cubic boron nitride cutting tools. In a similar comparison study carried out by Weinert and Berman (1993), it was observed that the lowest wear
rate was achieved with polycrystalline diamond (PCD) tools and chemical vapour deposited diamond inserts. Hung et al (1995) validated several tool wear models and stated that roughing with uncoated WC inserts and then finishing with PCD tools was the most economical way in machining SiC reinforced MMCs. Chambers and Stephen (1991) further demonstrated the advantage of using PCD inserts in the machining of MMC.

Experimental investigations involving measurement of chip curvature, chip thickness and cutting forces during orthogonal machining of these materials were carried out by Joshi et al (2000). It was found that at lower cutting speeds the shear angle for the unreinforced material appears to be less than that for the composite material, whereas the trend reverses at high cutting speeds. The machining studies revealed that increase in volume percentage of the SiC has not made any significant effect on the shear angle. It was also found that increase in volume percentage of SiC has not made any significant change in the cutting forces due to the low strain rate sensitivity of the material at elevated temperatures.

Gallab et al (1998) optimized the cutting condition for minimum tool wear on a PCD tool to effect a minimum tool change. The effect of various cutting parameters on the surface quality and the extent of the sub-surface damage due to machining with a PCD tool on the work piece were also investigated. It was found that the surface roughness improved with an increase in feed rate and cutting speed whereas it slightly decreased with an increase in the depth of cut. In contrary to the other literatures, they concluded that the machining of Al-SiC composites is most economical and safe at a speed of 900 m/min, with a depth of cut of 1.5 mm and feed rate as high as
0.45 mm/rev. The above cutting conditions are not practical in industrial usage point of view. Since the PCD tool is costly and relatively brittle and likely to form built up edge at lower cutting speeds, an alternate tool, which can work at the production level, is essential with less cost.

The relationship between cutting force and PCD cutting tool wear in machining silicon carbide reinforced aluminum was analyzed by Paulo Davim and Baptista (2000). The predominant wear in turning was observed on the flank face of the tool. The cutting force showed a slow progress at the initial stages of machining and then gradually increased with cutting time. The feed and depth of cut also proved to be more sensitive to the increase in flank wear. A correlation was established between the flank wear and the feed, depth of cut and cutting forces.

Weinert (1993) investigated the tool wear mechanism in machining metal matrix composites. The effect of grain size of the cutting tool materials (Cemented carbide, PCD) was analyzed in machining Al-SiC, Al-Al₂O₃ and Al B₄C composites. It was observed that from the topography of the flank wear of WC tools revealed that, there were grooves at the clearance face. These grooves are deep and mostly oriented parallel in cutting direction. With an increase in the grain size of the cutting tool, the quantity and depth of the grooves at the flank wear decreases. The grooves on the cutting tool occur due to mechanism of abrasion by micro cutting.

Davim (2000) performed turning tests to evaluate the wear resistance of PCD inserts in the machining of the continuously cast Al-(SiC)ₚ composites. The study showed that short chips are formed during machining and two body
and three body abrasion was the predominant wear mechanism. Chadwick et al (1990) conducted a number of cutting experiments in turning and recommended PCD as an effective tool in machining these materials. Smith and Cameroon May (1993) reviewed machining techniques for castable and preform infiltrated reinforced aluminum matrix composites. The effect of cutting speed on work piece was analyzed by varying the reinforcement. The results showed that the flank wear for taper tests were not reliable.

Review of literature indicates that only a few studies have investigated the problem in machining Al-SiC composites. Whilst previous investigations have confirmed that the superior performance of diamond inserts, more research is required about the possibility of using newly developed tools in turning which are cheaper as well as industrially practicable.

2.12.2 Milling

Few works have been carried out to machine metal matrix composites using milling process. Chandrasekaran et al (1997) investigated the influence of processing condition and reinforcements on the surface quality of finish machined aluminium alloy matrix composites. The MMC obtained through different manufacturing methods namely centrifugal casting, squeeze casting, powder processing and extrusion of ingot cast specimen were machined in milling and grinding operation with PCD and CBN tools. It was found that the influence of processing condition had a marginal effect on the surface quality in grinding. The volume content of SiC had a positive influence of the surface quality.
The quality of the $\text{Al}_2\text{O}_3$ MMC machined surfaces was better than the unreinforced alumina surfaces. Cronjager (1992) observed that the application of coolant or lubricant affected an increase in tool wear when the composites were machined with PCD tools and solid Carbide tools.

2.13 UNCONVENTIONAL MACHINING OF METAL MATRIX COMPOSITES

The search for new light weight materials with greater strength and toughness led to the development of a new generation of composite materials, although these create major challenges for machining. Having greater hardness and reinforcement strength, Composite materials are difficult to be machined by traditional techniques. Biing Hwa Yan et al (1993) Monaghan et al (1992) and Ramulu (2000) reported that the material removal mechanism in metal matrix often induces surface flaws and residual stresses. Therefore, there is a definite need to try unconventional methods of machining to machine these difficult to machine materials. The unconventional method should be selected in such a way that it has to enhance the machining performance of these materials. The enhancement of machining performance should lead to increased material removal rate, prolonged tool life and improved surface finish. Electric discharge machining and hot machining are the viable methods to meet these targets.

2.14 ELECTRIC DISCHARGE MACHINING (EDM)

Electrical discharge machining is an extremely prominent machining process among the newly developed nontraditional machining techniques. The
merits of the EDM technique become most apparent in machining metal matrix composites, which have the highest hardness in reinforcement.

Kremer et al (1989) defined EDM as a thermal process where material is removed by a succession of electrical discharges between electrode and a work piece plunged in a dielectric field.

EDM uses an electrode positioned at a fixed distance above the workpiece. The distance controls the energy at the cutting surface and is adjustable as a function of voltage across the gap. The electrode and workpiece are submerged in a dielectric fluid.

As the electrode is energised, ion columns are established between the electrode and the workpiece and controlled arcing occurs across the gap, resulting in localized heating. The cutting rate is proportional to the amount of energy, and the frequency controls the resulting surface finish. The thermal expansion of the locally heated area causes small molten particles to lift off the surface. Flushing of the dielectric in the cutting area results in the resolidification of these particles and washes them away from the surface of the workpiece. These particles are subsequently collected via local filtration equipment.

EDM method can make penetration of virtually any shape by utilizing electrodes fabricated in the desired hole. Since the electrode never contacts the workpiece, this process has extremely low reactive machining forces.

The performance of the process strongly depends on the discharge energy. Increasing the discharge energy leads to higher feed and speed and to
large craters on the work piece. The thermal way used with the process strongly acts on the metallurgical properties of the work piece, the high temperature being responsible for the structure transformation at the surface. According to Reda (1983) and Jilan et al (1984), the total affected zone in EDM surfaces shows three layers

- White layer, the solidification of which has been made very rapidly with an enrichment of carbon and full of micro cracks due to contraction and extension phenomenon during the brutal solidification of the metal.
- The tempered layer, where the metal has not been melted, but heated enough.
- The reheated layer which makes a transition between the tempered and the metal base.

The composition of the electrode, work material and the white layer determines the surface characteristics of the machined work piece. Many studies has been conducted to study the effect and methods to reduce the white layers. The literature review of these topics helps us to understand the mechanism of material removal in electric-discharge machining of Al-(SiC)_p composites.

2.15 RECENT ADVANCES IN EDM

Several researches have been conducted to study the effect of various parameters in EDM process. The dielectric plays an important role in EDM. Jeswani (1981) added graphite powder to the kerosene and their effect on the
material and electrode wear rate. Mohri et al (1999) analyzed the electrode wear process in EDM and observed that the growth of the black layer on the electrode was caused by the cracking of the carbon oil. The white layer formation on the EDM machined surface by die sinking machine was analyzed by Kruth et al (1995). The effect of work piece material, electrode material and the type of dielectric on white layer was studied.

The role of debris in the machining gap during electrical discharge machining was analyzed by Wirtsch et al (1990) and concluded that contamination of the dielectric severely affects the ignition.

In horizontal EDM (Kunieda et al, 1988) advantage was taken of the buoyancy of the bubbles for the smooth outflow of debris from the gap. A synchronous rotation of both the work piece and the electrode improves the stability of machining and accuracy of the machined component.

Bryun (1970) reported that alternating forced flushing with erosion periods resulted in a small improvement in the accuracy of production. As electrode is lifted off the spark during flushing, there was decrease in the average material removal rate. The self-flushing method (Masuzawa, 1983) entails use of special electrode movement in two axes for pumping action, which makes additional flushing redundant. MRR is augmented by this technique, but there is an increase in electrode wear at the edges and corners.

The effect of electrode vibration on flushing in the gap has been studied by researchers (Mitskevich, 1965) and (Abdul Kadir Erden, 1982). Ultrasonic vibration of the electrode (Kremer, 1989) is found to upgrade the process by accelerating the slurry circulation and creating pressure variation in the gap.
A magnetic field installed in the gap (De Bryun, 1978) is found to improve gap cleaning and thereby facilitates machining over a larger surface or to a greater depth without forced flushing. In planetary EDM (Snoeys, 1986) the flushing of the machine gap brought about by orbital motion of the electrode yields a better process response compared with that of conventional electrode.

2.16 EDM OF Al-SiC METAL MATRIX COMPOSITES

Muller and Monaghan (2000) and Hung et al (1994) investigated the effect of various EDM parameters in electric discharge machining of Al-SiC MMC. They found that Al-SiC MMC’s can be machined using EDM, despite the low electrical conductivity and the high thermal resistance of the SiC particles. The EDM process was however slow and the material removal rate was low. It was also found that the material removal rate increases with increasing discharge current and increased pulse duration upto an optimal value and thereafter decreases. It has also been shown that the material removal rate decreases with increased SiC ceramic contents.

Ramulu and Taya (1989) investigated the EDM machinability of SiCw/Al composites. It was recommended that the SiCw/Al composites can be easily machinable by EDM process and better surfaces can be obtained by controlling the cutting condition. EDM machining of SiCw/Al at high speed causes severe machining damage in the surface area.

The effects of various input parameters in EDM of LM 25 aluminum alloy was conducted by Karthikeyan et al (1999) and Arivazhagan et al
It was found that the MRR increases with an increase in the current and pulse duration but decreases with an increase in volume percentage of SiCp.

The machining characteristics of Al2O3 /6061 Al composites was investigated by Biing Hwa Yan et al (1999). The feasibility in using EDM techniques as a means of machining particulate MMC with different levels of silicon carbide content was carried out by Poon and Lee (1993). It was found that in EDM die sinking processes copper electrodes perform better than graphite in terms of tool wear and surface finish.

Most of the above techniques used intermittent lifting and lowering own of electrode for effective flushing of spark gap. Hence these techniques do not use the entire machining time. So there is a definite need to increase the machining efficiency in EDM process and alteration in the conventional process.

To overcome the above drawbacks, Philiph Koshy et al (1993) developed a rotating disk electrode. The electrode is rotated and sunk simultaneously to machine rectangular slot in a steel workpiece. The rotation of the electrode facilitates proper and adequate flushing of the gap which improves the material removal rate and the wear on the electrode is uniform.

Chow (1999) used a modified rotating disk electrode to microslot machine Ti-6Al-4V material. It was reported that rotating disk electrode has improved the debris removal and thereby the MRR. The finished parts exhibited less cracks and recast layer.
Being Haw Yan and Che Chung Wang (1998) studied the machining characteristic of Al–Al₂O₃ composites with a tube electrode. EDM drilling with a rotating solid electrode was confirmed to have a higher material removal rate and a lower surface roughness than that found in the use of a rotating solid electrode. Hence using a rotary electrode of solid or tubular type may improve the machinability of Al-SiC metal matrix composites.

2.17 WORKABILITY

The relative ease with which a metal can be shaped by deformation process such as forging, extrusion, rolling, pressing and drawing is generally referred to as workability (Dieter 1988). Generally workability depends on the state of stress, strain, strain rate and temperature in combination with metallurgical factors such as resistance of a metal to ductile fracture. The workability is classified as

(1) Intrinsic workability which depends on the previous history of the material, temperature, strain and strain rate of working.

(2) State of stress related workability depends on the die design and effects of friction and notches.

A proper combination of these two will result in a sound product with good mechanical properties. In case of materials with poor intrinsic workability, optimization of both intrinsic workability and state of stress workability are desirable. Generally, pure metals and single phase alloys exhibit the best workability expect when grain growth occurs at high temperatures.
Hence, the optimization of intrinsic workability requires a thorough understanding of the constitutive behavior of the material under processing conditions.

2.18 HOT WORKING

The strength of pure metals and alloys increases with increasing strain rate at a fixed temperature. The general kinetic equation for hot deformation (Jonas 1969).

\[ E = A \left( \text{Sinh} \ a \ \sigma \right)^n \exp \left( -\frac{Q}{RT} \right) \]  

(2.1)

Where A, a, n are temperature independent constants. The apparent activation energy (Q) for hot deformation is determined using the above equation and the value corresponds to the rate controlling the dynamic softening process.

2.19 MODELLING OF THE DEFORMATION

The optimization of hot workability requires an understanding of the constitutive behavior of the material under processing condition. Ashby (1982) and Raj (1981) developed maps which describe the deformation and fracture process that occur during processing. These maps help to understand the effects of strain, strain rate, temperature and microstructure on the flow behavior of metals during deformation processing.
2.19.1 Ashby Maps

In the Ashby maps, the normalized shear stress is plotted against homologous temperature. The maps are divided into regimes, within each of which a particular mechanism is dominant. The regime boundaries are the loci points at which two mechanisms contribute equally to the overall strain rate. The contours of strain rate are superimposed on the fields and they show the net strain rate that a given combination of stress and temperature will produce. Ashby and coworkers (1982) developed similar maps which give domain of various fracture processes.

2.19.2 Raj maps

Raj maps are developed considering the failure mechanism that can operative in a material over ranges of strain rate and temperature. These maps are useful for processing in the sense that they define the regions in which it is safe to process the work piece material and avoid defect nucleation.

Both Ashby and Raj maps are deterministic since they use shear strain rate equations which are valid for steady state. The equations depend on a number of basic atomic processes such as dislocation motion, diffusion, grain boundary, sliding, twinning and phase transformations. Both the maps are limited to simple systems and cannot be applied to complex commercial alloys since in these materials it is not always possible to identify the atomistic mechanisms unequivocally. As the maps are based on the atomistic theory, it is difficult to integrate them with continuum approaches. Also, process optimization is difficult to achieve ,using these atomistic approaches.
A continuum approach has been therefore developed by Prasad et al (1984) and revised by Gegel et al (1988) which is discussed briefly.

2.19.3 Dynamic material model

In this model, the work piece is considered to be a dissipater of power. The constitutive equation describes the manner in which the power is converted at any instant into two forms: thermal and micro structural, which are not recoverable by the system. The dissipated element can be considered to be non-linear, dynamic and irreversible. At any instant, the total power dissipated consists of two complementary parts: G content representing the temperature increase and J co content representing the dissipation occurring through micro structural processes. The power portioning between G and J is decided by the strain rate sensitivity (m) of flow stress (σ). At a given temperature and strain rate, J content is given by (Prasad et al 1984)

\[ J = \frac{m}{m+1} \sigma \dot{E} \]  

(2.2)

Where \( \dot{E} \) is the strain rate. The J co content of the work piece being non linear dissipater, is normalized (m=1) to obtain a dimensionless parameter

\[ \eta = \frac{J}{J_{\text{max}}} = \frac{2m}{m+1} \]  

(2.3)

The variation of \( \eta \) with temperature and strain rate constitutes a processing map. The various domains in the map may be correlated with specific micro structural processes and applied for micro structural control.
In hot deformation there are 'safe' and damage mechanism that occur in different strain rate temperature regimes. The safe mechanism involve dynamic recovery and dynamic recrystallisation, while the damage mechanisms are wedge cracking and void formation at hard particles. The damage processes are generally highly efficient in dissipating energy through production of new surfaces.

2.20 APPLICATION OF PROCESSING MAPS

The processing map is a more powerful tool for evaluating workability and controlling the microstructure during thermo-mechanical processing. The optimization of processing parameters may be done with the help of processing maps by identifying the peak in the efficiency of power dissipation in the safe regime of map. Radhakrisha Bhat et al (1995) developed processing maps for hot working of 6061 Al-10 Vol%. Al₂O₃ metal matrix composites. A domain of re-crystallization was identified using Dynamic Material Model for hot working of powder metallurgy 2124 Al-20 vol% SiCₚ metal matrix composites under hot working condition by Radhakrishna bhat et al (1992). Using processing maps the dynamic re-crystallization during hot deformation of aluminum was studied in detail by Ravichandran et al (1991). On the basis of flow stress data, the strain rate sensitivity (\(m\)) of the material was evaluated and used for establishing power dissipation maps following the dynamic material model. The effect of volume fraction of SiCₚ reinforcement on the processing map for 2124 Al matrix composites was analyzed using instability maps (Radha Krishna Bhat et al 2000). Venugopal et al (1993) developed processing maps for hot working of stainless steel type AISI 316. In the case of machining, a crack initiation in shearing helps to machine the
material easily. The domain other than the safe work region can be considered to be preferable for metal cutting in the machining point of view.

2.21 MECHANISM OF HOT DEFORMATION

The ductility which limits the deformation ratio usually depends on fracture nucleation and propagation mechanisms linked to the initial microstructure. These mechanisms are generally retarded by the restoration mechanisms (Mc queen 1975). At high temperatures grain boundary crack nucleation is diminished by accommodating grain deformation enhanced by dynamic recovery. In addition fissure growth is halted by migration of grain boundaries during dynamic re-crystallization. At high temperatures and low strain rates grain boundary sliding occurs which results in stress concentration at grain boundary triple junctions leading to wedge cracks. If the stress concentration is relieved by the diffusion flow of matter wedge cracking may be avoided, resulting in very high ductility which is referred to as super plasticity. The microstructure evolved from the micro mechanisms determines the product properties and hence its control is important in thermo mechanical processing. Since hot working is generally performed in several steps, the restoration processes, which are occurring during pause times at the working temperature, will also influence the final microstructure of the product.

The primary softening mechanism is dynamic recovery which counteracts the strain hardening due to dislocation interactions starting from the point of yielding up to a potential saturation regime in which annihilation and generation rates balance with each other. However, if the dislocation substructure continues to rise in density, it eventually creates nuclei and
provides driving force for dynamic re-crystallization. This mechanism increases the rate of softening by completely eliminating the substructure through grain boundary migration. The dynamic mechanisms are essentially similar to their counterparts which usually occur during annealing of cold worked metal. The difference is that the dynamic ones do not go to completion, i.e., removal of the deformation substructure does not occur completely since it is continuously being re-established by concurrent straining (Queen et al 1990).

2.22 INSTABILITY OF FLOW IN PROCESSING

During deformation processing of materials under certain combinations of temperature and strain rate, the materials exhibit poor workability due to various phenomenon such as dynamic strain ageing, formation of new phases (Ahlblom 1982), adiabatic shear deformation or regions of localized deformation (Timothy 1987), grain boundary and triple point cracks and hot shortness. The above phenomenon may also introduce inhomogeneous and produce components possessing microstructure such as shear band, strain marking (Padmavardhani et al 1991). Inhomogeneous deformation is generally associated with fluctuations (Rauch 1985) in force / time or force/travel characteristics of the deformation process. The phenomena which cause inhomogeneous deformation during hot working are known as flow instabilities. The regime of temperature and strain rate where deformation is not homogenous is termed as instability regions. These instability regimes are avoided during the deformation of metals.
2.23 CONTINUM CRITERIA

These criteria are based on the extreme principles in the irreversible thermodynamics of large plastic flow proposed by Zigler (1983). According to the principle of maximum rate of entropy production, a system undergoing large plastic deformation will be unstable if,

\[
\frac{dD}{d\dot{\varepsilon}} < \frac{D(\dot{\varepsilon})}{\dot{\varepsilon}}
\]  \hspace{1cm} (2.4)

Where \( D(\dot{\varepsilon}) \) is the dissipation function characteristics of the constitutive behavior of the work piece. On the basis of equation, Gegel and co-workers (1988) have derived an instability criterion given by:

\[
\frac{\delta s}{\delta \ln(\dot{\varepsilon})} > 0 \text{ and } \frac{\delta \eta}{\delta \ln(\dot{\varepsilon})} > 0
\]  \hspace{1cm} (2.5)

where \( s = \frac{1}{T} \left( \frac{\delta \ln \sigma}{\delta (1/T)} \right) \) and \( \eta = \frac{2m}{(m+1)} \) defined as an efficiency of power dissipation through micro structural changes, \( \sigma \) is the effective flow stress and \( T \) is the temperature of deformation. In physical terms, flow instabilities will occur when the applied rate of entropy input is higher than the rate of entropy generation by the work piece. The parameters \( \eta \) and \( s \) are determined as functions of temperature and the effective strain rate and the inequalities in Equation 2.5 are calculated to determine the instability regimes.

In driving Equation 2.5, Gegel et al (1988) have not separated the power dissipation function into those representing heat generation (G-Content) and micro structural dissipation function (J-Co-Content). Prasad (1990) applied the principle of separability of the rate of entropy production into the conduction entropy (heat generation) and internal entropy (micro structural changes) and
considered the dissipation function corresponding to the micro structural changes (J-Co-Content) for deriving a criterion for instability as:

$$\zeta(\dot{\varepsilon}) = (\delta \ln (m/(m+1))/\delta \ln \dot{\varepsilon}) + m < 0 \quad (2.6)$$

The variation of $\zeta(\dot{\varepsilon})$ with temperature and strain rate constitutes an instability map. The instability map delineates instability regions where $\zeta(\dot{\varepsilon})$ is negative and these could be avoided in processing. This instability criterion has been micro structurally validated in $\alpha$–Zr (Charavarthy et al 1991), Zircalloy and Cu-Zn alloys (Padmavardhani et al 1991). The advantages of the continuum criteria are that the approach is fundamental and instability maps may be directly superimposed on the processing maps for the purpose of optimization of workability (Gegel et al 1988 and Charavarthy et al 1991).

### 2.24 HOT MACHINING

Metal Matrix Composites are popularly used in the aerospace industry for their superior mechanical and thermal properties. However these materials are also known as difficult to machine materials, due to the accompanying high wear rate when conventional machining is used. Low cutting speed and as well as usage of costlier tools like PCD result in a high machining cost. Therefore there is a definite need to enhance the machining performance for these materials.

The enhancement of machining performance should lead to increased material removal rate, prolonged tool life, or improved surface finish. Hot machining has been conceived as a viable approach to achieve these goals. The
very concept of hot machining runs contrary to established metalworking practice. In the machining of ordinary metals, every effort is made to keep temperatures at the tool-work interface as low as possible to prevent tool damage. Since the poor machinability stems from the materials propensity to high strain hardening during machining, localized heating, thereby softening the materials can reduce the shear strength and strain hardening associated with chip formation.

Vedani and Gariboldi (2001) investigated the hot deformation behaviour of the different metal matrix composites over a range of temperatures and strain rates. At temperature over 573 K (300°C), Al/ SiC composites exhibits significantly reduced yield stress and tensile strength. Hot machining, on the other hand is an attempt to soften the work by heating it, thus making it easier to cut, and consequently lengthen the life of the tool.

To substantiate the above points a few works have been carried out. Hot machining provides a promising line of approach for the machining of high strength resistant alloys. Borrow (1966) reported for maximum tool life improvement in hot machining an optimum value of heating current has to be selected. A 200% improvement tool life was observed while hot machining En-23 steel at a speed at a 350 m/s with electric heating using current between 75 and 175A. Merchant and Krabacher (1951) have found that the maximum improvement in tool life is associated with an optimum temperature and machining speed. The tool life in hot machining was further improved by superimposing a steady magnetic field during hot machining (Raghuram and Muja, 1979). A low magnitude magnetic field was applied on a carbide tool
while machining on steel work piece. The range of speeds and heating current for the maximum tool life were estimated.

William Pentland et al (1960) has done a preliminary study on hot machining in which it was shown that machining at elevated temperatures improves the machining characteristics of impossible to machine metals. Simultaneously Schmidt and Roustik (1949) indicated that at elevated temperatures high strength die blocks could be machined at higher cutting speeds and feed rates with equivalent tool life. North American Aeronautics Company in 1958 showed that in hot drilling Inconel metal, there was 85% decrease in tool forces and upto 10 times increase in tool life.

In 1960 Spring Garden Institute machined excess weld material from railroad rails while they were still hot from welding. It was observed that there was three fold increase in tool life. Ellis and Barrow (1971) made some observations on the contact resistance hot machining process of steel using the carbide tool tip. The effects of hot machining on surface features and geometrical, metallurgical features of workpiece and chips were discussed. The results suggested that in hot machining the built up edge (BUE) would disappear at a lower value of heating current and at higher cutting speed. The effect of cutting speed on average chip thickness at different temperatures was observed. They attributed the variation in chip thickness to the elimination of B.U.E. formation.

Cutting ceramics with a technique of hot machining was done by Uehara and Takeshita (1986). To examine the possibility of hot machining of the ceramics, a mullite ceramic was heated by oxy acetylene flame and drilled
with tungsten carbide drills. The powdery chips in the normal machining have changed to flow type in the hot machining. With the promising result, five other ceramics were hot machined in turning with Oxy-acetylene flame as the heating means. The tool wear on the different cutting tools was getting reduced as the temperature is increased. It was concluded that the hot machining of the ceramics is a powerful means with high removal rate and good surface integrity.

Leshock et al (2000) presented a numerical and experimental analysis of plasma enhanced machining of Inconel 718. A three-dimensional finite difference model was established to determine the temperature distribution in a cylindrical workpiece subjected to intense local heating. Benefits of plasma enhanced machining are also demonstrated through the reduction of cutting forces and improved surface roughness with a wide range of cutting condition.

Hence to overcome the problems in the conventional machining, the above literature illustrates that hot machining is another viable method to machine difficult to machine materials such as Al-(SiC)\textsubscript{p} composites.