

A SURVEY ON END MILLING OF AL2024-SICP METAL MATRIX COMPOSITE

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Abstract - The advancement in automation and accuracy of machine tool has made it possible to produce high quality industrial products. One of the main perceptions of quality in mechanical products is its physical appearance. One of the most important factors in physical appearance is the surface roughness. A number of research publications addressed this issue of surface roughness measurement and analyses. This paper surveys the studies and analyses of surface quality improvement in end milling operation of Al/SiCp metal matrix composite. These materials are selected as they are most widely used in automobile and aerospace industry. The effect of spindle speed, feed rate, depth of cut and various percentage weight of silicon carbide are studied on surface roughness.

Keywords - Surface roughness (Ra), Taguchi optimization methodology, End milling, Aluminum Metal matrix composites.

INTRODUCTION

Milling is a process of producing flat and complex shapes with the use of multi-tooth cutting tool, which is called a milling cutter and the cutting edges are called teeth. The axis of rotation of the cutting tool is perpendicular to the direction of feed, either parallel or perpendicular to the machined surface. The machine tool that traditionally performs this operation is a milling machine. The most common cutting tool used with a vertical milling is an end-mill, which looks like a stubby twist drill with a flattened end instead of a point. An end mill can cut into a work piece either vertically, like a drill, or horizontally using the side of the end mill to do the cutting.

This horizontal cutting operation imposes heavy lateral forces on the tool and the mill, so both must be rigidly constructed. By making a series of horizontal cuts across the surface of a work piece, the end mill removes layers of metal at a depth that can be accurately controlled to about one one-thousandth of an inch (.001").

There are several different types of end mills that you can purchase, including diamond coated end mills, carbide end mills, tapered end mills, engraving end mills, in addition to those that are available in metric and non-metric measurements. End mills can cut a variety of metals, fabric, concrete, plastics, and textiles. However, despite of their durable construction, over time end mills must be sharpened to safeguard the edge and maintain greater cutting ability. End mills are used in the industrial milling processes.

Machinists are skilled individual who are specially trained in the operation of machine tools and who are in charge of stage machinery. They use end mills in their daily operations in the same manner as you might a drill bit. Each end mill has different fittings depending on the job it has to accomplish. Today, tungsten carbide end mills are selected tool used in the milling industries because of its durability and resistance to wear and tear.

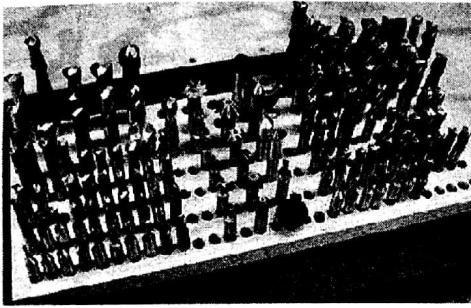


Figure 1. Milling Cutter

Milling cutters are used on the milling machine to remove material from the work piece. Typically the milling cutter is revolving at a calculated speed (RPM) and work is fed to the revolving cutter at a calculated feed rate. Milling cutters exist in a variety of shapes to match the particular requirement of the job. There are few basic types of materials used to make mill cutters.

High Speed Steel cutting tool, also called HSS, is a typical material for an end mill. It is inexpensive and exists in many sizes but has a limited cutting capacity. It will not cut very hard steels because, relatively speaking, it is too soft but is excellent for aluminum, mild steel, and other soft metals.

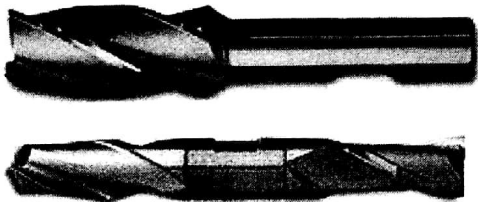


Figure 2. High Speed Steel Cutting Tool

Coated cutters have a solid carbide or HSS body with a coated cutting edge. The purpose of the coating is to make the cutting tool last longer or to be allowed to run the machine at a greater cutting speed. Titanium Nitride coating is one of the most popular coatings. End mills are also commonly produced with double ends. Although double-end end mills are limited in size (rarely exceeding 1" in diameter), they cost less to purchase as compared to two single-end end mills. Most end mills have spiral flutes with an angle of 30 degrees. Straight flutes (rendition below) are used rarely

because they are less efficient. *Increasing the number of flutes from 2 to 3 or more improves your surface finish at equivalent feed and speed.* End mills are cutters that have an end-cutting capability. They machine on the end as well as the sides. The multi-flute end mill will produce a better finish than the two flute end mill at the same RPM and feed but it will have less chip clearance space and therefore will be less convenient in a heavy cut of soft material. Multi-flute end mills are typically more expensive.

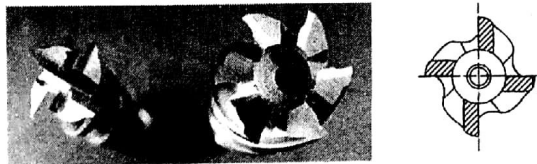


Figure 3. Centre & Non Centre cutting type End Mills

There are end mills that are center cutting and end mills that are not center cutting. In the case of the non-center cutting end mill, you cannot plunge into the material and will have to start your cut on the outside of the part. Non-center cutting end mills are more difficult to fabricate and are therefore more expensive, however they do lend themselves to hollow centers that can distribute coolant.

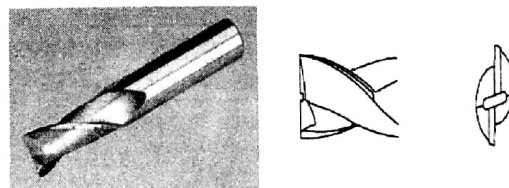


Figure 4. Two flute End Mill

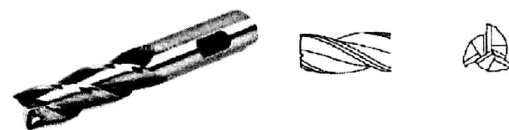


Figure 5. Three flute End Mill



Figure 6. Multi flute End Mill

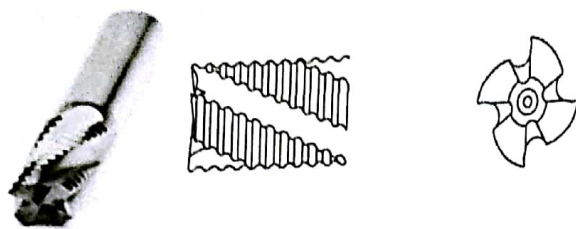


Figure 7. Roughing End Mill

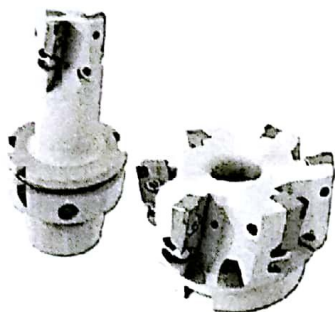


Figure 8. End mills with carbide & PCD inserts

END MILL CUTTER GEOMETRY AND NOMENCLATURE

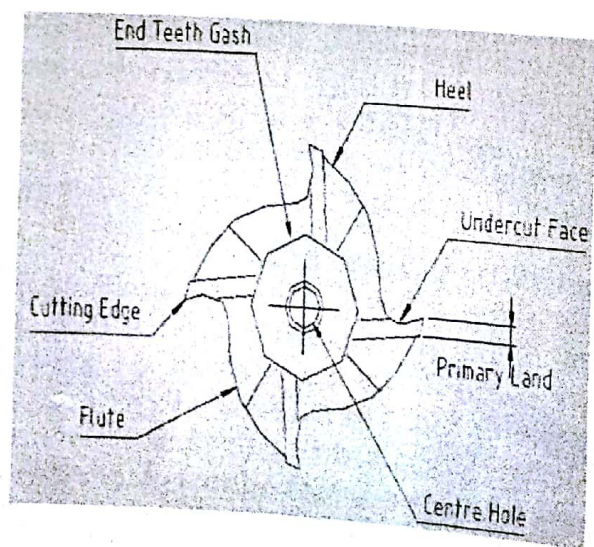
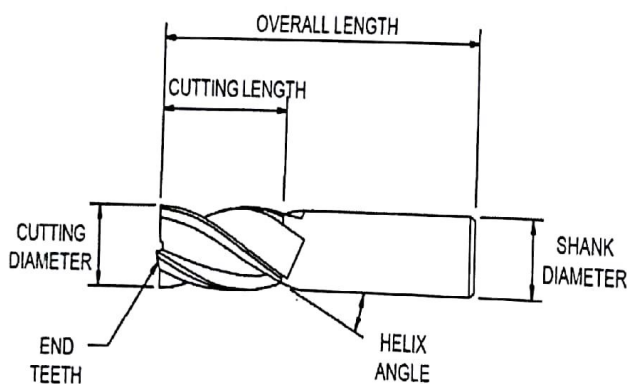


Figure 9. (b) End Mill Tool Geometry

END MILLING

There are mainly three types of end mill according to their shape these are:

- Flat end mill
- Ball nose end mill
- Bull nose end mill

The flat end mill having flat bottom end, these tools are used most common in the work shop. An end mill with full radius bottom called a spherical or a ball nose end mill and an end mill with a corner radius called bull nose end mill. Each type of end mill is used for specific type of machining. Standard flat end mill is used for all operation that required a flat bottom and sharp corner between the part wall and the bottom.

A ball nose end mill is used for simultaneous three dimensional (3D) machining on various surfaces. And bull nose type end mill is used either for 3D machining, or for a flat surface that required a corner radius between part wall and the bottom. Other shapes are also required for some special machining, for example a centre cutting end mill, a taper ball nose end mill. Machining operation performed by end mill

Figure9.(a)End Mill Cutter Geometry and Nomenclature

- Peripheral end milling and cantering
- Milling of slots and keyways
- Channel grooves, face grooves and recesses
- Facing operation of small areas, Facing operation for thin walls
- Counter boring
- Spot facing
- Deburring
- Chamfering

EXPERIMENTAL PROCEDURE

Vertical Machining Centre: The slot milling tests will be carried out on a CNC vertical machining center (VMC 850). The machining tests will be conducted under the specified conditions. The work piece material selected is Al2024-SiCp. The results demonstrate that one has to reevaluate the machine processes in the context of the capabilities of PCBN tools. The use of PCBN tools in milling can be an effective method of increasing material removal rates and productivity while reducing overall machining cost.

The vertical machining center is able to fabricate various engineering components with consistent accuracy and quality. These can turn out different sizes, dimensions, tolerances, designs and other technical specifications. Featured with long working life, the machine fundamentally consists of Spindle axis close to Z-axis guide ways that provides maximum cutting stability and minimum thermal distortions.

Machine used in this project for experiments is highly precise Hass's Vertical Machining Center VMC-850 with Maho controller. The VMC-850 is a three axis machine and capable to control all three axes simultaneously. The machine can perform multiplicity of operations in one setup. It

can perform face milling, profile mill contours, drill bore, counter bore, etc.

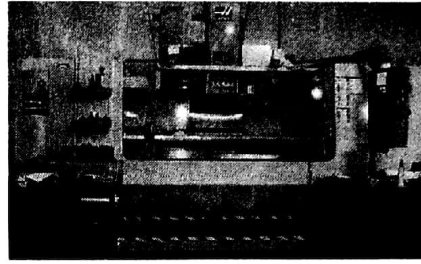


Figure 10. Vertical Machining Centre

All axis movements are controlled by high precision preloaded ball screws and are supported on heavy duty LM guide way. Hydraulic Counter Balance for Z-axis is provides better stability during high speed contouring as well as arrests head drop during power failures. Belt driven, highly rigid spindle is supported on high precision.

Machining Parameters: Feed per minute is used to adjust the feed change gears. Feed rate is dependent on the:

- Surface finish desired.
- Power available at the spindle (to prevent stalling of the cutter or work piece).
- Rigidity of the machine and tooling setup (ability to withstand vibration or chatter).
- Strength of the work piece (high feed rates will collapse thin wall tubing).
- Characteristics of the material being cut, chip flow depends on material type and feed rate. The ideal chip shape is small and breaks free early, carrying heat away from the tool and work.

Depth of cut: Depth of cut refers to the amount of material being taken per pass. This is how deep the tool is under the surface of the material being cut. This will be the height of the chip produced. Typically, the depth of cut will be less than or equal to the diameter of the cutting tool.

Feed rate: Feed rate is the velocity at which the cutter is fed, that is, advanced against

the work piece. It is expressed in units of distance per time for milling (typically inches per minute [ipm] or millimeters per minute); with considerations of how many teeth (or flutes) the cutter has then determining what that means for each tooth. Three types of feed in milling can be identified:

1. Feed per tooth f_z : the basic parameter in milling equivalent to the feed in turning. Feed per tooth is selected with regard to the surface finish and dimensional accuracy required. Feeds per tooth are in the range of 0.05~0.5 mm/tooth, lower feeds are for finishing cuts.
2. Feed per revolution f_r : it determines the amount of material cut per one full revolution of the milling cutter. Feed per revolution is calculated as:
$$f_r = f_z \cdot Z, z \text{ being the number of the cutter's teeth;}$$
3. Feed per minute f_m : Feed per minute is calculated taking into account the rotational speed N and number of the cutter's teeth z , $f_m = f_z \cdot z \cdot N = f_r \cdot N$

Work piece properties: Work piece properties affect the output properties like surface finish, material removal rate, power consumption etc. Work piece properties basically consider work piece shape, its material and hardness of the work piece. The knowledge of Work piece material and hardness is necessary for the selection of tool, machine parameters during machining.

The surface finish and material removal rate of soft material is high than that of hard material for e.g. the surface finish and material removal rate of machined aluminum is high as compare to the steel.

Generally work piece properties are not count in parameter optimization because the experiments performed on the specified material work piece thus hardness and material properties assume to be constant during experiment. These are used only for tool selection.

Cutting phenomena: Cutting phenomena basically counts the vibration during process, chip formation and friction in cutting zone. The effect of vibration is easily seen on the machined surface as irregularities on the machined surface. These irregularities decrease the surface finish. In conventional machines the probability of chatter is high but in the CNC machine the vibration is limited. Friction in cutting zone affects the surface finish, power consumption and the force on the tool.

Friction is due to the behaviour of work piece and the tool material. Chip formation in any machining operation affect the output, sometimes due to high temperature on the cutting surface, tool is temporary weld with work piece or the chip make the built up edges with machined surface which affect the surface finish.

Output characteristics: There are many output characteristics but surface finish and material removal rate are most important in production and quality.

Surface Finish: The term surface finish is well known but the concept is understood more in qualitative terms than in quantitative terms. This is evident from the fact that many industries continue to specify finish as rough, good, smooth, glossy, mirror etc. None of these terms are sufficiently accurate and besides, they tend to convey different meanings to different people. It is in the common interest to adopt a quantitative method of evaluation with appropriate inspection techniques which will eliminate the variable subjective factor.

When different surfaces are compared, it is possible to distinguish them in terms of reflectivity (dull or shiny appearances), smoothness, the presence of chatter marks, or the visual scratch pattern. However, analysis shows that conclusions drawn from such observations are often incorrect. A typical example is the widespread belief that highly reflective surfaces have a better surface finish than those which are dull in

appearance. As a matter of fact, precision lapped surfaces usually have a dull appearance even though they may have the best possible surface finish.

Surface Texture: The terms surface finish and surface roughness are used very widely in industry and are generally used to quantify the smoothness of a surface finish. In 1947, the American Standard B46.1-1947, "Surface Texture", defined many of the concepts of surface metrology and terminology which overshadowed previous standards.

A few concepts are discussed and shown as follows [Brosheer, 1948; Hommel, 1988; Olivo, 1987; ASME, 1988]:

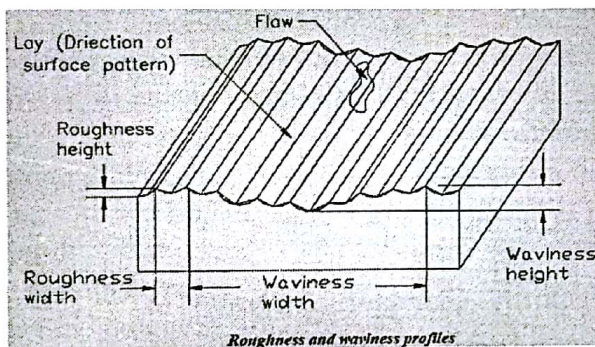


Figure 11. Roughness and wave profiles

Surface Finish Parameters: Surface finish could be specified in many different parameters. Due to the need for different parameters in a wide variety of machining operations, a large number of newly developed surface roughness parameters were developed. Some of the popular parameters of surface finish specification are described as follows:

Roughness average (Ra): This parameter is also known as the arithmetic mean roughness value, AA (arithmetic average) or CLA (center line average). Ra is universally recognized and the most used international parameter of roughness. Therefore, Where Ra = the arithmetic average deviation from the mean line, L = the sampling length, y = the ordinate of the profile curve. It is the arithmetic mean of the departure of the roughness profile from the mean line.

Root-mean-square (rms) roughness (Rq): This is the root-mean-square parameter corresponding to Ra:

$$R_q = \sqrt{\left[\frac{1}{L} \int_0^L (Y(x))^2 dx \right]} \quad (2)$$

$$R_a = \frac{1}{L} \int_0^L |Y(x)| dx \quad (1)$$

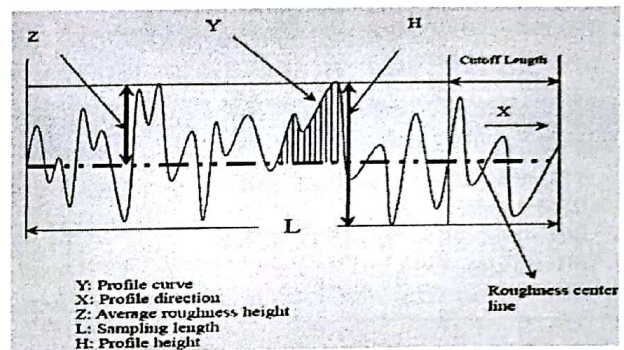


Figure 12. Roughness parameters

Instruments used with operation and objective of measurements: One of the measurable output characteristics is surface Roughness. Instrument used in this project for measurement of surface Roughness is Mitutoyo SurfTest SJ-201P. The SurfTest SJ-201P (Mitutoyo) is a shop-floor type surface-roughness measuring instrument, which traces the surface of various machined parts and calculates the surface roughness based on roughness standards, and displays the results. The workpiece is attached to the detector unit of the SJ-201P will trace the minute irregularities of the workpiece surface. The vertical stylus displacement during the tracing is processed and value is digitally displayed on the liquid crystal display of the SJ-201P. Another quality characteristic is MRR and it is calculated by the formula volume/time.

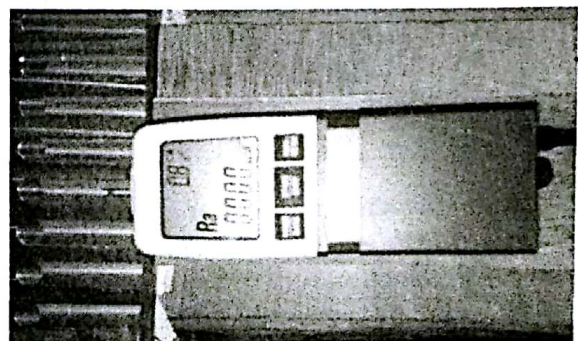


Figure 13. Mitutoyo Surface Roughness Tester

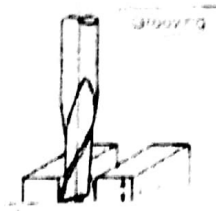
Requirements for Efficient Machining of Aluminum:

Calculation of Cutting Speed

$$V = \frac{\pi \times D \times N}{1000} \quad N = \frac{1000 \times V}{\pi \times D}$$

Feed Calculation

$$F = N \times f_r \quad f_r = \frac{F}{N \times Z}$$



- V: Cutting speed
- π : 3.14
- D: End mill diameter (mm)
- N: Spindle speed (rpm)
- F: Feedrate (mm/min)
- f_r : Feed per revolution (mm/rev)
- f_t : Feed per tooth (mm/tooth)
- Z: Number of teeth

MACHINING FORMULAS

SFM = 0.262 x D x RPM
 RPM = (3.82 x SFM) / D
 IPR = IPM / RPM or CHIP LOAD x F
 IPM = RPM x IPR
 CHIP LOAD = IPM / (RPM x F) or IPR / F

Figure 14. Milling Formulae

Material removal rate basically depend upon the feed rate, spindle speed, tool diameter and depth of cut. It is important output characteristic in milling or every machining process because MRR has direct relation with the production. And quick and high production is the need of modern production system. Thus every company focuses on the optimization of the technical parameters for high material removal rate. In end milling, the cutter generally rotates on an axis vertical to the work piece.

It can be tilted to machine tapered surfaces. Cutting teeth are located on both the end face of the cutter and the periphery of the cutter body. In the end milling we use the multipoint cutting tool and the MRR is high comparatively than single point cutting tool use in turning. But milling is use in high speed machining in the modern industry and for higher production there is the necessity of high MRR.

For each different application we have a different MRR that increases with the engagement section of the cutter on the work piece. The recent Dormer Catalogue was produced with simple icons that show the different applications.

Input Parameters & output characteristics of End Milling:

a) Input parameters: In the end milling process there are mainly four input parameters which responsible for output like surface finis and material removal rate they are:

- Machine parameter
- Work piece
- Cutting phenomena
- Cutting tool properties

b) Output characteristics are

- Surface finish and
- Material removal rate

LITERATURE REVIEW

P. S. Sivasakthivel et al(2010) [49] conducted experiments on aluminum Al 6063 by high speed steel end mill cutter and tool wear was measured using tool maker's microscope. The helix angle is the most significant parameter which reduces tool wear. The tool wear is minimal in between 400 - 450 helix angles. The increase in spindle speed and axial depth of cut reduces the tool wear. The decrease in radial depth of cut reduces tool wear.

Chin-Chun Chang et al (2010) [9] investigated the heat treatment process using dual aging for the 7050 Aluminum alloy with the Taguchi method to optimize process parameters. Pre-aging temperature, pre-aging time, re-aging temperature, and re-aging time are important factors

influencing these optimization criteria & influence factors for micro hardness performance.

Sundara Murthy et al (2010) [57] studied provides the optimum cutting conditions for end milling of Aluminum 6063 under minimum quantity lubrication machining. The highest cutting speed, medium feed rate and medium depth of cut produces lowest surface roughness.

Sivarao et al (2010) [55] observed that high speed machining (Al 6061) has emerged to become one of the most versatile material removal processes in industries. In gaining optimum cutting conditions, the investigation of the relationship between cutting conditions and technical performance factors such as tangential forces generated during machining is of great importance. MRR, horsepower and tangential forces were all found to be increased with the amplification of cutting depth. Cutting forces in the form of tangential forces increases when depth of cut is increased. An increase in tangential forces induces a detrimental effect on the surface finish. Surface roughness increases with increasing tangential force.

Kromanis et al (2008) [36], developed a technique to predict a surface roughness of part to be machined according to technological parameters & find relationships between surface roughness (Average absolute deviation of the surface) of machined workpiece and used technological parameters (cutting speed; feed ; cutting depth). They concluded that technological parameter range also plays a very important role on surface roughness. Study results can be used by technologists and other manufacturing specialists to set up cutting parameter in end-milling.

Jaharah A. G et al(2008) [34] found that new challenge in machining (High speed milling of Ti-6Al-4V using coated carbide tools) is to use high cutting speed in order to increase

the productivity. Effect of feed rate on surface roughness is more significant compared to other cutting parameters. The top layer of the machined surface experiences work hardening process, which is higher than the average hardness of the workpiece material.

H.S. Lu et al(2008) [25], investigated the effect of optimal cutting parameters design of cutting processes in side milling for SKD61 tool steels and founded that the improvement of tool life and metal removal rate from the initial cutting parameters to the optimal cutting parameters are 54% and 97%.The proposed approach can effectively improve the cutting performance.

Robert B. Mason et al (2007) [53] studied the corrosion and degradation aspect of composite structures is more complex than monolithic counterparts. MMCs have greater tendency to corrode. One reason for this tendency is the establishment of galvanic cells linking two constituent phases where the reinforcement is electrically conductive. This is the case with aluminum reinforced with graphite. But galvanic corrosion also occurs with semiconductor reinforcements such as SiC in aluminum. The problem becomes more severe when SCC comes into play .Also pitting corrosion is detrimental where application of high cycle stresses is there.

Hudayim Basak et al (2008) [21], investigated different burnishing parameters (number of revolution, feed, number of passes, and pressure force) of aluminum with burnishing apparatus. Surface roughness is affected negatively if the applied force is increased. The best surface roughness has been Obtained with 200 N force and 0.3 feed. The conclusion was fuzzy logic is a suitable technique that may be efficiently used to optimize the burnishing process.

J. Wang, Q. Zhang et al (2007) [33], plane rake faced drill point design has been

presented for drilling high-tensile steels with surface coated drills. Experiment to cut an ASSAB 4340 high-tensile steel with 7-13mm Tin coated HSS drills has been showed that the modified drills can reduce the thrust force by as much as 46.9% with an average of 23.8%, as compared to the conventional drills under the corresponding cutting conditions. Similarly, the reduction of torque is 13.2% on average with the maximum of 24.9%.

Chang Ching-Kao & H. S. Lu et al (2006) [25] Investigated the optimal cutting parameter selection of heavy cutting process in side milling for SUS304 Stainless steel using the grey-fuzzy logics analysis method. Side mill utilizes the peripheral cutting edge of an end mill to perform broad surface machining on a vertical wall of a work piece. The study revealed that there are generally two important indexes to evaluate the performance of heavy cutting process are tool life and metal removal rate.

Wassanai Wattanuchariya et al (2006) [64] studied the three materials: aluminum, brass and cast iron were tested. The CNC machining center was used throughout the process. The results show that the surface roughness of the metallic parts is significantly related to spindle speed and feed rate. As the feed rate increases, the roughness is generally increased. Among three materials, aluminum yields better surface finish with Ra about 0.25 μm , where brass is approximately 1.31 μm , follow by cast iron with 2.57 μm . The optimal machining conditions occur at the speed of 1400, 1000, and 800 RPM for aluminum, brass, and cast iron; with the feed rate of 50, 100, and 20 mm/sec, respectively. Therefore, it is possible to select appropriate machining conditions in finishing steps of metallic part production in order to yield better surface finish and save time and cost during machining step.

Metin Kok et al(2006) [38] studied the machinability of 2024Al/Al₂O₃ particle

composite was investigated in terms of tool wear, tool life and surface roughness by turning specimens with TiN (K10) coated and HX uncoated carbide tools in different cutting conditions. . The surface roughness of the workpiece was mostly affected by cutting speed. The optimum surface roughness in the machining of MMCs was obtained at a cutting speed of 160 m min⁻¹ for K10 tool while the maximum surface roughness values appeared in the machining of the aluminum matrix alloy at the cutting speed of 100 m min⁻¹ for HX tool.

Paul Prevey et al (2009) [48] showed that the corrosion fatigue performance was greatly improved by the Low Plasticity Burnishing (LPB) process. Whether used as a repair process or as an initial condition, LPB increased the fatigue life of the specimens by up to an order of magnitude compared to the traditionally used shot peening (SP) process. The depth of pitting correlates directly with the depth of the compressive residual stress field in terms of extending fatigue life. Once a pit becomes deep enough to penetrate the compressive stress layer, nucleation of cracking begins and fatigue failure is imminent. By inducing a deep enough compressive stress field, cracking from pitting is mitigated. X-ray diffraction showed that the LPB process induced a greater depth and magnitude of residual compression than the traditional SP process. This difference in depth of compression was reflected in the improved corrosion fatigue performance of the LPB processed specimens.

D. Lu et al [16] investigated that the temperature was an important factor in micro cutting due to its influence on the flow stress in the micro machining of aluminium 7050.

U. Zuperl et al (1995) [60], investigate the characteristics parameters in milling by using PSO evaluation technique. The integrated system of neural network and

swarm intelligence is an effective method for solving multi-objective optimization problems & conclude the MRR is improved by 28%, machining time reduction of up to 20% is observed.

CONCLUSION

Due to the soft and "sticky" nature of aluminum, specific geometries and characteristics of a carbide end mill are required for efficient machining. Many cutting tool manufacturers offer end mills specifically designed for aluminum for this reason. A sharp edge and high rake angles are needed to separate a chip from the parent material. Positive rake angles up to 25 degrees radial and 20 degrees axial are common. A high helix angle, generally around 45 degrees is also desirable. The helix helps move chips up and out of the cutting zone and also generates an excellent surface finish. The angle also helps soften the impact at entrance of cut, resulting in a smoother, quieter cut.

For aluminum milling a two- or three-flute end mill works best because this allows for larger flute areas. A core diameter of slightly less than 50 percent of cutter diameter is optimum for the same reason. An open flute design is essential for easy chip movement away from the cutting zone. Surface finish on the flute is also critical. Long-chipping, low silicon aluminum alloys have a tendency to stick to cutting tools. As a heated chip flows over the flute it will try to adhere to the tool surface. The flute surface must be very smooth to counteract this tendency. Climb milling gives definite advantages and shows significant benefits where a good quality surface finish is needed.

Extremely slick commercial tool coatings are also available that reduce the friction coefficient on the flute surface. A good example is one that has a friction coefficient of 0.1, less than half that of TiCN. Coolant is important for chip evacuation and keeping

the tool cool. Common choices include using an air gun with mist coolant, or flood coolant. Flood coolant with high enough pressure to move chips out of the way is preferable especially if using an uncoated tool. When using a coated tool the air gun with mist coolant is often all that is needed.

When chip management becomes a problem consider using a coolant-through end mill. Coolant ducts exit in the flute area and help move chips out of the cutting zone. Roughing tooth profiles are also helpful in reducing the size of the chip, making it easier to manage and blow out of the way. All of these elements help reduce the probability of built up edge (BUE), a common failure mode when a general-purpose end mill is used in aluminum machining. BUE is the accumulation of work piece material on the cutting edge. Once this occurs the cutting action becomes a tearing action. Surface finish drops immediately and spindle load will increase dramatically. If you are cutting a full width slot, tool breakage is most likely to happen before you can get to the feed hold control.

Whenever possible try to avoid using a dead sharp corner. Sharp corners tend to break down quickly. Using a corner radius or chamfer type end mill will increase tool life. For full width slotting a two-flute end mill is recommended. You can plunge in Z up to 1 x diameter before moving in X-Y or better yet try ramping into the desired depth. Run at sfm 1,000, rpm 7,640, ipt .003, ipm 46. The metal removal rate will be 11.5 cubic inches/minute, half of the peripheral milling example above. However, once the slot is in be sure to program feeds and speeds for peripheral milling again to open up the cavity.

PCD Tools

In many instances, when carbide is used in milling operations, high rake angles (>20°) and high clearance angles (>25°) are required. These geometries are no longer

necessary when using PCD. In fact, in many cases, the reduced rake angle of 5° and clearance angles of 10° have provided a more rigid setup allowing for successful applications in milling of tough material with severe interrupted cuts. All in all, PCD Milling inserts offer excellent economy through an increase in tool life and by making it possible to achieve high quality at high speeds. Cutting speeds as high as 3000 mts/min, with feed of 2500 mm and depth of cut per pass -2.5 mm are possible.

Dry running can easily be applied and the results are excellent with surface finish of 0.8 to 0.4 in Ra and flatness within 30 microns. The economic benefits of using PCD are further contributed to when considering the time saved by eliminating frequent machine-downtime processes such as tool changing and indexing. The edge preparation of the cutting tools is also important. An edge chamfer of 15° - 20° for widths of 0.20-0.25 mm along with edge honing of the radius is a must, depending on the application and job materials. The combination of negative cutter geometry and chamfer will produce higher cutting forces and require more horsepower, generating very high temperatures.

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