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Experimental Investigation of CNC Milling Machining Parameters for Aluminum Alloys

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Abstract

The objective of this research is to utilize Taguchi methods to optimize the material removal rate for machining operation and the effects of CNC machining processes on aluminum samples. There are three important cutting parameters namely, cutting speed, feed rates and depth of cut, which has been considered during the machining of Aluminum alloy. This research examines the effects of process parameters on Material Removal Rate (MRR) during machining on CNC. An Orthogonal array has been selected and constructed to find the optimal levels and to analyze the effect of the turning parameters. The signal-to-noise (S/N) ratio has been calculated to construct the analysis of variance (ANOVA) table to study the performance characteristics in dry turning operations. ANOVA has shown that depth of cut has significant role in producing higher MRR. The optimal results have been verified through conformation experiments with minimum number of trials as compared with full factorial design. The best cutting parameters for material removal rate has been found as cutting speed 1000 RPM, feed 0.20 mm/rev and depth of cut 1.5 mm on the basis of ANOVA analysis.

Key Words: ***Taguchi method, CNC Turning, Cutting Parameters, ANOVA, MRR.***

CUTTING TOOL MATERIALS

The classes of cutting tool materials currently in use for machining operation are high-speed tool steel, cobalt-base alloys, cemented carbides, ceramic, polycrystalline cubic boron nitride and polycrystalline diamond. Different machining applications require different cutting tool materials. The Ideal cutting tool material should have all of the following characteristics:

- Harder than the work it is cutting
- High temperature stability
- Resists wear and thermal shock
- Impact resistant

Chemically inert to the work material and cutting fluid To effectively select tools for machining, a machinist or engineer must have specific information about:

- The starting and finished part shape
- The work piece hardness
- The material's tensile strength
- The material's abrasiveness
- The type of chip generated
- The work holding setup

The power and speed capacity of the machine tool some common cutting tool materials are described

Carbon steels:

Carbon steels have been used since the 1880s for cutting tools. However carbon steels start to soften at a temperature of about 180oC. This limitation means that such tools are rarely used for metal cutting operations. Plain carbon steel tools, containing about 0.9% carbon and about 1% manganese, hardened to about 62 Rc, are widely used for woodworking and they can be used in a router to machine aluminum sheet up to about 3mm thick. High speed steels (HSS):

HSS tools are so named because they were developed to cut at higher speeds. Developed around 1900 HSS are the most highly alloyed tool steels. The tungsten (T

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series) was developed first and typically contains 12 - 18% tungsten, plus about 4% chromium and 15% vanadium. Most grades contain about 0.5% molybdenum and most grades contain 4 -12% cobalt.It was soon discovered that molybdenum (smaller proportions) could be substituted for most of the tungsten resulting in a more economical formulation which had better abrasion resistance than the T series and undergoes less distortion during heat treatment. Consequently about 95% of all HSS tools are made from M series grades. These contain 5 - 10% molybdenum, 1.5 - 10% tungsten, 1 - 4% vanadium, 4% Chromium and many grades contain 5 - 10% cobalt. HSS tools are tough and suitable for interrupted cutting and are used to manufacture tools of complex shape such as drills, reamers, taps, dies and gear cutters. Tools may also be coated to improve wear resistance. HSS accounts for the largest tonnage of tool materials currently used. Typical cutting speeds: 10 - 60 m/min. Cast Cobalt alloys:

Introduced in early 1900s these alloys have compositions of about 40 - 55% cobalt, 30% chromium and 10 - 20% tungsten and are not heat treatable. Maximum hardness values of 55 - 64 Rc. They have good wear resistance but are not as tough as HSS but can be used at somewhat higher speeds than HSS. Now only in limited use. Carbides:

Also known as cemented carbides or sintered carbides were introduced in the 1930s and have high hardness over a wide range of temperatures, high thermal conductivity, high Young's modulus making them effective tool and die materials for a range of applications. The two groups used for machining are tungsten carbide and titanium carbide; both types may be coated or uncoated. Tungsten carbide particles (1 to 5 micrometer) are bonded together in a cobalt matrix using powder metallurgy. The powder is pressed and sintered to the required insert shape. Titanium and niobium carbides may also be included to impart special properties. A wide range of grades are available for different applications. Sintered carbide tips are the dominant type of material used in metal cutting. The proportion of cobalt (the usual matrix material) present has a significant effect on the properties of carbide tools. 3 - 6% matrix of cobalt gives greater. hardness while 6 - 15% matrix of cobalt gives a greater toughness while decreasing the hardness, wear resistance and strength.

TOOL WEAR

Tool wear in machining is defined as the amount of volume loss of tool material on the contact surface due to the interactions between the tool and work piece. Specifically, tool wear is described by wear rate (volume loss per unit area per unit time) and is strongly determined by temperature, stresses, and relative sliding velocity generated at the contact interface. Metal cutting tools are subjected to extremely arduous conditions, high surface loads, and high surface temperatures arise because the chip slides at high speed along the tool rake face while exerting very high normal pressures (and friction force) on this face. The forces may be fluctuating due to the presence of hard particles in the component microstructure, or more extremely, when interrupted cutting is being carried out. Hence cutting tools need:

- Strength at elevated temperatures
- High toughness & High hardness
- High wear resistance

During the past 100 years there has been extensive research and development which has provided continuous improvement in the capability of cutting tool. A key factor in the wear rate of virtually all tool materials is the temperature reached during operation; unfortunately it is difficult to establish the values of the parameters needed for such calculations. However, experimental measurements have provided the basis for empirical approaches. It is common to assume that all the energy used in cutting is converted to heat (a reasonable assumption) and that 80% of this is carried away in the chip (this will vary and depend upon several factors - particularly the cutting speed). This leaves about 20% of the heat generated going into the cutting tool. Even when cutting mild steel tool

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temperatures can exceed 550oC, the maximum temperature high speed steel (HSS) can withstand without losing some hardness. Cutting hard steels with cubic boron nitride tools will result in tool and chip temperatures in excess of 1000oC. During operation, one or more of the following wear modes may occur:

(a) Flank
(b) Notch
(c) Crater
(d) Edge rounding Edge chipping
(e) Edge cracking
(f) Catastrophic failure

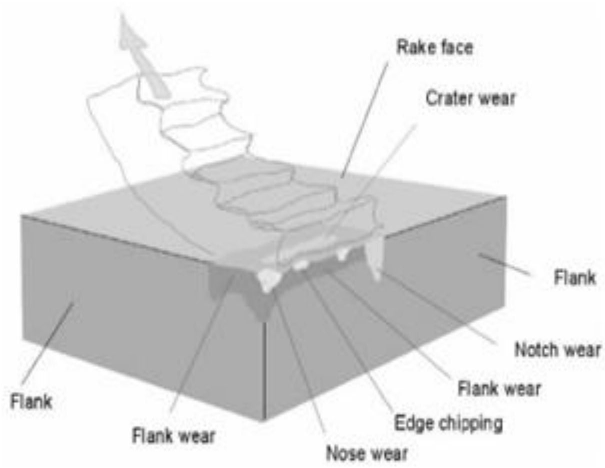

Fig 1 : different modes of wear

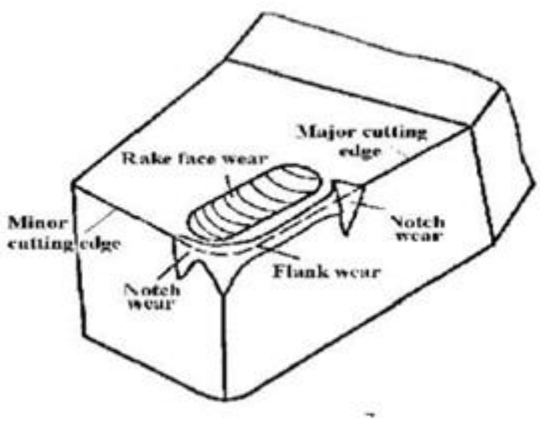

Fig 2: Tool Wear phenomena

Cutting tools are subjected to an extremely severe rubbing process. They are in metalto-metal contact between the chip and work piece, under conditions of very high stress at high temperature. The situation is further aggravated (worsened) due to the existence of extreme stress and temperature gradients near the surface of the tool. During machining, cutting tools remove material from the component to achieve the required shape, dimension and surface roughness (finish). However, wear occurs during the cutting action, and it will ultimately result in the failure of the cutting tool. When the tool wear reaches a certain extent, the tool or active edge has to be replaced to guarantee the desired cutting action. Rake face wear:

Crater wears:

The chip flows across the rake face, resulting in severe friction between the chip and rake face, and leaves a scar on the rake face which usually parallels to the major cutting edge. The crater wear can increase the working rake angle and reduce the cutting force, but it will also weaken the strength of the cutting edge. The parameters used to measure the crater wear can be seen in the diagram. The crater depth KT is the most commonly used parameter in evaluating the rake face wear.

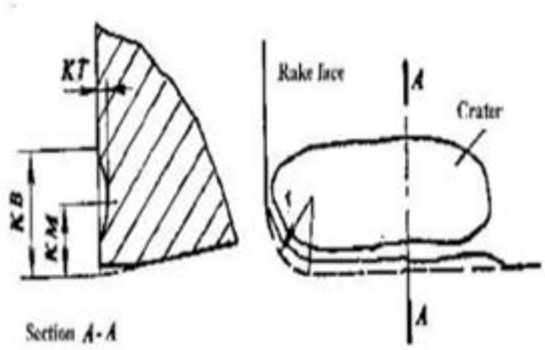

Fig 3: Crater Wear

Flank wear (Clearance surface): Wear on the flank (relief) face is called Flank wear and results in the formation of a wear land. Wear land formation is not always uniform along the major and minor cutting edges of the tool. Flank wear most commonly results from abrasive wear of the cutting edge against the machined surface. Flank wear can be monitored in production by examining the tool or by tracking the

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change in size of the tool or machined part. Flank wear can be measured by using the average and maximum wear land size VB and VBmax.

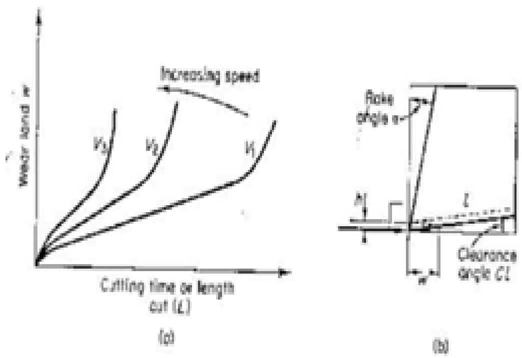

Fig 4:Flank Wear

Due to micro-cracking, surface oxidation and carbon loss layer, as well as microroughness at the cutting tool tip in tool grinding (manufacturing). For the new cutting edge, the small contact area and high contact pressure will result in high wear rate. The initial wear size is VB=0.05-0.1mm normally. After the initial (or preliminary) wear (cutting edge rounding), the micro-roughness is improved, in this region the wear size is proportional to the cutting time. The wear rate is relatively constant. When the wear size increases to a critical value, the surface roughness of the machined surface decreases, cutting force and temperature increase rapidly, and the wear rate increases. Then the tool loses its cutting ability. In practice, this region of wear should be avoided.

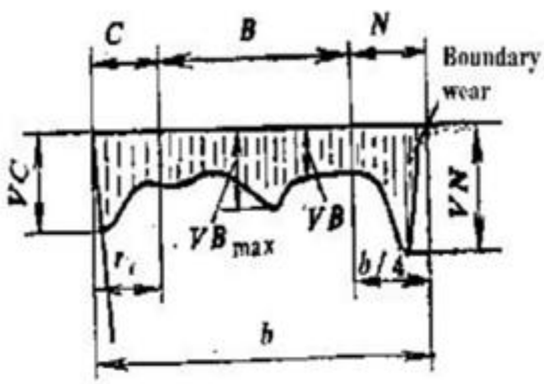

Fig 5: Typical stages of tool wear in normal cutting situation

Flank wear and chipping will increase the friction, so that the total cutting force will increase. The component surface roughness will be increased, especially when chipping occurs. Flank wear will also affect the component dimensional accuracy. When form tools are used, flank wear will also change the shape of the component produced.

TOOL LIFE

There is no single universally accepted definition of tool life. The life needs to be specified with regard to the process aims. A common way of quantifying the end of a tool life is to put a limit on the maximum acceptable flank wear, VB or VBmax. Typical figures are:

The constants n and C may be found for specific work piece and tool material and feed, f, either by experiment or from published data.

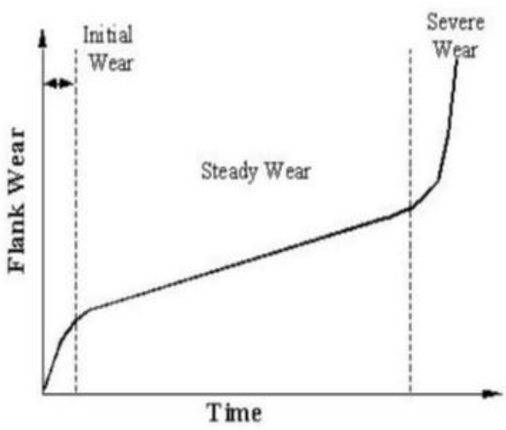

Fig 6: Different regions of wear

HSS tools, roughing	1.5 mm
HSS tools, finishing	0.75 mm
Carbide tools	0.7 mm
Ceramic tools	0.6 mm

Mathematically the tool life can be expressed in the following equation (the Taylor equation): $VT^n = C$, Here

V	Cutting speed
T	Tool life
n, C	Constants

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SURFACE STRUCTURE AND PROPERTIES

Surface roughness is an important measure of product quality since it greatly influences the performance of mechanical parts as well as production cost. Surface roughness has an impact on the mechanical properties like fatigue behavior, corrosion resistance, creep life, etc. It also affects other functional attributes of parts like friction, wear, light reflection, heat transmission, lubrication, electrical conductivity, etc. Before surface roughness, it is also necessary to discuss about surface structure and properties, as they are closely related. Upon close examination of the surface of a piece of metal, it can be found that it generally consists of several layers (Figure 1.16). The characteristics of these layers are briefly outlined here

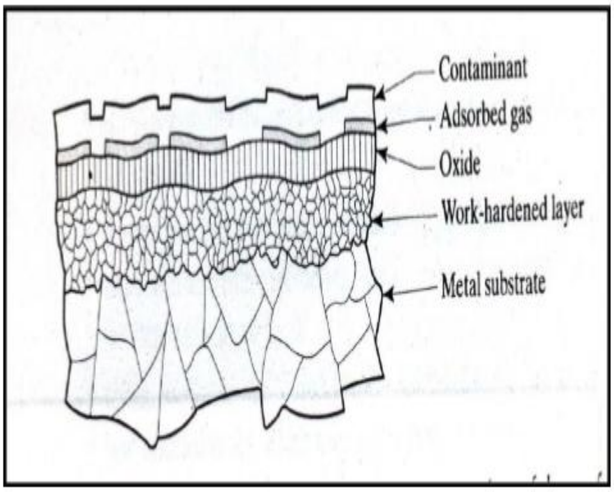

Fig7: Schematic of a cross-section of the surface structure of metals

1. The bulk metal, also known as the metal substrate, has a structure that depends on the composition and processing history of the metal.
2. Above this bulk metal, there is a layer that usually has been plastically deformed and work-hardened to a greater extent during the manufacturing process. The depth and properties of the work-hardened layer (the Surface Structure) depend on such factors as the processing method used and how much frictional sliding the surface undergoes. The use of sharp tools and the selection of appropriate processing parameters result in surfaces with little or no disturbance. For example, if the surface is produced by machining using a dull and worn tool, or which takes place under poor cutting conditions, or if the surface is ground with a dull grinding wheel, the surface structure layer will be relatively thick. Also, non-uniform surface deformation or severe temperature gradients during manufacturing operations usually cause residual stresses in the work-hardened layer. 3. Unless the metal is processed and kept in an inert (oxygen-free) environment, or is a noble metal such as gold or platinum, an oxide layer forms over the work-hardened layer. a. Iron has an oxide structure with FeO adjacent to the bulk metal, followed by a layer of Fe3O4 and then a layer of Fe2O3, which is exposed to the environment.

3. Aluminum has a dense, amorphous (without crystalline structure) layer of Al2O3, with a thick, porous hydrated aluminum-oxide layer over it. 4. Under normal environmental conditions, surface oxide layers are generally covered with absorbed layers of gas and moisture. Finally, the outermost surface of the metal may be covered with contaminants such as dirt, dust, grease, lubricant residues, cleaningcompound residues, and pollutants from the environment. Thus, surfaces have properties that generally are very difficult from those of the substrate. The oxide on a metal surface is generally much harder than the base metal. Consequently, oxides tend to be brittle and abrasive. This surface characteristic has several important effects on friction, wear, and lubrication in materials processing, and on products.

SURFACE INTEGRITY

Surface integrity is the sum of all the elements that describes all the conditions exiting on or at the surface of a work piece. Surface integrity has two aspects. The first is surface topography which describes the roughness, ‘lay’ or texture of this outermost layer of the work piece, i.e., its interface with the environment. The second is surface metallurgy which describes the nature of the altered layers below the surface with respect to the base of the matrix material. This term

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assesses the effect of manufacturing processes on the properties of the work piece material.

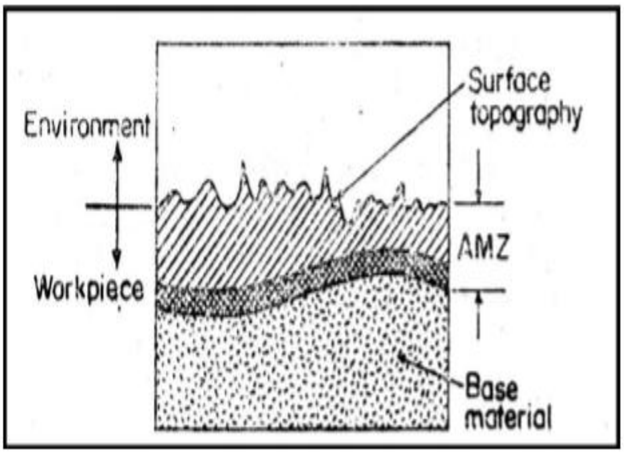

Fig 8: Various layers of a surface

Surface integrity describes not only the topological (geometric) features of surfaces and their physical and chemical properties, but their mechanical and metallurgical properties and

SURFACE FINISH IN MACHINING

The resultant roughness produced by a machining process can be thought of as the combination of two independent quantities:

a. Ideal roughness, b. Natural roughness. c. Ideal roughness:

Ideal surface roughness is a function of feed and geometry of the tool. It represents the best possible finish which can be obtained for a given tool shape and feed. It can be achieved only if the built-up-edge, chatter and inaccuracies in the machine tool movements are eliminated completely. For a sharp tool without nose radius, the maximum height of unevenness is given by:

$$Ra=f/(\cot\phi-\cot\beta) \quad \text{------------------------} \ (a)$$

characteristics as well. Surface integrity is an important consideration in manufacturing operations because it influences properties, such as fatigue strength, resistance to corrosion, and service life.

Here f is feed rate, φ is major cutting edge angle and β is the minor cutting edge angle. The surface roughness value is given by, Ra = Rmax/4

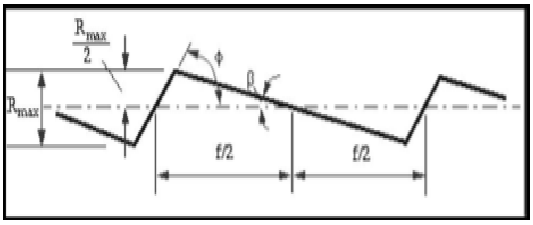

Fig9: Idealized model of surface roughness

Practical cutting tools are usually provided with a rounded corner, and figure below shows the surface produced by such a tool under ideal conditions. It can be shown that the roughness value is closely related to the feed and corner radius by the following expression:

$$R_a = \frac{0.0321 f^2}{R}, \text{ where r is the corner radius.}$$

Natural roughness:

In practice, it is not usually possible to achieve conditions such as those described above, and normally the natural surface roughness forms a large proportion of the actual roughness. One of the main factors contributing to natural roughness is the occurrence of a built-up edge and vibration of the machine tool. Thus, larger the built up edge, the rougher would be the surface produced, and factors tending to reduce chip-tool friction and to eliminate or reduce the built-up edge would give improved surface finish.

FACTORS AEFFECTING THE SURFACE FINISH

Whenever two machined surfaces come in contact with one another the quality of the mating parts plays an important role in the performance and wear of the mating parts. The height, shape, arrangement and direction of these surface irregularities on the work piece depend upon a number of factors such as:

A) The machining variables which include

a) Cutting speed

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b) Feed, and
c) Depth of cut.

B) The tool geometry
Some geometric factors which affect achieved surface finish include:
a) Nose radius
b) Rake angle
c) Side cutting edge angle, and
d) Cutting edge. C) Work piece and tool material combination and their mechanical properties

D) Quality and type of the machine tool used,
E) Auxiliary tooling, and lubricant used, and
F) Vibrations between the work piece, machine tool and cutting tool.

MEASUREMENT OF SURFACE ROUGHNESS

Inspection and assessment of surface roughness of machined work pieces can be carried out by means of different measurement techniques. These methods can be ranked into the following classes:
1. Direct measurement methods
2. Comparison based techniques
3. Non contact methods
4. On-process measurement

Direct measurement methods

Direct methods assess surface finish by means of stylus type devices. Measurements are obtained using a stylus drawn along the surface to be measured. The stylus motion perpendicular to the surface is registered. This registered profile is then used to calculate the roughness parameters. This method requires interruption of the machine process, and the sharp diamond stylus can make micro-scratches on surfaces.

Stylus equipment One example of this is the Brown and Sharpe Surfcom unit. Basically, this technique uses a stylus that tracks small changes in surface height, and a skid that follows large changes in surface height. The use of the two together reduces the effects of non-flat surfaces on the surface roughness measurement. The relative motion between the skid and the stylus is measured with a magnetic circuit and induction coils. Schematic diagram of surface roughness measurement technique by stylus equipment.

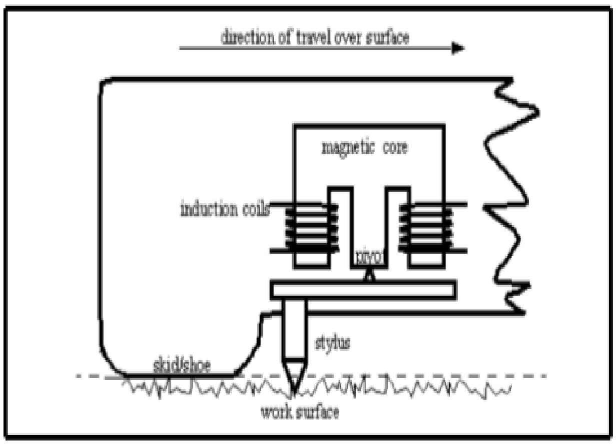

Fig 9: Schematic diagram of surface roughness measurement technique by stylus equipment

The actual apparatus uses the apparatus hooked to other instrumentation. The induction coils drive amplifiers, and other signal conditioning hardware. The then amplified signal is used to drive a recorder that shows stylus position, and a digital readout that displays the CLA/Ra value. The paper chart that is recorded is magnified in height by 100000: 1, and in length by 82: 1 to make the scale suitable to the human eye. The datum that the stylus position should be compared to can be one of three,
a. Skid - can be used for regular frequency roughness
b. Shoe - can be used for irregular frequency roughness
c. Independent - can use an optical flat

Comparison based techniques

Comparison techniques use specimens of surface roughness produced by the same process, material and machining parameters as the surface to be compared. Visual and tactile sensors are used to compare a specimen with a surface of known surface finish. Because of the subjective judgment involved, this method is useful for surface roughness Rq >1.6 micron.

Non contact methods

There have been some works done to attempt to measure surface roughness using non contact technique. Here is an electronic speckle correlation method given as an example. When coherent light illuminates a rough surface, the diffracted waves from each point of the surface mutually interfere to form a pattern which appears as a grain pattern of bright and dark regions. The spatial statistical properties of this speckle image can be related to the surface characteristics. The degree of correlation of two speckle patterns produced from the same surface by two different illumination beams can be used as a roughness parameter

On-process measurement

Many methods have been used to measure surface roughness in process. For example: a. Machine vision: In this technique, a light source is used to illuminate the surface with a digital system to viewing the surface and the data being sent to a computer for analysis. The digitized data is then used with a correlation chart to get actual roughness values. b. Inductance method: An inductance pickup is used to measure the distance between the surface and the pickup. This measurement gives a parametric value that may be used to give a comparative roughness. However, this method is limited to measuring magnetic materials. c. Ultrasound: A spherically focused ultrasonic sensor is positioned with a non normal incidence angle above the surface. The sensor sends out an ultrasonic pulse to the personal computer for analysis and calculation of roughness parameters.

FACTORS INFLUENCING SURFACE ROUGHNESS IN TURNING

Generally, it is found that the factors influencing surface roughness in turning are

- Depth of cut: Increasing the depth of cut increases the cutting resistance and the amplitude of vibrations. As a result, cutting temperature also rises. Therefore, it is expected that surface quality will deteriorate.
- Feed: Experiments show that as feed rate increases surface roughness also increases due to the increase in cutting force and vibration.
- Cutting speed: It is found that an increase of cutting speed generally improves surface quality.
- Engagement of the cutting tool: This factor acts in the same way as the depth of cut.
- Cutting tool wears: The irregularities of the cutting edge due to wear are reproduced on the machined surface. Apart from that, as tool wear increases, other dynamic phenomena such as excessive vibrations will occur, thus further deteriorating surface quality.

Use of cutting fluid:

The cutting fluid is generally advantageous in regard to surface roughness because it affects the cutting process in three different ways. Firstly, it absorbs the heat that is generated during cutting by cooling mainly the tool point and the work surface. In addition to this, the cutting fluid is able to reduce the friction between the rake face and the chip as well as between the flank and the machined surface. Lastly, the washing action of the cutting fluid is considerable, as it consists in removing chip fragments and wear particles. Therefore, the quality of a surface machined with the presence of cutting fluid is expected to be better than that obtained from dry cutting. (vii) Three components of the cutting force: It should be noted that force values cannot be set a priori, but are related to other factors of the experiment as well as to factors possibly not included in the experiment, i.e. force is not an input factor and is used as an indicator of the dynamic characteristics of the work piece— cutting tool— machine system. Finally, the set of parameters including the above mentioned parameters that are thought to influence surface roughness, have been investigated from the various researchers.

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CONCLUSION

The research has demonstrated an application of the Taguchi method for investing the effects of cutting parameters on material removal rate in turning aluminum metal. With analysis of results in this work using S/N ratio approach and ANOVA provides a systematic and efficient methodology for the optimization of cutting parameters. The material removal rate is mainly affected by cutting speed, depth of cut and feed rate, by increasing any one the material removal rate is increased. The parameters considered in this experiment are optimized to attain maximum material removal rate. The best parameters for material removal rate has been found in Table 2 as cutting speed 1000 RPM in level 3, feed 0.20 mm/rev in level 3 and depth of cut 1.5 mm in level 3 on the basis of ANOVA analysis ACKNOWLEDGEMEN

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