CHAPTER 2

LITERATURE REVIEW

Exhaustive literature is available on the machinability of steels. This chapter gives brief narration of significant research, specifically related to ‘Machinability studies of carbon and alloy steels’, till this date. The standard and specific literature survey includes the topic which characterises the machinability aspects in sequential order: machinability test methods, machinability index and its evaluation approaches; tool wear and tool life, surface roughness and surface integrity studies; micro hardness and SEM investigations; and chip morphology and crater wear studies. The literature survey also includes interaction of cutting parameters with respect to the work materials undertaken for the present work. The brief summary and conclusions of the literature survey are drawn to the objectives laid in the current research at the end of chapter.

2.1 Machinability test methods

Fredrickson, G.O et al. (1954) developed a ‘Method and Apparatus for Machinability Testing’. The method of determining the machinability of a steel workpiece of known composition comprising the steps of feeding an alternating current at a controllable amperage and at a predeternined voltage between two predetermined positions on the workpiece, and measuring the reactance to said current flow between two predetermined intermediate positions on said work piece.

Valembois, P.V et al.(1982) developed Optical Inspection method for determining machinability. In a method for determining the machinability of a metal substrate for use in an electromechanical recording apparatus a surface of a foundation is coated with a layer of metal. The metal layer is machined such that the metalized surface of the foundation is substantially flat and smooth. After the machining step, the metal surface is inspected for depressions with a microscope using a differential interference contrast technique. The number of depressions observed is indicative of the machinability of the coated foundation.

Zeng, J. (2000) developed automatic machinability measuring and machining methods and apparatus. Here a method for measuring the machinability of a material which includes piercing a hole through a material to be tested while simultaneously measuring a pierce time duration and calculating a machinability number from the pierce time duration. The apparatus includes any of a pressure sensor, an acoustic sensor, an optical sensor, a load cell, a mechanical switch and combinations thereof to measure the pierce-time duration.

Hiroshi Yaguchi (2005) reported six methods of machinability testing of carbon and alloy steels that are carried out at the author's company Inland Steel Company. The six methods are (1) Automatic screw machine test, (2) Plunge test, (3) Drill force test, (4) Single-point turning test for carbide tools, (5) Single-point turning test for high speed steel tools and (6) Drill eccentricity test. The first one is a long term test in which various machining operations such as drilling, forming and parting are performed in sequential fashion. The part growth and roughness's are the responses that are used to characterise the machinability of these materials. Also this method requires a large amount of steel, close monitoring and manpower. The second test is a bit modification of the first one with less amount of steel required, whereas other aspects are similar to the first test. The third test is not used to characterize machinability but to present only relative rating of machinability. The fourth and fifth test uses modified form of ISO 3685-1977(E). Here, machinability is compared based on either wear rate at a common cutting speed among all the samples tested or the higher cutting speed used to reach a certain length of tool life, which is determined by the length of flank wear. The sixth test is another test requiring specialised skill to monitor the entire test process.

Venkatrao R. (2006) discusses machinability evaluation of work materials using a combined multiple attribute decision-making method and presented a logical procedure to evaluate the machinability of the work material for a given machining operation and also proposed global machinability index to evaluate and rank the work materials. The proposed method is used: to select the best work-tool combination for a given machining operation; and to find proper cutting conditions for machining the given work material.

Salak A. et al. (2006) presented a short time face turning as a new method for machinability testing of PM steels, using common ring shaped test specimens, performed at constant revolutions of the lathe. The method was tested on five different grades of Fe–C and Distaloy type materials. The critical number of cutting passes up to a tool flank wear of V_b= 0.3 mm, critical time, critical volume of removed material, surface finish and morphology of the chips were the criteria for checking the technical effectivity of the applied method. The results attained show that the face turning test method used here is simple and easy and can fulfil many requirements for assessing the machinability of PM steels in turning. The authors also confirmed here the sensitivity of the test method used to the workpiece material properties with regard to the evaluated criteria, as, e.g. critical number of passes up to flank wear of the tool V_b-0.3 mm, critical time to test an alloy, critical volume of removed material, surface finish and morphology of the chips.

Karin Bjorkeborn et al. (2008) recommended the Volvo Standard Machinability test (one of the short term) as a potential method for assessing machinability of materials. A common case hardening steel, 20MnCrS5 was chosen here for investigations. With suitable altered heat treatment four varieties of microstructures of the same steel were obtained. The Volvo test made it possible to rank material by tool wear with relatively small samples and low material volumes. The authors stated that approximately 800 mm length of bar and 50 mm in diameter is needed for testing a material and the other traditional test with respect to tool wear are more costly to perform, both in time and material consumption.

Coppini et al. (2009), discusses and proposes new approach for applications of machinability and machining strength under a new point and index called Coppini Index(CI). The reliability of the proposed test was based on experimental data from the literature. The best way to apply machinability index and machining strength index is put forward. Otherwise, at this moment, the authors are doing experimental laboratory research to evaluate the best way to organize appropriate samples to attend different kind products for respective materials makers.

Arriola et al.(2011) made an attempt to develop a practical tool for the scientific design of more machinable materials by short run test and to reduce the need for tedious, time consuming and expensive machinability tests, ISO-3685. The relationship between machinability index of the analyzed steels and in-process parameters (feed forces, temperature and plastic strain) measurements results was determined. Lower feed forces, lower friction values, lower temperatures and higher plastic strain values correlate with better machinability index.

2.2 Machinability Index Evaluation Approaches

Table 2.1: Machinability ratings in percentage of various common metals

AISI Steel	MR	Hardness Brinell
C1109	85	137-166
C1115	85	147-179
C1118	80	143-179
C1132	75	187-229
C1137	70	187-229
B1111	90	179-229
B1112	100	179-229
B1113	135	179-229
A4023	70	156-207

Elso Kuljanic et al. (2010) summarized various machinability evaluation approaches. The authors states that the first publications in machinability of steel rating were done by Sorenson.J and Gates. W in 1929. A graphical representation of the general relation of machinability ratings - relative cutting speeds to hardness for hot-rolled SAE steels was made. A 100% rating was given to SAE 1112 steel cold rolled. Later on in 1943 Boston et al. published a general machinability index-rating for more common metals and alloys as in Table 2.1 (Annealed prior to cold drawing or cold rolling in the production of the steel specially mentioned). The ratings are expressed in terms of relative values. These figures are often called “percent machinability”, and are representing the relative speed to be used with each given material in order to obtain a given tool life. For example, a material whose rating is 50 should be machined at approximately half the speed used for the material rating 100, if equal tool life is desired for either of them. The rating values in Table 2.1 are based on a

Table 2.2: Machinability ratings in grades of some common stainless steel (hot-rolled, annealed)

AISI Steel	Hardness Brinell	MR
410	135-165	C
416	145-185	A
430	145-185	C
446	140-185	C
302	135-185	D
303	130-150	B
316	135-185	D

A – Excellent, B – Good,
C – Fair, D - Poor

rating of 100 for steel AISI B1112, cold rolled or cold drawn when machined with a suitable cutting fluid at cutting speed, V_c = 56 m/min under normal cutting conditions using high-speed-steel tools. In Table 1 the ratings given for different classes of alloys, represent their relative machinability within a given class, but the ratings for any class is not comparable with those for any other class.

The second approach in machinability rating is in terms of equivalent cutting speed. The cutting speed number is the cutting speed which causes a given flank wear land in 60 minutes. Such a cutting speed is called economical cutting speed. However, the tool life of 60 minutes is not always economical any more. At times the economical tool life for minimum machining cost is about 10 minutes or less in turning. Therefore, the corresponding cutting speed in such cases is much higher than the tool life of 60 minutes.

The third approach in machinability ratings represents relative cutting speed values where the ratings are given as letters, Table 2.2. “A” indicates a high permissible cutting speed and “D” a lower cutting speed.

The fourth approach is the correlation of tool life and the microstructure of the metal. Generally speaking hard constituents in the structure (oxides, carbides, inclusions) result in poor tool life, and vice versa. In addition, the tool life is usually better when the grain size of the metal is larger. Woldman (1947) studied the correlation of microstructure of steels and tool life. Average relations of tool life and surface finish to microstructure of steel were reported as “good”, “fair”, “fair to good” and “poor” as in Table 2.3.

Table 2.3: Relation of tool life and surface finish to microstructure of steels

Class of steel	**Structure**	**Tool Life**	**Surface Finish**
Low – carbon steels	Cold drawn, small grain size	Good	Good
	Normalised	Good	Fair
Mild medium carbon steel	Pearlitic, moderate grain size	Good	Good
	Pearlitic, small grain size	Fair	Good
	Pearlitic, large grain size	Good	Fair
	Spheroidized	Fair	Poor

Machinability index is an approximate value indicating the machinability of different engineering materials. Such information can be useful in the design of mechanical parts. For example, if there are different materials that can be used for a given part and have different machinability index, the material with greater machinability index should be chosen in order to increase the productivity and decrease the machining cost. It has to be pointed out that data published approximately 70 years ago reflect the workpiece materials and especially the tool material which were very different from those in use today.

2.3 Tool wear and tool life

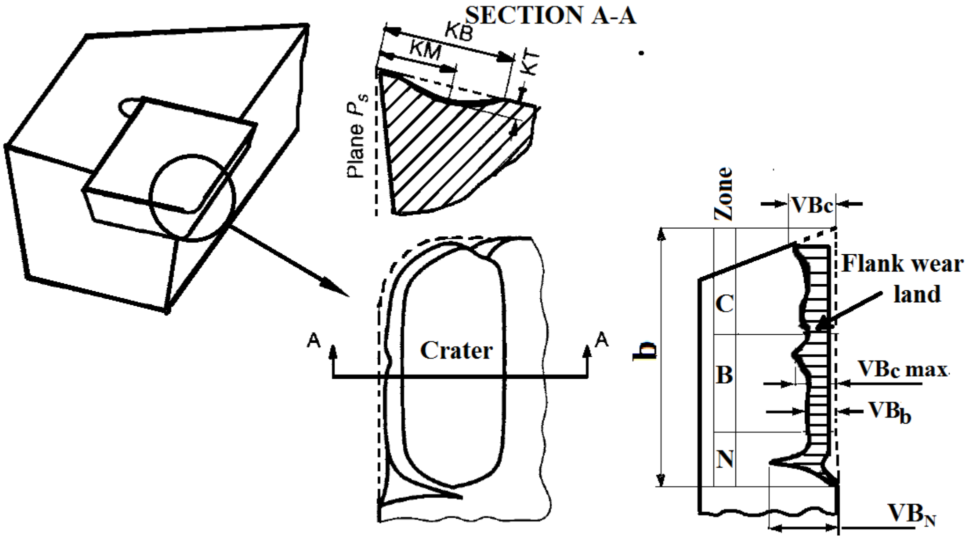

Figure 2.1: ISO Characterization of flank wear land and rake face wear crater

ISO 3685:1993(E) is an international standard for tool-life testing with single-point turning tools which contains recommendations applicable to both laboratories and manufacturing units. This standard can be used with suitable modifications for specific applications. It states that flank wear is the best known type of tool wear which has uniform width along the middle portion of the straight part of the cutting edge. The width of the flank wear is easy to measure. The growing width of the flank wear land leads to a reduction in the quality of the tool. The crater wear occurs on the rake face which can be measured as additional information but should not be used as tool-life criteria. Further surface roughness, cutting forces, and temperature may be measured as additional information only and is not covered in this standard. Chip formation is normally not recommended for determining tool life but, however it is useful as a ‘control instrument’.

Trent, E. M (1958) clearly stated that flank wear occurred under all cutting conditions and does not follow the same laws as cratering, build-up and deformation. There are often no critical changes in the rate or type of flank wear with varying cutting speed and feed, except those associated, for example, with deformation, which already delineated. The flank wear occuring in short time cutting tests has been studied. The results suggest that the rate of wear is greatly influenced by the pattern of temperature distribution and flow of the work material around the cutting edge .

Hong Tsu Young (1996) studied the cutting temperature responses to flank wear.Tool wear has been shown to be strongly temperature dependent and therefore an attempt can be made to measure and control the cutting temperature with a view to obtain optimum machining conditions.

Valery Marinov (1996) analyzed the influence of cuting conditions and parameters of the abrasive inclusions in the work material on the amount of abrasive wear of the carbide cutting loads. The results show that abrasive wear increases approximately linearly with the cutting temperature due to the change of the abrasive capability of some abrasive inclusions with work hardness comparable with that of the tool material. Another conclusion is that the amount of the worn metal increases to some extent with the size of the abrasive particles due to the larger size of the carbide conglomerates split off by the particles when they move along the tool surface.

Lim, .C.Y.H et al. (2001)studied the effects of work material on tool wear. Wear maps showing the wear behaviour of titanium carbide (TiC)-coated cemented carbide tools during dry turning of various types of steel have been presented in earlier studies. The maps have demonstrated that tool wear rates vary with cutting speeds and feed rates used. They have also shown that there is a range of cutting conditions, called the safety zone, within which tool wear rates are the lowest. Wear rate maps constructed for the machining of AISI 1045 and AISI 4340 steels show that flank wear rates are at least half an order of magnitude larger when machining the latter grade. It is believed that greater hardness, toughness and strength of the AISI 4340 grade result in higher cutting stresses and tool temperatures, leading to more severe flank wear. The wear maps also show that despite differences in actual wear rates, the contours of the two maps are similar at low to moderate cutting speeds and feed rates. However, the transition to severe flank wear occurs at lower cutting speeds and feed rates in AISI 4340 steels. This transition is not reflected accurately in the wear map for various grades of plain carbon and low-alloy steels presented in previous investigations. Nevertheless, the contour and location of the safety zone in all three wear maps are similar, suggesting that wear maps specific to the work material may not be necessary. The earlier map for general grades of steel remains a useful starting point in the selection of the machining conditions that will combine a maximum rate of metal removal with an acceptable level of tool wear.

Sumit Kanti Sikdar and Mingyuan Chen (2002) studied the relationship between flank wear area and cutting forces for turning operations of AISI 4340 steel with a single point carbide tool insert. The study indicates a good correlation between cutting forces and the three-dimensional flank wear surface area in turning operations. All cutting forces increase with the increase of the flank wear surface area. Increasing flank wear area results in an increasing area of contact between the tool tip and the workpiece. The greater the value of the flank wear area, the higher the friction of the tool on the workpiece and high heat generation will occur, this ultimately causes the higher value of cutting force. The rate of increase (the tangential force increases by 6%, the axial force increases by 13% and the radial force increases by 64%) of axial and radial cutting force is higher than the tangential cutting force, when tool insert begins to fail.

Tay, Francis et al. (2002) studied the topography of the flank wear surface and presented the relationship between the maximun flank wear and the topography parameters (roughness parameters) of the flank wear surface during the turning operation. The greater the roughness value of the flank wear surface, the higher the friction of the tool on the workpiece, so that greater heat generation will occur, which ultimately causes tool failure.

Flank wear of cutting tools is often selected as the tool life criterion because it determines the diametric accuracy of machining, its stability and reliability. Viktor P. Astakhov (2004) argues that the existing criteria of flank wear are insufficient for its proper characterization. Their existence is due to the lack of knowledge on the contact conditions at the tool flank-workpiece interface. The properties of the work and tool materials, tool geometry and the cutting regime determine the contact phenomena of the tool-workpiece interface. As such, the cutting speed has the strongest influence. The current paper compares different characteristics of the evaluation of flank wear. In the machining of difficult-to-machine materials and in high speed machining, plastic lowering of the cutting edge is the predominant cause of premature tool breakage. This lowering is a result of high-temperature creep of the tool material. The contact process at the mentioned interface is analysed through the experimental assessment of the contact stresses, and the full validity of Makarow's law is confirmed, i.e. 'minimum tool wear occurs at the optimum cutting speed'. A new concept of tool resources is proposed and discussed. This resource is defined as the limiting amount of energy that can be transmitted through the cutting wedge until it fails.

Boulger Francis (2005) discusses various aspects of machinability of steels. The machinability of carbon and alloy steels is affected by many factors: such as composition, microstructure, and strength level of steel; the feed, speeds, and depth of cut; and the choice of cutting fluid and cutting tool material. The measures of machinability are based on: tool life; cutting speed; power consumption; comparison with standard steel based on experience in machine shops; quality of surface finish; and feeds resulting from a constant thrust force.

Alden Kendall (2005) discusses in detail: the wear environment; wear mechanisms; machine, cutting test and tool wear interactions; tool replacement; tool life testing; and future trends. Cutting tool wear is localized on specific surfaces where stress, strain, velocity, and temperature are above critical levels. It is important to understand where these critical conditions exist and how they interact to cause tool wear. He describes the phenomenon of three wear mechanisms (initial, steady state, and tertiary) and it exists in all types of tool wear. A detailed in-house tool life testing program points have been discussed. Depending on off-line laboratory testing and model development will eventually become too costly and time consuming for the current and future automated machining systems. Local data bases that store performance information concerning to the production of each feature will be able to access the progressive wear of the tool more precisely.

Luo, X. et al. (2005) developed a flank wear rate model for accurate prediction of tool flank wear land width with minimum cost. The model is based on the cutting force, cutting temperature simulation and empirical model. The new tool wear rate model is also evaluated by the cutting tests. Results of the tool wear cutting test indicate that cutting speed has more dramatic effect on tool life than feed rate.

Bouzid Sai, W. (2005) investigated tool wear in high speed turning of AISI 4340 steel. A commercially available coated insert has been used to turn an AISI 4340 steel at speeds placed between 325 m/min and 1000 m/min. The flank wear was measured in connection to cutting time. This is to determine the tool life defined as the usable time that has elapsed before the flank wear has reached the criterion value. It is shown that an increase in cutting speed causes a higher decrease of the time of the second gradual stage of the wear process. This is due to the thin coat layer which is rapidly peeled off when high-speed turning. The investigation included the realization of a wear model in relation to time and cutting speed. An empirical model has also been developed for tool life determination in connection with cutting speed. On the basis of the results obtained it is possible to set optimal cutting speed to achieve the maximum tool life. A wear equation is proposed to describe the three stages of the wear process. For cutting speeds higher than 650 m/min, the tool life remains constant, so it is advantageous to use high values of cutting speed.

Factors such as cutting speed, feed rate, tool material, etc., are well known to have an effect on tool wear in metal turning. However, reliable methods of wear prediction over a broad spectrum of cutting circumstance remain elusive, suggesting that not all factors have been recognised as significant and thus considered. Boud (2007) studied the finding that bar diameter has an influence on tool temperature and, by implication, on tool wear. Thus, a factor not previously considered in wear theories in turning is shown to be significant. This finding is put forward to exemplify the need to identify all parameters influencing temperature and heat flow before theorising on tool wear. Such identification enables an objective benchmark to be set for assessing the validity of existing theories on wear.

Yahya Isik (2007) conducted a series of test in order to determine the machinability of tool steels. The tests have been done under various combinations of speed, feed and depth of cut. This study presents a different approach to investigate the correlation of tool wear, tool life and surface roughness. Cutting speed is the most influential parameter on tool life, feed rate is the second most one, and cutting depth is the least influential parameter. At the end of the tool life, considerable increase in cutting forces are observed, but the increase rate varies according to the cutting tool and the workpiece. The amount of flank wear and the cutting force are appropriate parameters to determine the tool life. Prediction of tool wear becomes possible on condition that the cutting speed range, recommended for the tools, is employed.

Beside the increase in the cutting forces, complications concerning the surface quality and dimensional tolerances, increases in vibration and heat are all indicators of that the wear amount has increased and the tool has come to the end of its tool life. In the experiments which were conducted by using coated tools, it was observed that the flank wear is a more influential parameter for the fracture than the crater wear. There is a direct relationship between cutting forces and flank wear. But it is always possible that the tool fracture occurs unexpectedly.

Taylor, F. W (1906) has done extensive investigation on machinability testing to find an answer for the three significant questions: “What tool shall I use? What cutting speed shall I use? What feed shall I use?” After so many years and with availability of modern facilities, still there are difficulties to find the right answer to the above questions.

Michael Finn (2008) developed and proposed American Foundry Society (AFS) machinability test for evaluating the machinability of cast iron as the standardized test in his presentation. The International Standards Organisation specification for the machinability test in long turning steel bars was modified for face turning cast iron discs using an uncoated tungsten carbide insert to machine four grades of cast iron: two grades of ductile cast iron, ASTM A536 65-45-42 and 80-55-06; and two grades of gray cast iron, ASTM A159 G1800 and G3000. Except speed all the cutting parameters were common for all the work materials and flank tool wear was noted for each of the workmaterial. A Taylor curve was plotted for each of the work-material using the three different cutting speeds against flank tool wear. The machinability of the workmaterial was determined for 30 minutes of tool life, V_{30} . The validation of V_{30} for all the work material was done was done on another machine.

Attanasio, A et al. (2011) suggested that crater wear rate is influenced by both cutting speed and feed rate, while flank wear rate seemed to be mainly effected by cutting speed. This can be related to the wear mechanisms. When the crater wear is present, the wear mechanisms are the abrasion, deeply affected by cutting speed, and the diffusion, heavily influenced by cutting temperature. On the other hand, the flank wear mechanism is mainly due to abrasive phenomena which are strongly affected by cutting speed. Furthermore, it was found that the thickness of white and dark layers increase with increasing of tool flank wear. Moreover, higher cutting speed generates thicker white layers and thinner dark layers. In addition, smaller feed rates moderately influence the white layers thickness, while the latter rises with higher feed rate. In contrast, the dark layer thickness decreases with the increasing of the feed rate.

Ali Riza Morecu (2011) studied tool wear performances; wear mechanisms, surface roughness characteristics of AISI 52100 steel. The cutting speed had the greatest effect on the optimal testing conditions followed by the cutting tool’s hardness. The feed rate was also effective on the tool life of the cutting tool. It was shown that the cutting tool life was decreased with increasing cutting speeds in all cutting conditions. Finally he concluded that among all the cutting parameters, the cutting speed was found to be more effective for the tool life and a negligible effect for the surface roughness, but the feed rate was dominant for the surface roughness.

Michael Finn (2012) in his presentation discusses many aspects of Machinability Testing of steels. He enlisted some standard machinability tests: ISO 3685-E Spec

(Long Turning); ISO 8688-1-E Spec (Face Milling); ISO 8688-2-E Spec (End Milling); ASTM E618-81 Spec (Form Turning); Inland Steel Plunge Test (Plunge Turning); and AFS standard Machinability Test (Face Turning) and yet today he finds that ‘machinability’ still is an issue which needs to be addressed specifically. He proposed technical road map to handle the machinability related issues. He also promotes the idea of internal tool life standards.

Siddhapura, A and Paurobally, R (2013) reported that flank wear is the most commonly observed and unavoidable phenomenon in metal cutting. A wide variety of monitoring techniques have been developed for the online detection of flank wear. In order to provide a broad view of flank wear monitoring techniques and their implementation in tool condition monitoring system (TCMS), this paper reviews three key features of a TCMS; signal acquisition; signal processing and feature extraction; and artificial intelligence techniques for decision making. As many as 132 publications were discussed on tool condition monitoring or tool wear detection in turning only along with their benefits and limitations.

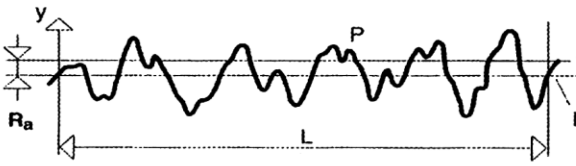

Figure 2.2: Ra of a surface profile P on a sampling length L

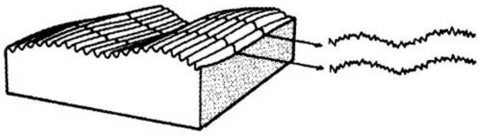

Figure 2.3: Parallel surface profiles on a turned surface

2.4 Surface roughness

Kopac, J and Bahor, M (2001) made analysis of surface roughness of fine turning process on workpieces with different work materials and technological past. The technological past of the workpiece material is very important input data in planning technological processes, but it is in practice sometimes unknown because of bad transparency or past technological operations. This is essential as the workpiece undergoes different destructive and non-destructive testing methods for assessing the required mechanical and chemical properties. These work-materials previously undergo hot-rolling, normalizing, annealing, cold-drawing, tempering or hardening.

Thus workpiece material properties and its machinability can differ from one steel to steel in spite of the same chemical structure.

Surface texture is an important quality characteristic of the machined surface. The authors concentrates on surface roughness as it is control variable. Roughness average (Ra) on the sampling length L is the arithmetic average value of the distance of the profile from the centre line throughout the sampling length (figure 2.2). Roughness average is in some literature denoted as CLA (center line average), although in America the term AA (arithmetic average) has been used. Mathematically, Ra can be calculated as:

$$R_a = (y_1 + y_2 + \ldots\ldots.. + y_n) / n \qquad (2)$$

Characteristics of the roughness average (Ra) are as follows:

1. The Ra value over one sampling length represents the average roughness, therefore the effect of a single spurious, non-typical peak or valley will be averaged out and has only a small influence on the Ra value;
2. Usually in practice, assessments are made over several consecutive sampling lengths and then the average is accepted as the Ra value; this ensures that the Ra is typical for the examined surface;
3. The direction of measurement is very important for roughness assessment and depends on the kind of machining operation and on the shape of the workpiece;
4. The Ra gives no information about the shape of the irregularities or the profile;
5. The Ra value is in micrometer (mm) or micro inch (min) units
6. The Ra does not give full information about the surface roughness, because the same Ra value can be measured on different types of surfaces. Therefore to overcome that, the value R_{max} is very often added.

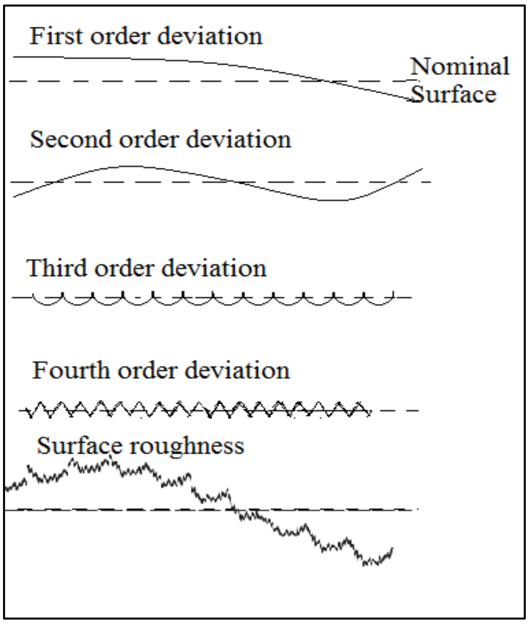

Figure 2.4: Surface form deviations

The usage of roughness average Ra is limited and is inappropriate for the characterization of very rough, very smooth and very short surfaces. The surface texture of the machined surface is fortunately the same within a proportionally large region. This means that if the surface roughness profile is assessed on two parallel locations of the examined surface, then only small differences can be noted `between, surface profiles. They differ one from another just in small details (figure 2.3). This fact enables us to control specified surface texture through the measurement of particular characteristics of the machined surface.

The effect of alloying elements and its corresponding mechanical properties of the samples were also assessed by the surface roughness. The roughness of the machined surface was taken both as mean value of the highest roughness peaks R_z and the mean arithmetic deviation of the roughness Ra.

The authors have analyzed the interaction between workpiece material and machining conditions for the two tempered steels which are frequently used in practice. Experimental results show what machining parameters have to be used at different combinations of cutting tool-workpiece material for the achievement of desired roughness of the machined surface.

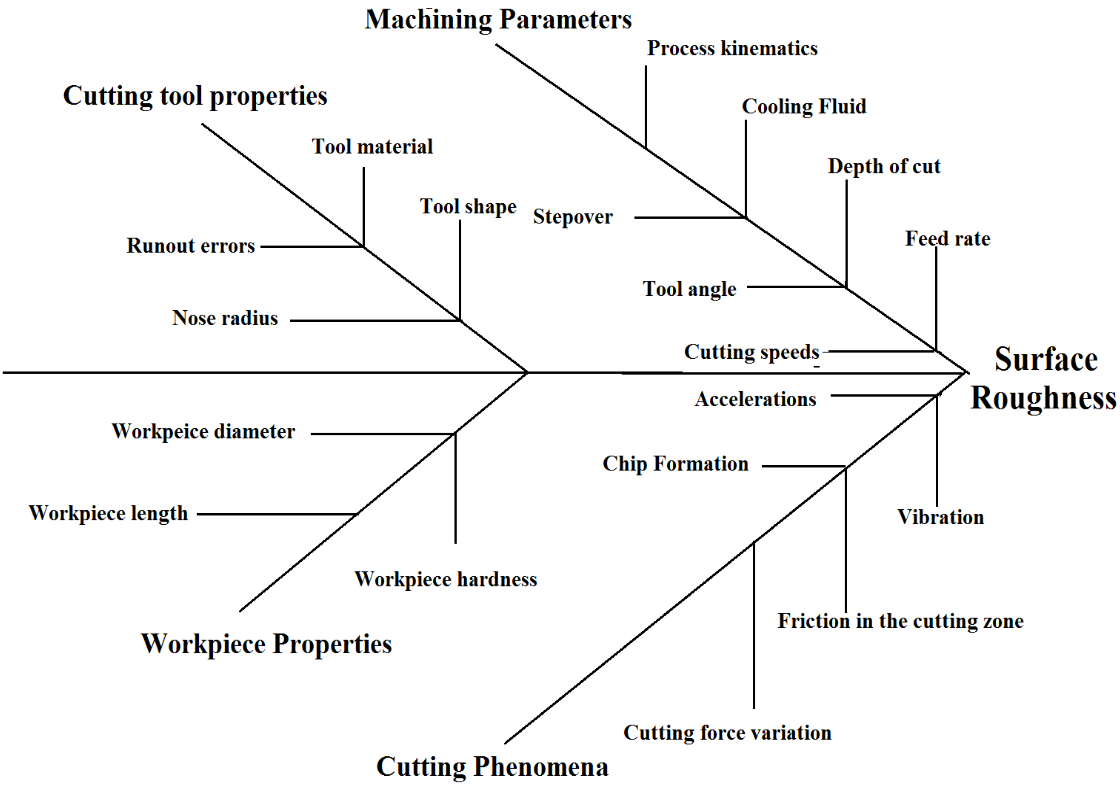

Figure 2.5: Fish bone diagram with the parameters that affect surface roughness

Benardos, P.G and Vosniakos,G.C (2003) discussed and presented various methodologies and strategies that are adopted by researchers in order to predict surface roughness. The author discusses various surface form deviations as shown in figure 2.4. Surface roughness refers to deviation from the nominal surface of the third up to sixth order. First-order and second-order deviations refer to form, i.e. flatness, circularity, etc. and to waviness, respectively, and are due to machine tool errors, deformation of the workpiece, erroneous setups and clamping, vibration and workpiece material inhomogenities.

Third-order and fourth-order deviations refer to periodic grooves, and to cracks and dilapidations, which are connected to the shape and condition of the cutting edges, chip formation and process kinematics. Fifth-order and sixth-order deviations refer to workpiece material structure, which is connected to physical–chemical mechanisms acting on a grain and lattice scale (slip, diffusion, oxidation, residual stress, etc.). Different order deviations are superimposed and form the surface roughness profile. All the methodologies that are presented in this paper have certain advantages and disadvantages when compared to one another, but AI is seen to be most promising approach of all. Finally, the author presents the set of parameters that are thought to influence surface roughness is diagrammatically displayed in figure 2.5.

Radu Pavel et al. (2005) presented the aspects related to surface quality for a case of interrupted and continuous hard turning. New findings concerning the evolution of common surface roughness parameters as well as the evolution of surface topography with the increase of tool wear are presented. A good correlation between flank wear aspect and machined surface were observed. The major wear mechanism was found to be the abrasion of the binder material by the hard particles of the workpiece. The analysis of surface topography confirmed that the negative of the flank wear profile is replicated on the machined surface. A `strong correlation between evolution of notch wear and that of surface finish was observed.

Cemal Cakir. M et al. (2009) presented a mathematical model of cutting parameters for predicting surface roughness. Among the cutting parameters, the feed rate has the greatest influence, followed by the cutting speed. Higher feed rates lead to higher roughness values, whereas cutting speed has a contrary effect and cutting depth has no significant effect.

Ebrahimi, A and Moshksar, M. M (2009) conducted an experimental investigation to determine the effects of cutting speed, feed rate, hardness, and workpiece material on the flank wear land and tool life of coated cemented carbide inserts in the hard turning process. The authors found that at low cutting speeds, in the range of 10-50 m/min, the flank wear of the tools were adhesive, abrasive and fracture of fatigue. For AISI 1045 and AISI 5140, because the existence of the hard particles of molybdenum and chromium in substrate of these materials, adhesive wear and micro chipping were the main factors of damage. At low cutting speed, each of material shows the high cutting forces, and then for high cutting speed these forces are reduced. The reason of the high cutting force at low speed was the low temperature and formation of BUE on the contact zone. In addition, because of high temperature at increased cutting speed, cutting forces decreased and plastic deformation occurred.

2.5 Surface integrity and chip morphology studies

Meng Liu et al. (2004) studied the effect of the tool nose radius and the tool wear on the residual stress induced in hard turning process. With the increase of the tool wear, the residual compressive stress beneath the machined surface increases remarkably. The effect of the nose radius on the residual stress distribution decreases greatly with the increase of the tool wear.

Jawahir, I. S et al. (2011) proposed and summarized recent advances of surface integrity in material processes. The extensive Round Robin study conducted with 12 participants from 9 countries reveal the experimental process capability for producing surface integrity parameters such as surface roughness, hardness, depth of SPD layer and the associated residual stresses in a range of machining operations such as turning, milling, grinding, EDM, etc. Five different workmaterials: AISI 316L, AISI 1045, AISI 52100, IN 718 and Ti-6A-4V were studied for the analytical and numerical predictive capability for surface integrity parameters in terms of cutting forces, temperature and residual stresses.

Virginia G. N et al. (2012) studied the effect of cutting parameters in the surface residual stresses generated by turning in AISI 4340 steel. Surface integrity of the part deteriorates with increase in cutting feed. An increase in tool nose radius implies higher tool/workpiece contact areas, that results in higher temperature due to friction and less plastic deformation (the pressure per unit area diminishes), leading to more tensile surface residual stresses, although roughness improves. The use of coated tools results in better roughness values but the surface residual stresses tend to be more tensile, because the coating acts as a thermal barrier, introducing more heat into the workpiece and therefore favouring the thermal factor that leads to tensile stresses.

Kevin Chou (2002) proposed an approach to apply machining as an alternative to surface hardening of steel parts. The attempt is to utilize wear land rubbing, together with mechanical loading, to achieve hardening mechanism at machined surface. An AISI 4340 steel bar was machined with 1.2 mm flank wear land (V_b) showed 30 μm deep hardened layer (49 HRC versus 29 HRC). Furthermore the machined surface has about 7% austenite volume fraction, an evidence of phase transformation, these results suggest the possibility of utilizing the machining to surface harden the parts.

Surfaces that have undergone machining usually retain properties induced during processing. Some of these properties can be undesirable thus requiring that the component undergoes further treatment. Previous studies on cutting have shown that the cutting parameters can be regulated to produce machining outcomes beneficial for component service life. Hermann Autenrieth et al. (2009) studied surface workhardening and residual stresses induced by micro cutting processes for AISI 1045 steels. The influence of the ploughing effect on residual stresses, surface deformation and work hardening, and the tool quality were investigated. Tensile residual stresses, caused by the heat generated in the material during the cutting process, were observed in all investigated specimens. An increase of the ploughing effect resulted in higher residual tensile stresses at the surfaces of the specimens. The depth of plastic deformation created in the material by the micro-cutting process also increased with an increase of the ploughing effect. A gradient in the hardness of the material was observed after micro-cutting. A systematic study of the influence of the cutting tool edge radius revealed that additional processes inherent to the machining process, namely the build-up of new edges at the tool front, can significantly influence the results of the micro-cutting process.

Ben Salem. S (2012) investigated the effect of cutting parameters on chip formation in orthogonal cutting**.** The cutting parameters influence the morphology of chip. The type and the shape of chip depend directly on the physical and mechanical properties of machined material. As the cutting speed increases, the chips become relatively ductile. Thus, more the cutting speed increases more the chips are segmented microscopically The cutting force necessary to machining is decreased when machining is carried out with a higher cutting speed. This paper proposes some ideas for mathematical models for the cutting force and facilitates the choice of the cutting conditions in case of machining of the tool steel.

2.6 MOTIVATION AND OBJECTIVES OF PROPOSED RESEARCH

2.6.1 Summary of literature survey, research gaps and motivation

The highlights of research work on machinability studies made so far by the way of literature survey is summarised as ahead.

- The work-materials used for evaluating machinability as mentioned in the literature are past old and are meant for some special and specific purpose. Also it is doubtful that these machinability ratings could be duplicated.
- The tests of machinability for such work-materials are typically done by traditional longitudinal cylindrical turning method which is costly to perform, both in time and material consumption.
- The ability to reproduce such tests is possible at high end production/research centres and is impossible in ordinary shop floor conditions.
- Data available for machinability ratings are very disperse, old, do not have a common benchmark and not in line with the current grade of steel.
- Data for comparing and ranking machinability of variety of steels at common benchmark are not readily available either with retailer/end user or supplier. Also the available data is difficult to interpret on the local conditions.
- The study on machinability made so far are very material/process selective and does not take into account the complimentary studies of any other parameters like surface finish, work hardening and chip morphology.

Most researchers have made considerable study on machinability (using turning and milling operations) on specialised material like powder metal steels, tool steels, super alloys etc., for selecting optimum process parameters. There is a need for a simple, logical, easy and convenient procedure which affords industry with an efficient and effective means to evaluate the machinability of the work materials.

Considering the above research gaps as motivation, the work under the generalized title of "Machinability studies on carbon and alloy steels using face turning," has been undertaken for the purpose of research work, where five common grades of steels are taken for the study. This purpose shall provide useful economic machining solutions to fulfill the objectives of knowing in advance the machinability of steels.

Further the study shall demonstrate the technical effectivity of face turning method. The present research deals with the study of machinability of selected carbon and alloy steels (commonly used 5 grades) using face turning method. The face turning method of testing the machinability is cheaper, quicker, easier and reliable method of testing machinability ratings in comparison to the other available methods.

2.6.2 General objectives

Machinability is not a property of the material but an attribute. With this attribute, factors like tool life, cutting speed and surface finish has been taken as general objectives of the research under the title and problem statement of "Machinability studies on the carbon and alloy steel using face turning".

The machinability approach used herein is the machinability ratings in terms of equivalent cutting speeds which cause the stipulated flank wear, V_b-0.3mm, for 60 mins .of tool life (Elso Kuljanic et al. 2010).

The proposed study on the face turning method in the broader sense shall encompass:

- the machinability aspects of steels ranging from low carbon steel to high carbon steel which shall include alloy steels.
- the ability of the current method to detect the effect of slight change in chemical composition, microstructure and mechanical properties on the machinability.
- the effect of change in cutting speeds on : tool wear development and wear mechanisms involved in machining; tool life studies and machinability indices of the work-material; surface roughness of the machined surfaces; work hardening effects caused by face turning and chip morphology.
- the machinability ranking of group of steels varying closely in their chemical constituents namely carbon, chromium, nickel etc.
- the ability of the tested results to repeat and reproduce.

Thus the general objectives shall demonstrate and convince the ability of face turning method as a potential short time method for testing the machinability of carbon and alloy steels.

2.6.3 Specific objectives

The specific objectives for the said research as laid ahead are being undertaken according to some of the guidelines indicated in the International standard ISO-3685: 1993[E] and American Foundry Society (AFS) standard machinability tests.

1) To identify the work-material grade and geometry; tool-material grade and geometry; machining parameters and experimentation resources.

2) To determine the development of tool wear behavior and wear mechanism of the work-material for different cutting speeds by face turning.

3) To investigate the effect of slight change in chemical composition of the work-material by the face turning method

4) To investigate tool life for the work-material at different cutting speeds and establish a tool life curve [Taylor’s curve] and tool life equation model for the work-materials and validate the results.

5) To rank the work-materials according to their machinability tests by face turning operation.