CHAPTER 2

INTRODUCTION

2.1 Surface Finish

Surface finish is one of the essential quality control parameter to ensure that functional surfaces of manufactured parts conform to specified standards. Surface finish of parts can significantly affect their friction, wear, fatigue, corrosion, tightness of contact joints, positioning accuracy, etc. Surface finish is important factor for manufacturing process monitoring and quality control inspection. A change in any part of the production process will result in a change in one or more measurable parameters of the component. Surface finish in particular is very sensitive to changes in production, even alteration in the composition of the material or hardness of surface will be reflected as a change in the texture of the machined component. Tool wear, strains in the material and incorrect machining conditions can all leave their mark measured at the end of the chain of production processes; it is an important control means.

In many engineering applications surface finish is closely allied to function, particularly when the surface of interest is having relative motion with another surface (a function which has been very aptly described as ‘its neighborliness to adjacent surfaces’). One may find enormous engineering applications of mating components that require control of surface finish. Some are listed below.

For efficient lubrication, an oil film of a certain thickness must be maintained on the surface and it is found that the roughness valleys are essential for holding oil. Some parts depend on friction or bonding for their functions. Parts which clamped are held more securely if they are rough, but one cannot make the rule ‘rougher the better’; a push – fit pin must not have excessive roughness because the abrasion resulting from pressing the parts together may seriously impair, or even destroy, the fit. Another application in which the surface finish has been found to have considerable influence on performance is the use of lip seal ( incorporated between the differential housing and brake mechanism on a motor vehicle rear axle) to prevent the escape of hydraulic fluids or lubricants. If the finish of the shaft is too smooth it will be difficult to maintain a fluid film between the shaft and the elastomer seal. On the other
hand if the shaft finish is too rough, it will cause abrasion of the seal and lead to eventual failure. An examination of the surface finish left on many engineering metal surface as a result of a machining operation will often reveal tool or machine defects, incorrect tool setting of faulty operating procedures (such as wrong feed or tool speed). The appearance of a surface is sometimes of importance (cosmetic feature). Sheet steel, for example, is used for decorative surfaces and for motor car bodies and components such as bumpers. It is found that surface finish has considerable influence on the keying of paint and plating, as well as on the evenness of its appearance. Much electrical equipment generates heat which could damage, or even destroy, a component if the heat is not removed. The efficiency with which the heat can be conducted across a junction between two metal surfaces is partly dependent on their texture. The resistance of electrical contacts is also dependent on surface finish. Many materials are formed by rolling, extruding or drawing through a die and any surface imperfections, such as roughness, scratches or wear marks, on the rollers or dies tend to impress corresponding marks on the product. Above examples will serve to show that exploring surface finish has a very practical significance.

Surface finish consideration begins at the design stage, with the designer specifying, wherever necessary, the texture required to give a desired performance – this implies that the designer must have the necessary understanding of surface finish and knowledge of how it is measured. The production engineer must then plan the work so that the machine tools used are capable of producing that finish and, since the finish is almost entirely the result of the machining process, the machine operator should be aware of what surface texture is. The inspector must then – as on of his checks- satisfy himself that the finish is within the tolerance laid down by the designer. This involves measurement.

The measurement of engineering surface finish is becoming increasingly important due to the benefits incorporated with it. The benefits of measuring surface finish with respect to quality and cost-control are as follows:

- The efficiency of the manufacturing process is improved through performance evaluation.
- The number of parts rejected by the customer (scrap) due to inferior surface finish is reduced.
- A part is manufactured with the maximum permissible roughness, thereby reducing manufacturing costs.
- The part quality is enhanced by optimizing surface finish.

There are numerous ways exist to measure a part surface, as well as different methods are available to quantify the measured result. To estimate the nature of surface, surface profilometers and some optical techniques are available. One almost universal method of measurement is stylus instrument. This technique can be found throughout the world, in the laboratory, standard room and workshop. It is accepted as widely used traditional or conventional method to evaluate the nature of the surface. Thus, inspection is normally done through the use of stylus type instruments, which correlate the motion of a diamond-tipped stylus (Figure 2.1) to the roughness of the surface under investigation [1]. A precision diamond stylus is drawn through the surface being detected and the perpendicular motion is amplified electronically as shown in figure 2.2 and figure 2.3. The accuracy of stylus method depends on the radii of diamond tips. When the surface roughness falls below 2.5μm (relatively rough surface), the stylus instruments are affected by large system error [2]. Figures 2.4 and 2.5 show the comparison of profiles measured with different stylus radius. As the surface with deep valleys, the stylus, because of its large tip size, may not able to penetrate fully to the bottom. Stylus instruments, for example, are inherently slow in operation and they yield accurate results and often used for very fine surface off-line measurements. The major disadvantage of using a stylus instrument for such measurements is that it requires direct physical contact which limits the measuring speed and yield scratches on a surface. The surface may be degraded or squashed due to the force imparted by stylus on surface during the measurement. In addition, the instrument readings are based on a limited number of line samplings, which may not represent the real characteristics of the surface. This kind of deviation may cause serious errors in the surface quality assessment especially when the surface profile is periodic. Because of these drawbacks, contact type instruments are not suitable for high-speed automated inspection [1, 2, 3, 4, 5, and 6]. Increasing levels of automation has indeed demanded closer tolerances on even primary manufactured parts like forgings and castings.

Although the conventional measurements of finish, stylus instruments have excellent capabilities and wide range, they are normally used for inspecting machined surfaces of good finish. Further the procedure is a post process approach which is not amenable for automation. Thus, there is a need to look at other procedures for the assessment of medium
Figure 2.1 Diamond stylus tip [11]

Figure 2.2 Stylus tip moves on surface profile [11]

Figure 2.3 Schematic of Piezo – Electrical transducer of stylus instrument [11]
Figure 2.4 Comparison of profiles measured with different stylus radii [11]

Figure 2.5 The use of larger radius stylus reduces the apparent amplitude of closely spaced irregularities (solid line – path traced by 2.5 μm radius stylus and dotted line – path traced by 12.5 μm radius stylus) [12]
finish in shop floor applications which could be automated with ease. In the recent past, higher levels of automation in the shop floor has focused the attention on the application of fast, reliable and cost effective procedures for evaluating surfaces of medium finished parts. This can be done with using a digital image processing technique [4].

A solution to the texture analysis problem will greatly advance the image processing fields and it will also bring much benefit to many applications in the areas of industrial automation and remote sensing. In recent years, with the advent of high-speed general-purpose computers and powerful high speed vision systems, image analysis has become easier, faster and more flexible. Images of surfaces captured using digital image processing method can be used to identify, analyze and quantify surface texture after the implementation of quality improvement algorithms. Unlike the stylus instruments, the digital image processing technique has the advantages of being non-contact and is capable of measuring an area of the surface rather than a single line which makes it a three dimensional evaluation [5].

2.1.1 Average Roughness Parameter (Ra)

The grandfather of all roughness parameter is average roughness, ‘Ra’. In the past, it was known as CLA, Center Line Average in England, or AA, Arithmetic Average in USA. ‘Ra’ can be measured in micrometer (μm) or micro inches (μinch).

The selection of the correct filter parameter (λc, cut off length) is important to the validity of the measurement. Changing the filter cut-off length will normally affect the measured result. The selected filter cut-off length must be at least 2.5 times the peak spacing. This means that at least two peaks and valleys (normally many more) are to be found in each cut-off length. The profile assessed over a length equal to five times the cut-off length to include adequate sample or roughness peaks and valleys. However, the total traverse length is six times the cut-off length as shown in figure 2.6

To calculate the value of average roughness, first of all reference line or datum is to be decided. For practical purpose the reference adopted for most parameters is the center line of the profile (sometimes called the mean line). This is the straight line that runs centrally through the peaks and valleys. Mathematically it is positioned such that, within the sampling length (cut off length), the sum of the area enclosed by the profile above the center line
equals the sum of those below it as shown in figure 2.7. In this figure 2.7, over a length of surface L, the center limit is a line drawn such that the sum of the areas embraced by the surface profile above the line is equal to the sum of those below the line. Areas A, C, E, G, I = Areas B, D, F, H, J, K.

The center line defined by this criterion of equal areas is not unique; there may be many such lines which meet this condition, all differing in slope relative to the profile. Sometimes a different reference line is used, called the least squares mean line. This is line positioned so that the sum of the squares of the deviations of the profile from the line is minimum as shown in figure 2.8, unlike the equal area reference lines do not always coincide, but the difference this makes to parameter values is not very important. The least squares mean line is positioned such that the sum of \( a^2 + b^2 + c^2 + \cdots + n^2 \) is a minimum. Center line is determined graphically from a recorded profile it can be drawn as a straight line. However, when it is determined by instrumental means (e.g. an electric filter) from the electrical waveform representing the profile, the centerline may be curved, but this will not significantly affect the measured result.

The quantity ‘Ra’ is the average deviation of the profile from the mean line. In layman’s terms, ‘Ra’ is the average distance from the profile to the mean line over the length of assessment. ‘Ra’ is determined by the following formula,

\[
Ra = \frac{1}{l_m} \int_0^{l_m} |y(x)| \, dx ; \quad \text{where } l_m = \text{assessment length} = \text{five times the cut off length}
\]

\[
y(x) = y_1, y_2, \ldots ;
\]

\[
\int_0^{l_m} |y(x)| \, dx = y_1 + y_2 + y_3, \ldots
\]

The parameter ‘Ra’ is primarily used to monitor a production process where gradual changes in the surface finish due to cutting tool wear can occur. Because the roughness average is measured, defects in the surface do not influence the measured result, greatly. Therefore an instrument measuring ‘Ra’ will have a higher measuring repeatability than an instrument measuring a parameter sensitive to individual peaks and valleys. The derivation of ‘Ra’ can be graphically illustrate as shown in figures 2.9 and 2.10. The portion of the profile below the
Figure 2.6 Cut-off length ($A_c$) and Transverse length ($l_d$) [11]

Figure 2.7 Derivation of the center line [12]

Figure 2.8 least square mean line [12]
Figure 2.9 Mathematical derivation of $Ra$ [12]

a) Profile with center line

b) lower portion of profile inverted

c) $Ra$ is the mean height of the profile

Figure 2.10 Graphical derivation of $Ra$ [12]

a) Profile with center line

b) lower portion of profile inverted

c) $Ra$ is the mean height of the profile
center line within the sampling length L are inverted and placed above the center line. ‘Ra’ is then the mean height of the resulting profile. Mathematically, ‘Ra’ is the arithmetic average value of the departure of the profile from the center line throughout the sampling length.

2.2 Digital Image Processing

Processing the visual information by computer has been drawing a very significant attention of the researchers over the last few decades. The process of receiving and analyzing visual information by the human species is referred to as sight, perception or understanding. Similarly, the process of receiving and analyzing visual information by digital computer is called digital image processing. Image processing involves changing the nature of an image in order to either improve its pictorial information for human interpretation or render it more suitable for autonomous machine perception. Processing of an image includes improvement in its appearance and efficient representation. So the field consists of not only feature extraction, analysis and recognition of images, but also coding, filtering, enhancement and restoration. The entire process of image processes and analysis starting from the receiving of visual information to the giving out of description of the scene, may be divided into three major stages which are also considered as major sub-areas, and are given below:

i. Discretization and representation: converting visual information into a discrete form; suitable for computer processing; approximating visual information to save storage space as well as time requirement in subsequent processing.

ii. Processing: improving image quality by filtering etc.; compressing data to save storage and channel during transmission.


In the initial stage, the input is a scene (visual information), and the output is corresponding digital image. In the secondary stage, both the input and the output are images where the output is an improved version of the input. And, in the final stage, the input is still an image but the output is a description of the contents of that image.
Image representation and digitization:

The Oxford dictionary defines the word image as the optical appearance of something produced in a mirror or through a lens. Image may be formed by radiant energy and devices. However, optical images are most common and are most important. Amount of light (radiant) energy received at a point of a scene by an observer or by an image sensor varies with direction and distance of that point. Radiant energy is recorded at corresponding points on a plane to form an image. Hence, the brightness and color recorded in an image may be represented as a function of several variables. The simplest kind of intensity (optical) image one can think of is a black and white (B/W) image. These images are most common and are represented by a function of two variables \( g(x,y) \) is the grayness or brightness or intensity of the image at the spatial coordinate \((x,y)\). A multispectral image is a vector-valued function having number of components equal to that of spectral bands and is represented by \([g_1(x,y),
g_2(x,y), \ldots, g_n(x,y)]\) at each \((x,y)\).

As image is represented by infinite numbers of points and that each point contains one of the infinite intensity values and obviously such a representation is not possible in any digital computer. Computer processing of image requires that image be available in digital form. Image digitization includes two steps: sampling and quantization. Digitizing the coordinate values is called sampling and digitizing the amplitude (intensity) values is called quantization. If the function \(f(x,y)\) is sampled (Nyquist criterion of sampling theorem) at a rate equal to a greater than twice its highest frequency, it is possible to recover completely the original function from its samples. Thus a continuous image is digitized at sampling points which called pixels. A pixel represents the elemental part of an image. Each matrix element represented by one of the finite set of discrete values known as quantization. Number of gray levels typically is an integer power of 2. The result of sampling and quantization is a matrix of real numbers.

Thus, a digital image consists of picture elements with finite size – these pixels carry information about the brightness of a particular location in the image.
2.2.1 **Fundamental Steps in Digital Image Processing**

Fundamental steps in digital image processing shown in Fig. 2.6 are Image acquisition, Image enhancement (pre processing), Segmentation, Representation and description and last one is Recognition. It does not imply that every step is applied to an image. According to different purposes for different applications, suitable steps are to be chosen.

**Image Acquisition:**

The first step in the process is image acquisition – that is, to acquire a digital image. To do so it requires an imaging sensor and the capability to digitize the signal produced by the sensor. This can be done using either a CCD camera or a scanner. CCD stands for “charge – coupled device”. This is an array of light sensitive cells called “photosites” each of which produces a voltage proportional to the intensity of light falling on them. In CCD sensors, every pixel's charge is transferred through just one output node to be converted to voltage, buffered, and sent off chip as an analog signal. Colors are obtained by the use of red, green and blue filters. While in CMOS (Complementary Metal Oxide Semiconductor) sensor, each pixel has its own charge – to – voltage conversion. CCD are used in most digital cameras as they produce very good results, can be made with high resolution and are robust against noise. CMOS chips have the advantage of being cheaper to produce and require less power to run than a CCD chip; however they are more susceptible to noise.

**Preprocessing:**

After obtaining digital image, the next step deals with preprocessing that image. The key function of preprocessing is to improve the image in ways that increase the chances for success of the other processes. Typically contrast enhancement and adjustment, filtering to remove noise and improve quality and correction for sensor distortion may all be desirable during this stage. These operations only change the pixel values of the digitized image within the frame store, or subsequent display memory, and do not seek to make any fundamental change in the information content of the captured image. It has already said that use of digital preprocessing techniques is for image improvement. Image improvement is a term coined to
Image enhancement:

The enhancement techniques can be divided into three categories: 1. Contrast intensification 2. Noise-cleaning or smoothing and 3. Edge sharpening or crispening.

1. Contrast intensification: One of the most common defects found in the recorded image is its poor contrast. This degradation may be caused by inadequate lighting, aperture size, shutter speed and/or non-linear mapping of the image intensity. The effect of such defects is reflected on the range and shape of the graylevel histogram of the recorded image. In this case, the contrast can be improved by scaling the graylevel of each pixel, so that image graylevel occupy entire dynamic range available. The operation may be called histogram stretching, since the graylevel histogram reveals the overall appearance of the image.
2. Smoothing: Smoothing operation is used primarily to diminish the effect of spurious noise and to blur the false contours that may be present in a digital image. These unwanted effects may be due to detection and recording error or transmission channel noise or digitization error or some combination of these factors. During removal of noise, smoothing techniques may degrade the sharp important details. Smoothing algorithms have been developed in both spatial domain and frequency domain.

3. Image sharpening: The image degradation generally involves blurring. Being an integration operation blurring attenuates high spatial frequency components which suggest that observed/recoded image can be enhanced by differentiation in spatial domain.

Restoration:

One of the major application areas of image processing techniques is improving the quality of recorded images. No imaging system gives images of perfect quality because of degradations caused by various reasons. So, the image needs to be restored for subsequent computer processing and/or human viewing. Image restoration technique deals with those images that have been recorded in the presence of one or more sources of degradation. The restoration technique can be defined as the estimation of the original image or ideal image from the observed one by the effective inversion of degradation phenomena through which the scene was imaged. This technique requires the knowledge of the degradation phenomena.

Image compression:

Users of digital image processing techniques usually have to handle a large volume of data. Storing image data for future use needs large storage space. Similarly transmitting image data in reasonable time needs wide channel capacity. To reduce these requirements the technique we use is called data compression. So, compression techniques represent (almost) same pictorial information in a more compact form by removing redundancies. In essence, compression techniques represent image data using fewer bits than what is required for original image.
Image Segmentation:

Segmentation can broadly defined as partition or broken up an input image into meaningful regions or segments. Image segmentation refers to the process of partitioning an image into groups of pixels which are homogeneous with respect to some criterion. Different groups must not intersect each other, and adjacent groups must be heterogeneous. Segmentation algorithms are area oriented instead of pixel oriented. Image segmentation can be performed in three different approaches which are (i) region approach (ii) boundary approach, and (iii) edge approach. Region growing is an approach to image segmentation in which neighboring pixels are examined and added to region class if no edges are detected. Region splitting is a top-down approach and it begins with a whole image and divides it up such that the segregated parts are more homogenous than the whole. An image can be segmented by the thresholding operation in which a histogram of the image can be used as a tool to select the threshold value. Edges are basically discontinuities in the image intensity due to changes in the image structure. Among Robert, Prewitt, Sobel kernels any one can be used to detect the edges in an image.

Representation and Description:

After an image has been segmented into regions, the resulting aggregate of segmented pixels usually is represented and described in a form suitable for further computer processing. Basically, representing a region involves two choices (1) The regions can be represented in terms of its internal characteristics (the pixel comprising the region, such as texture or skeletal shape). (2) The regions can be represented in terms of its external shape characteristics (its boundary, corners etc.). The next task is to describe the region based on the chosen representation. For example, a region may be represented by its boundary, and the boundary described by features such as its length, the orientation of the straight line joining its extreme points, and the number of concavities in the boundary.

Recognition:

Object recognition deals with the recognition of the patterns in an image. Object recognition is the study of how machines can observe the environment, learn to distinguish patterns of interest and make reasonable decisions about the categories of patterns. An
attempt to develop a machine to mimic human capability is the starting point of object recognition. As the number of expected targets becomes larger and larger, it becomes difficult for a human observer to identify an object from images of poor quality. Hence, there is a need to develop a knowledge-based recognition system. Different approaches to pattern recognition include statistical approach, structural approach and neural network approach.

2.2.2 Applications of Digital Image Processing

Digital image processing techniques are used in a variety of fields. Many application oriented image analyzers are available and are working satisfactorily in real environment. The following are a few major application areas:

1. Industrial machine vision applications: Industrial applications of machine vision include measurement and gauging, integrity check and quality control, process control and parts identification.

   - Measurement and gauging
     - Measurement of belt width
     - Measurement of tool wears
     - Analysis of crack formation
     - Gauging of spark plug

   - Integrity checking and quality control
     - Safety – critical inspection
     - Inspection of automotive valve spring assemblies
     - Checking correct printing of a lot code
     - Surface quality inspection
     - Paint finish assessment
     - Inspection of machined components
     - Visual inspection of printed – circuit board

   - Process control
     - Controls of flatness in float glass manufacture
     - Eliminate surface defects in photographic film
Fiber analysis in wood panel industry

- Parts identification
  - Robotic guidance and control
  - Identification of car bodies by outline
  - Sorting of automotive casting
  - Classification of automotive axels prior to spray painting
  - Inspection while manufacturing integrated circuit
  - Automatic decoration of chocolates
  - Sorting of fish by species, size determination and inspection
  - Automatic wafer inspection

2. Remote sensing: Natural resources survey and management; estimation related to agriculture, hydrology, forestry, mineralogy; urban planning; environment and pollution control; cartography, registration of satellite images with terrain maps; monitoring traffic along roads, docks and airfields.

3. Bio-medical: ECG, EEG, EMG analysis; cytological, histological and stereological applications; automated radiology and pathology; X-ray image analysis; mass screening of medical images such as chromosome slides for detection of various diseases, mammograms, cancer smears; CAT, MRI and other tomographic images; routine screening of plant samples; 3-D reconstruction and analysis etc.

4. Scientific applications: High energy physics; bubble chamber and other forms of track analysis; etc.

5. Criminology: Human faces recognition and matching; finger print identification; forensic investigation; etc.

6. Military applications: Missile guidance and detection; target identification; navigation of pilot less vehicle; reconnaissance; and range finding; etc.

7. Astronomy and space applications: Restoration of images suffering from geometric and photometric distortions; computing close-up picture of planetary surfaces; etc.
8. Meteorology: Short term weather forecasting, long term climatic change detection from satellite and other remote sensing data; cloud pattern analysis; etc.

9. Printing and graphic arts: Color fidelity in desktop publishing; art conservation and dissemination; etc.

10. Information technology: Facsimile image transmission, videotext; video conferencing and videophones; etc.

11. Office automation: Optical character recognition; document processing; cursive script recognition; logo and icon recognition; identification of address area on envelope; etc.

2.3 Advantages of Digital Image Processing over Conventional Stylus Instrument

Digital image processing method has grabbed all attention due to advent of automation and non contact type technique. It has the following advantages over the widely used stylus type surface roughness tester.

❖ Image processing technique can be incorporated in a manufacturing line where in hundred percent online inspection in real time is possible. Image processing inspection can also reveal surface defects such as cracks, notches, etc, apart from surface characteristics.

❖ Image processing technique for surface quantification is a non physical contact method and no force is applied to the surface under inspection. This method does not leave any scratches or marks on the inspected object, so it is not a destructive testing like stylus method. It does not degrade the surface of inspecting object.

❖ No possibility of large system error like stylus instrument in which diamond tip radius of probe cannot drop far into a smaller gap of valleys of surface less than 2.54 μm.
Unlike the stylus instrument, the image processing technique is capable of measuring an area of the surface rather than a single line which makes it a three dimensional evaluation.

This system can be operated and controlled from a remote location. PC based image process technique is considered relatively inexpensive when compared to other inspection equipment that measure fine surface finish. By changing the system software the same image process technique can be used for other inspection tasks.

2.4 Composites

Composites are an important class of materials available to humankind. Its study by metallurgists, material scientists, mechanical, civil and chemical engineers become paramount for using them on a large scale in engineering and other applications. The field is so vast that it is truly an interdisciplinary subject in nature and overlaps many areas of metals, ceramics, polymers, etc. Composites are natural as well as artificial. Natural composites are as old as creation itself. Modern composite materials had a beginning in the 1930's from then on the progress have been rapid and phenomenal. In recent years its study has assumed a lot of importance.

Composites offer several outstanding properties as compared to conventional materials. Composite is a material formed by a combination of two or more chemically distinct and insoluble phases whose properties and structural performance are superior to those of the constituents acting independently.

Composite is the result of the combination of a reinforcement (such as fibers or particles) supported by a binder (matrix) material (the continuous phase in the composite). The matrix has three functions:

a) Support and transfer the stresses to the fibers, which carry most of the load.

b) Protect the fibers against physical damage and the environment.

c) Reduce propagation of cracks in the composite by virtue of the ductility and toughness of the matrix.
According to the matrix, composites are classified as metal matrix, polymer matrix, metallic matrix and intermetallic matrix composites. The purpose of reinforcements is different for different matrices. Metal matrices are reinforced with fiber chiefly to improve their high temperature strength. Polymers are reinforced normally to increase stiffness and strength while ceramic and intermetallic matrices are reinforced mainly to increase the fracture toughness. Although the term matrix has the connotation of being the greater amount of material, it may in fact have the lesser volume fraction. In fact the matrix needs only to wet and form a continuous phase around the reinforcement. The composite performance is influenced by the following matrix properties:

- Elastic constant
- Yield and ultimate strength under tension, compression or shear
- Failure strain of ductility
- Fracture toughness
- Resistance to chemicals and moisture
- Thermal and oxidative stability

One of the most advanced and promising engineering materials is the carbon fiber reinforced carbon – matrix composite, often termed a carbon – carbon composite, as the name implies, both reinforcement and matrix are carbon. These materials are relatively new and expensive. Their desirable properties include high – tensile moduli, tensile strength retained at temperatures in excess of 2000° C, creep resistance, and relatively large fracture toughness values. Furthermore carbon – carbon composites have low coefficients of thermal expansion and relatively high thermal conductivities coupled with high strengths give rise to relatively low susceptibility to thermal shocks. A major draw back of these materials is their propensity to high temperature oxidation.

In addition, they are also classified according to the form of the reinforcement such as particulate, fiber, and laminar composite. For most of the applications the reinforcements has a higher strength and modulus than the matrix. A particulate composite is one in which the ‘particulate’ reinforcement has roughly equal dimensions in all directions. Thus, particles may be rods, spheres, flakes, and many others shape whose aspect ratios (ratio of length to the cross – sectional dimensions) are about one. In these composites, the size, shape, and distribution, in addition to the amount and modulus of the particles affect the composite
properties. Smaller sizes and also more round shapes are usually better. Uniform distribution of the particles should be strived for, in metals and crystalline ceramics, whereas the particles must not be along the grain boundaries.

A fiber composite is one in which the reinforcements have aspect ratios much greater than one. Fiber composites are further classified according to (1) discontinuous or short fiber composites, and (2) continuous fiber reinforced composites. In discontinuous or short fiber composites the properties vary with the length of the fiber. When the length of the fiber is such that any further increase in length no longer increases the modulus of the composite, then the composite is continuous fiber reinforced. Most continuous fiber composites have, in fact, fiber lengths comparable to the overall dimensions of the component or structure.

Laminar composites are composed of at least two layers of materials (one for each constituent), whose two dimensions are much larger than the third. For example, plywood is a laminated composite that is made by bonding together several sheets of discontinuous or continuous fiber composites.

Applications:

Composites are widely used in both military and civilian industries. They are used in the manufacture of a variety of products ranging from aircraft, spacecraft, satellites, missiles and rockets, to sports goods, marine equipments and automobile components. Composites can be designed and fabricated to obtain various properties that suit specific applications.

2.5 Carbon – Carbon Composites

The development of high – tech materials aims at meeting the specific technological requirements of the modern society. In the last century, new types of metallic, ceramic and polymeric materials have been developed in the context of advances in aerospace, aeronautical, nuclear, and chemical industries. Among them, carbon – carbon composites are one of the most promising and advanced high temperature engineering materials. Carbon – carbon composites rank first among composite materials with a spectrum of properties and applications in various sectors. As the name implies, both reinforcement and matrix are carbon, i.e. carbon fibers reinforced in carbon matrix system. Some of the most important and
useful properties of carbon – carbon composites are light weight, high strength at high temperature (3000 °C) in non-oxidizing atmospheres, low coefficient of thermal expansion, high thermal conductivity (higher than that of copper and silver), high thermal shock resistance and low recession in high pressure ablation environments. The mechanical strength of carbon – carbon composites increase with temperature, in contrast to the strength of metal and ceramics, which decrease with increasing temperature. These extraordinary properties of carbon – carbon composites have made these materials extremely useful for aerospace and defense applications such as brake discs, rocket nozzles, leading edges of re-entry vehicles, furnace heating, thermal management components in space vehicles, etc. to those for common man as biomedical implants, glass and high temperature glass and ceramic industry, etc. In the American space shuttle, wherein the fuselage nose and the leading edge of the wings are manufactured from carbon – carbon composites and have withstood a total of 100 missions under the extreme re-entry condition (Kochendorfer 2001). A national programme has been launched in India for indigenous development of carbon – carbon composite and related technologies. These composites have been successfully developed and used as nose – tip for the Agni missile and as brake pads for LCA.

2.5.1 Carbon Concept

Carbon is truly remarkable element existing as four allotropes, diamond, graphite, carbines and fullerenes, each having significant scientific and technological importance. Its most abundant allotrope, graphite, can take many forms with respect to microstructure, amorphous to highly crystalline structure, highly dense with density 2.2 g / cm³ to highly porous with density 0.5 g / cm³ and different shapes. These types of graphite are called synthetic carbon and in technical terms, engineered carbons. Examples are cokes, graphite electrodes, mechanical carbons, glassy carbons, carbon black, porous carbons, activated carbons, carbon fibers and composite etc.

Solid carbons are preferred for structural applications under extreme environmental conditions of temperature or corrosion (liquid as well as gaseous), etc. This is mainly because, theoretically, carbon materials with covalently bonded atoms possess very high specific strengths (40 – 50 GPa) and retain this strength at high temperatures in the temperature range over 1500 °C. However, the normal bulk synthetic graphite exhibits less than 2 % of the theoretical strength. Carbon fibers are a few microns thick, light weight, very
strong and stiff black synthetic fibers with long aromatic molecular chains comprising mainly carbon. These fibers are capable of maintaining their structure and properties under extreme conditions of temperature and pressure and therefore can be used with all types of matrices, polymer, ceramic and metal, employing different composite processing techniques. Over the past three decades, carbon fibers have proved to be the main reinforcement for advanced composites for a wide range of applications. Interest in carbon fibers as reinforcement for composites for structural applications started with the demand from the aeronautical sector for light weight, strong and stiff material. Subsequently its application extended to civilian sector, especially in sports goods and biomedical sectors. Though major consumption of carbon fibers is for polymer matrix composites, there are the only choice materials for special application high temperature composites with specific high thermal and thermo – mechanical properties. This kept alive the interest in carbon and carbon fiber research.

Though it has many industrial applications and attractive properties, graphite is mechanically weak. Typically the tensile strength of high – grade polycrystalline graphite at room temperature is of the order of 35MPa compared to 135MPa for cast iron. At 2500 °C the tensile strength of graphite increases to 55MPa whereas most metals would have melted. Hence, in order to take advantage of its thermal capability in structural requirements it demands massive sections to cope with the loads. The compressive strength of graphite is typically 90MPa at room temperature, whereas 180MPa at 2500 °C, so structural designs must be unconventional to take advantage of the higher compressive strength. Graphite is used in conjunction with a strong and heavy structural material, such as steel, to give mechanical support. These mechanical advantages are especially evident in aerospace uses of graphite where its low density, high heat of ablation, and excellent thermal resistance are otherwise valuable.

The development of carbon fibers started in the late 19th century. Over the years the carbon fiber manufacturing technology grew and today we have high performance carbon fibers economically produced from polycrylonitirle (PAN) precursor fibers. The processes use to produce fiber involve first the stretching of the PAN precursor fiber to orient the polymer molecules parallel to the fiber axis and then stabilizing this oriented structure under tension in an oxidizing environment. Finally, after stabilization the fibers are heat treated at high temperatures, ranging from 1000 °C to 3000 °C, in an inert environment. Since PAN based carbon fibers are non – graphitizing, the potential is less for improving certain
properties like tensile modulus and thermal conductivity. This resulted in the development of pitch based carbon fibers having the tensile modulus as high as 850 GPa, a very close to the theoretical modulus.

2.5.2 Carbon – Carbon Composite Concept

Carbon – carbon composites are a generic class of synthetic, pure carbon materials consisting of carbon fibers reinforced in a carbon matrix. Basically, these composites are made of fibers in various directions and carbonaceous polymers and hydrocarbons as matrix precursors. Their density and properties depend on the type and volume fraction of reinforcement, matrix precursors used and end heat treatment temperature. Composites made with thermosetting resins as matrix precursors possess low densities (1.55 – 1.75 g / cm$^3$) and well – distributed micro porosity whereas those made with pitch as the matrix precursor, after densification exhibit densities of 1.8 – 2.0 g / cm$^3$ with some mesopores, and those made by the CVD (Chemical Vapor Deposition) technique with hydrocarbon gases, possess intermediate densities and matrices with close porosities. The former (resin based) composites exhibit high flexural strength, low toughness and low thermal conductivity, whereas the latter (pitch and CVD based) can be made with very high thermal conductivity (400 – 700 W/MK) in the fiber direction. Carbon – carbon composites, which are first introduced in the late 1950s, were only used as an ablative material until the late 1960. Thereafter these were used in space shuttle programs. Carbon – carbon composites are used in a variety of sectors requiring high mechanical properties at elevated temperatures, good frictional properties for brake pads in high speed vehicles or high thermal conductivity for thermal management applications. However, for extended life applications, these composites need to be protected against oxidation either through matrix modifications with Si, Zr, Hf, etc. or by multilayer oxidation protection coatings consisting of SiC, silica, zircon, etc.

2.5.3 Processing of Carbon – Carbon Composites

Like carbon, carbon – carbon composites can also be manufactured by using different techniques such as all solid pyrolysis (chemical decomposition by heat in the absence of oxygen) using thermosetting resins, or pitch route using liquid infiltration carbonization route or CVD (Chemical Vapor Deposition) route. Fabrication method of carbon – carbon composites involve fabrication of three dimensional or multi dimensional porous carbon fiber
performs having the desired shape or a porous carbon – carbon skeleton with carbon fibers and a carbonaceous matrix followed by their densification. The densification can be achieved through vapor phase infiltration wherein the hydrocarbon gases such as methane, propane, etc. infiltrate into porous fibrous structure heated to temperature of 1000 – 1400 °C and are made to crack therein. Commercially, isothermally heated stack of components are impregnated simultaneously in a large size furnace. Principally, the gases should infiltrate into the pores and interfilamentary spaces and then crack. But these gases have a tendency to crack at the outer surface itself which blocks the passages and causes closed pores. In order to have dense composites, the surfaces are ground and the components are reinfiltrated. CVD is a very slow process and it takes month together to get dense carbon – carbon composites. Porous structures can also be impregnated with liquid phase pitch/phenolic resin followed by carbonization and high temperature heat treatment (1000 – 2700 °C). Pyrolysis of the pitch/resin matrix can be done under normal pressure or under high pressure. Depending on the densification approach, two or more densification cycles are required to get the desired density.

2.5.4 Properties of Carbon – Carbon Composites

Carbon – carbon composites in the true sense, cover a large range of materials with the targeted properties. The properties of interest are strength and stiffness, fracture toughness, frictional properties, thermal conductivity and resistance to oxidation at high temperatures. The mechanical properties of the constituents and their volume fraction, bonding, and crack propagation mechanism control the mechanical properties of the composites, whereas thermal properties are governed by thermal transport phenomena. Moreover, the constituents, both reinforcement and matrix, are likely to undergo a change in properties during processing as influenced by heat treatment temperature, differential dimensional changes, thermal stresses etc. All these factors influence the ultimate properties of the composites.

2.5.4.1 Mechanical Properties of Carbon – Carbon Composites

The strength and fracture of carbon – carbon composites are governed by Cook – Gorden theory for strengthening of brittle solids, which states that if the ratio of the adhesive strength of the interface to the cohesive strength of the solid is in the right range, a large
increase in strength and toughness otherwise brittle material is achieved. Composites with strong fiber/matrix bonding fail catastrophically without fiber pull-out while those with controlled interface fail in mixed tensile cum shear mode exhibiting high strength. Fracture modes and the strengths of different types of carbon-carbon composites are affected by processing temperature. Mechanical properties of the composites are dependent on the fiber architecture and the direction of the measurement of the properties with respect to fiber orientation. These composites exhibit a range of high fracture toughness (20 – 100 Nm m\(^{3/2}\)) and good creep and fatigue resistance. When subjected to high temperature testing, carbon-carbon composites have been found to exhibit about 10 – 20 % increase in mechanical properties at 2000 °C under inert atmosphere. However, in air, the properties drop down to 10 – 20 % depending on the temperature and time i.e. the weight loss. Carbon is a stable and highly used material for nuclear applications. So is carbon-carbon composites. Under neutron irradiation at low fluence levels of 10\(^{21}\) n / cm\(^2\), these composites exhibit an increase in strength and fracture toughness by 20 – 30 % and Young’s modulus by about 30%.

2.5.4.2 Thermal Properties of Carbon-Carbon Composites

Carbon-carbon composites being of heterogeneous structure consisting of fibers, matrix and pores, with the first two having a variety of microstructures, estimation of their thermal transport properties becomes complex. However, carbon-carbon materials with tailored thermal conductivities can be fabricated by proper choice of constituents, their configuration, and processing conditions. Composites having highly oriented graphitic fibers or matrices or their combination, like vapor-grown carbon fibers and matrix or mesophase pitch-based carbon fibers and matrix, exhibit very high thermal conductivities of the order of 250 – 350 W/MK in the fiber direction. Though these composites exhibit highly anisotropic character and low conductivities in transverse directions, there is always scope of improvement by varying the fiber architecture and their addition in different forms and ways. Coefficient of thermal expansion of the composites is dictated largely by the fiber orientation. It is 0 -1 ppm / °C in the fiber direction and 6 – 8 ppm / °C in a direction perpendicular to the fibers.
2.5.4.3 **Frictional Properties of Carbon – Carbon Composites**

Carbon – carbon composites have widened the scope of applications of carbon based materials in wear related applications from bearing seals and electrical brushes to brake pads for heavy duty vehicles such as military, supersonic and civilian aircrafts to trucks and railways. This has been due to basic tribological properties of carbon with additional high strength and thermal conductivity contribution from the reinforcing fibers. Carbon – carbon composites exhibit low coefficient of friction $\mu$ in the fiber direction (0.3 – 0.5) and (0.5 – 0.8) in the perpendicular direction. Wear rates follow similar trends (0.05 – 0.1) and (0.1 – 0.3 mm). The friction and wear mechanism of carbon – carbon composites on application of brakes is quite complex and various factors like peak temperature, formation of debris and films on sliding surfaces further effect the coefficient of friction etc.

In general, for fabricating brake discs for different vehicles, different types of fibers (PAN and pitch based strength and high thermal conductivity) are used in a number of configurations, either alone or in combinations with carbon matrix derived from different type of precursor, pitch or CVD. In commercial carbon – carbon brake pads, carbon fiber fabric plies are with fiber tows inserted in the direction and pitch / CVD route for densification. However, choice of the constituents and processing parameters is at the discretion of the manufactures.

2.5.5 **Oxidation Protection of Carbon – Carbon Composites**

Carbon is prone to reaction with oxygen at temperature of 450 °C and above. For long time application of these composites at elevated temperature in a normal environment, it is essential that these composites be protected against oxidation. Therefore studies on oxidation protection of carbon – carbon composites are as important as the developments of the composites themselves. Oxidation protection systems for carbon – carbon composites are based on (i) modification of matrix through addition of some oxidation inhibitors (like B, Si, Zr or their compounds) or / and (ii) deposition of ceramic coatings on the surface. These coatings are generally multilayer coatings of functionally gradient materials of carbides, nitrides and oxides of Si, Zr, Ta, Al, etc.
2.5.6 Applications of Carbon – Carbon Composites

Carbon – carbon composites as brake discs

The development of high-speed large-capacity aircrafts not only require improved aero engines but also necessitates the development of aircraft braking systems made of light weight materials with a smooth frictional behavior capable of withstanding high temperature. This is particularly important for aborted takeoffs of large inertia planes. During aborted takeoffs the temperature of the frictional surface may rise to more than 2000° C in about 20 s. The conventional steel disk brakes, if successful in stopping the aircraft in an emergency are likely to get destroyed by warping or melting due to the intense heat generated during the stop.

Carbon-carbon composites which are stable at high temperatures and have excellent friction and wear characteristics are the obvious solution to this problem. Carbon-carbon brake materials have a density of about one-fourth of steel-cermet brakes and more than twice the heat capacity. These physical characteristics along with the frictional and thermal superiority of carbon-carbon composites provide them with nearly four times the stopping power of copper or steel brakes. Airbus A320 can operate 2500 landings per overhaul with C-C brakes (figure 2.12) as compared with 1500 landings per overhaul with metal brakes.

Since there has been continuous research and development going on to further reduce the weight and improve performance. As a result, at present almost all military aircrafts such as the USF.14,F.15,F.16,F.18,and French Mirage 2000, as well as commercial aircrafts such as Boeing 747, Airbus , Concorde, Canadair challenger, and Gulfstream III have employed carbon-carbon composites as brake disk materials. The potential for significant growth in C-C brakes is further underlined by the interest shown by manufactures of racing cars, heavy duty surface transport systems and passenger cars in utilizing C-C in their advanced automotive braking systems. For surface transport systems, the temperature required for brake operation is quite low (400°C-600°C), and therefore relatively cheap designs and normal processing methods of two dimensional C-C composites can be utilized for such applications.
The aerospace field continues to be one of the primary areas of application of C-C composites. The classic examples are the thermal protection system of space shuttles, rocket nozzles, exit cones, and nose tips (figure 2.14) of re-entry vehicles etc. The utility of C-C composites in space shuttle program as wing leading edges (figure 2.13) and nose caps, which during re-entry operations may encounter temperatures close to 2000° C, this is well beyond the operation temperature of metals. Each orbiter wing contains 22 leading edge C-C airfoil panels and 22 sealing strips of C-C. The nose cap is around 140 cm in diameter. These components provide thermal protection to the instrumentation from the searing heat of re-entry and maintain structural integrity over multiple missions, especially under conditions of subzero temperatures in outer space to close to 1700° C during entry into the atmosphere. In addition to the space shuttles, all American and European strategic nuclear missiles employ C-C nose cones and heat shields.

C-C composites for such applications are required to possess high thermal conductivity and high specific heat so that the component operates as a heat sink, absorbing the heat flux without any problem. The porosity should be low and uniform so as to have a uniform low ablation/erosion.

Other components used for aircraft industries are gas rudders and thrust deflectors for military aircrafts and expansion nozzle of a hypersonic propulsion unit. In rocket motors with a solid propellant system, the throat and exit cone (figure 2.15 and 2.15) are made of C-C composites. The exhaust gases from the propellant chamber pass out through the throat and then finally out through the exit cone.

Aeroengine and turbine components

The efficiency of heat engines is greatly improved by operating them at high temperatures, permitting high combustions. The choice of C-C composites in jet engine rotors and stators offers the possibility of operating at temperatures well in excess of 500°-600° C higher than those used in conventional engines with high temperature alloys. Furthermore, the use of C-C composites results in a significant reduction in weight and reduced engine size and fuel consumption.
Figure 2.12 C/C composite brake disks for aircraft

Figure 2.13 C/C leading edge

Figure 2.14 C/C nose tip
Concerted efforts are being made in the USA and Europe to develop turbine components using C-C composites. The basis of this development is the utilization of the high tensile strength of the fiber materials, which allows the compensation of the centrifugal stress on the blades. This in turn, subjects the blades to additional compressive pre-stresses. It has developed various C-C jet engine components which include turbine wheels, combustion chambers, and exhaust nozzles.

Diesel engine components

Piston-driven engines such as diesel engines can also operate with increased efficiency and reduced weight if cooling requirements are minimized through the use of materials which function efficiently at high temperatures. C-C is currently being evaluated for many such applications. The components for which C-C materials may potentially be used include piston crowns, valves, cylinder liners, and connecting rods. C-C pistons have a lower density than the conventional aluminum light weight piston. Moreover, with the latter pistons, because of the advantageous low coefficient of thermal expansion of C-C composites, the piston to cylinder wall clearance can be kept very low so that piston rings and skirts are not necessary. The efficiency of adiabatic diesel engine can be enhanced to approximately 48% thermal efficiency by increasing the operating temperature to about 1100°C from about 300°C for a basic diesel engine. This is feasible with C-C composites only.

Refractory materials

It is well known that polygranular carbon and graphite materials are refractory materials par excellence in a nonoxidizing environment. With carbon fiber reinforcement, the mechanical properties of these carbon refractories can be further improved, thereby opening up new fields of industrial applications. Instead of thick walled fine-grained polycrystalline graphite in die manufacturing, thin walled C-C composite dies is utilized to withstand repeated applications. One interesting and innovative use is the metallurgical hot forging process in the superplastic stage. The air inlet channels of the European JF90 are made from high temperature titanium alloys having superplasticity at about 1000°C. The hot forming is performed by a simple blowing up of tubes that are closed at one end. The mould is made of
two dimensional C-C composites. C-C tool segments, pressure plates, and resistance elements use as reusable moulds for cobalt-based products and hot sintering applications.

C-C bolts, screws, nuts, and washers (figure 2.17) are used where high temperatures and severe chemical conditions are present. The strength and stiffness at high temperatures guarantees high fastening stability. The systems made of C-C composites are self-fastening at high temperatures. These parts are used in the semiconductor industry in furnace construction, and in other high temperature apparatus and equipments such as (figure 2.18) liners, plates, crucibles sleeves, and other auxiliary aids. C-C composites are also used as heating elements, especially if extreme conditions of mechanical properties and temperature distribution are required together. Other commercial applications include sintering trays (figure 2.19) for carbonizing and carbiding furnaces.

Carbon and graphite is not wetted by molten glass. Additionally, C-C composites possess a higher thermal shock resistance and impact toughness, and their porosity and thermal conductivity may be controlled; hence, there is no impairment of glass surfaces. Therefore, C-C materials are used in various parts of glass-container-forming machines. They are used in channeling systems to carry the gobbets of molten glass, as molds for crystal glass products, and as an asbestos replacement for hot end glass contact elements for moving hot glassware articles.

Carbon – carbon composites for use at intermediate temperature

C-C materials, having high thermal and electrical conductivities and resistance to most chemicals, are used as electrodes and other structural components in fuel cells. C-C composites are the materials of choice even for vanes for rotary vane compressors and vacuum pumps.

C-C composites may be preferred for nuclear waste storage containers. They may be used on laser shields to protect space based satellite systems from the heat of high powered laser beams.
Figure 2.15 Convergent – divergent nozzle for solid rocket motor

Figure 2.16 C/C integral nozzle throat and exit cone

Figure 2.17 C/C fasteners [22]
Figure 2.18 C/C liners and plates [22]

Figure 2.19 C/C sintering tray [22]
Carbon – carbon components for chemical process

Elemental carbon, because of its exceptional purity and its complete inertness in acid, alkaline, and salt solutions and in organic solvents, is one of the most corrosion-resistant materials. Synthetic granular carbon is used in many chemical industries, in particular, as heat exchangers. C-C packings are highly effective for separation columns used to separate liquid mixtures in distillation rectification plants. They are also used as stirrers, feed pipes, support grids, filter plates, and thin-walled heat exchangers.

Carbon – carbon composites as biocompatible materials

Elemental carbon is considered to be the most biocompatible of all known materials. It is compatible with blood, soft tissues, and bones, as is evidenced by the successful replacement of ligaments with carbon fibers in human's knees and ankles. The biomedical applications of carbon fibers in combination with carbon matrix are utilized for bone plates in osteosynthesis and as endoprostheses to replace conventional steel plates which have a modulus and order of magnitude higher than that of bone.

For a normal healthy person, maximum tensile stresses on the femur during walking have been estimated to be about 50-60 MPa in the longitudinal direction and are expected to undergo over $10^{12}$ load cycles per year. General-grade C-C composites typically exhibit two to three times the tensile strength estimated for the femur neck and almost a negligible loss in mechanical properties even after $10^7$ cycles at 90% of the original stress. The major advantage of such implants is the cementless fixation of the stem within the femur. The high impact properties of C-C composites together with their biocompatibility render these materials suitable for use as heart components.

2.6 Conventional Machining of Composites

Though superior to conventional materials in physical properties, composites pose certain difficulties in attaining acceptable machined edges and drilled holes. Machining and drilling success is fiber related and totally independent of composite material matrix.
Though, most composite structures are fabricated to near net shape, assembling of them requires machining. The most useful machining technique is trimming operation, including the method, cutting tools and speeds to obtain the final shape and configuration of cured composite parts, using circular saws, router cutters, and abrasive tools. Hole generation is a major activity in the manufacture of structural assemblies of aircraft. The quality of holes is critical to the life of the fastened joints. Hole characteristics such as waviness/roughness or lack of axial straightness and roundness, can cause stress concentration at the fastener assemblies, leading to premature failure.

Machining with solid tools using conventional machining methods can develop the following flaws:

1) Surface delamination: Separation of plies where the cutter enters and exits the material.
2) Internal delamination: Separation that develops between plies as a result of improper machining and drilling.
3) Fiber/resin pullout: Tearing away of fiber or resin from the wall of the machined edges or drilled hole.
4) Splintering

In addition to these manufacturing problems excessive tool wear is a problem to be reckoned with. To minimize this effect cutting tools made of tungsten carbide or diamond can be used but require precise coordination of feed rates and speed to achieve high productivity and quality parts.

2.7 Non-Conventional Machining

Human race always produced products that serve to make life easier and more enjoyable by using tools and intelligence. Through the centuries both the tools and the energy sources to power these tools have evolved to meet the increasing sophistication and complexity of mankind’s ideas.

The twentieth century has seen the creation of products made from the most durable and consequently, the most un-machinable materials in history. In an effort to meet the manufacturing challenges created by these materials, tools have now evolved to include such
as alloy steel, carbide, diamond, and ceramics. A similar evolution has taken place with the power sources and machine tool technologies as well. Newer machines with greater accuracies, faster machining rates, and efficiencies are available. Moreover, newer manufacturing processes known as nontraditional processes, suitable for material removal, forming and joining are also introduced in order to meet the challenges raised by the difficult to machine materials.

Conventional manufacturing primarily rely on electric motors and hard tool materials to perform tasks such as drilling, turning, milling, etc. Conventional forming operations are performed with the energy from electrical motors, hydraulic, and gravity. Similarly, material – joining processes are conventionally accomplished with thermal energy sources such as electric arc and burning gases.

In contrast, nontraditional manufacturing processes harness energy sources considered unconventional till recent years. Material removal can now be accomplished with electrochemical reactions, high temperature plasmas, and high-velocity jets of liquids and abrasives. Materials which in the past have been extremely difficult to form, are now formed with magnetic fields, explosives and shock waves from powerful electric sparks. Material joining capabilities have been expanded with the use of high-frequency sound waves and beams of electrons and coherent light.

In the past 50 years, over 20 nontraditional manufacturing processes have been invented and successfully implemented in to production. The reason for large number of nontraditional processes is that each process has its own characteristics, capabilities and limitations, hence no one process is best for all manufacturing situation.

Nontraditional processes are sometimes applied to increase productivity either by reducing the number of overall manufacturing operations required to produce a product or by performing operations faster than the previously used method. It is also used to reduce the number of rejects experienced by old manufacturing method by increasing repeatability, reducing in – process breakage of fragile work pieces, or by minimizing detrimental effects on work pieces properties. Quite often, nontraditional processes are able to provide a capability that simply cannot be met with conventional techniques, for example, drilling
small holes with aspect ratios of 150:1, forming titanium sheet without experiencing spring back, or metallurgically joining two materials without the use of heat, etc.

Because of the aforementioned attributes, nontraditional processes of manufacturing have experienced steady growth since their introductions. An increase growth rate for these processes in the future is assured because nontraditional processes currently possess unlimited capabilities when compare with conventional processes, except for volumetric material removal rates. Many of these processes are available with computer controls so that even unfamiliar people can use these machines and thereby accelerating acceptance, assured reliability and repeatability.

2.8 Electrical Discharge Machining

Conventional machining processes involve shearing of the material by a shaped tool made of harder material apart from generating large amount of forces. Electrical Discharge Machining (EDM) is a thermo – electrical process that uses spark discharges to remove material from an electrically conductive work piece through melting or vaporization. Though there are other thermo – electrical processes, like electron – beam machining, EDM has the most practical advantages and is the one most widely applied in manufacturing engineering. Since there is no contact between the work piece and the tool (electrode) no cutting forces are experienced so that extremely fragile work piece can be machined easily without damage. Moreover, the high temperature generated during the process enables material removal independently of its hardness. A shaped electrode defines the area in which spark erosion will occur, thus determining the shape of the resulting cavity or holes in the work piece.

2.8.1 Process Principles

EDM is a process for producing holes, external shapes, profiles or cavities in an electrically conductive work piece by means of the controlled applications of high – frequency electrical discharges to vaporize or melt the work piece material in a particular area. So, the machining system comprises an electrically conductive work piece positioned in the EDM machine and connected to one pole of the pulsed direct current (DC) power supply. An electrically conductive electrode, shaped to match the dimensions of the desired cavity or hole, is connected to the remaining pole of the power supply. The electrode and the work
piece are then positioned in such a way that a small gap is maintained between the two. The electrical discharges are the result of controlled pulses of direct current and occur between the tool electrode (usually negative) and the electrically conductive material of the work piece (usually positive). The tool and work piece is separated by a small gap, 0.01 to 0.5 mm. To provide a controlled amount of electrical resistance in the gap, a dielectric fluid is flooded between the electrode and the work piece.

When a DC pulse with a voltage exceeding the breakdown voltage of the gap (determined by the size of the gap and the insulating resistance of the dielectric fluid) is applied to initiate the discharge between the negatively charged electrode and the positively charged work piece, an intense electrical pressure is created at the point where the gap is the narrowest due to surface irregularities. As a result of this field naturally occurring microscopic contaminants suspended in the dielectric fluid begin to migrate and concentrate at the strongest point in this field. Simultaneously, negatively charged particles are emitted from the work piece. These electrons are accelerated in the presence of the electric field collide with the dielectric molecules causing the latter to be robbed off their free electrons. This process grows and multiplies with secondary emissions followed by an avalanche of electrons and ions. Together these contaminants and charged particles result in the formation of a high-conducting ionized channel across the gap.

As the voltage between the electrode and work piece increases at the beginning of the pulse, the temperature of the material making the conductive bridge increases. A small portion of the dielectric fluid and the charged particles in the conductive bridge vaporizes and ionizes resulting in the formation of a spark channel between the two surfaces. The ionized channel is formed of plasma (i.e. gas ionized at very high temperature, around 8000 - 12000 °C) consisting of metallic atoms vaporized both from the work piece and the tool electrode, positive ions and electrons. The electric energy discharged into the gap produces electrodynamic waves and travel at high speed causing shock impact and high temperature rise at the electrode surfaces. The instantaneous temperature may reach as high as 10,000 °C causing localized vaporization of the electrodes.

Approximately at the mid point of the electrical pulse, the power supply decreases the voltage delivered to the gap, but raises the current. This has an effect of increasing both the temperature and pressure in the spark channel. The extremely high temperature of the spark
melts and vaporizes a small amount of the material from the surface of both the electrode and work piece at the points of spark contact. The gaseous by-products of vaporization form a bubble, which rapidly expands outward from the spark channel.

When the electric pulse is terminated, the spark and heating action are stopped instantly. The violent inrush of relatively cool dielectric fluid results in an explosive expulsion of a molten metal from both the electrode and work piece surfaces, resulting in the formation of a small crater in both surfaces. Small rapidly solidified balls of material and gas bubbles represent the residue from the cycle. The dielectric fluid acts to remove these by-products from the gap. This entire sequence takes place in a period of only microseconds to milliseconds.

In actual practice, the mentioned sequence above is repeated anywhere from thousands to hundreds of thousands of times each second. The result is a uniform erosion of material from both the electrode and the work piece. As the process progresses and the electrode advance towards the work piece to maintain a constant gap distance, a hole or cavity is created in a reverse image of the electrode.

To minimize the material removal or wear on the electrode, the operating parameters, polarity, and electrode material are selected to match the specific application. In this way, the rate of wear on the electrode can be a small fraction of that experienced by the work piece.

2.8.2 Equipment

One of the most commonly used non-traditional equipment in industry is the EDM. It is available in configurations ranging from manually operated to sophisticated computer controlled machines. Regardless of their complexity, all EDM systems comprise four major sub-assemblies namely power supply, dielectric system, electrode, and the servo-system.

2.8.3 Power Supply

The power supply is an important part of any EDM system. It transforms the alternating current (AC) into the pulsed DC required to produce the spark discharge at the machining gap.
Sensing the voltage between the electrode and work piece is an additional function of the EDM power supply. Because direct relationship exists between this voltage and the electrode – work piece gap, this signal is used to control the servo system, enabling it to maintain a constant gap distance throughout the EDM cycle.

To facilitate the selection of the optimum parameters for a wide range of cutting conditions, EDM power supplies must be able to control pulse voltage, current, pulse duration, duty cycle, pulse frequency and electrode polarity.

An additional circuit is used in most EDM power supplies is a cutoff or fault protection circuit. If an over-voltage, over current, or DC arc occurs as a result of short circuit between the electrode and work piece, the cut-off circuit terminates the power and alerts the operator.

2.8.4 Dielectric System

It consists of the dielectric fluid, delivery devices, pumps and filters. The dielectric fluid should have low viscosity and high electrical resistance. Commonly used dielectric fluids are hydrocarbon oil, silicon based oils, and deionised water. Deionised water is rarely used because it results in undesirably high electrode wear rate. Dielectric fluid performs three functions. It acts as an insulator between the electrode and work piece, as a coolant to carry away the amount of heat generated by the sparks, and as a flushing medium to remove the eroded material from the spark gap. Of the three dielectric functions, flushing is the most critical for optimum process efficiency. Poor flushing, results in stagnation of the dielectric fluid and a build up of tiny machining residue particles in the gap. Stagnation usually results in low MRR or short circuit. The fluid must be of low unit cost and posses the following properties:

1) Low viscosity to ensure efficient flushing
2) High flash point
3) Non – toxic
4) Non – corrosive
5) High latent heat
6) A suitable dielectric strength, e.g. 180 V per 0.025 mm, and
7) Rapid ionization at potentials in the range of 40 – 400 V followed by rapid de-ionization.

Several methods are available for flushing the dielectric fluid through the cutting zone. Either pressure or suction can be used with equally good results. Different EDM flushing techniques are: suction through electrode, suction through work piece, pressure through electrode, pressure through work piece, and jet flushing.

Whenever flammable dielectric fluids are being used, submersion of the work piece is recommended to reduce the chances of accidental dielectric fluid fires. Because it is more cost effective to reuse the dielectric fluid, it is usually cleaned, recycled, and returned to the cutting gap. Pumps and disposable filters perform this function.

2.8.5 Electrodes

The EDM electrode is the tool that determines the shape of the hole or cavity ultimately generated. The most important criteria for electrode selection are the electrode material and design. The common requirements for candidate electrode materials are that they be readily available, easily machinable, exhibit low wear be electrically conductive, and provide good surface finish on the work piece. Low electrode wear rate is associated with a high melting point of the material: graphite has a very high value, 3500 °C, followed by tungsten, 3400 °C. However, in practice, consideration of cost (e.g. graphite is cheap, tungsten very expensive), rate of wear, ease or fabrication, availability, performance in terms of material removal rate, surface texture produced, etc., combined to reduce the range of materials.

Copper and brass are two commonly used materials that meet most of these criteria, although they exhibit a relatively high wear rate. It justified by production rates, techniques available for molding electrodes from this material.

Graphite and copper are by far the most versatile electrode materials. Both are easily machinable and are available in various grades for applications to all work piece materials. Because the temperature at which graphite vaporizes is so much higher than any metal, the wear rates of graphite electrodes are extremely low. The most important property of the
graphite electrode is grain size, which governs the wear rate, surface finish, and removal rates. A graphite electrode with finer grains reduces electrode wear rate, surface finish is improved, and material removal rates are increased. Brittleness is the biggest draw back of the graphite, especially with thin graphite electrodes.

An EDM cavity is always larger than the electrode used to machine it. The difference between the size of the electrode and the size of the cavity is called the overcut. All electrode materials and configurations produce an overcut in the work piece. The amount of overcut is predictable and can be determined by the work piece, electrode material, and EDM operating parameters. Compensation for overcut must be taken into consideration when selecting or designing EDM electrodes.

Allowances must also be made for electrode wear. Electrodes wear the fastest at the sharp corners and edges. Wear characteristics of various electrode materials used are quantified using wear ratio, i.e., the comparison between the volumes of the work piece material removed versus the volume of electrode worn. Depending upon the applications and material combinations this number can be as high as 100:1 for extremely low – wear combinations.

2.8.6 Servosystem

The servosystem is commanded by signals from the gap voltage sensor system in the power supply and controls the infeed of the electrode to precisely match the rate of material removal rate. If the gap voltage sensor system determines that a piece of electrically conductive material has bridged the gap between the electrode and work piece, the servosystem will react by reversing direction until the dielectric fluid flushes the gap clear. When the gap is clear the infeed resumes and cutting continues.

The selection of the dielectric flushing has direct effect on the function of the servosystem. If the flushing technique being used is inefficient in removing the process by-products from the cutting gap, the servosystem may have to spend most of the time reversing to clear the cutting gap. This results in extremely long cycles. However if an efficient flushing system is used to remove the by-products, the servosystem will spend no time retracting, resulting in much faster cycles.
2.8.7 Process Parameters

The selection of the EDM parameters is important in determining the accuracy and surface finish obtained for particular applications. On most EDM, system parameters are manually selected, although some CNC units have the capability to adjust and match parameters for various applications.

As current is increased, each individual spark removes a large crater of material from the work piece. Although the net effect is an increase in material removal rates, when holding all other parameters constant it also has the effect of increasing surface roughness. The same effect is also observed when spark voltage is raised.

Increasing spark frequency and holding all other parameters constant, results in decrease in surface roughness. This is because the energy available for material removal during a given period is shared by a large number of sparks; hence the corresponding crater size is reduced.

The spark voltage and current determine the gap between the electrode and work piece. Typical values for the gap ranges from 0.012 to 0.050 mm. The smaller the gap, the closer the accuracy, better the finish and slower the material removal rate. As the gap decreases, efficient flushing becomes difficult to achieve.

Increasing the pulse duration of the sparks has the effect of increasing the removal rate, increasing the surface roughness, and decreasing the electrode wear. The pulse duration varies from a few microseconds to several milliseconds.

There exists a correlation between the machining parameters and machinability components like, stock removal, overcut, surface finish, electrode wear, fatigue strength and surface integrity in EDM. Moreover the overcut and the total thickness of the damaged surface layer are related.
2.8.8 Process Capabilities

Electrical discharge machining is capable of machining all electrically conductive materials regardless of hardness. The process is particularly well suited for drilling irregularly shaped holes, slots, and cavities and is also well suited for simultaneously drilling many small holes of one or multiple diameters.

This is a precision process with accuracies of ± 0.025 to ± 0.127 mm easily achieved. Volumetric material removal rate depends upon the selection of parameters such as power, dielectric and electrode material.

2.8.9 Surface Structure

A layer created by molten metal solidifying on the workmetal surface is called recast layer. More significantly one can say that because material is removed from the work piece by thermal action a layer of melted and solidified material, known as recast, remains on all surfaces machined by EDM. The depth of the heat – affected zone for a given material will depend on the characteristic and energy of the discharges, e.g. in a finishing operation it may be no more than 0.002 mm, whereas for a roughing cut it may be 0.2 mm.

Typically a machined surface will exhibit three layers after exposure to high – energy discharges. (1) A recast layer is formed by molten metal particles being re – deposited on the work piece surface; this layer in steel work pieces may by harder than the parent metal. (2) A layer which has reached melting point, but not dispersed and which remain as a recast layer. (3) An annealed layer, of hardness less than that of the parent material. The recast layer in metals is typically between 0.025 to 0.05 mm in thickness and is extremely hard, in excess of HRC 65, and brittle. Because of the poor physical properties of these surfaces, especially as micro cracks may be present, recast is often mechanically or electrochemically removed from the surfaces of critical products that require high level of fatigue resistance, e.g. in aerospace applications.
2.9 Graphite

Graphite is a crystalline, low density and soft allotrope of carbon. The crystalline structure of graphite consists of hexagonal rings forming thin parallel plates. The plates are bonded to each other by weak Van der Waals forces. The layered structure of graphite allows sliding movement of the parallel graphene plates. Weak bonding between the plates determines softness and self-lubricating properties of graphite.

2.9.1 Characteristics of Graphite

Graphite has characteristics representative of both metals and non-metals and thus is generally classified as a metalloid. It is the thermodynamically stable modification of carbon at high temperatures and once formed, no phase transitions occur on cooling to room temperature. Graphite has thermal and electrical characteristics usually associated with metals. Also, these are the properties most affected by the anisotropy of graphite.

Graphite is relatively soft and greasy; steel gray to black color with a metallic sheen. It possesses good machinability, low wettability, high strength, high electrical and thermal conductivity. It has thermal shock resistant and oxidation (graphite starts to be oxidized in oxidizing atmosphere at 500 °C). Graphite is highly refractory material.

Compared to metals and ceramics, the elastic modulus of graphite is quite low and is affected by the directionality of the atom layers. The modulus of graphite increases with temperature. Graphite is a soft material even though the hardness within the atom layers approaches that of diamond.

The specific heat of graphite at room temperature is low and increases with temperature. Polycrystalline commercial graphite has approximately one third of the thermal conductivity of copper. The conductivity parallel to the atom layers is generally somewhat greater than that in the perpendicular direction. In pyrolytic graphite, the conductivity in the direction of the atom layers is very high; in fact, values exceeding that of copper have been reported. The conductivity in the perpendicular direction is lower by a factor of hundred. The thermal conductivity of graphite increases with temperature.
The thermal expansion of graphite is low in comparison to metals, being about one fourth that of iron. In the direction perpendicular to the atom layers the thermal expansion is approximately one third higher than that in the parallel direction. The rate of expansion increases with temperature. Graphite has excellent thermal shock resistance for a brittle material due to its high thermal conductivity, low thermal expansion and low elastic modulus.

Although graphite is considered an electrical conductor, the electrical resistivity of polycrystalline commercial graphite is several hundred – fold higher than that of copper. At low and moderate temperatures, the temperature effect is negative, but becomes positive at high temperatures.

Graphite is highly inert to chemical attack at normal temperatures. It is sufficiently oxidation resistant for practical utilization at moderate temperatures but deteriorates rapidly at high temperatures. The chemical activity of graphite is increased in the presence of very strong oxidizing agents.

2.9.2 Applications of Machined Graphite

Today, in era of high performance technologies, machined graphite is available to match the needs of different applications from extremely complex three dimensional electrodes for the mold and die industries to technologically advance products for the semiconductor, electronics and aerospace sectors.

Some of the major applications of machined graphite are listed below.

- Continuous casting technology: Machined graphite are used mainly in continuous casting technology of non – ferrous and precious metals as dies (molds), mandrels, melting and casting crucibles.

- Glass and Ceramic industry: Machined graphite are being used as tools, moulds, take out tongues, scoops, scrapper blades and equipment of slide in beams of the manufacturing of laboratory glass, technical glass, float glass and hollow glass. Furnace components for manufacturing high performance ceramics also use machined graphite.
➢ Refractory: When processed into plates and molds, graphite are used to manufacture refractory materials in complex geometric shapes to cater for furnace linings used in iron and steel, glass, aluminum, concrete and ceramic industries. Machined graphite is also used as shaping tools for above as well as crucibles.

➢ Gas injection and gas distribution system: Machined graphite is selected for gas injection and distribution systems used in non-ferrous metal melts.

➢ Electro chemistry and chemical process technology: Corrosion-resistant heat exchangers, spreaders in distillations columns, pumps (valves, rotors, vanes, etc.), quenchers, vessels and reactors, packing rings and seals, roller guides and safety disks etc. are made up of machined graphite. Besides these, electrodes for aqueous and organic electro synthesis, electrodes for chemical separation processes, anodes and cathodes for electrolysis of lithium, sodium, magnesium and fluorine are made up of graphite.

➢ Medical technology: Machined graphite discs as heat sinks for x-ray anodes, Dental crucibles for melting precious metal alloys, operating materials for manufacturing of mechanical heart valves.

➢ Nuclear power plant and energy technology: Tiles made of machined graphite are used for lining of nuclear fusion reactors, containment shells for nuclear transportation, structural components, reflectors, moderators, etc. Carbon fiber materials are used to reinforce the rotor blades of wind turbines and to provide key components for fuel cells.

➢ Aerospace technology: Molds made of machined graphite for manufacturing aerospace components.

➢ Solar technology: High purity fine grain graphite allows the production of both silicon and solar wafers and cells. In the manufacture of solar silicon pre-products, the crucibles, and various other molds are made from machined graphite.
Other significant uses of graphite in brushes for electric motors, in carbon fiber reinforced plastics, in heat resistant composites such as reinforced carbon-carbon composites. Products made from carbon fiber graphite composites include space age applications, robot arms, fishing rods, golf clubs shafts, bicycle frames and pool sticks. Graphite foils use in valve packing and gaskets.

2.10 Literature Survey

Sampath et al [5] discussed in detail the optical principle for gauging surface roughness. They described the advantages of characterization of surface as

- Surface characterization is very vital for design, manufacturing and inspection. Surface roughness (or surface finish) utilizes to characterize the surface.
- Along with the specified tolerances, surface finish is used to characterize the accuracy of a surface.
- Surface roughness has direct influence on the wear behavior and quality of production.
- Friction and wear characteristics of mating surfaces are influenced to a large extent by their surface finish.
- Fatigue life of rotating components or parts can be improved by providing a finer finish.
- Manufacturing process for a component is much time selected based on the specified tolerances and surface roughness on that component.
- Amount of wear on the tool can be correlated with a value of surface roughness to know whether a tool is worn out or not.
- There are various methods to measure surface roughness - contact methods, electrical methods and in-process optical methods. Most widely used technique in industry is stylus method but not suitable for automatic inspection. For that non-contact optical method (image processing) is utilized.

Attempt has been made to analyze the images of precalibrated gauge blocks. Images were captured with charge coupled device (CCD) camera. Then images were transferred with a frame grabber to PC and those images were threshold into more gray levels. Light intensity along a line parallel to machining marks was recorded and analyzed. The observations were
made from the pixel graphs (image pattern generated by the vision system). The height of the bump in the graph indicated the intensity value. An increase in the height of bump in graph indicated the increase in intensity value of reflected light and width of bump indicated the scattering of the reflected light. Brightness reflected by a rough surface can shine while that reflected by a smoother one may look dull. Sampath also suggested idea to develop statistical tool to correlate with surface roughness which can also be programmed with acceptance/rejection policies. Thus total visual automation of surface can be achieved.

Ramamoorthy et al [1] used statistical approach for characterizing the textural features produced by various machining operations (namely grinding, milling and shaping) from the digitized images. The experiments were carried out for machined surface with a 25 x 25 grey level matrix of the image as a basis. Textural features were found out which were based on statistics.

The frequency distribution of the grey values and relative frequency distribution which describes how often one grey tone in a specified is simply attributed to the repetitive pattern in which elements or primitives are arranged. Since the textural properties of the image carry useful information for discrimination purposes, it is important to develop features for texture.

The features perceived by means of computer vision and to use some of them to characterize by processing the digital image (a) in terms of coarseness (b) in terms of contrast (c) in terms of regularity. In experimental procedure the values of grey level intensity matrix, the surface was viewed through a solid state charge injection device camera with a high magnification. That was interfaced with an HP computer and the intensity values of any point are directly displayed on the monitor with the image in a range of 0-255 grey levels. From grey level histogram (first order statistics) the following observations were made.

- As the surface became increasingly smooth, the reflectivity increased, resulting in higher grey level values.
- Grey level values presented in the histogram were occurring almost (distribution of frequencies non uniform) and showed dominance of grey levels with lower value as well as it gave a high standard deviation.
Roughness ‘Ra’, which measured using stylus instruments, was plotted against the variance for the different textures and good correlation was found out. Histograms do not carry any information regarding the relative position of the pixel intensities with respect to each other. Positions of the pixels were achieved through the co-occurrence matrix. Co-occurrence matrix is a grey level intensity matrix which depends on the number of grey levels chosen and the matrix size. This co-occurrence matrix presents a picture of the number of times that a grey level intensity value occurs with another grey level value e.g. as its right neighbor, or its left neighbor, or one pixel to the right or one pixel below, or just as neighbors. This condition is known as ‘position operators’ which decide the formation of co-occurrence matrix. The position operator used in this was ‘one pixel to the right’ as it was felt that the intensities from the reflection of two neighboring pixels were most critical in the analysis of texture.

Observation was made that the elements of these co-occurrence matrices were evenly distributed for smooth (ground and milled) surfaces compared with the roughly shaped surfaces. If three dimensional plots were drawn then the elements tend to shift along the diagonal as the surfaces become smoother. Co-occurrence matrices were found to be more sensitive changes in surface finish than were those calculated from the first order statistics.

Younis [2] employed a microcomputer based vision systems to analyze the pattern of light scattered from a surface of tool steel, copper and brass specimens to derive a roughness parameter. It was inferred that the microscopic waveform of the surface profile modulated the incident light beams whose intensities and scattering angles could be described as functions of the amplitudes and wavelengths of the surface topography.

A CCD camera captured the images of the surface of tool steel, copper and brass specimens. A frame grabber board digitized the images which were stored in one of the four frame buffers for subsequent analysis by computer.

A grey level coefficient (a_{cell}) between the pixel and its eight surrounding pixels was found out. Then an averaged grey level coefficient for the whole image was then subsequently obtained. The grey level intensity at any pixel was affected the high specks around that point.
Graphs were drawn between the surface roughness (Ra) and the grey level coefficient ($\mu_{cell}$) for tool steel, brass and copper. Good correlation was found out. It was concluded that as tool steel and brass had different modes of tearing and fracture during grinding it rose to a different types of surface profile. Hence optical correlation curve for a given material was unique and may be related to the properties of the material. The repeatability of the optical technique was proven to be much better than the stylus traditional technique.

M.B.Kiran et al [7] conferred few approaches - image process, light sectioning method and phase shifting approach using grating projection. In those, it was established that direct image approach was quick and easy to apply on the shop floor level. It was identified the surface texture and indicated the process of manufacture.

After capturing the images of flat surfaces, which were prepared by different manufacturing processes - rough ground, milled, shaped, cast and sand blasted surfaces, preprocessing was done. First step of preprocessing was frame averaging. Number of frames of same specimen was taken and each frame was averaged against the previous one. This procedure is effective on gaussian random noise. Then a low pass filter was applied to image in which each pixel is replaced with a weighted sum of the neighborhood, which allows a reduction in the gaussian random noise. Finally the image was processed by applying a median filter in which each pixel was replaced by the median pixel value of its neighborhood which reduced the “salt and pepper effect”.

Histograms (first order statistics) of the image intensity distribution obtained. It gave the contrast attributes. There was discrimination visible in the histograms so it's possible to compare the finish of surfaces. Good correlation was found out between variance of the intensity distribution and Ra value measured by stylus instrument.

As first order statistics was insufficient to describe the texture, second order was used. That approach was based on the concept of texture units. Texture unit describes the local texture aspect of a given pixel. Thus the statistics on the occurrence frequency of all the texture units over a whole image should reveal the texture of the image. Different textures were composed of particular texture units with different distributions. Thus texture of an image could be characterized by the texture spectrum. Texture spectrum is the frequency distribution of all
the texture units with the abscissa indicating the texture unit label, NTU and the ordinate representing the occurrence frequency. It was established that the texture spectra were different for different surfaces with respect to the height of the principal peaks and the position of the principal peaks. It was found from the experiments that the texture spectrum was unique to a particular machined surface.

In paper presented by Lee et al [3] carried out study to measure ‘Ra’ under a variation of cutting conditions by building a polynomial network for computer vision for turning process. A digital camera captured the images of the surfaces texture which were prepared under different operating conditions. For further computer processing, image function g(x,y) must be digitized both spatially (image sampling) and in amplitude (amplitude digitization or grey level quantization). After that the extraction of features of image texture, major peak frequency F1 and principal component magnitude squared value F2 could be calculated from the image texture by Fourier Transform (FT). The standard deviation of grey level (STD) in spatial domain also could be got by the statistic method. These features could be used as input data of an abductive polynomial network, the ‘Ra’ measured by the vision system can be calculated directly.

Abductive network can be recognized as a special class of biologically inspired networks with machine intelligence and can be used effectively as a predictor estimating the output of complex systems. Abductive network is a group method of data handling technique. In an Abductive network, complex systems are decomposed into smaller, simpler sub-systems and grouped into several layers using polynomial function nodes.

A comparison of ‘Ra’ measured by vision system and ‘Ra’ measured by stylus method was done. ‘Ra’ evaluate by vision measuring system is closely to the value ‘Ra’ of stylus instrument. Thus self-organized polynomial to model vision measuring system on surface roughness inspecting has been established.

Machine vision approach was carried out to evaluate the surface roughness of machined surfaces of shaped, milled and ground specimens by Rajneesh kumar et al [8]. A good correlation was established between surface roughness (Ra) measured with stylus instrument and optical parameter grey level average. Arithmetic average of the grey level, a feature of the surface image, was used to predict the actual surface roughness of the work.
Cubic convolution interpolation method has proved to be the optimal choice for the magnification of digital images. Digital image magnification techniques suffer from the limitation that they do not introduce any new information to the original image. Interpolation methods are usually employed in magnification of digital images. Edge blurring is more severe with magnification techniques. Magnification of digital images is basically a problem of brightness interpolation in the input image which is also a low resolution image. It starts with the geometric transformation of the input pixels which are mapped to a new position in the output image. A geometric transform is a vector function $T$ that maps the pixel $(x,y)$ to a new position $(x',y')$. Brightness value of the pixel $(x',y')$ in the output image needs to be computed, where $x'$ and $y'$ lie on the discrete raster. The co-ordinate of the point $(x,y)$ in the original image can be obtained by inverting the planar transformation. $(x,y) = T^{-1} (x',y')$. Generally, the real co-ordinates after inverse transformation do not fit the input image discrete raster, and so brightness is not known. The only information available about the originally continuous image function $f(x,y)$ is its sampled version.

To get the brightness value of the point $(x,y)$ the input image was resampled. After image magnification (cubic convolution interpolation), the edges were enhanced by linear edge crispening which can be performed by discrete convolution, unsharp masking and fourier domain filtering depending upon the nature of image. The mask should be of high-pass form, as edges are high frequency features. The calculation of optical roughness value, from these magnified and improved images had a better correlation with average surface roughness (Ra). It has also inferred that the optical estimation seems more promising for machining operations which produce a uniform and regular surface texture (such as grinding).

Dhanasekar et al [9] utilized the machine vision system to identify, analyze and quantifying the surface texture of shaped, milled and grounded specimens with quality improvement algorithms. Surfaces with different textures were obtained by controlling the machining parameters of machining processes grinding, milling and shaping. Surface images were grabbed using a CCD camera and were then pro-processed to eliminate effects due to
illumination and noise. Low pass filter was applied to the image obtained, hence reducing the salt and pepper effect.

Geometric search technique was applied for improving the quality of images by enhancing the edges in image processing. Optical surface roughness ‘Ga’ was found out before geometric search applied and as well as it was found out after applying the geometric search. Correlation of ‘Ga’ with the ‘Ra’ (measured by stylus) before and after applying geometric search technique was found out. Due to higher correlation coefficient better correlation was found out between ‘Ra’ and ‘Ga’ after applying geometric search technique.

Garza et al [10] utilized the digital image processing to quantify the hot shortness cracking in medium carbon steel with variations in copper content, oxidation temperature, and oxidation time. Hot shortness is defined as ‘brittleness in metal in the hot forming range’. The hot shortness defects in a deformed specimen appear as cracks on the surface that can occur during the deformation of steels at high temperatures. Residuals elements copper, tin and antimony which are not eliminated during the steel-making process have a lower melting point than iron. The rapid oxidation at the deformation temperatures and the extremely low solubility of these residual elements in iron oxide provides the means to create enrichment zones of a liquid phase at the interface between the oxide and the steel. The liquid phase can penetrate the grain boundaries and in the presence of tensile stress components can create the surface defect known as hot-shortness.

The flanged compression steel specimens were oxidizing at the testing temperature and deformed in compression in a Gleeble thermo-mechanical testing machine. Sectioned epoxy specimen was ground leaving an opaque finish before being photographed. Specimen was illuminated from the bottom. The clear epoxy allowed the light to travel around the specimen surface highlighting the exterior of the cracked surface and leaving unilluminated the metal. This backlighting method created a contrast image that revealed the crack features. Image-J, image processing software was used for the digital image analysis. A filter was applied to the image converting it into only two colors, black and white, without any grey levels in between. A processing routine that detected the contrast edge from the two color image was applied. This processing produced an image of the silhouette of the specimen. It contained information about the surface cracking.
Proper specimen preparation – mounting in clear epoxy, sectioning, back illumination photographing and image processing – resulted in data amenable for computerized analysis. Original radius profile measured from the specimen and corrected radius profile were drawn. Then cracking index was calculated. Crack index is the product of the length times the depth summed over all of the identified cracks. Crack index has unit of area and provides a good quantitative measure of the surface cracking conditions. Thus it has been established that DIP technique allowed for an objective, quantitative and standard method for analyzing the surface cracking and for comparing results of large number of specimens.

Literature survey shows that researchers quantify the surface finish of conventional metallic materials machined by conventional machining processes using digital image processing. Researchers have used gray level analysis and Fourier spectrum analysis to extract the textural features of machined metallic material specimens. This work belongs to the estimation of surface roughness of machined surfaces of high-tech materials like carbon-carbon composite. It has been observed, through literature survey, that no work has been reported on the estimation of the surface finish of carbon-carbon composites, machined by EDM, with the non-contact type digital image processing. Moreover, estimation of surface roughness values from optical parameters leading to online inspection of machined C-C composites has not been investigated so far.