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Study and Analysis of Cutting Parameters of Rubber Rollers Using Doe Technique

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Abstract

Rubbers include natural rubbers and synthetic rubbers. Natural rubber is a naturally occurring substance obtained from the exudations of certain tropical plants. Synthetic rubber is artificially derived from petrochemical products. Among the most important synthetics are styrene-butadiene, polybutadiene, and isoprene as well as ethylene-propylene rubbers. The prices of these synthetics have been historically in the range of natural rubber prices and their markets have, although to varying degrees, overlapped those of natural rubber.

Rubbers have wide applications in automobile, aerospace, electrical and many other manufacturing industries, but still not much work has been done on its quality characteristics with different input process parameters. A thorough understanding of the process behaviour is very crucial in order to control the castings in terms of quality. In this work, the main quality characteristics, namely surface roughness and hardness were modelled both linear and non linear, with respect to process parameters Speed, Feed and Depth of cut and analysed using Design of Experiments Methodology with Response Surface Method.

The effects of process parameters were explained with main effect plots and response surface plots. Finally multi response optimization, using desirability function approach was done on the best fitted models.

Key Words: *Surface Roughness, DOE, Minitab*

INTRODUCTION OF MATERIAL AND CUTTING TOOL

Natural rubber from the latex yielding trees Hevea and Castilla was known to South American Indians in early times (pre-Columbian era). Latex was allowed to evaporate naturally and processed into usable articles (such as balls used in ritualistic games). "Caoutchouc", the world first used to describe the condensed juice of the Hevea tree, was the French spelling of an indigenous term for "weeping wood."

The world rubber industry began to develop in the 1800s, with the invention of the masticator and the vulcanization process. Demand for rubber grew rapidly with the invention of the solid and later the pneumatic rubber tire and the demand for rubber insulation by the electrical industry.

With a view to spreading rubber cultivation, seeds of the Hevea brasiliensis were smuggled from Brazil to the United Kingdom in 1876 at the instigation of the British India Office. Seedlings were raised at Kew Gardens and then shipped to Ceylon (Sri Lanka) and Singapore, where H.N. Ridley, director of the Singapore Botanic Gardens, introduced new horticultural and tapping methods. Seeds of the rubber tree were later brought to other tropical regions, especially the Malay area and Java and Sumatra, marking the origin of the rubber plantation industry in Asia.

Rubbers include natural rubbers (NR) and synthetic rubbers (SR). Natural rubber is a naturally occurring substance obtained from the exudations of certain tropical plants. Synthetic rubber is artificially derived from petrochemical products. Among the most important synthetics are styrene-butadiene, poly butadiene, and isoprene (commonly classified as the "general purpose" SR), as well as ethylene-propylene rubbers (often referred to as "specialty rubbers"). The prices of these synthetics have been historically in the range of natural rubber prices and their markets have, although to varying degrees, overlapped those of natural rubber. Synthetic rubbers are materials with distinctive chemical structures, whereas the emphasis with natural rubber lies on different types and grades within one single broad category.

Composition of Natural rubber (Table- 1)

Latex is a poly dispersed colloidal system of rubber particles in an aqueous phase. With Hevea latex, the dry rubber content varies between approximately 28-40%, although it may rise to 45-50% after a long period of non-tapping. The rubber produced from latex contains, besides the hydrocarbon, relatively small quantities of protein, carbohydrates, resin-like substances, mineral salts, and fatty acids.

Table -1: Composition of Natural Rubber

Proteins	2-2.7%
Resins	1.5-3.5%
Sugars	1-2%
Ash	0.4-0.7%
Sterol glucosides	0.07-0.47%
Water	55-65%

Natural rubber is either exported as "latex concentrates" or processed into "dry/solid rubber" (in sheet, crepe or block forms). Latex concentrate is made from freshly tapped field latex, uncoagulated, dry rubber is prepared from coagulated field latex (sheet rubbers and pale crepes) or remilled rubber sheets (estate brown, thin brown, thick blanket, and flat bark crepes). Dry rubber is either visually graded (sheets and crepes) or classified by instruments (block rubber). Over the years, technically specified rubber in block form has become increasingly important at the expenses of other rubbers.

SURFACE FINISH AND HARDNESS

Surface finish typically refers to a level of polishing or texture intended for, or resulting on, a surface. On a lens, it is usually desirable to have as little roughness on a lens surface as possible, if light is being guided, so that light is scattered as little as possible but this roughness (or smoothness, ideally) doesn't include the general curvature of the surface shape. In other applications, roughness may need to be optimized: an adhesive may need a certain amount of roughness to permit air pockets for hardening, while presenting enough surface area to bond.

Surface roughness also known as surface profile Ra is a measurement of surface finish it is topography at a scale that might be considered "texture" on the surface. Surface roughness is a quantitative calculation of the relative roughness of a linear profile or area, expressed as a single numeric parameter (Ra).In three dimensional optical profilometry, roughness is usually expressed as surface area roughness (Sa). Profile roughness (Ra) can be extracted as a line through an area. The surface roughness parameter used to evaluate surface roughness in this study is the Roughness average (Ra). This parameter is also known as the arithmetic mean roughness value, Arithmetic Average (AA), or Centre line Average (CLA).The average roughness is the area between the roughness profile and its centre line as shown in Figure

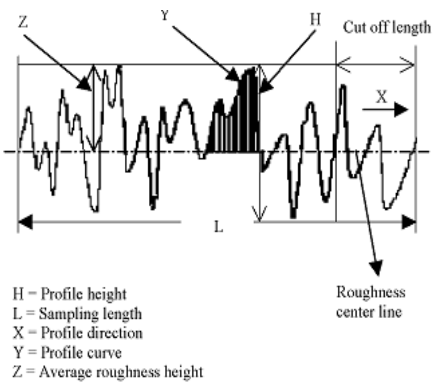

Fig -1: Surface roughness profile

The conclusion caused by the subjective element in surface finish measurement can be eliminated by using various machines which can record the surface profile with a very large magnification in the vertical direction. The surface profile is usually measured in a direction perpendicular to the lay of the surface - i.e. the predominant direction of the scratch marks. A typical profile is shown in Fig. 5.2. Analysis shows that the profile is composed of three distinct types of irregularities. The first type of irregularity is a form of error which is usually of a magnitude which can easily be detected by conventional measuring methods. The second type of irregularity consists of waviness with fairly regular spacing which can be attributed to vibrations of the machine. The third type of irregularity consists of closely spaced peaks and valleys superimposed on the first two types of irregularities. These peaks and valleys can be correlated with the shape, size and motion of the cutting tool.

It is clear that surface finish should be related to the height of the irregulations. However, depending on the length (X, Y, Z) over which measurements are made and the relative heights of the different types of irregularities, it is possible to get widely varying values (H1, H2, H3). Each value may be relevant depending on the functional properties desired - viz; bearing area, flatness (or straightness), smoothness (for appearance or corrosion resistance)

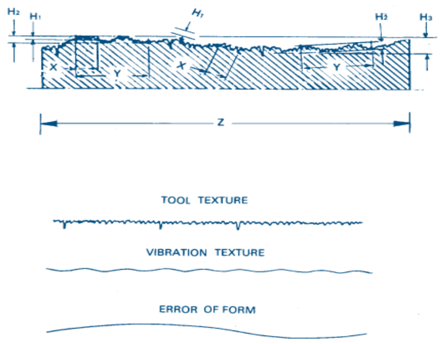

Fig -2: Typical Profile

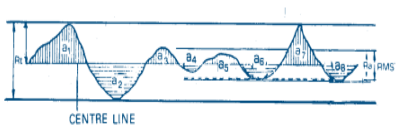

Fig -3: Magnified sectional view of the surface

The profile shown in fig. 3 is a highly magnified sectional view of the surface. Within the selected cut-off length, it is possible to draw a centre line in such a way that the areas of the peaks above the line are equal to the areas of the valleys below the line. The theoretical average deviation of the profile from the centre-line can be determined by integration which is the basis on which the relevant electrical instruments function. However, sufficiently accurate results will also be obtained by measuring the ordinates (vertical height or depth) at various points on the profile and calculating the average value by the following equation:

Average value = h1+ h2+ ... + Hn / n

The average value is expressed in micro inches (millionths of an inch) or microns (millionths of a meter) depending on the system of measurement. Besides the arithmetical average value, two other systems are also used quite often. The system which was popular till recently gave a root-mean-square (RMS) value which is derived by the following equation:

$$\text{RMS value} = \sqrt{\frac{h_1^2 + h_2^2 + \ldots + h_n^2}{n}}$$

Surface roughness is an index of product quality as it influences the performance of mechanical parts as well as production cost. Surface roughness has an impact on the mechanical properties like fatigue behavior, corrosion resistance, creep life etc. It also affects other functional attributes of parts like friction, wear, light reflection, heat transmission, lubrication, electrical conductivity etc. As a result, there have been a great many research developments in modeling surface roughness and optimization of controlling parameters to obtain a surface finish of desired level since only proper selection of cutting parameters can produce a better surface finish. But such studies are far from complete since it is very difficult to consider all the parameters that control the surface roughness for a particular manufacturing process. Figure shows a fishbone diagram with the parameters that affect surface roughness

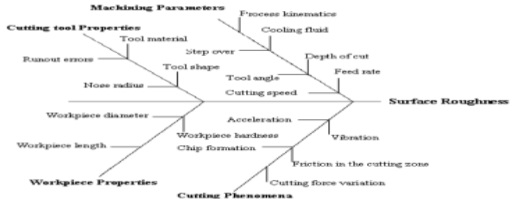

Fig -4: Fishbone diagram showing parameters affecting surface roughness

Surface roughness has received serious attention for many years. It has formulated an important design feature in many situations such as parts subject to fatigue loads, precision fits, fastener holes, and aesthetic requirements. In addition to tolerances, surface roughness imposes one of the most critical constraints for the selection of machines and cutting parameters in process planning. A considerable number of studies have investigated the general effects of the speed, feed, and depth of cut on the surface roughness.

Surface roughness have been important factors in predicting the machining performances of any machining operation. Surface roughness is mainly the result of process parameters such as tool geometry (i.e., nose radius, edge geometry, rake angle, etc.) and cutting conditions (feed rate, cutting speed, depth of cut, etc.).The impact of three factors the feed rate, nose radius and cutting edge angles on surface roughness is depicted. In the past various methods have been used to quantify the impact of machining parameters on part finish quality. Thiele et al used a three factor full factorial design to determine the effects of work-piece hardness and tool edge geometry on surface roughness in finish hard turning using CBN tools. After completion of the experiments, an Analysis of Variance (ANOVA) was conducted to predict the effect of edge geometry and feed rate on surface quality. Chouet al conducted experiments for hard turning of AISI 52100 steel using CBN tools to predict the effect of CBN content on surface roughness. In their experiments, two factor- three level fractional factorial design was used and the effects of cutting edge geometry, work-piece hardness, feed rate and cutting speed on surface roughness were experimentally investigated. In another study, Ozel et al performed experiments on hard turning of various steels using CBN tools and identified the factors affecting the surface roughness, tool wear, cutting forces and surface integrity. A multiple regression model was developed to predict surface roughness in turning operations relating spindle speed, feed rate, depth of cut and vibration amplitude which were taken as input parameters. The predicted surface roughness was compared with experimental values. In milling operation, vibration signals were used to predict surface roughness and the predicted accuracy was as high as 96%. A sensor fusion technique was used to estimate online surface finish and dimensional deviations during the turning process. In this method, the cutting feed, depth of cut and two components of the cutting force (the feed and radial force components) were used to build a fusion model by using neural networks for online estimation.

Process modelling and optimization are the two important issues in manufacturing products. The manufacturing processes are characterized by a multiplicity of dynamically interacting process variables. A greater attention is given to accuracy and surface roughness of product by the industry these days. Surface finish has been one of the most important considerations in determining the machinability of materials. Surface roughness and dimensional accuracy are the important factors required to predict machining performances of any machining operations. The predictive modelling of machining operations requires detailed prediction of the boundary conditions for stable machining. The number of surface roughness prediction models available in literature is very limited. Most surface roughness prediction models are empirical and are generally based on experiments in the laboratory. In addition it is very difficult in practice, to keep all factors under control as required to obtain reproducible results. Generally these models have a complex relationship between surface roughness and operational parameters, work materials and chip- breaker types. Optimizations of machining parameters are not only increases the utility for machining economics, but also the product quality increases to a great extent. In this context, an effort has been made to estimate the surface roughness using experimental data. It has also been made an attempted to optimize the surface roughness prediction model using a Genetic Algorithmic approach.

Since turning is the primary operation in most of the production processes in the industry, surface finish of turned components has greater influence on the quality of the product. Surface finish in turning has been found to be influenced in varying amounts by a number of factors such as feed rate, work material characteristics, work hardness, unstable built-up edge, cutting speed, depth of cut, cutting time, tool nose radius and tool cutting edge angles, stability of machine tool and work-piece setup, chatter, and use of cutting fluids.

Taraman used Response Surface Methodology (RSM) for predicting surface roughness of different materials. A family of mathematical models for tool life, surface roughness and cutting forces were developed in terms of cutting speed, feed, and depth of cut. Hasegawa et al., conducted 34 factorial designs to conduct experiments for the surface roughness prediction model. They found that the surface rough increased with an increase in cutting speed. Sundaram and Lambert considered six variables i.e. speed, feed, and depth of cut, time of cut, nose radius and type of tool to monitor surface roughness.

To improve the efficiency of these turning processes, it is necessary to have a complete process understanding and model. To this end, a great deal of research has been performed in order to quantify the effect of various hard turning process parameters to surface quality. These factors can be divided into,

1. Setup variables
2. Tool variables
3. Work-piece variables.

In order to gain a greater understanding of the turning process it is necessary to understand the impact of the each of the variables, but also the interactions between them. It is impossible to find all the variables that impact surface roughness in turning operations. In addition, it is costly and time consuming to discern the effect of the every variable on the out put. In order to simplify the problem, one needs to eliminate or select specific variables that correspond to practical applications.

Most of the instruments available commercially are based on a mechanical-cum-electronic principle. A diamond-tipped stylus is mechanically moved over the surface and the deflections of the stylus are converted into electrical signals are then amplified electronically and passed through an analyzer (or computer) which indicates the appropriate value on a suitably calibrated scale. In some cases there is provision for recording the surface profile in the form of a graph. A great majority of the instruments have pick-up heads with spherical skids. These skids provide a datum surface which follows the major form errors of the measured surface and helps in eliminating the effect of such errors on the surface finish value.

It is perhaps worth pointing out that the cut off length is not related to the stroke length of the pick-up head. The latter value is chosen to suit the dimensions of the work-piece. Thus, for example, a short stroke would be required on a piston ring and a longer stroke on a large spindle though cut-off values may be idenical in both cases. Longer stroke lengths or repetitive measurements are desirable so that individual defects (like deep scratches etc.) do not unnecessarily result in rejections).

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

1. Ideal Roughness

Ideal surface roughness is a function of only feed and geometry. It represents the best possible finish which can be obtained for a given tool shape and feed. It can be achieved only if the built-up-edge, chatter and inaccuracies in the machine tool movements are eliminated completely. For a sharp tool without nose radius, Practical cutting tools are usually provided with a rounded corner, and figure below shows the surface produced by such a tool under ideal conditions.

2. Natural Roughness

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

A roughness value can either be calculated on a profile or on a surface. The profile roughness parameter (Ra, Rq,...) are more common. The areal roughness parameters (Sa, Sq,...) give more significant values.

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1. Profile roughness parameters

Each of the roughness parameters is calculated using a formula for describing the surface. There are many different roughness parameters in use, but Ra is by far the most common. Other common parameters include Rz, Rq, and Rsk. Some parameters are used only in certain industries or within certain countries. For example, the Rk family of parameters is used mainly for cylinder bore linings, and the Motif parameters are used primarily within France.

Since these parameters reduce all of the information in a profile to a single number, great care must be taken in applying and interpreting them. Small changes in how the raw profile data is filtered, how the mean line is calculated, and the physics of the measurement can greatly affect the calculated parameter.

By convention every 2D roughness parameter is a capital R followed by additional characters in the subscript. The subscript identifies the formula that was used, and the R means that the formula was applied to a 2D roughness profile. Different capital letters imply that the formula was applied to a different profile. For example, Ra is the arithmetic average of the roughness profile, Pa is the arithmetic average of the unfiltered raw profile, and Sa is the arithmetic average of the 3D roughness.

Each of the formulas listed in the tables assumes that the roughness profile has been filtered from the raw profile data and the mean line has been calculated. The roughness profile contains n ordered, equally spaced points along the trace, and yi is the vertical distance from the mean line to the ith data point. Height is assumed to be positive in the up direction, away from the bulk material.

2. Amplitude parameters

Amplitude parameters characterize the surface based on the vertical deviations of the roughness profile from the mean line. Many of them are closely related to the parameters found in statistics for characterizing population samples. For example, Ra is the arithmetic average of the absolute values and Rt is the range of the collected roughness data points.

The average roughness, Ra, is expressed in units of height. In the Imperial (English) system, Ra is typically expressed in "millionths" of an inch. This is also referred to as "micro-inches" or sometimes just as "micro".

The amplitude parameters are by far the most common surface roughness parameters found in the United States on mechanical engineering drawings and in technical literature. Part of the reason for their popularity is that they are straightforward to calculate using a computer.

3. Slope, spacing, and counting parameters

Slope parameters describe characteristics of the slope of the roughness profile. Spacing and counting parameters describe how often the profile crosses certain thresholds. These parameters are often used to describe repetitive roughness profiles, such as those produced by turning on a lathe.

4. Bearing ratio curve parameters

These parameters are based on the bearing ratio curve (also known as the Abbott-Firestone curve.) This includes the Rk family of parameters. Sketches depicting surfaces with negative and positive skew. The roughness trace is on the left, the amplitude distribution curve is in the middle, and the bearing area curve (Abbott-Firestone curve) is on the right.

METHODOLOGY

"Design of experiment (DOE) is a structured, organized method that is used to determine the relationship between the different input parameters (X) affecting a process and the out put parameters of that process (Y)". This method was first developed in the 1920s and 1930s by Sir Ronald. A Fisher, the renowned mathematician and geneticist.

Statistical design of experiments refers to the process of planning the experiment so that appropriate data that can be analysed by statistical methods will be collected, resulting in valid and objective conclusions. The statistical approach to experimental design is necessary to get meaningful conclusions from the data. Thus, there are two aspects to any experimental problem: the design of experiment and the statistical analysis of the data. These two subjects are closely related because the method of analysis depends directly on the design employed.

Design of experiment involves designing a set of experiments, in which all relevant factors are varied systematically. When the results of these experiments are analysed they help to identify optimal conditions, the factors that are more influential on the results and those that are not, as well as details such as the existence of interactions and synergies between the factors.

In general, experiments are used to study the performance of processes and systems. A model shown in the figure can represent the process or system. We can visualize the process as a combination of the machines, methods, people, and other resources that transform some input into an output that has one or more observable responses. Some of the process variables x1, x2, ….., xp are controllable, whereas other variables z1, z2, ….., zq are uncontrollable.

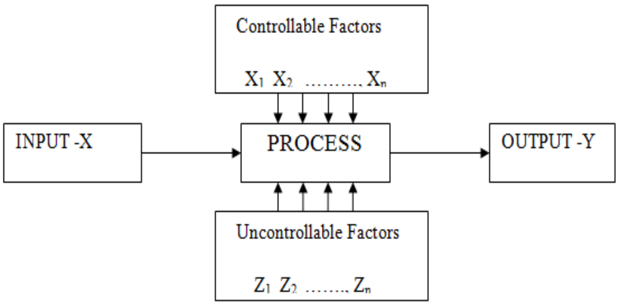

Fig -5: General model of a process or system

1. Determining which variables are most influential on the response Y (output).
2. Determining where to set the influential factors X's so that Y response is almost always near the desired nominal value.
3. Determining where to set the influential factors X's so that variability in response Y is small.
4. Determining where to set the influential factors so that the effects of the uncontrollable variables Z1, Z2 ….Zn are minimized.

Steps of Design of Experiment

1) Recognition of and statement of the problem.
2) Identification of process parameters (input variables), levels and ranges.
3) Selection of response variables.
4) Choice of experimental design.
5) Conduction of experiments and recording of the response variables.
6) Development of mathematical models, using linear and/or non linear regression modelling.
7) Checking the statistical adequacy of the model through significance test (F-test) and ANOVA test.
8) Performance evaluation of the developed models using some random test cases.

Principles of Experimental Design

9) Replication

Replication means repetition of the basic experiment. It enables the estimation of magnitude of experimental error against which the differences among treatments are judged. It reflects sources of variability both between runs and potentially within runs. Replication has two important properties.

1 It allows the experimenter to obtain an estimate of the experimental error. This estimate of error becomes a basic unit of measurement for

determining whether observed differences in the data are really statistically different.

2 If a sample mean is used to estimate the effect of a factor in the experiment, replication permits the experimenter to obtain a more precise estimate of this effect.

2. Randomization

It is the corner stone underlying the use of statistical methods in experimental design. By randomization both the allocation of the experimental material and the order in which individual runs or trials of the experiment are to be performed are randomly determined. Statistical methods require that the observations be independently distributed random variables. Randomization also assists in 'averaging out' the extraneous factors that may be present.

3. Blocking

A group of homogeneous units is referred to as a block. Blocking is a design technique used to improve the precision with which comparisons among the factors of interest are made. Often blocking is used to reduce or eliminate the variability transmitted from nuisance factors i.e. factors that may influence the experimental response but in which we are not directly interested. Generally a block is a set of relatively homogeneous experimental conditions.

6.1.5 Full Factorial Design

• Full Factorial Design in Two Levels

A common experimental design is one with all input factors set at two levels These levels are called `high' and `low' or `+1' and `-1', respectively. A design with all possible high/low combinations of all the input factors is called a full factorial design in two levels.

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If there are k factors, each at 2 levels, a full factorial design has 2k runs

Table -2: Number of runs for 2k full factorial design

Number of factors	Number of runs
2	4
3	8
4	16
5	32
6	64
7	128

The full factorial design is referred as the technique of defining and investigating all possible Conditions in an experiment involving multiple factors while the fractional factorial design investigates only a fraction of all the combinations. Full factorial design of experiments with the parameters set at their respective two levels, can be used to develop linear relationships between the input-output parameters. The advantages of full factorial design of experiments lies in the fact that the number of experiments required is less, though the analysis provides complete information on the main and interaction effects of input parameters on the response. However, the main problem with this linear model lies in the fact that the curvature effect (if any) in the response function will not be recognized [28]. Other limitations of the two level full factorial designs are- they are inefficient in time and cost, when the number of the variables is large; they require strict mathematical treatment in the design of the experiment and in the analysis of results, the same experiment may have different designs, thus produce different results; further, determination of contribution of each factors is normally not permitted in this kind of design.

Response surface methodology is a collection of experimental strategies, mathematical methods, and statistical inference which enable an experimenter to make efficient empirical exploration of the system of interest. The work which initially generated interest in the package of techniques was a paper by Box and Wilson in 1951.Many times these procedures are used to optimize a process. For example, we may wish to maximize yield of a chemical process by controlling temperature, pressure and amount of catalyst.

The basic strategy has four steps:

1. Procedures to move into the optimum region
2. Behavior of the response in the optimum region
3. Estimation of the optimum conditions
4. Verification

Now let's set up the problem. We have p factors. Call them x1, x2, ... , xp. We have a response y, and a function φ, such that

E(y) = φ(x1, x2,..., xp).

Initially, φ is usually approximated by a first order regression model over narrow regions of x, that is, where there is little curvature. That is,

$$E(y) = \beta_0 + \beta_1 x_1 + \cdots + \beta_p x_p = \beta_0 + \sum_{i=1}^{p} \beta_i x_i.$$

In regions of higher curvature, especially near the optimum, second order models are commonly used: Therefore, the overall strategy is to use first order models to "climb" the response surface and then higher order models to explore the optimum region. Let us now consider the first phase of experimentation. There are basically two issues that will be considered. First the types of experimental designs are used and then procedures to determine where the next experimental design should be run. In regions of higher curvature, especially near the optimum, second order models are commonly used:

$$\begin{aligned} E(y) &= \beta_0 + \beta_1 x_1 + \cdots + \beta_p x_p \\ &\quad + \beta_{11} x_1^2 + \cdots + \beta_{pp} x_p^2 \\ &\quad + \beta_{12} x_1 x_2 + \cdots + \beta_{p-1,p} x_{p-1} x_p \\ &= \beta_0 + \sum_{i=1}^{p} \beta_i x_i + \sum_{i=1}^{p} \beta_{ii} x_i^2 + \sum_{i} \sum_{j>i} \beta_{ij} x_i x_j. \end{aligned}$$

Therefore, the overall strategy is to use first order models to "climb" the response surface and then higher order models to explore the optimum region. Let us now consider the first phase of experimentation. There are basically two issues that will be considered. First the types of experimental designs are used and then procedures to determine where the next experimental design should be run.

The RSM is a set of techniques that encompasses

1. The designing of a set of experiments for adequate and reliable measurement of the true mean response of interest
2. The development of mathematical model with best fits
3. Finding the optimum set of experimental factors that produces maximum or minimum value of response
4. Representing the direct and interactive effects of process variables and surface roughness through two dimensional graphs.
5. The adequacy of the model has been checked through test and plotting scatter diagram.

Central composite designs are response surface designs that can fit a full quadratic model. In a central composite design, several factors can vary between low and high values. For convenience, suppose each factor varies from -1 to +1. One central composite design consists of cube points at the corners of a unit cube that is the product of the intervals [-1, 1], star points along the axes at or outside the cube, and centre points at the origin. A central composite design always contains twice as many star points as there are factors in the design .the star points represent new extreme values (low or high) for each factor in the design.

Central composite designs are of three types. Circumscribed (CCC) designs are as described above. Inscribed (CCI) designs are as described above, but scaled so the star points take the values -1 and +1, and the cube points lie in the interior of the cube. Faced (CCF) designs have the star points on the faces of the cube. Faced designs have three levels per factor, in contrast with the other types, which have five levels per factor.

- Box Behnken Design

The Box-Behnken design is an independent quadratic design in that it does not contain an embedded factorial or fractional factorial design. In this design the treatment combinations are at the midpoints of edges of the process space and at the centre. These designs are rotatable (or near rotatable) and require 3 levels of each factor. The designs have limited capability for orthogonal blocking compared to the central composite designs.

Both the central composite designs and box behnken designs are used for estimating second order responses surfaces.

Table -3: Number of Runs Required by Central Composite and Box-Behnken Designs

Number of Factors	Central Composite	Box-Behnken
2	13 (5 center points)	-
3	20 (6 center point runs)	15
4	30 (6 center point runs)	27
5	33 (fractional factorial) or 52 (full factorial)	46
6	54 (fractional factorial) or 91 (full factorial)	54

3. Steps of Response Surface Method

RSM is a sequential procedure and its procedure for modeling and analysis of the effects of processing parameters on the performance characteristics in any process or system includes the following steps:

- Defining the independent input variables and desired responses with the design constraints.
- Adopting the CCD and/or Box behnken to plan the experimental designs.
- Performing the regression analysis with the quadratic model of RSM.
- Performing the statistical analysis of variance (ANOVA) for the independent input variables and to find which parameter significantly affects the desired response.
- Determining the situation of the quadratic model of RSM and to decide whether the RSM model needs screening variables.
- Conducting confirmation experiment and verify the predicted performance characteristics.

Advantages of DOE

- Improved process yield.
- Reduces variability.
- Reduces product development time.
- Reduces overall costs.
- Evaluation and comparison of basic design configuration
- Evaluation of material alteration.
- Determines key product design parameters that impact product performance.
- Selection of design parameter so that the product will work well under a wide variety of field conditions, that is, so that the product is robust.

3.1 Modelling Tools and Techniques Used

The methods of collecting the experimental data, i.e. design of experiments (DOE) and procedure for developing the linear and non linear models, i.e. response surface methodology (RSM) have been used as tools and techniques in the present work.

3.1.1 Conventional Statistical Regression Analysis Based on Design of Experiments

Statistical designed experiments are outstanding in comparison with the conventional engineering experiment approach of varying one variable at time. The most important advantage of statistical design of experiments (DOE) lies in the fact that several variables are simultaneously studied for a more complete insight into the combined effects of the factors on the response under investigation. The experiments usually involve a larger number of variables. The well planned statistically designed experiment requires a less number of experiments compared to the conventional engineering experimental approach.

The DOE combined with response surface methodology (RSM) is a powerful statistical tool to develop the input-output relationships RSM is an empirical modelling approach using polynomials as the local approximations to the true input-output relationships. The statistical regression analysis based on DOE consists of the following steps:

- Identify the important process parameters and their feasible upper and lower limits.
- Decide on the number of replicates. Replicates make the test of significance possible by providing an estimate of experimental error. it also makes the

statistical test more sensitive and increases the precision.

• Develop the design matrix based on the number of variables and their levels chosen.

• Conduct the experiments with input variable combinations as per the design matrix and record the corresponding response values.

• Use response surface methodology to develop linear or non linear relationships. Some responses may have linear relationships and others may have non linear with the input parameters. As the interdependency of the out-put responses cannot be considered in the statistical models, hence a separate model is to be developed for each response.

• Check the statistical adequacy of the model through significance test, ANOVA test, coefficient of determination (i.e. R2 value) and coefficient correlation (i.e. R value).

• Analyse the effect of variables on the responses with the help of main effect plots (linear models) and surface plots (non-linear models).

• Test the performance (practical stability) of the developed models using some random test cases.

The DOE techniques used in the present work are

• 2-level full factorial design

• Face centred central composite design

6.3 Experimental Set-up

6.3.1 Dispersion Kneader Machine

Ordinary kneading machine works is by a pair of co-ordination and the rotation of the blades (often was Z-shaped) produced a strong shearing action of the semi-state or leaving thick rubber-like materials, plastic materials can respond quickly to obtain a uniform mixture stirring.

Operation

1. Check the kneading machine to ensure that no debris has been fastening belt guard, the gear reducer oil level in the oil and 1 / 2 to 2 / 3.

2. The operator must wear uniforms, wearing helmets, masks and goggles and other protective clothing.

3. Kneader should be reconfirmed at the moving parts inside and no foreign body and staff only after closing the boot.

4. The observation of machine operation when the current space is in the range observed the functioning of mechanical drive components is good, if vibration or abnormal sound, etc causes then immediately stop inspection, troubleshooting.

5. Shut out of the water cooling pump valve, hand the flexibility to offer fixed cooling water pump, cooling water pump to move the observed shift is correct.

6. Water valve is fully open, start the cooling water pump. Open the valve in the process of cooling water pump. If the pressure gauge reaction is not normal, immediately stop the pump and replace the pressure gauge before continuing.

Applications

• Rubber compounds and end products

• Plastic compounds & end products

• Polymer based compounds and end products

6.3.2 Guidelines for Designing Experiment

1. Recognition of and statement of the problem

It is usually helpful to prepare a list of specific problems or questions that are to be addressed by the experiment. A clear statement of the problem often contributes substantially to better understanding of the phenomenon being studied and the final solution of the problem. It is also important to keep the overall objective in mind; for example is this new process or system in which case the initial objective is likely to be characterization or factor screening or is it a mature or reasonably well-understood system that has been previously characterized in which case the objective may be optimization? There are many possible objectives of an experiment, including confirmation (is the system performing the same way now that it did in the past?),discovery (what happens if we explore new materials ,variables , operating conditions, etc.?), and stability(under what conditions do the response variables of interest seriously degrade?).

2. Choice of factors, levels, and range

When considering that may influence the performance of a process or system, the experimenter usually discover that these factors can be classified as either potential design factors or nuisance factors. The potential design factors are those factors that the experimenter may wish to vary in the experiment. Often we find that there are a lot of potential design factors, and some further classification of them is helpful. Some useful classifications are design factors, held-constant factors, and allowed-to-vary factors. The design factors are the factors actually selected for study in the experiment. Held-constant factors are variables that may exert some effect on the response, but for purposes of the experiment these factors are not of interest, so they will be held at a specific level.

Once the design factor has been selected, he or she must choose the ranges over which these factors will be varied, and the specific levels at which runs will be made. Thought must also be given to how these factors are to be controlled at the desired values and how they are to be measured.

3. Selection of the response variable

In selecting the response variable, the experimenter should be certain that his variable really provides useful information about the process under study. Most often, the average or standard deviation (or both) of the measured characteristic will be the response variable. Multiple responses are not unusual. Gauge capability (or measurement error) is also an important factor. If gauge capability is inadequate, only relatively large effects will be detected by the experiment or perhaps additional replication will be required.

Test Equipment used for Measuring Parameters

Shore hardness and surface roughness tests were conducted on all the samples, produced after all experimentation techniques and also on random test samples. The details of important test equipments used and measurement of responses in experimental study are given below:

1. Surface Roughness Tester / Talysurf

Surface roughness was measured using the Taylor Hobson (UK) make Talysurf of model Surtronic 3+ available in the Metrology laboratory of our college. The equipment uses the stylus method of measurement, has profile resolution of 12 nm and measure roughness up to 100μm and has the display of LCD Matrix, 2lines x 16 characters. In our case, a tracing length of 8mm and traverse speed of 1mm/s were used for the measurement of surface roughness. The indicated "Ra "was noted as specific surface roughness.

2. Shore Durometer

The Shore Durometer hardness was used to measure hardness .Shore measures hardness in terms of the elasticity of the material. The hardness value is determined by the penetration of the Durometer indenter foot into the sample.

CONCLUSIONS

Design of experiments methodology with response surface method was used for modelling the responses like, surface roughness and hardness which are the most important quality characteristics in Rubber Rollers. Both linear and non linear regression analysis were conducted on all responses. The result showed that the process parameters such as Speed, Feed and Depth of cut were having a linear relationship with responses. The linear models developed had shown significant effects of process parameters on responses. The effects of different process parameters on the responses were studied with the help of main effect and interaction plots.

The statistical adequacy of each model was tested by ANOVA test. It was found that, all the developed models by FFD and CCD were statistically adequate and could be used for making predictions. Further the developed models were tested/ validated with the help of 16 random test cases. The linear regression models based on FFD was found to be the best fitted models for responses, surface roughness and hardness.

9.2 Scope for future work

As Rubbers have wide applications in automobile, aerospace, electrical and many other manufacturing industries, but still not much work has been done on its quality characteristics with different input process parameters.

The machining variables are divided into three main categories. These are tool variables, work piece variables and set-up variables. Tool variables includes tool material, nose radius, tool wear, tool geometry, tool vibration, machine tool rigidity, and tool overhang etc. Work piece variables include work piece material, length and diameter etc. Set-up variables include cutting speed, feed rate, depth of cut etc. In the present work only set-up variables are considered. Tool variables and work piece variables can also be optimized by using design of experiment.

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