OPTIMISATION OF ABRASIVE WEAR OF RICE HUSK REINFORCED EPOXY COMPOSITE BY USING RESPONSE SURFACE METHODOLOGY

A PROJECT REPORT SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF

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By

SATISH KUMAR DALAI (110ME0162)

PREETISH PRASAD CHAND (110ME0283)

DEPARTMENT OF MECHANICAL ENGINEERING

NATIONAL INSTITUTE OF TECHNOLOGY

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National Institute of Technology

Rourkela

CERTIFICATE

This is to certify that the thesis entitled "***OPTIMISATION OF ABRASIVE WEAR OF RICE HUSK REINFORCED EPOXY COMPOSITE BY USING RESPONSE SURFACE METHODOLOGY***" submitted to the National Institute of Technology, Rourkela (Deemed University) by PREETISH PRASAD CHAND, Roll No. 110ME0283 for the grant of the Degree of Bachelor of Technology in Mechanical Engineering is a record of bonafide research work performed by him under my supervision and direction. The outcomes presented in this thesis has not been, to the best of my knowledge, submitted to any other University or Institute for the honour of any degree or diploma.

The thesis, as per my opinion, has arrived at the benchmarks satisfying the prerequisite for the award of the degree of **Bachelor of Technology** as per regulations of the Institute.

Date: **(Prof. S. K. Acharya)**

Dept. of Mechanical Engineering

National Institute of Technology

Rourkela-769008

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Place: Rourkela

Date:

Preetish Prasad Chand
Department of Mechanical Engineering
National Institute of Technology, Rourkela
India 769008

ABSTRACT

Wear is the disintegration or sideways uprooting of a material from its "derivative" and unique position on a solid surface performed by the movement of an alternate surface. The requirement for relative movement between two surfaces and mechanical contact between asperities is a paramount refinement between mechanical wear contrasted with different courses of action with comparative results. The wear analysis is possible by expository procedures like Response Surface Methodology. Response Surface Methodology (RSM) is an accumulation of statistical and mathematical techniques helpful for creating, enhancing, and upgrading methodologies. It additionally has important requisitions in the outline, advancement, and definition of new items, and also in the change of existing item plans. The broadest provisions of RSM are in the modern world, especially in circumstances where several input variables conceivably impact some performance measure or quality characteristic of the product or process. . The current point of the project embodies the accumulation of information from investigations led over a range of input parameters (factors) and determining the optimal response (output) for the various combinations/interactions of factors. The material picked here is rice husk reinforced epoxy composites. As rice husk is an agricultural waste material, these husks have no business interest .They might be utilized as filler material for structuring light weight polymers composites. In this way, a polymer matrix composite comprising of rice husk fibres has been created. The different input parameters are Sliding Velocity, Volume portion of fibre and load. The reaction we wish to minimize is the wear loss of the material. The full factorial configuration experimentation has been expected to model the abrasive wear response. These two different second order regression equations for abrasive wear rate (Δw) and Erosion Rate (ER) have been evaluated after implementation of Analysis of variance (ANOVA) at 95% confidence level. To have an assessment of pure error and model fitting error, some of the experimental trials are replicated in both the cases and the adequacy of the models is also investigated by the examination of residuals. The mathematical models which are developed to predict the abrasive wear characteristics has been found to be statistically valid and sound within the range of the factors.

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LIST OF SYMBOLS

A	Analysis of variance
FFD	Full factorial design
GS	Abrasive grit size
H (t)	Sample thickness at any time t
k_0	Specific Wear rate
L	Applied Normal Load
P_{break}	Maximum load at failure
R^2	Coefficient of determination
R^2_{adj}	Adjusted coefficient of determination
R_e	Volume fraction of reinforcement
RSM	Response Surface Methodology
S_d	Sliding Distance
t	Time
W	Wear rate
W_t	Weight after time‘t’
Δw	Wear loss/ Weight loss
ŵ	Cumulative weight loss

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CHAPTER 1

BACKGROUND AND MOTIVATION

It is adept that innovative improvement relies on upon developments in the field of materials. One need not be a master to understand the concepts of most developed turbine or air-craft design basics. Technology is of no utilization if satisfactory materials to manage the administration loads and conditions are not accessible [1]. Whatever the field may be, the last constraint on headway relies on upon materials. Composite materials in this respect speak to only a monster venture in the ever-steady attempt of improvement in materials [2, 3].

Strictly talking, the thought of composite materials is not another or late one. Nature is brimming with samples wherein the thought of composite materials is utilized. The coconut palm leaf, for instance, is only a cantilever utilizing the idea of fibre fortification. Wood is a fibrous composite: cellulose strands in a lignin network [4]. The cellulose filaments have high elasticity yet are exceptionally adaptable (i.e. low stiffness), while the lignin grid joins the strands and outfits the solidness. Bone is yet an alternate illustration of a common composite that backs the weight of different parts of the body. It comprises of short and delicate collagen strands inserted in a mineral network called apatite. Notwithstanding these characteristically happening composites, there are numerous other designing materials that are composites in an exceptionally general manner and that have been being used for long time. The carbon dark in elastic, Portland concrete or black-top blended with sand, and glass filaments in pitch are regular illustrations. Accordingly, we see that the thought of composite materials is not that later. All things considered, one can securely stamp the inception of the different control of the composite materials as the start of the 1960's [5-8]. It might not be excessively off the imprint to say that a coordinated innovative work exertion in composite materials started in 1965. Since the early 1960's, there has been an expanding interest for materials that are stiffer and stronger yet lighter in fields as differing as aviation, vitality and civil developments. According to Berghezan, the composite material is to be composed in such a path, to the point that the unique segments hold their distinct aspects and the composite exploits their prevalent properties without bargaining on the shortcoming of either.[9,10]

There are fundamentally three sorts of composite material relying upon the matrix material utilized.

- Metallic composite
- Polymeric composite
- Ceramic composite

Lately, common fibre fortified with polymer matrix have gotten the consideration worldwide because of their minimal effort, lightweight, renew ability, combustibility ,low density ,high specific strength and biodegradability. Numerous sorts of regular strands are accessible in plenitude, for example, jute, and banana, rice husk which have turned out to be great and proficient fortifications. Fibre Reinforced Polymer (FRP) composites are the most advanced kind of composites [11-14]. They are exceptionally efficient in view of their minimal cost, high quality, strength and basic manufacturing procedures. In spite of the fact that FRP composites have particular detriments like low working temperature, high coefficient of thermal and moisture expansion, low elastic properties in transverse direction, still they are very helpful. [15]

The extent that fortification is concerned, fibres possess a substantial weight fraction in FRP composite as they need to convey most extreme measure of a load when the load acts on the composite. The simplicity of accessibility and simplicity of manufacturing have incited researchers to utilize provincially accessible cheap fibres .Studies have been going on to test their possibility of reinforcement purposes and the degree up to which they can satisfy the particulars of strengthened polymer composites for tribological requisitions [16-18].

Rice husk is one of the least expensive characteristic fibres accessible in India. Rice is a stand out amongst the most prevalent and largest grown farming crops in India. Essentially, rice husk is generated as agricultural waste in tremendous amount. It is the external sheath encompassing the paddy grain and records for 20-25% of the aggregate weight. The paramount properties of rice husk are that it is a fibrous material and has an extensive variety of angle degree. In this manner, it might be utilized as a suitable reinforcement as a part of polymer composites. [19, 20]

The current project manages discovering a requisition to this significant waste and optimising the abrasive wear loss of the composite. The objectives are:

- ✓ To create a polymer matrix composite (epoxy resin) utilizing rice husk as reinforcement and contemplating abrasive wear behaviour of the composite with diverse operating parameters.
- ✓ To perform Response surface methodology analysis for optimising abrasive wear loss of rice husk reinforced epoxy composite.

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CHAPTER 2

LITERATURE SURVEY

2.1 LITERATURE SURVEY

Literature survey is done to get the foundation data on the issues to be recognized in the present work and to centre the significance of the present study. The aim is to present an exhaustive understanding of different aspects of natural fibre reinforced polymer composite with special regard for their abrasive wear behaviour. It additionally stresses on Response Surface Methodology technology to optimise the wear loss of the polymer composites.

2.2 NATURAL FIBER REINFORCED POLYMER COMPOSITES

Natural fibre reinforced polymer composites are hybrid with their properties, with characteristics of both regular fibres and polymers. At the outset of the twentieth century, wood- or cotton fibre reinforced phenol- or melamine formaldehyde resins were manufactured and utilized as a part of electrical provisions for their non-conductive and heat-resistant properties. Fuse of natural fibres into polymer is currently a standard innovation to enhance the mechanical properties of polymer. Mechanical properties like tensile strength and young's modulus are improved at last items (composites) as the fibres in the composites estimate the tensile strength and young's modulus of the materials [21].

One of the biggest zones of latest development in natural fibre plastic composites is the automotive industry, where natural fibres are favourably utilized as a consequence of their low density and expanding environmental pressures. Natural fibres composites discovered requisition where load bearing capacity and dimensional dependability under moist and high thermal conditions are of second order significance. For instance, flax fibre reinforced polyolefin are widely utilized today within the auto business, however the fibre demonstrations predominantly show its usage as filler material in non-structural interior panels [22]. Natural fibre composites utilized for structural purposes do exist, yet then usually with manufactured thermo-set matrices which obviously restrain the environmental profits [23, 24].

Plant fibres, for example, hemp, flax and wood, have substantial potential as reinforcement in structural materials because of the high aspect ratio and high specific strength - and firmness of the fibre filaments [25-27]. Apart from high specific mechanical properties and positive ecological effect, different profits from utilizing natural fibres worth specifying are low cost, ease of processing, low apparatus wear, no skin aggravation and great thermal and acoustic insulating properties [28].

A complete biodegradable framework may be gotten if the matrix material likewise originates from a renewable asset. Cases of such materials are lignophenolics, starch and Poly Lactic acid (PLA). Some of these systems show empowering outcomes. Case in point Oksana et al. [29] have reported that flax fibre composites with PLA network can rival and even beat flax/polypropylene composites as far as mechanical properties. In a late study [30] it was observed that composites of poly-L-lactase corrosive (PLLA) fortified by flax fibres can demonstrate specific malleable modulus tensile modulus equivalent to that of glass/polyester fibre composites. The specific strength of flax/PLLA composites was less than that of glass/polyester, however higher than that of flax/polyester.

The constrained utilization of natural fibre composites is additionally joined with some major disadvantages. The fibres for the most part show low capacity to hold fast to basic non-polar matrix materials for proficient stress transfer. Besides, the fibres exhibit hydrophilic nature which makes them susceptible to water uptake in damped conditions. Characteristic fibre composites have a tendency to swell extensively with water uptake and as a result mechanical properties, for example, stiffness and strength are adversely affected. Then again, the regular fibre is not latent. The fibre-lattice adhesion may be enhanced and the fibre swelling decreased by chemical, enzymatic or mechanical adjustments [31].

There is numerous requisition of natural fibre composite in regular life. For instance, jute is a typical reinforcement for composites in India. Jute filaments with polyester resins are utilized within structures, lifts, pipes, and panels [32].Natural fibre composites can likewise be exceptionally savvy material for requisition in building and development ranges (e.g. walls, roof, parcel, window and entryway outlines), stockpiling gadgets (e.g. bio-gas compartment, post boxes, and so on.), furniture (e.g. seat, table, instruments, and so forth.), electronic gadgets (outer casting of cell telephones), automobile and railway coach interior parts (inward bumpers and guards), toys and different random provisions (head protectors, suitcases).

Throughout the last few years, an arrangement of works has been carried out to supplant the routine manufactured fibre with natural fibre composites [33-40]. For example, hemp, sisal, jute, cotton, flax and broom are the most normally fibres used to strengthen polymers like polyolefin [40, 41], polystyrene [42], and epoxy resins [43]. Also, strands like sisal, jute, coir, oil palm, bamboo, biogases, wheat and flax straw, waste silk and banana [35,36,41-50] have turned out to be great and powerful support in the thermo set and thermoplastic lattices. By and by, some aspects of natural fibre reinforced composite behaviour still inadequately understood, for example, their viscous-elastic, viscos-plastic or time-subordinate behaviour because of creep and fatigue loadings [51], interfacial bond [52, 53], and tribological properties. Little data concerning the tribological execution of natural fibre fortified composite material [46-48, 54] has been accessible in the written works. In this connection, long plant fibres, in the same way as hemp, flax [52, 53] and bamboo [47, 48] have significant potential in the production of composite materials for tribe provisions. In like manner, rice husk strands might additionally have respectable potential as support for polymer and may give favourable circumstances when utilized as a substitute for conventional synthetic glass fibre.

In the wake of assessing the available literatures accessible on the common fibre composite endeavours are put to comprehend the essential needs of the developing composite industry. The conclusions drawn from this is that, the achievement of consolidating vegetable common fibres with polymer matrices brings about the enhancement of mechanical properties of the composite contrasted with the matrix material. These fillers are shabby and nontoxic and could be acquired from renewable source and are effectively recyclable. Additionally notwithstanding of their low strength, they can prompt composites with high specific strength due to their low density.

Subsequently, necessity of this work is to plan Polymer Matrix Composites (PMCs) rice husk fibre as reinforcement material. To enhance the interfacial bond between the fibre and the matrix, the surface change of the fibre must be carried out chemically. The composite will then be subjected to distinctive weathering condition like steam, saline and sub-zero condition. The mechanical properties of the composite will be assessed alongside dampness ingestion qualities.

2.3. RESPONSE SURFACE METHODOLOGY-TECHNIQUE

Reaction surface procedure, an exploratory technique at first created and depicted by Box and Wilson, has been utilized with significant achievement in a wide assortment of circumstances, particularly in the fields of chemical engineering and compound designing. It was the motivation behind this paper to audit the writing of response surface methodology, underscoring particularly the practical provisions of the system and its utilization in day by day life [55].Response surface Methodology (RSM) is a gathering of apparatuses created in the 1950s with the end goal of deciding ideal working conditions in requisitions in the chemical industry. This article surveys the advancement of RSM in the general ranges of test plan and examination and shows how its part has been influenced by developments in different fields of applied statistics [56]. An audit about the provision of Response Surface Methodology (RSM) in the improvement of explanatory systems is critical. The hypothetical standards of RSM and steps for its provision are depicted to acquaint book lovers with this multivariate measurable procedure. Symmetrical test plans (three-level factorial, Box–Menken, focal composite, and Doehlert outlines) are thought about as far as attributes and proficiency. Besides, late references of their utilization in systematic science are exhibited.

Various response optimisation applying desirability criteria in RSM and the utilization of fake neural systems for demonstrating are of imperativeness and hold significance in improvement [57]. Due to the across the board utilization of exceedingly robotized machine devices in the business, manufacturing needs reliable models and systems for the expectation of yield execution of machining procedures. The forecast of ideal machining conditions for great surface completion and dimensional exactness assumes an exceptionally critical part in procedure arranging. The present work manages the study and advancement of a surface roughness prediction model for machining mild steel, utilizing Response Surface Methodology (RSM). The experimentation was completed with Tin-coated tungsten carbide (CNMG) cutting devices, for machining mild steel work-pieces coating an extensive variety of machining conditions. A second request scientific model, regarding machining parameters, was produced for surface harshness expectation utilizing RSM. This model gives the component impacts of the unique procedure parameters. An endeavour has additionally been made to upgrade the surface unpleasantness expectation model utilizing Genetic Algorithms (GA) to improve the goal capacity. The GA system gives least and most extreme qualities of surface harshness and their particular ideal machining conditions [58]. Reaction surface strategy (RSM) is the most prevalent advancement technique utilized within late years. There are such a variety of works focused around the requisition of RSM in substance and biochemical methodology. Then again, few articles were distributed about the limit and convenience of it. In this paper, we took a gander at a percentage of the RSM articles distributed throughout the last few years. We attempted to distinguish basic slip-ups made in the provision and the limits of RSM. We put forth two imperative inquiries. These inquiries are "Can RSM be utilized for enhancement of all synthetic and biochemical methods without any impediment?" We could address these inquiries focused around the perceptions got from assessed articles [59]

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CHAPTER 3

WEAR

3.1. INTRODUCTION

Wear is likely the hugest yet the slightest comprehended part of tribology. In materials science, wear is the disintegration or sideways uprooting of a material from its "subordinate" and unique position on a solid surface performed by the activity of an alternate surface. The requirement for relative movement between two surfaces and starting mechanical contact between asperities is a critical qualification between mechanical wear contrasted with different courses of action with comparative results. Wear is the attributes of a designing framework which fundamentally is reliant on different variables like load, speed, temperature, hardness, vicinity of foreign material and the natural conditions. It is identified with communications between the given surfaces and all the more particularly to the evacuation and distortion of material on a surface because of mechanical action of the inverse surfaces.

The wearing conditions lead to the wear of materials which is because of broadly fluctuated wearing conditions. Wear may happen because of surface damage, evacuation of material from one or both solid surfaces in sliding, rolling or effect movement with respect to each other. Much of the time, wear happens through the unevenness of surface, roughness, ruggedness which is known as surface asperities. Wear happens because of surface connections at these asperities. Throughout relative movement between two surfaces, material evacuation can happen on one contact surface, may bring about exchange to mating surface or may break detached as particles. The wear resistance of a material is identified with its microstructure. Along these lines, wear research emphasis is put on microstructure.

3.2. THEORY OF WEAR

Wear happens as a result of collaboration between two surfaces with a relative movement between them. It is a methodology of dynamic loss of material from the connecting surfaces. Different wear hypotheses have been proposed in which the physico-mechanical attributes of materials and different physical conditions are considered. In 1940, Holm recognized the nuclear component of wear and decided the volume of substance worn over unit sliding way. The grip hypothesis of wear was produced by Barwell and Strang in 1952.they likewise proposed a hypothetical comparison indistinguishable in structure with Holm's mathematical statement. In 1957, the weariness hypothesis of wear was advanced by Kragelski which has been broadly acknowledged. It fundamentally states that throughout wearing, the contact between two surfaces is discrete and when these contacts are taken together, they structure the genuine contact zone. The severities infiltrate into one another and straighten out in the contact region. This reasons push and strain inside the surface. In sliding, an altered volume of material is subjected to the above activity more than once which debilitates the material and reasons bursting of the material. Evans et al. mulled over the scraped area wear conduct for 18 polymers and they recognized that Low Density Poly Ethylene (LDPE) indicated the most reduced wear rate in scraped area against rough mild steel, however a higher wear rate in scraped area with coarse corundum paper. Unal et al. Mulled over abrasive wear behaviour of polymeric materials. They presumed that the particular wear rate diminishes with the lessening in rough surface harshness. They additionally presumed that, the abrasive wear incorporates micro-breaking, micro-cutting, and micro-furrowing systems. Though in an alternate test , they inferred that the sliding rate has stronger impact on the particular wear rate. In 1973, the vitality hypothesis of wear was brought into light by Fleischer. It states that the detachment of wear particles obliges a certain volume of material and in this manner aggregates a critical specific internal energy. It ought to be remembered that throughout sliding, a huge share of work done is dispersed as heat and a little parcel of the energy is put away as interior potential vitality. At the point when the potential energy achieves the critical value, plastic flow of material happens in the specified portion and cracks are structured. Besides the specified hypotheses, different speculations have been proposed to clarify the mechanisms of wear. However the essential thought of every last one of speculations is the frictional work. As to the utilization of natural fibres as reinforcement for tribology requisitions in polymer composites, a few works have been endeavoured on characteristic fibres like jute, cotton, palm oil, coir, betel nut, , wood flour and bamboo powder as reinforcement

3.3. TYPES OF WEAR

In most fundamental wear studies where the issues of wear have been an essential concern, the dry friction has been researched in order to keep away from the impacts of lubricants. Dry friction is characterized as contact under unintentional lubricated conditions yet it is well realized that it is rubbing under oil by climatic gasses, particularly by oxygen. A crucial plan to group wear was first advanced by Burwell and Strang. Later Burwell [176] altered the order to incorporate five different sorts of wear, in particular

1) Abrasive wear
2) Adhesive wear
3) Erosive wear
4) Surface fatigue
5) Corrosive wear

1) Abrasive wear

Abrasive wear could be characterized as the wear that happens when a hard surface slides against and cuts groove from a softer surface. It is answerable for most disappointments in practice. Hard particles or asperities that cut or score one of the rubbing surfaces produce abrasive wear. This hard material may be begun from one of the two rubbing surfaces. In sliding mechanisms, abrasion spot can emerge from the current asperities on one surface because of the wear pieces. These are over and over disfigured and in this way get work solidified by oxidation until they got to be harder than either or both of the sliding surfaces, or from the extrinsic entrance of hard particles, for example, dirt from outside the system. Two body abrasive wear happens when one surface removes material from the second, despite the fact that this mechanism regularly changes to three body abrasion as the wear flotsam and jetsam go about as an abrasive between the two surfaces. Abrasives can go about as in grinding where the abrasive is settled with respect to one surface or as in lapping where the abrasive tumbles preparing asperities rather than a scratch. As per the late review, abrasive wear is answerable for the biggest measure of material loss in modern practices.

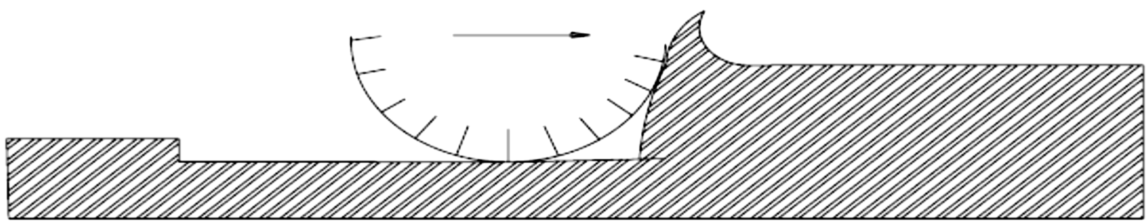

Figure 3.1: Schematic representations of the abrasion wear mechanism

2) <u>Adhesive wear</u>

Adhesive wear might be characterized as the wear because of confined boding between contacting solid surfaces .It causes material exchange between two surfaces. It can likewise cause material loss from either of the surfaces. For adhesive wear to happen, it is fundamental for the surfaces to be in close contact with one another. Surfaces, which are held separated by lubricating films, oxide films and so on diminish the propensity for adhesion to happen.

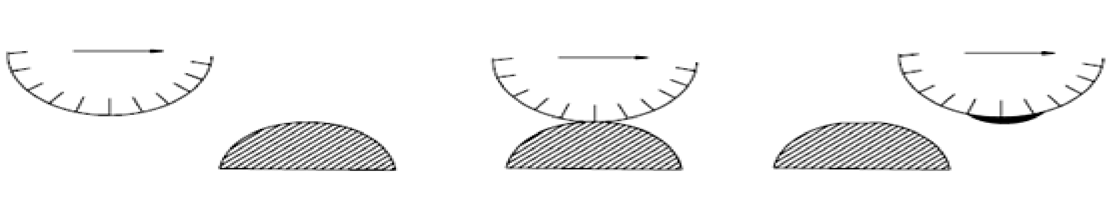

Figure 3.2: Schematic representations of the adhesive wear mechanism

3) Erosive wear

At the point when strong particles are encroached on a surface, material evacuation happens which is known as erosive wear. Erosion is created by a gas or a fluid, which could conceivably convey, en trained solid particles, impinging on a surface. At the point when the angle of impingement is little, the wear handled nearly closely resembles abrasion area. At the point when the edge of impingement is typical to the surface, material is relocated by plastic stream or is ousted by brittle failure.

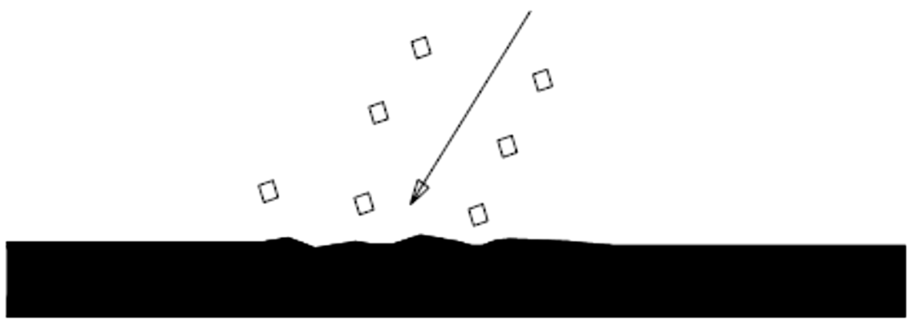

Figure 3.3: Schematic representations of the erosive wear mechanism

4) Surface Fatigue Wear

Fatigue wear of a solid surface is brought on by fracture emerging from material exhaustion. The expression "Fatigue" is connected to the failure phenomenon where a solid is subjected to cyclic stacking including tension and compression over critical stress. Rehashed loading causes the generation of micro cracks, usually underneath the surface, at the site of pre-existing point of shortcoming. On consequent loading and unloading, the micro crack proliferates. When the crack achieves the critical size, it alters its direction to rise up out of the surface, and in this way flat sheet like particles are disengaged during wearing. The amount of stress cycles needed to cause such disappointment diminishes as the relative magnitude of stress increments. Fatigue wear is essentially brought about because of vibration.

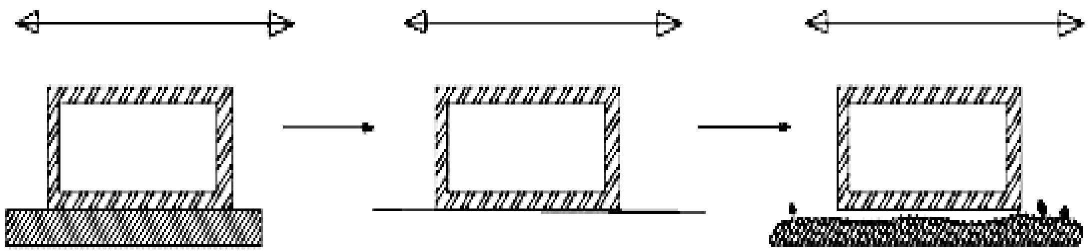

Figure 3.4: Schematic representations of the surface fatigue wear mechanism

5) *Corrosive Wear*

Most metals are thermodynamically unstable in air. They respond with oxygen to structure an oxide, which generally create layer or scales on the surface of metal or amalgams when their interfacial bonds are poor. Corrosion wear is the continuous destroying or disintegration of unprotected metal surfaces by the impacts of the air, acids, gases, soluble bases, and so forth. This kind of wear makes pits and punctures and may in the end break up metal parts.

3.4. SYMPTOMS OF WEAR

Literature accessible on the rate of controlling abrasive wear component show that it may change unexpectedly from each other at certain sliding speeds and contact loads, bringing about unexpected changes in wear rates. The clashing brings about the abrasive wear writing emerge mostly due to the contrasts in testing conditions, yet they likewise make clear that a deeper understanding of the abrasive wear component is obliged if a change in the wear resistances of the polymer matrix composites is to be accomplished. It is by and large perceived that abrasive wear is impacted by numerous parameters. Research centre scale investigation, if planned legitimately permits cautious control of the tribological systems where by the impacts of distinctive variables on wear conduct of PMCs could be detached and decided. Advancements are still under approach to investigate creative fields for tribo-requisition of natural fibre base materials. In this section, an endeavour has been made to study the capability of utilizing Rice

Husk fibre tribological requisitions. In the current study the impact of fibre loading, sliding speed and normal load on abrasive wear behaviour of rice husk reinforced epoxy composite has been assessed. A rundown of the appearance of the worn out surface and different wear mechanisms is shown below.

Types of wear	**Symptoms**	**Appearance of the worn-out surface**
Abrasive	Presence of clean furrows cut out by abrasive particles.	Grooves
Adhesive	Metal transfer is the prime symptoms.	Seizure, catering rough and torn-out surfaces.
Erosion	Presence of abrasives in the fast moving fluid and short abrasion furrows.	Waves and troughs.
Corrosion	Presence of metal corrosion products.	Rough pits or depressions.
Fatigue	Presence of surface or subsurface cracks accompanied by pits and spalls.	Sharp and angular edges around pits.
Impacts	Surface fatigue, Small micro particles or formation of spalls.	Fragmentation, peeling and pitting.
Delamination	Presence of subsurface cracks parallel to the surface with semi-dislodged or loose flakes.	Loose, long and thin sheet like particles
Fretting	Production of voluminous amount of loose debris.	Roughening, seizure and development of oxide ridges

Table 3.1: - Symptoms and appearance of different types of wear

3.5. PREPARATION OF COMPOSITE FOR TEST

To conduct the required test, the following materials have been used in the composite.

- Rice husk fibres
- Epoxy
- Hardener

- **Rice Husk Fibres**

Rice husk is an agricultural waste material. It is plentifully available in rice-producing nations. These are common sheaths that are formed on rice grains throughout their growth. They are evacuated during the refining of rice. Accordingly, these husks have no commercial interest.

As rice husk is a stringy material and an extensive variety of aspect ratio, it could be utilized as filler material for structuring light weight polymers composites. Along these lines, a polymer matrix composite comprising of rice husk fibres has been created.

- .**Epoxy Resin (Polyepoxides)**

Epoxy resins are a class of reactive polymers and propolymers which contain epoxide groups. Epoxy resins may be reacted either with themselves through catalytic homopolymerisation or with a wide range of co reactants called hardeners. The cross-linking reaction is called Curing. The inclusion of epoxy resin helps to form thermosetting polymer with strong temperature resistance and chemical resistance.

- **Hardener**

The hardener with IUPAC name NNO-bis (2aminoethylethane-1,2diamin) has been used with epoxy designated as HY951. It has a viscosity of 10-20 MPa at 298K.

Fibre Preparation

The rice husks were gathered locally. They were washed a few times with plain water to evacuate the dust particles and outside pollutions held fast to them. The cleaned rice husk strands are dried in the daylight. After that, these rice husk fibres were sieved with sifter shaker. A specific size of rice fibre is picked for completing the trial experiment.

Preparation of specimens for dry sliding wear test

Fibres are prepared by taking after the strategies as demonstrated previously. A certain measure of epoxy resin and hardener (10:1 degree by weight) was altogether blended in glass container. To evacuate the air bubbles, the mixture was set in a vacuum chamber. The weighted amount of fibres (0, 5,10,15,20 vol %) were added to resin with required amount of hardener. A steel mould has been planned and created in the work-shop and utilized for arrangement of barrel shaped (pin) sort example of length 35mm & track range of 50 mm. The mixture of rice husk fibre and epoxy resin has been put into the barrel shaped cavity present in the mould and after that the two parts of the mould are altered appropriately. Throughout blending, a percentage of the resin blend may be pressed out. Satisfactory forethought has been taken for squeezing out of resin-blend during preparation of composites. In the wake of closing of the mould, the examples specimens were permitted to set in the mould at the room temperature for 24 hrs. With the end goal of correlation the matrix material was likewise thrown under comparative condition. After curing the specimens were taken out from the mould, finished ground to obliged shape, sizes for wear testing.

3.6. DRY SLIDING WEAR TEST

Dry sliding wear test has been completed under multi-pass condition on a pin-on-plate sort wear testing machine (according to ASTM G-99 standard) supplied by Magnum Engineers, Bangalore (Figure A and B). Abrasive paper of 400 grade (coarseness-23 µm) has been stuck on a turning disc (EN 31 Steel disc) of 120mm diameter using double-sided adhesive tape. The specimens under tests were settled to the specimen holder. The holder alongside the specimen (Pin) was situated at a specific track diameter. This track diameter is to be changed after each one test (i.e.) a new track is to be chosen for every specimen. A track radius of 50 mm was chosen for this trial and was kept steady for the whole experiment. For each one test, new abrasive paper was utilized and the sample was rubbed for an aggregate sliding distance of 471.25m. Throughout experiment, the specimen stays fixed and disc turns. Load is applied through a dead weight loading system to press the pin against the disc. The velocity of the disc or engine rpm could be changed through the controller and interval time might be set by the assistance of timer provided at the control board. The mass loss in the example after each one test was evaluated by measuring the weight of the specimen prior and then afterward each one test utilizing an electronic offset with a precision of ± 0.001 mg. Satisfactory forethought has been taken that the specimen under test are consistently cleaned by woollen material to keep away from ensnarement of wear trash and attain consistency in the exploratory strategy. Test pieces are cleaned with acetone before and after each one test. The machine is fixed with data acquisition system with 'MAGVIEW-2007' software from which the frictional force that arises at the contact can be read out/recorded directly. The test under which the experiment has been carried out is given in Table below. There are three design factors namely Sliding Velocity (consisting of 3 levels), Load (consisting of 4 levels) and Volume fraction of fibre (consisting of 5 levels). Thus, there are (3*4*5) =60 sets of combinations of wear experimental data were recorded and accordingly, the wear loss corresponding to them was determined so as to optimise the wear loss.

The experimental set-up and operating conditions with the input parameters are illustrated in the next page.

Figure 3.5: (A) **Figure 3.5: (B)**

Experimental set-up (A) Pin-on-disc type wear testing machine,

(B) Composite sample under abrasive wear test

Test Parameters	Units	Values
Weight fraction of fibre	%	0,5,10,15 and 20
Load	N	5,7.5,10 and 15
Sliding velocity	m/s	1.0472,1.5708,2.0944
Track radius	mm	50
Temperature	°C	20

Table 3.2: Test Parameters for Dry Sliding Wear Test

3.7. CALCULATION AND RESULT

The results obtained from dry sliding wear test are represented as follows:

Table 3.3: Experimental Results from Dry Sliding Wear Test

	Blocks	Sliding Velocity	Load	Volume Fraction	Wear Loss
1	1	1.0472	5.0	0	0.26
2	1	1.0472	5.0	5	0.16
3	1	1.0472	5.0	10	0.12
4	1	1.0472	5.0	15	0.13
5	1	1.0472	5.0	20	0.15
6	1	1.0472	7.5	0	0.31
7	1	1.0472	7.5	5	0.19
8	1	1.0472	7.5	10	0.12
9	1	1.0472	7.5	15	0.13
10	1	1.0472	7.5	20	0.16
11	1	1.0472	10.0	0	0.40
12	1	1.0472	10.0	5	0.21
13	1	1.0472	10.0	10	0.15
14	1	1.0472	10.0	15	0.20
15	1	1.0472	10.0	20	0.21
16	1	1.0472	15.0	0	0.55
17	1	1.0472	15.0	5	0.29
18	1	1.0472	15.0	10	0.17
19	1	1.0472	15.0	15	0.24
20	1	1.0472	15.0	20	0.27

	Blocks	Sliding Velocity	Load	Volume Fraction	Wear Loss
21	1	1.5708	5.0	0	0.44
22	1	1.5708	5.0	5	0.28
23	1	1.5708	5.0	10	0.18
24	1	1.5708	5.0	15	0.21
25	1	1.5708	5.0	20	0.25
26	1	1.5708	7.5	0	0.55
27	1	1.5708	7.5	5	0.32
28	1	1.5708	7.5	10	0.21
29	1	1.5708	7.5	15	0.26
30	1	1.5708	7.5	20	0.29
31	1	1.5708	10.0	0	0.87
32	1	1.5708	10.0	5	0.42
33	1	1.5708	10.0	10	0.23
34	1	1.5708	10.0	15	0.29
35	1	1.5708	10.0	20	0.33
36	1	1.5708	15.0	0	0.92
37	1	1.5708	15.0	5	0.43
38	1	1.5708	15.0	10	0.38
39	1	1.5708	15.0	15	0.40
40	1	1.5708	15.0	20	0.43

	Blocks	Sliding Velocity	Load	Volume Fraction	Wear Loss
41	1	2.0944	5.0	0	0.65
42	1	2.0944	5.0	5	0.38
43	1	2.0944	5.0	10	0.27
44	1	2.0944	5.0	15	0.30
45	1	2.0944	5.0	20	0.35
46	1	2.0944	7.5	0	0.80
47	1	2.0944	7.5	5	0.44
48	1	2.0944	7.5	10	0.36
49	1	2.0944	7.5	15	0.45
50	1	2.0944	7.5	20	0.48
51	1	2.0944	10.0	0	0.96
52	1	2.0944	10.0	5	0.43
53	1	2.0944	10.0	10	0.37
54	1	2.0944	10.0	15	0.45
55	1	2.0944	10.0	20	0.50
56	1	2.0944	15.0	0	1.02
57	1	2.0944	15.0	5	0.49
58	1	2.0944	15.0	10	0.41
59	1	2.0944	15.0	15	0.54
60	1	2.0944	15.0	20	0.59

- **Wear loss** is estimated by calculating the wear loss of mass after each test for the specimen. The weight loss due to wear is calculated by taking the difference between initial weight and final weight.

Wear loss = $(\Delta w) = (w_a - w_b)$ **gm.**, Where Δw is the weight loss in gm. and w_a and w_b are the weight of the sample after and before the abrasion test in gm.

- ***The abrasive wear rate*** (W) can be calculated by using the following formula:

$$W = \frac{\Delta w}{(\rho \times S_d)}$$

where 'W' is the wear rate in cm3/m, 'ρ' is the density of the composite, Δw the weight loss in gm. and 'S_d' is the sliding distance in m.

- ***The specific wear rate*** **(k_0)** can also be calculated by using equation:

$$k_0 = \frac{\Delta w}{(\rho \times S_d \times L)}$$

Where 'k_0' is the specific wear rate in m^3/Nm, 'Δw' is the weight loss in grams, 'S_d' is the sliding distance in meter, and 'L' is the applied load in N.

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CHAPTER 4

RESPONSE SURFACE METHODOLOGY

4.1 INTRODUCTION

Optimizing alludes to enhancing the execution of a framework, a procedure, or an item so as to get the greatest profit from it. The term optimization has been regularly utilized as a part of analytical chemistry as a method for uncovering conditions at which to apply a system that handles the best conceivable response .Response surface methodology (RSM) is a collection of factual and scientific strategies helpful for creating, enhancing, and improving methodologies. It likewise has imperative requisitions in the outline, improvement, and detailing of new items, and in the change of existing item outlines. The most far reaching requisitions of RSM are in the modern world, especially in circumstances where many data variables conceivably impact some execution measure or quality normal for the item or procedure. This execution measure or quality trademark is known as the response. It is regularly measured on a continuous scale, despite the fact that trait reactions, positions, and tactile reactions are not unexpected. Most certifiable-provisions of RSM will include more than one response. The info variables are sometimes called independent variables, and they are liable to the control of the designer or researcher, at any rate for purposes of a test or an examination.

When applying the RSM system, it is first important to pick an exploratory outline that will characterize which trials ought to be completed in the trial area being studied. There are some experimental matrices for this reason. Exploratory outlines for first-order models (e.g., factorial designs) might be utilized when the information set does not exhibit curve. Be that as it may, to inexact a response capacity for exploratory information which can't be depicted by linear functions. Test outlines for quadratic reaction surfaces ought to be utilized, for example, full factorial, Box–behnken, central composite, and Doehlert plan.

4.2 TERMS USED IN RSM

Before illustrating the importance of Response Surface Method on optimisation, some key terms are introduced regarding RSM.

- *Experimental domain* is the experimental field that must be investigated. It is defined by the minimum and maximum limits of the experimental variables studied.
- *Experimental design* is a specific set of experiments defined by a matrix composed by the different level combinations of the variables studied. Doehlert is an example of a second-order experimental design. This design defines a specific set of combinations for the levels of variables that must be applied experimentally to obtain the responses.
- *Factors or independent variables* are experimental variables that can be changed independently of each other. Typical independent variables comprise the pH, temperature, reagents concentration, microwave irradiation time, flow rate, atomization temperature, and elution strength, among others.
- *Levels* of a variable are different values of a variable at which the experiments must be carried out. The variable pH, for example, can be investigated at five levels: 4, 5, 6, 7 and 8 in the optimization of a spectrophotometric method.
- *Responses or dependent variables* are the measured values of the results from experiments. Typical responses are the analytical signal (absorbance, net emission intensity, and electrical signal), recovery of an analysis, resolution among chromatographic peaks, percentage of residual carbon, and final acidity, among others.
- *Residual* is the difference between the calculated and experimental result for a determinate set of conditions. Low residual values are desired for a good mathematical model fitting to some experimental data.

4.3 STEPS OF RSM

1) Designing a set of experiments from which data is to be recorded
2) Determining a mathematical model fitting the data
3) Testing of adequacy of the model developed (statistical significance of model)
4) Determining the optimal value of the response

(1) ***Designing a set of experiments***

A FULLY FACTORIAL DESIGN (FFD) has been selected consisting of 3 design factors.

i. Sliding Velocity(3 levels)
ii. Load (4 levels)
iii. Volume fraction of fibre(5 levels)

Thus, (3*4*5)=60 combinations of experimental data from dry erosion test are implemented here.

For Convenience, the experimental data has been converted into coded values.

The upper and lower level of the factors have been coded as +1 and -1, respectively and the coded values of any intermediate levels can be calculated using the expression given below .

$$X_i = \frac{2X - (X_{max} + X_{min})}{(X_{max} - X_{min})/2}$$

Where X_i is the required coded value of a factor of any value X from X_{min} to X_{max}, X_{min} the lower level of the factor and X_{max} is the upper level of the factor.

(2) ***Determining a mathematical model fitting the data***

In this project, a second-order (quadratic) polynomial response surface mathematical model is employed to analyse the parametric influences on various response criteria. The second-order model helps to understand main effect as well as the quadratic effect of each factor separately and the two-way interaction amongst these factors combined. This second-order mathematical model can be represented as follows:

$$y = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_i x_i^2 + \sum_{i=1}^{k} \sum_{j=1}^{k} \beta_{ij} x_i x_j + \varepsilon \qquad \text{for } i<j$$

where β_0, β_i (i = 1, 2, . . . , k) and β_{ij} (i = 1, 2, . . . , k, j = 1, 2, . . . , k) are the unknown as regression coefficients to be estimated by using the method of least squares. In this equations ε are experimentally random errors and x_1, x_2………. x_k are the input variables that influence the response y, k is the number of input factors. The least square technique is being used to fit a model equation containing the said regressors or input variables by minimizing the residual error measured by the sum of square deviations between the actual and the estimated responses. This involves the calculation of estimates for the regression coefficients, i.e. the coefficients of the model variables including the intercept or constant term. The dimensions of the regression coefficients and the constant are evaluated such that, the model equation maintains dimension similarity. However calculated coefficients and model consistency need to be tested for statistical significance. In this respect, the statistical test named ANOVA (Analysis of Variance) has been performed.

(3) Testing of adequacy of the model developed

ANOVA calculates various rational terms which determine the statistical consistency of the system.

- *Fishers F-ratio*-

It is the ratio between the regression mean square and the mean square error. If the calculated value of F-value is higher than the tabulated F-value, then the model is said to be adequate at desired significance level α. In the current work the α-level is set at 0.05, i.e. the confidence level is set at 95%.

- *P- value or Probability of significance*-

For testing the significance of individual model coefficients, the model is refined by adding or deleting coefficients through backward elimination, forward addition or stepwise elimination or addition algorithms. It involves the determination of P- value or probability of significance that relates the risk of falsely rejecting a given hypothesis. If the P-value is less than or equal to the α-level , the effect of presence of the variable term is significant. If the P-value is greater than the α-level, the presence of variable term is not significant.

❖ *Coefficient of determination (R^2) and Adjusted coefficient of determination (R^2_{adj})-*

Additional checks are also needed in order to determine the goodness of fit of the mathematical models by determining the coefficient of determination (R^2) and adjusted coefficient of determination (R^2_{adj}). The R^2 is the proportion of the variation in the dependent variable explained by the regression model. On the other hand, R^2_{adj} is the coefficient of determination adjusted for the number of independent variables in the regression model. For a good model, values of R^2 and R^2_{adj} should be close to each other and also they should be close to 1.

(4) *Determining the optimal value of the response*

After analysing all the statistical significance, the response surface analysis is then done in terms of the fitted surface. If the fitted surface is an adequate approximation of the true response function, then analysis of the fitted surface will be approximately equivalent to analysis of the actual system.

Thus, the following criteria have been used during the course of the project.

Input Parameters: Sliding Velocity, Load, Volume Fraction

Output: Wear Loss

Data taken from experiment: Dry Sliding Wear Test

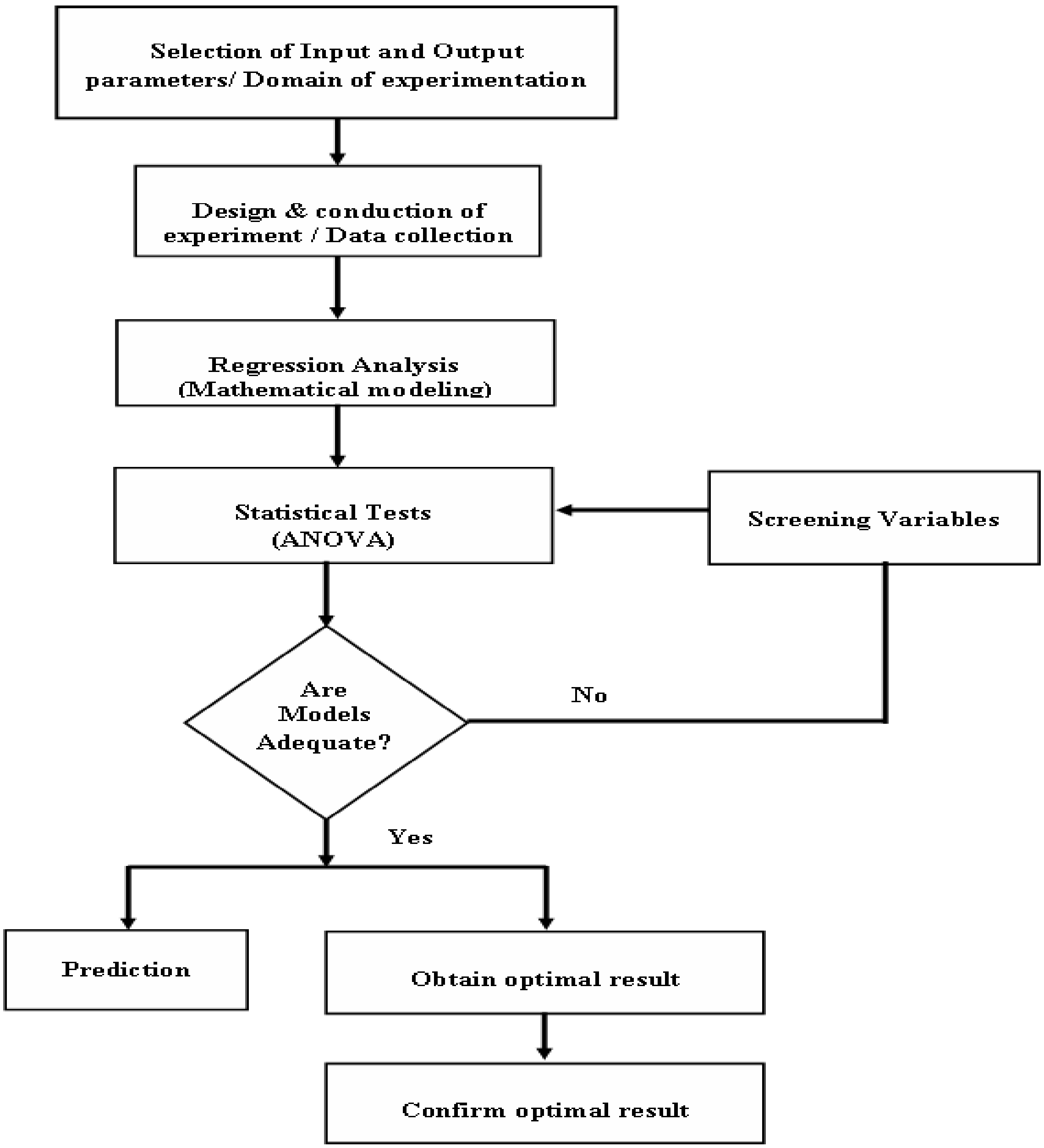
Test material: Rice husk reinforced epoxy composite

Software used for analysis*:* MINITAB 16

Experiment Design*:* Full Factorial Design (FFD)

Optimization method used: Response Surface Method (RSM)

4.4 METHODOLOGY



4.5. RSM RESULTS AND GRAPHS USING MINITAB 16

The following steps were followed to obtain the results in MINITAB using the data observed from the experiments.

- **Step 1** : Open MINITAB
- **Step 2** : We can see the Session manager/Project manager and Worksheet windows. The session manager gives the overall view of the ongoing work while worksheet is used to store the data in row and column format for later manipulations.

Figure 4.1 Worksheet

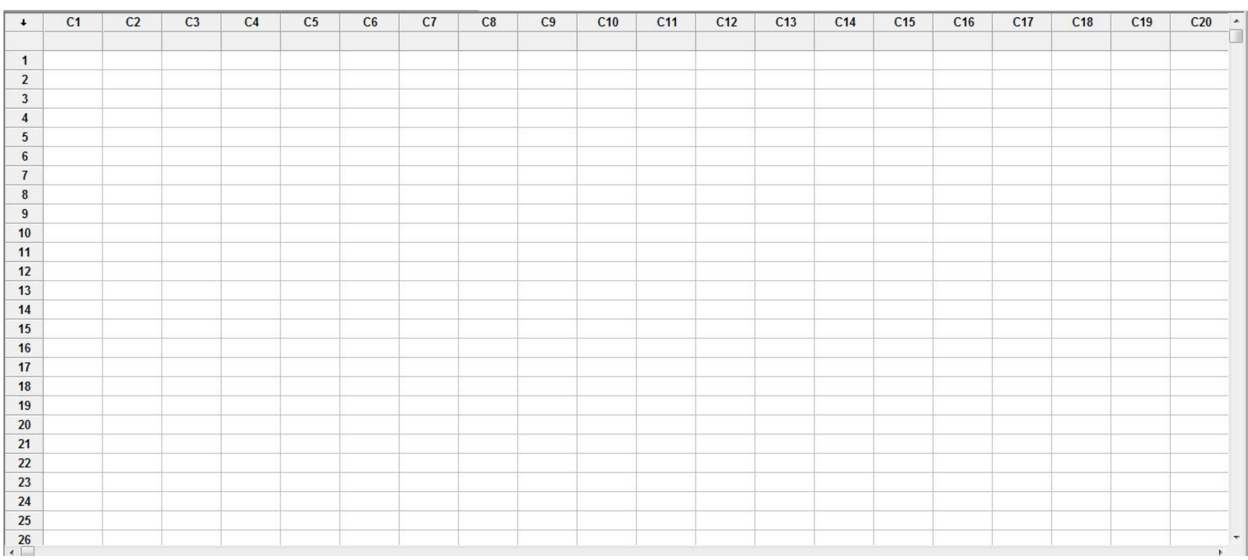
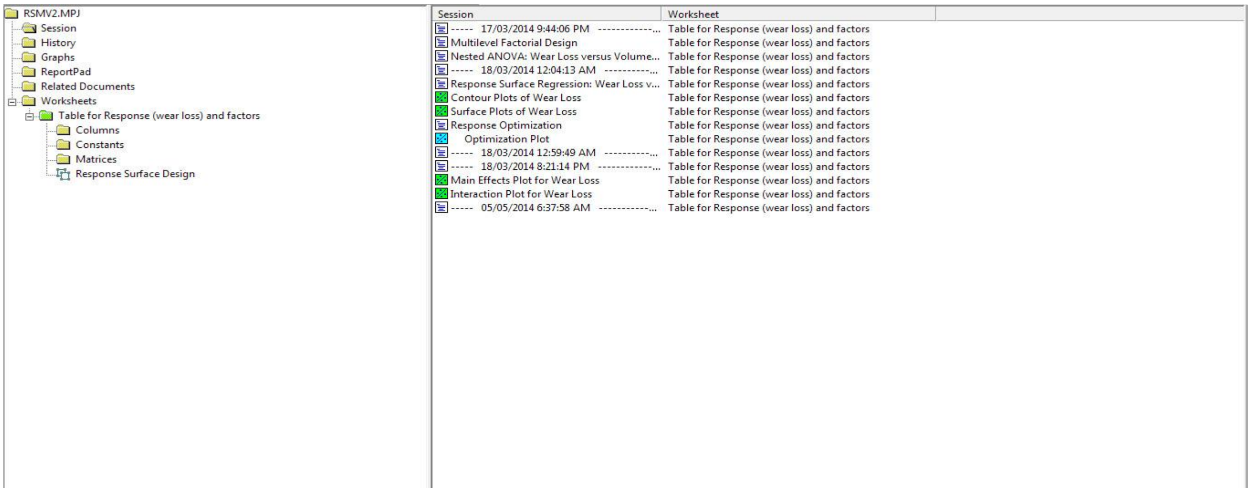


Figure 4.2 Session Manager



- **Step 3:** Fill up the data into the various columns after naming the columns appropriately.

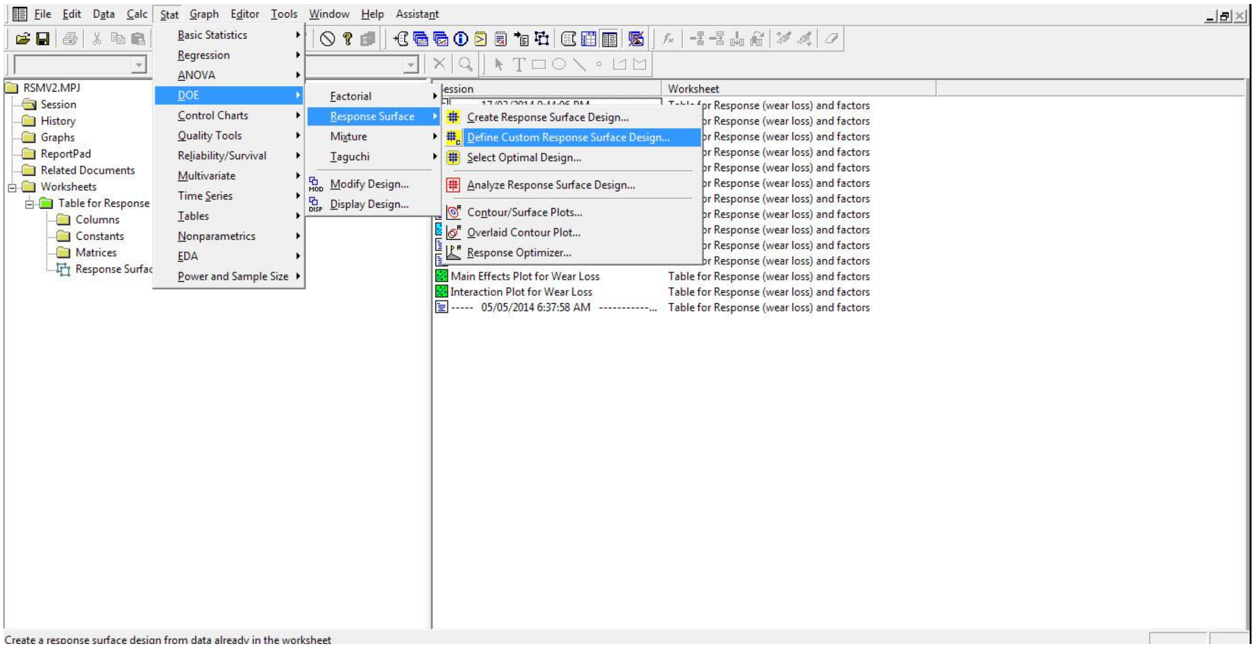
Figure 4.3 Worksheet Data

↓	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21
	Blocks	Sliding Velocity	Load	Volume Fraction	Wear Loss	FITS1	RESI1	COEF1	QUAD1	PFit1	PSEFit1	CLimLo1	CLimHi1	PLimLo1	PLimHi1			
1	1	1.0472	5.0	0	0.26	0.315650	-0.055650	-0.330542	3.00000	-0.2104	0.1857	-0.5834	0.1625	-0.6121	0.1913			
2	1	1.0472	5.0	5	0.16	0.107489	0.052511	-0.042558	0.00000	0.7490	0.8735	-1.0054	2.5034	-1.0118	2.5098			
3	1	1.0472	5.0	10	0.12	0.017185	0.102815	0.037921	0.00000	-1.5743	5.2745	-12.1684	9.0197	-12.1695	9.0208			
4	1	1.0472	5.0	15	0.13	0.044739	0.085261	0.499495	7.00000	-7.1805	13.3875	-34.0700	19.7090	-34.0705	19.7095			
5	1	1.0472	5.0	20	0.15	0.190150	-0.040150	0.002357	6.00000	-16.0694	25.2122	-66.7096	34.5707	-66.7098	34.5709			
6	1	1.0472	7.5	0	0.31	0.395573	-0.085573	-0.000941	5.00000	-0.1470	0.1808	-0.5102	0.2162	-0.5397	0.2457			
7	1	1.0472	7.5	5	0.19	0.177889	0.012111	-0.065656	-0.33054	0.8817	0.8694	-0.8645	2.6279	-0.8709	2.6343			
8	1	1.0472	7.5	10	0.12	0.078061	0.041939	-0.000762	-0.04256	-1.3723	5.2705	-11.9585	9.2139	-11.9596	9.2149			
9	1	1.0472	7.5	15	0.13	0.096091	0.033909	-0.006732	0.03792	-6.9092	13.3836	-33.7909	19.9725	-33.7913	19.9730			
10	1	1.0472	7.5	20	0.16	0.231978	-0.071978	0.005544	0.49950	-15.7288	25.2083	-66.3612	34.9035	-66.3614	34.9038			
11	1	1.0472	10.0	0	0.40	0.463740	-0.063740		0.00236	-0.0953	0.1802	-0.4573	0.2666	-0.4869	0.2962			
12	1	1.0472	10.0	5	0.21	0.236531	-0.026531		-0.00094	1.0027	0.8686	-0.7420	2.7474	-0.7484	2.7538			
13	1	1.0472	10.0	10	0.15	0.127180	0.022820		-0.06566	-1.1821	5.2698	-11.7667	9.4026	-11.7678	9.4036			
14	1	1.0472	10.0	15	0.20	0.135686	0.064314		-0.00076	-6.6496	13.3828	-33.5298	20.2306	-33.5302	20.2310			
15	1	1.0472	10.0	20	0.21	0.262049	-0.052049		-0.00673	-15.4000	25.2075	-66.0308	35.2308	-66.0310	35.2311			
16	1	1.0472	15.0	0	0.55	0.564799	-0.014799		0.00554	-0.0273	0.1891	-0.4072	0.3526	-0.4355	0.3809			
17	1	1.0472	15.0	5	0.29	0.318543	-0.028543			1.2093	0.8767	-0.5515	2.9702	-0.5578	2.9765			
18	1	1.0472	15.0	10	0.17	0.190145	-0.020145			-0.8368	5.2776	-11.4372	9.7635	-11.4382	9.7645			
19	1	1.0472	15.0	15	0.24	0.179603	0.060397			-6.1658	13.3906	-33.0616	20.7300	-33.0620	20.7304			
20	1	1.0472	15.0	20	0.27	0.286918	-0.016918			-14.7775	25.2153	-65.4239	35.8689	-65.4241	35.8691			
21	1	1.5708	5.0	0	0.44	0.501700	-0.061700			-0.2315	0.1849	-0.6028	0.1399	-0.6317	0.1688			
22	1	1.5708	5.0	5	0.28	0.275914	0.004086			0.7103	0.8728	-1.0428	2.4635	-1.0491	2.4698			
23	1	1.5708	5.0	10	0.18	0.167985	0.012015			-1.6306	5.2738	-12.2235	8.9622	-12.2245	8.9632			
24	1	1.5708	5.0	15	0.21	0.177914	0.032086			-7.2544	13.3869	-34.1427	19.6339	-34.1431	19.6343			
25	1	1.5708	5.0	20	0.25	0.305700	-0.055700			-16.1610	25.2116	-66.7999	34.4779	-66.8001	34.4782			
26	1	1.5708	7.5	0	0.55	0.588881	-0.038881			-0.1691	0.1801	-0.5308	0.1927	-0.5604	0.2223			

- **Step 4 :**

We can start filling up the worksheet with the experiment data. This step is integrated into ***Design of Experiment*** step. Since we are concerned with **RESPONSE SURFACE** so we need to go to tool bar: Stat **> DOE > Response Surface > Define Custom Response Surface …** (*the custom response surface is chosen since we want to do a FFD i.e., Full Factorial Design)*

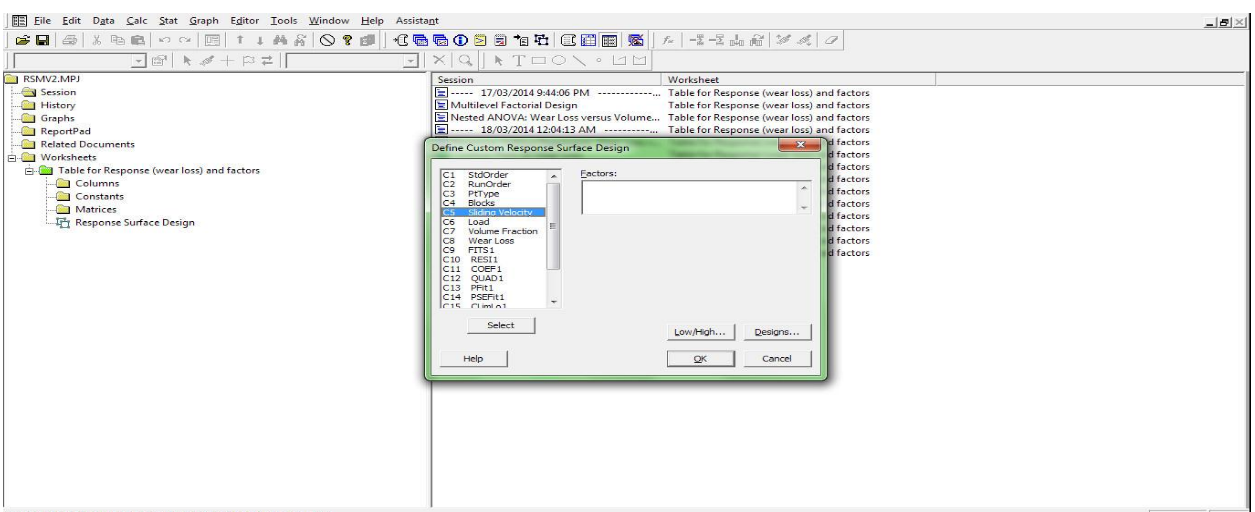
Figure 4.4 DOE Step



- **Step 5 :**

Select the Influence/Input Parameters from the columns in the worksheet as **FACTORS** that affect the Response Surface. We select ***Sliding Velocity, Volume Fraction and Load***.

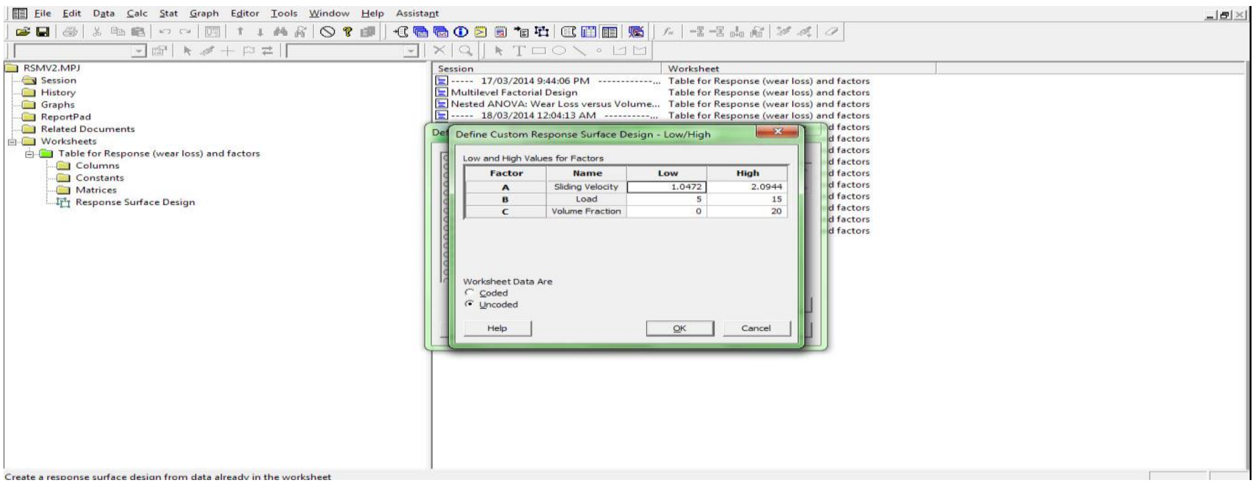
Figure 4.5 Input Parameter Selections



- **Step 6 :**

Provide the Low and High levels for the factors selected in the previous steps. This can be taken from the worksheet or this is fixed before conducting the experiment. Further we choose the values to be in uncoded format.

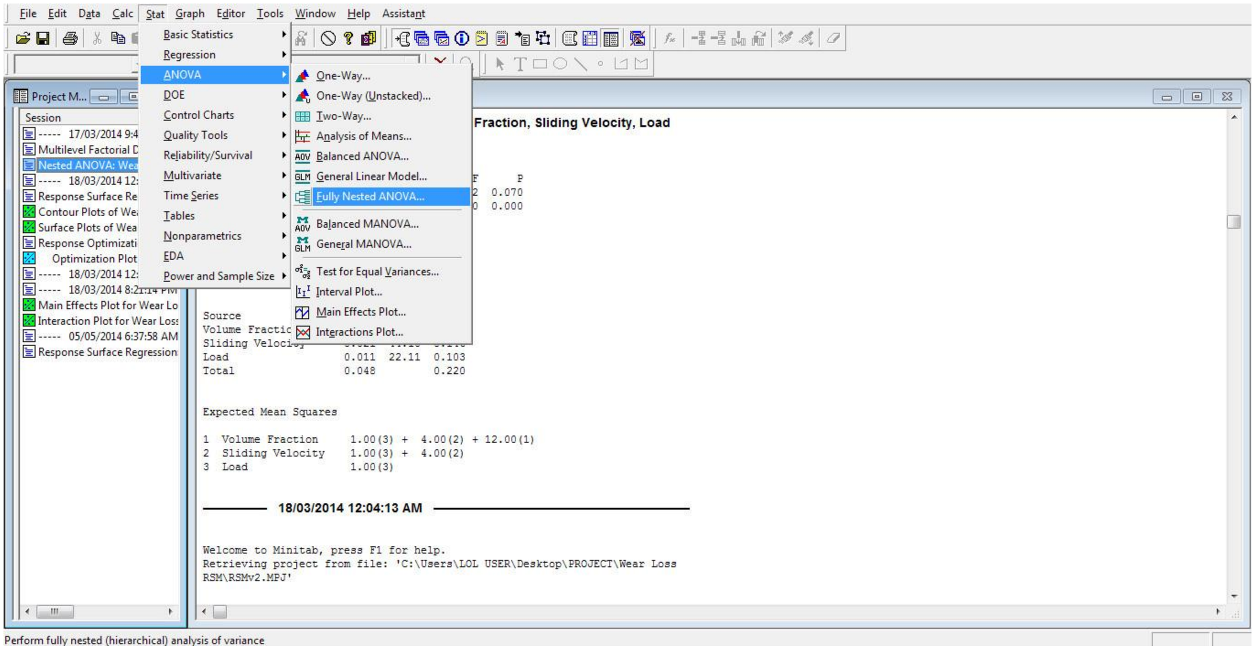
Figure 4.6 Low/High Values



- **Step 7 :**

Performing **ANOVA** on the data in worksheet. Go to toolbar : **Stat > ANOVA > Fully Nested ANOVA …**

Figure 4.7 ANOVA analysis



- **Step 8 :**

Select the ***Wear Loss*** as response and ***Sliding Velocity, Volume Fraction and Load*** as factors and press ok.

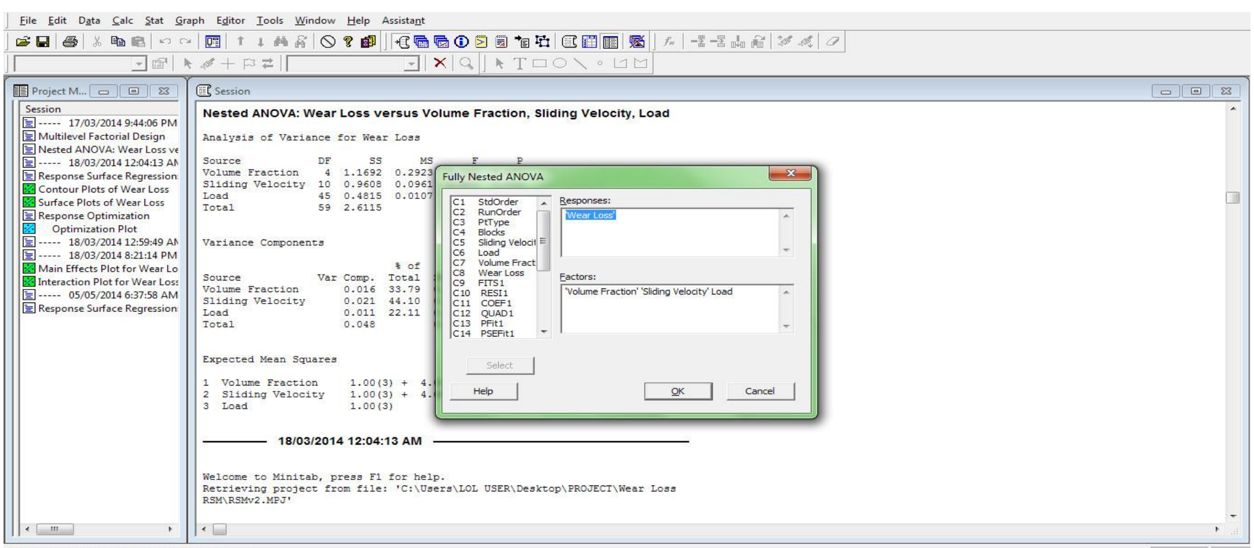


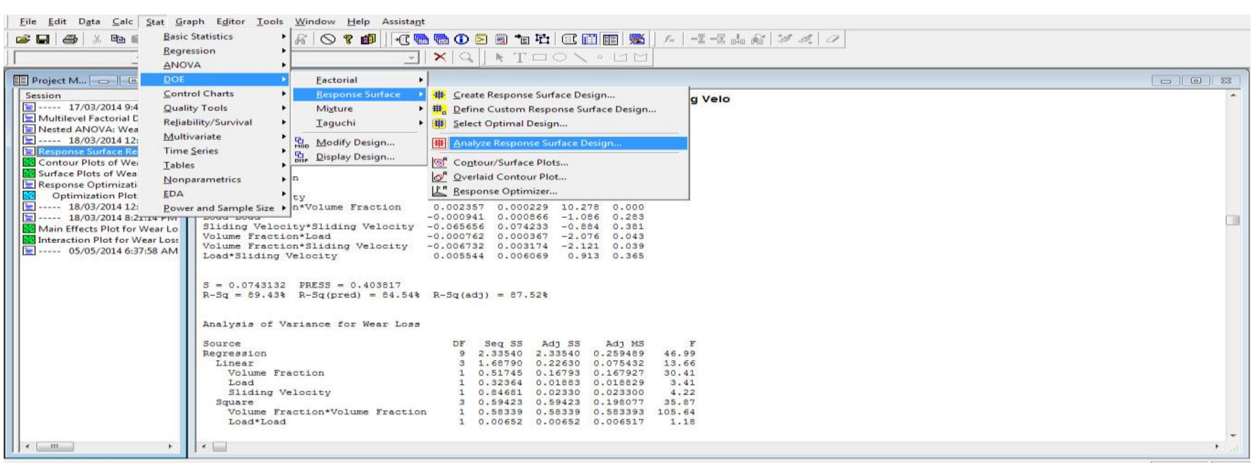
Figure 4.8 ANOVA analysis result

```
Nested ANOVA: Wear Loss versus Volume Fraction, Sliding Velocity, Load

Analysis of Variance for Wear Loss

Source            DF      SS      MS      F      P
Volume Fraction    4  1.1692  0.2923  3.042  0.070
Sliding Velocity  10  0.9608  0.0961  8.980  0.000
Load              45  0.4815  0.0107
Total             59  2.6115


Variance Components

                                 % of
Source            Var Comp.  Total  StDev
Volume Fraction       0.016  33.79  0.128
Sliding Velocity      0.021  44.10  0.146
Load                  0.011  22.11  0.103
Total                 0.048         0.220


Expected Mean Squares

1  Volume Fraction     1.00(3) +  4.00(2) + 12.00(1)
2  Sliding Velocity    1.00(3) +  4.00(2)
3  Load                1.00(3)
```

- **Step 9** :

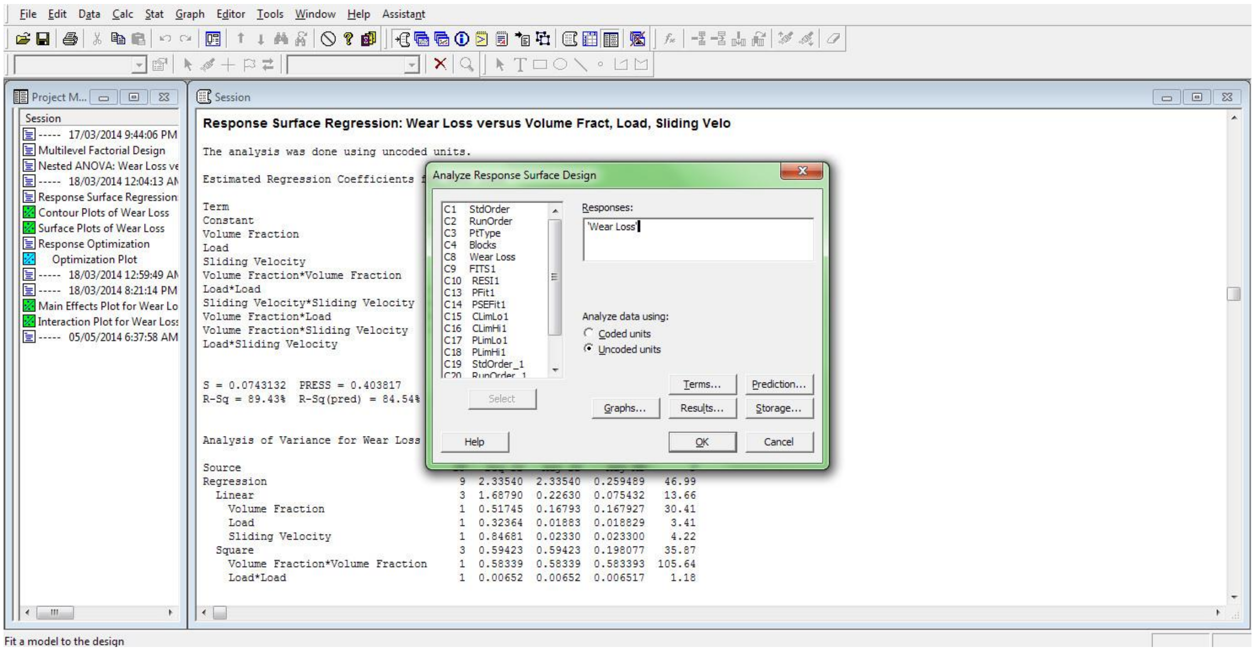
Analysing the Response Surface Design. Go to toolbar: **Stat > DOE > Response Surface > Analyse Response Surface Design …**

Figure 4.9 RS Analysis



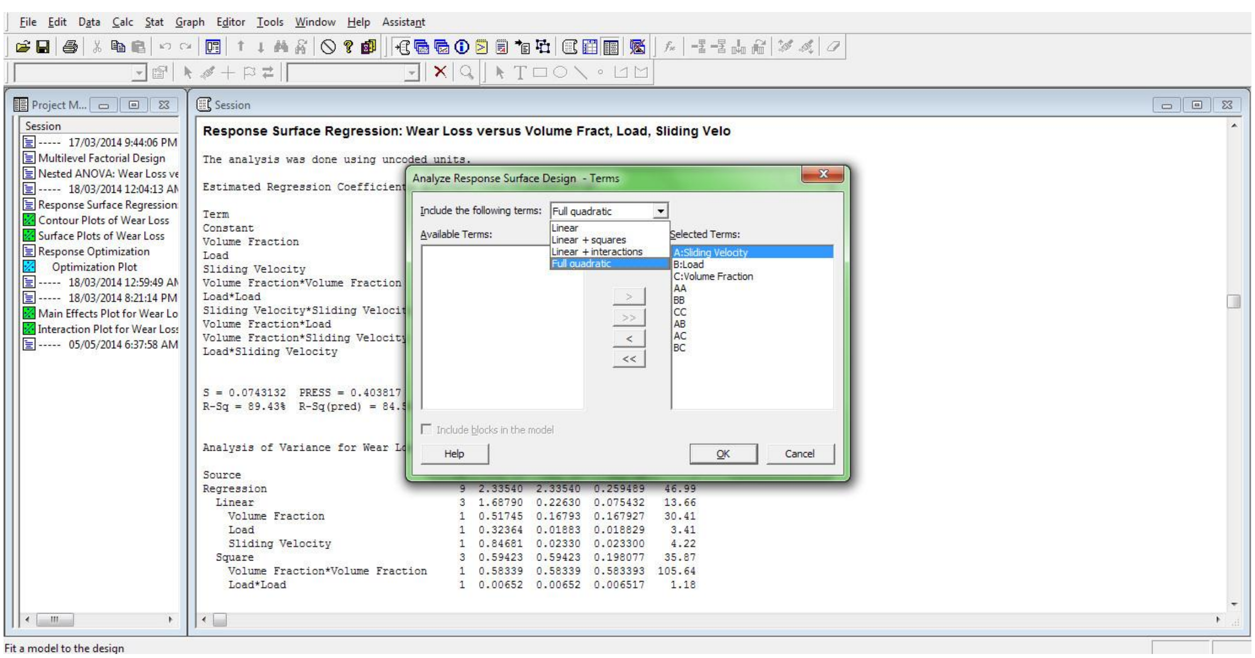
- **Step 10:** Choose ***Wear Loss*** as the response.

Figure 4.10 RS Analysis



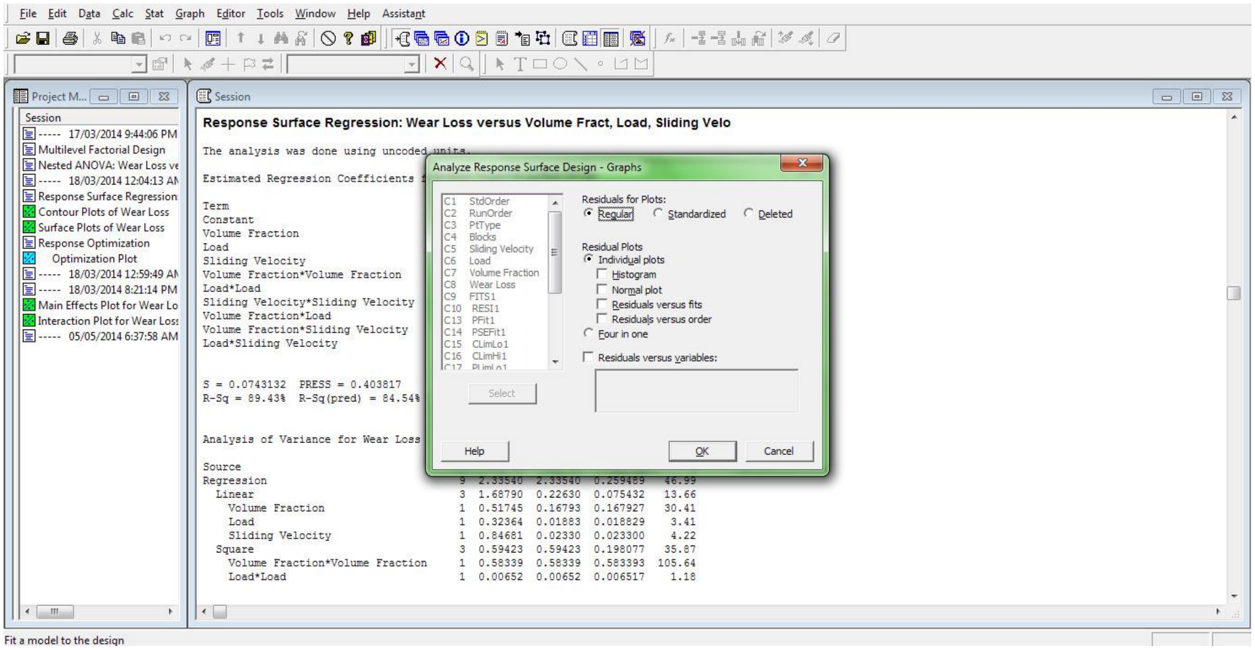
Press the **Terms …** button and select the Full Quadratic from the drop down list.

Figure 4.11 RS Analysis



Skip the **Prediction …** button and press the **Graphs …** button and select the residual plots needed.

Figure 4.12 RS Analysis Plots



Then press the **Results …** and **Storage …** buttons and select the results to be displayed and the results to be stored in **MINITAB** database for future use.

Figure 4.13 RS Analysis results display options

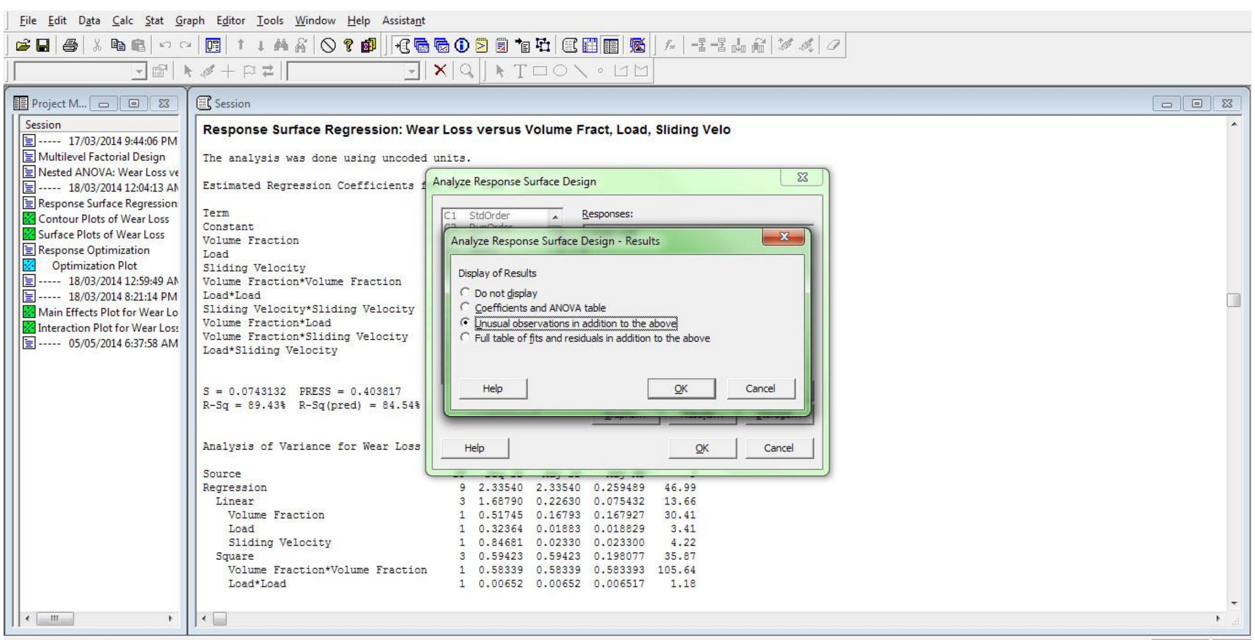
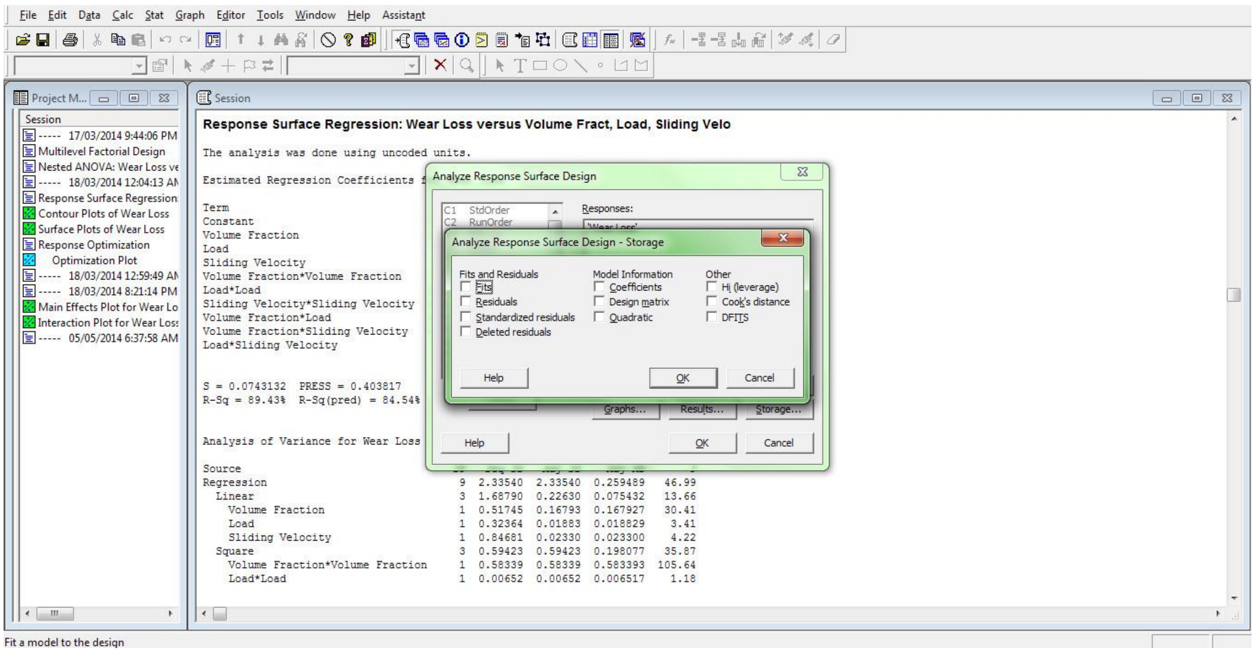


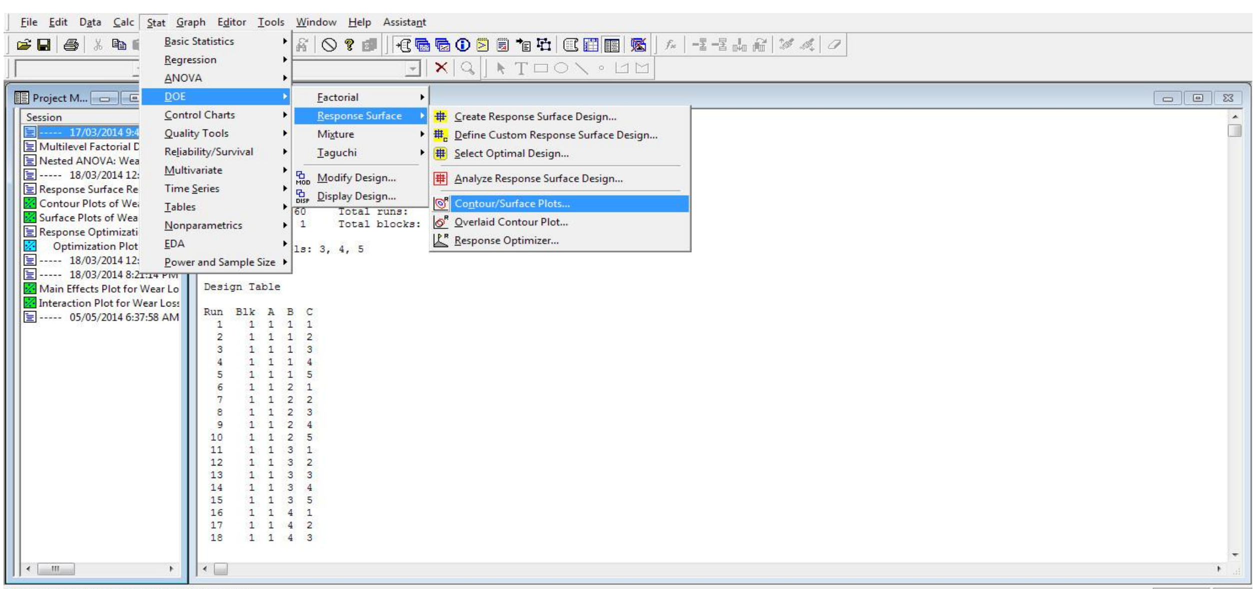
Figure 4.14 RS Analysis Storage options



- **Step 11 :**

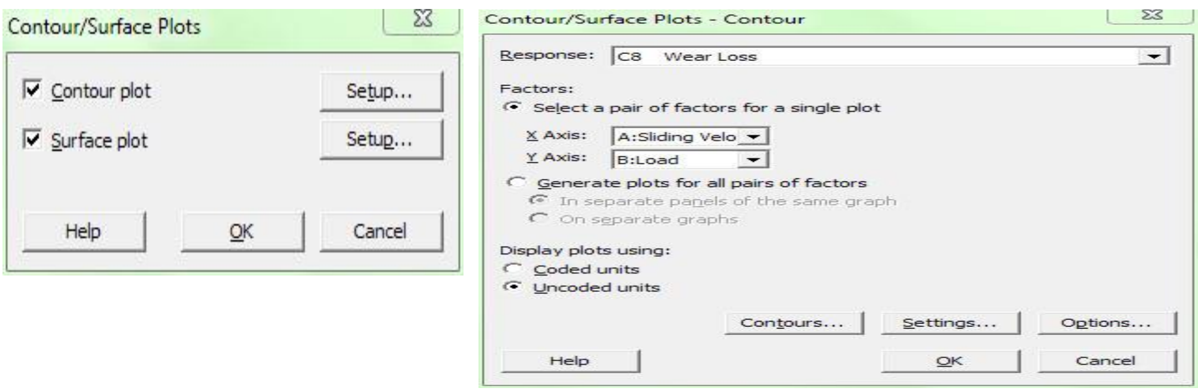
Generating the **Contour and Surface Plots**. Go to toolbar: **Stat > DOE > Response Surface > Contour/Surface Plots …**

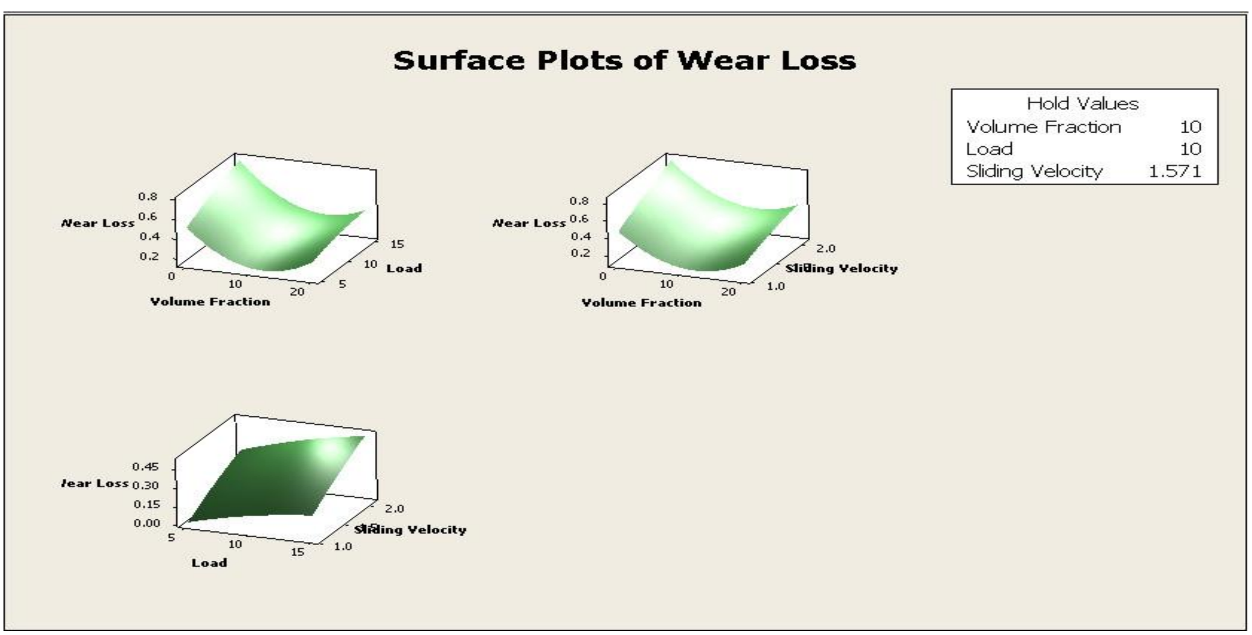
Figure 4.15 Surface/Contour Plots



Tick the boxes besides contour and surface plot options and proceed to adjust the preferences for your plot.

Figure 4.16 Surface and Contour Plots





- **Step 12 :**

Main Effects Plot. go to toolbar : **Stat > ANOVA > Main Effects Plot …** and select the response and influence variables.

Figure 4.17 Main Effects Plot

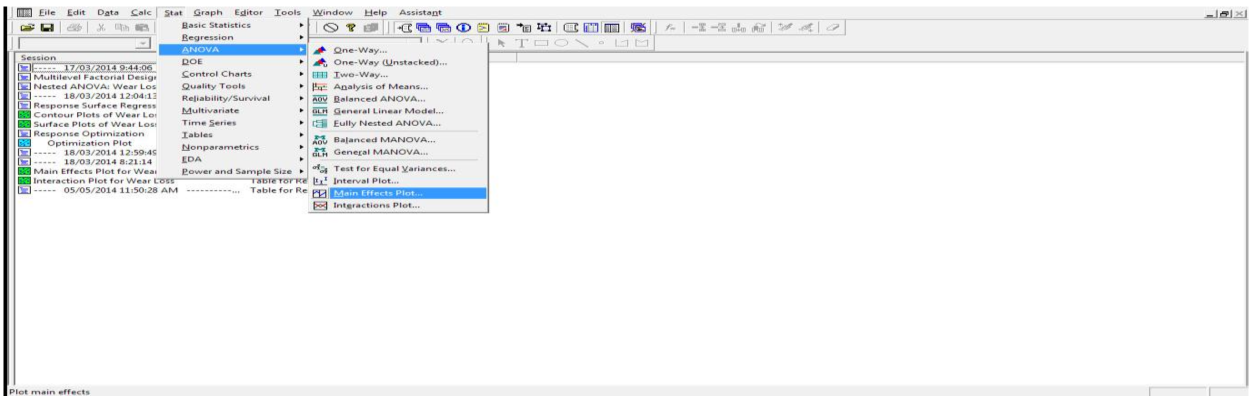
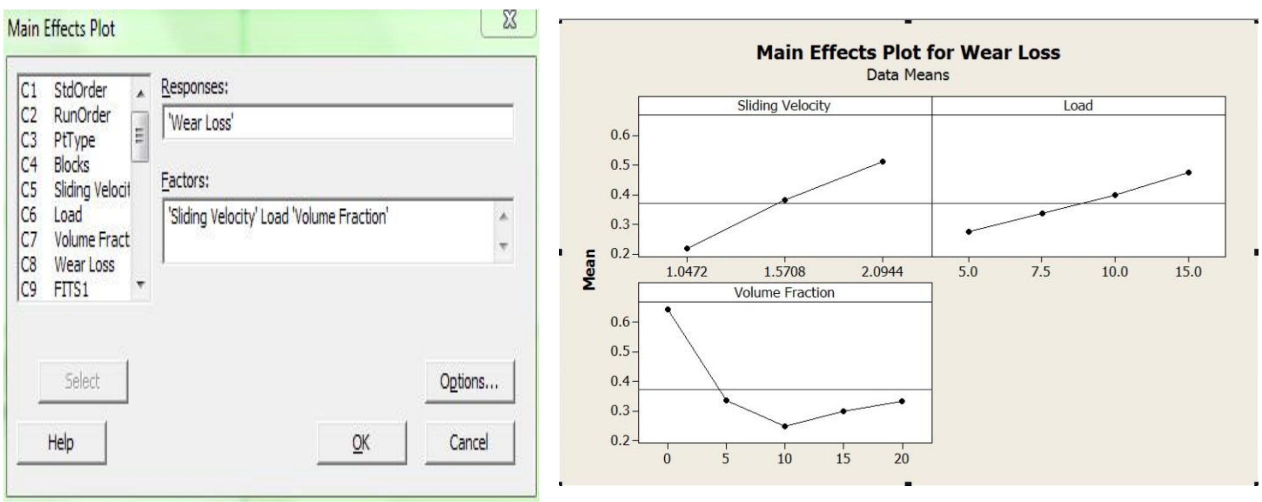


Figure 4.18 responses and factors selection for main effects plot



- **Step 13:**

Interactions Plot. Go to toolbar: **Stat > DOE > ANOVA > Interactions Plot …** and again select the responses and factors.

Figure 4.19 Effects Plot for Wear Loss

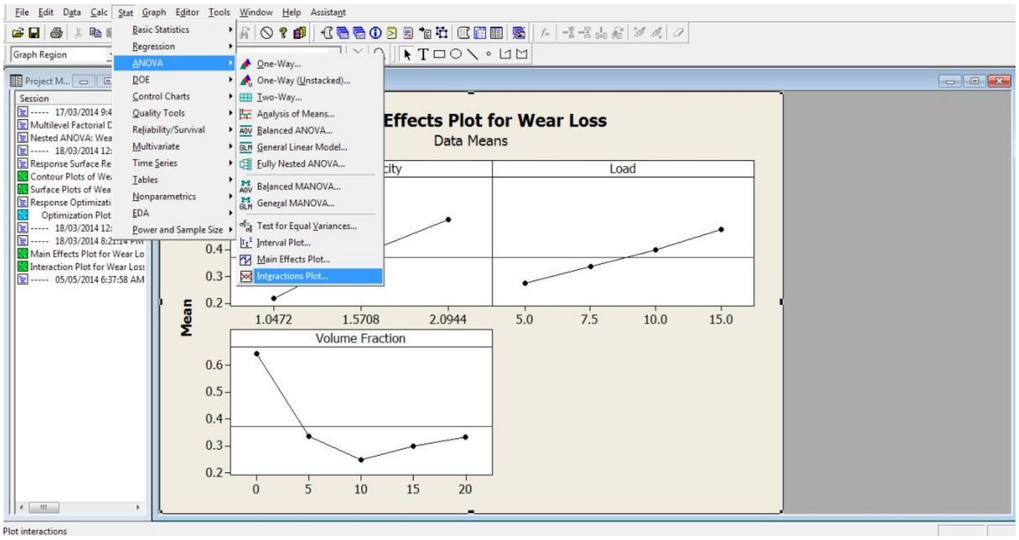
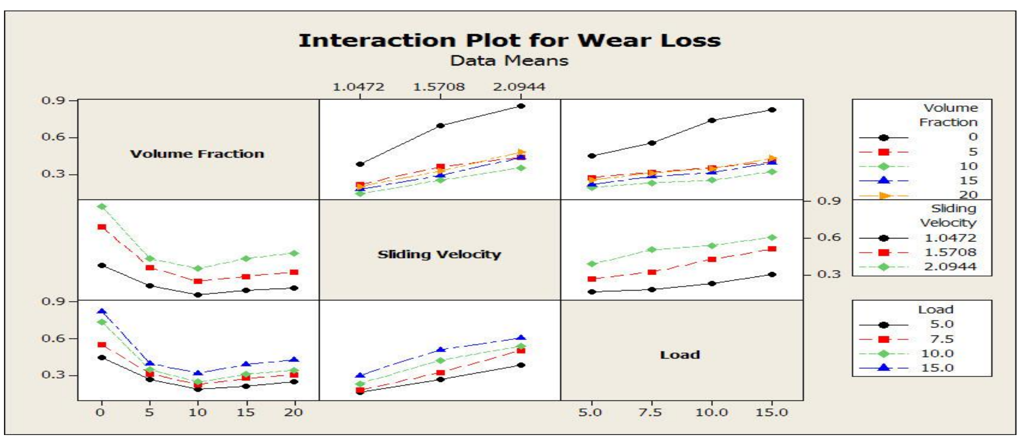


Figure 4.20 Interaction Plot for Wear Loss



Step 14: Save the Project.

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CHAPTER 5

RESULTS AND INTERPRETATIONS

5.1 ANALYSIS OF VARIANCE FOR WEAR LOSS

Nested ANOVA: Wear loss vs. Sliding Velocity, Volume Fraction and Load

Table 5.1 (Nested ANOVA: Wear loss vs. Sliding Velocity, Volume Fraction and Load)

Analysis of Variance for Wear Loss

Source	DF	SS	MS	F	P
Volume Fraction	4	1.1692	0.2923	3.042	0.070
Sliding Velocity	10	0.9608	0.0961	8.980	0.000
Load	45	0.4815	0.0107		
Total	59	2.6115			

Variance Components

Interpretation:

For the wear loss analysis with α-level of 0.05:

- The p-value for the Volume Fraction factor is greater than the chosen α-level of 0.05, indicating that the different Volume Fractions do not contribute a significant amount of variability to the Wear Loss.

- The p-value for the Sliding Velocity factor (p-value = **0.000**) is less than 0.05, indicating that the different Sliding velocities contribute a significant amount of variability to the Wear Loss.

5.2 VARIANCE COMPONENETS

Table 5.2 (Variance Components)

Variance Components

Source	Var Comp.	% of Total	StDev
Volume Fraction	0.016	33.79	0.128
Sliding Velocity	0.021	44.10	0.146
Load	0.011	22.11	0.103
Total	0.048		0.220

Interpretation:

The results of wear Loss analysis indicate the following:

- The variance for the Volume Fraction factor is **0.016**, which represents **33.79%** of the total variance in the analysis.
- The Sliding Velocity factor has the largest variance, **0.021**. This represents **44.10%** of the total variance in the analysis.
- The variance due to Load in the analysis is **0.011**, or **22.11%** of the total.

It is apparent from these data that the Sliding Velocity variability is the biggest source of inconsistency in the Wear Loss.

5.3 EXPECTED MEAN SQUARES

Table 5.3 (Expected Mean Squares)

Expected Mean Squares

1	Volume Fraction	1.00(3) + 4.00(2) + 12.00(1)
2	Sliding Velocity	1.00(3) + 4.00(2)
3	Load	1.00(3)

Interpretation:

For Wear Loss Analysis:

- Represents the variance for the first term in the model (Volume Fraction, variance = 0.016).
- Represents the variance for the second term in the model (Sliding Velocity, variance = 0.021).
- Represents the variance for the third term in the model (Load, variance = 0.011).

Thus, for example, the mean square for the Volume Fraction factor is estimated as follows:

1.00(3) + 4.00(2) + 12.00(1)

= 1.00*(0.011) + 4.00*(0.021) + 12.00*(0.016) = 0.287

5.4 RESPONSE SURAFCE REGRESSION

Response Surface Regression: Wear Loss versus Volume Fraction, Load, Sliding Velocity

Table 5.4 (Response Surface Regression: Wear Loss versus Volume Fraction, Load, Sliding Velocity)

The analysis was done using uncoded units.

Estimated Regression Coefficients for Wear Loss

Term	Coef	SE Coef	T	P
Constant	-0.330542	0.220539	-1.499	0.140
Volume Fraction	-0.042558	0.007718	-5.514	0.000
Load	0.037921	0.020537	1.846	0.071
Sliding Velocity	0.499495	0.243177	2.054	0.045
Volume Fraction*Volume Fraction	0.002357	0.000229	10.278	0.000
Load*Load	-0.000941	0.000866	-1.086	0.283
Sliding Velocity*Sliding Velocity	-0.065656	0.074233	-0.884	0.381
Volume Fraction*Load	-0.000762	0.000367	-2.076	0.043
Volume Fraction*Sliding Velocity	-0.006732	0.003174	-2.121	0.039
Load*Sliding Velocity	0.005544	0.006069	0.913	0.365

S = 0.0743132 PRESS = 0.403817
R-Sq = 89.43% R-Sq(pred) = 84.54% R-Sq(adj) = 87.52%

Interpretation:

- Volume fraction = VF
- Sliding Velocity = SV
- Load = L
- **Interaction terms:**

  The **p-value** of VF*L is < **0.05** so it's a significant interaction effect. That is, the effect of Volume Fraction on Wear Loss depends on Load. **p-value** of VF*SV < **0.05** so it is a same case as above. Since **p-value** of L*SV > **0.05** so this interaction term is not taken as significant.
- **Squared effects:**

  Squared terms are used to evaluate whether or not there is curvature (quadratic)in the response surface. Since only **p-value** of VF*VF < **0.05** so, only this term is significant, that is the relationship between Wear loss and VF follows a curved path rather than linear.

- **Linear effects:**

  P-value of VF & SV < **0.05** so they exert good deal of linear effect on Wear loss. While **p-value** of Load > **0.05** so wear loss does not change significantly with change in Load.

- ***COEFFICIENTS*** **:**

  Wear Loss = **-0.330542** – **0.042558**(VF) **+ 0.037921**(L) + **0.499495**(SV) **+ 0.002357** $(VF)^2$ **- 0.000941** $(L)^2$ **- 0.065656**$(SV)^2$ - **0.000762**(VF*L) – **0.006732**(VF*SV) + **0.005544**(L*SV)

- ***R-squared***:

  For the wear loss data, **89.43%** of the variation in wear loss is explained by model, the predicted R is **84.54%,** and the adjusted R is **87.52%.**

5.5 ANALYSIS OF VARIANCE FOR WEAR LOSS

Table 5.5: (Analysis of variance of Wear Loss)

Analysis of Variance for Wear Loss

Source	DF	Seq SS	Adj SS	Adj MS	F	p
Regression	9	2.33540	2.33540	0.259489	46.99	0.000
Linear	3	1.68790	0.22630	0.075432	13.66	0.000
Volume Fraction	1	0.51745	0.16793	0.167927	30.41	0.000
Load	1	0.32364	0.01883	0.018829	3.41	0.071
Sliding Velocity	1	0.84681	0.02330	0.023300	4.22	0.045
Square	3	0.59423	0.59423	0.198077	35.87	0.000
Volume Fraction*Volume Fraction	1	0.58339	0.58339	0.583393	105.64	0.000
Load*Load	1	0.00652	0.00652	0.006517	1.18	0.283
Sliding Velocity*Sliding Velocity	1	0.00432	0.00432	0.004320	0.78	0.381
Interaction	3	0.05327	0.05327	0.017756	3.22	0.031
Volume Fraction*Load	1	0.02381	0.02381	0.023810	4.31	0.043
Volume Fraction*Sliding Velocity	1	0.02485	0.02485	0.024851	4.50	0.039
Load*Sliding Velocity	1	0.00461	0.00461	0.004608	0.83	0.365
Residual Error	50	0.27612	0.27612	0.005522		
Total	59	2.61152				

Interpretation:

- In view with the interaction, squared and linear effects discussed earlier the regression model is deemed significant.

➢ **Residual Error:** The residual error measures amount of variation in the response left unexplained by the model. If repeated response values are observed at certain settings of the predictors, the unexplained variation can be divided into two parts (Lack-of-Fit and Pure Error).

5.6 UNUSUAL OBSERVATIONS FOR WEAR LOSS

Table 5.6: (Unusual observations for Wear Loss)

Unusual Observations for Wear Loss

Obs	StdOrder	Wear Loss	Fit	SE Fit	Residual	St Resid
31	31	0.870	0.664	0.027	0.206	2.98 R
36	36	0.920	0.780	0.036	0.140	2.15 R
57	57	0.490	0.677	0.034	-0.187	-2.83 R

R denotes an observation with a large standardized residual.

Interpretation:

For the Wear Loss data, three observations, number **31, 36** and **57** has a standardized residual of **2.92, 2.15** and **-2.83.** Therefore, the response surface model does not sufficiently account for the observed level of the response variable, Wear Loss = **(0.870, 0.920, and 0.490)**

5.7 RESIDUAL PLOTS

Figure 5.1 (R vs. L)

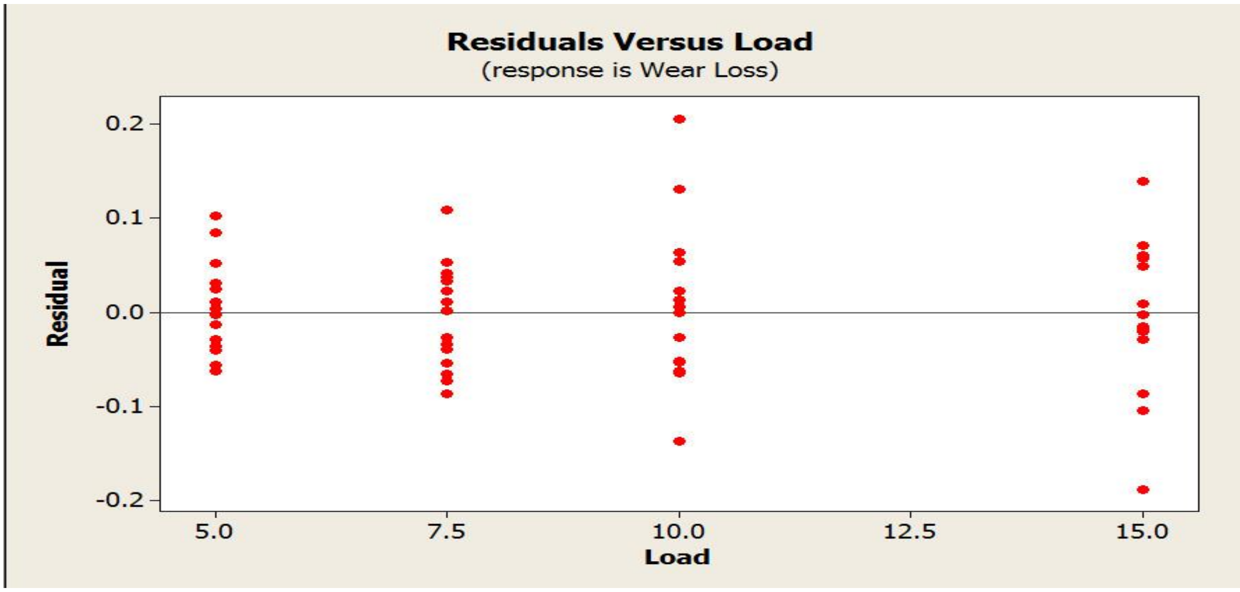
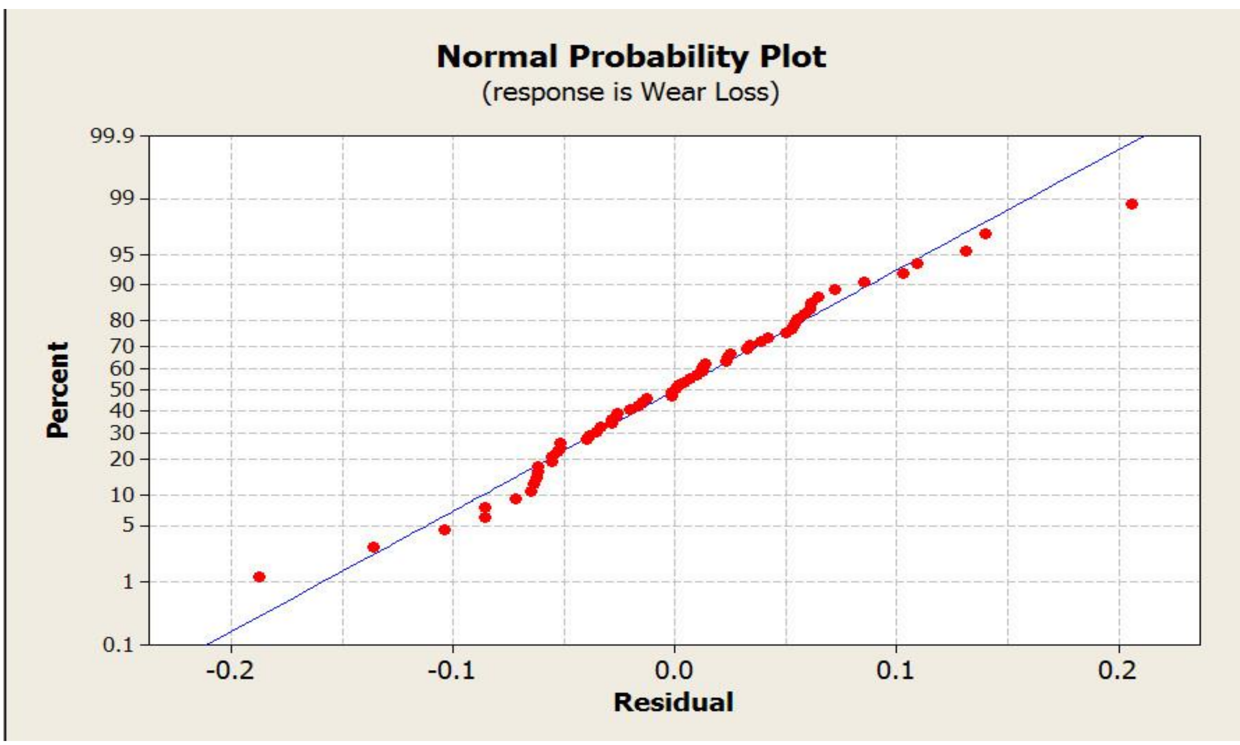


Figure 5.2 (Normal Probability Plot)



Interpretation:

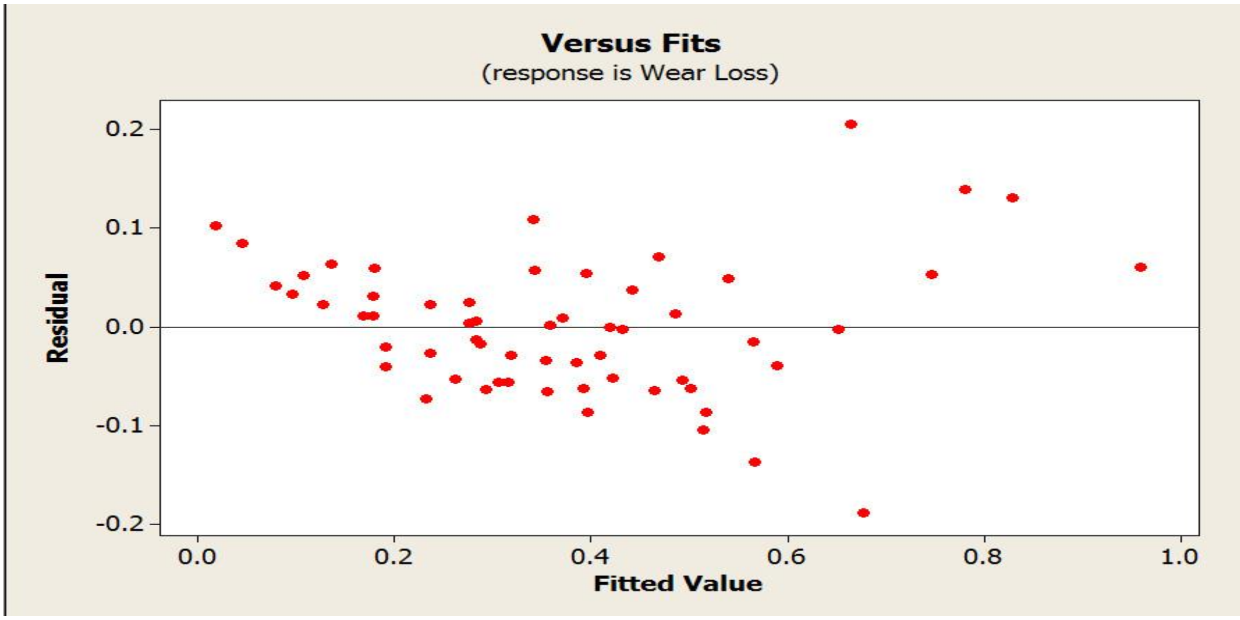
This graph plots the residuals versus their expected values when the distribution is normal. The residuals from the analysis should be normally distributed. In practice, for balanced or nearly balanced designs or for data with a large number of observations, moderate departures from normality do not seriously affect the results.

The normal probability plot of the residuals should roughly follow a straight line. Use this plot to look for the following:

	This pattern...	Indicates...
I.	Not a straight line	Non normality
II.	Curve in the tails	Skewness
III.	A point far from the line	An outlier
IV.	Changing slope	An unidentified variable

Except for two outlier points no signs of non-normality and skewness were observed.

Figure 5.3 (Residual vs. Fits)



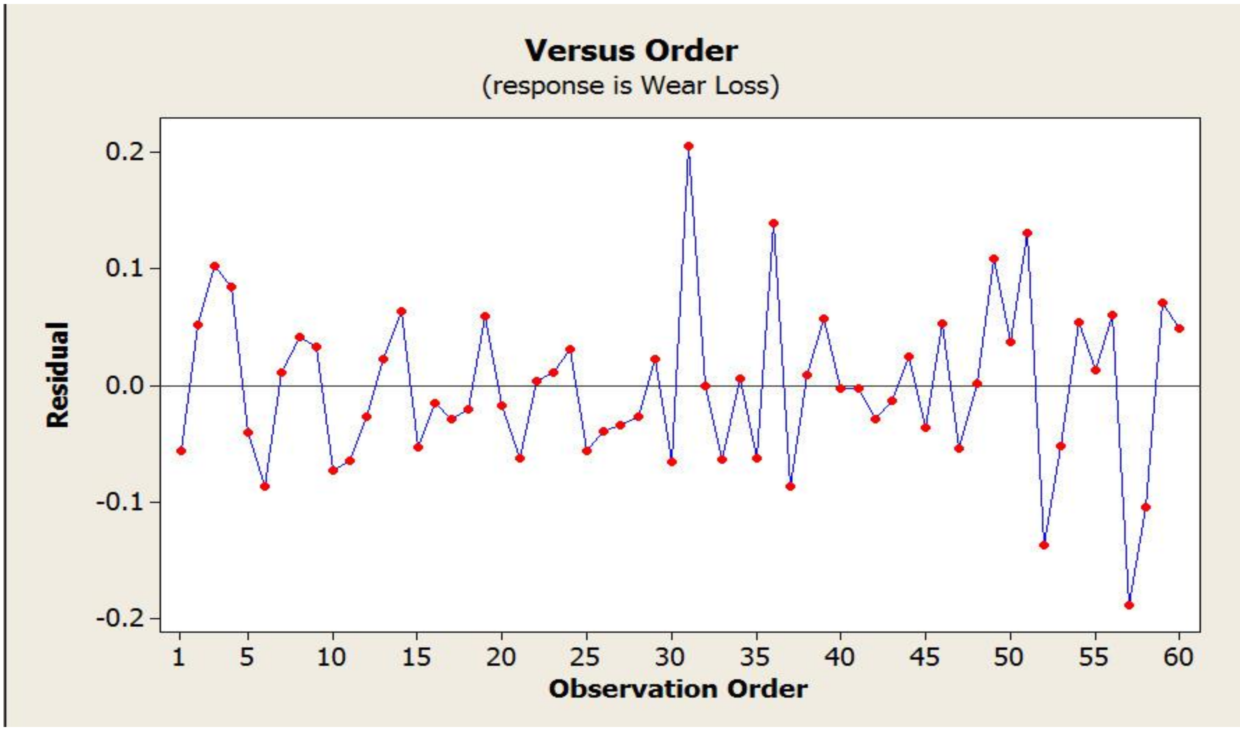
Interpretation:

This graph plots the residuals versus the fitted values. The residuals should be scattered randomly about zero. Use this plot to look for the following:

THIS PATTERN	INDICATES
• Fanning or uneven spreading Of residuals across fitted values	Non-constant variance
• Curvilinear	Missing high order term
• A point far away from zero	An outlier
• A point far away from the Other points in the x-direction	An influential point

Based on this plot, the residuals appear to be randomly scattered about zero. No evidence of non-constant variance, missing terms, outliers, or influential points exists.

Figure 5.4 (Residual vs. Order of Variables)



Interpretation:

This graph plots the residuals in the order of the corresponding observations. The plot is useful when the order of the observations may influence the results, which can occur when data are collected in a time sequence or in some other sequence, such as geographic area. This plot can be particularly helpful in a designed experiment in which the runs are not randomized.

The residuals in the plot should fluctuate in a random pattern around the center line. Examine the plot to see if any correlation exists between error terms that are near each other. Correlation among residuals may be signified by:

· An ascending or descending trend in the residuals

· Rapid changes in signs of adjacent residuals

The residuals appear to be randomly scattered about zero. No evidence exists that the error terms are correlated with one another.

Figure 5.5 (Residuals vs. Volume Fraction)

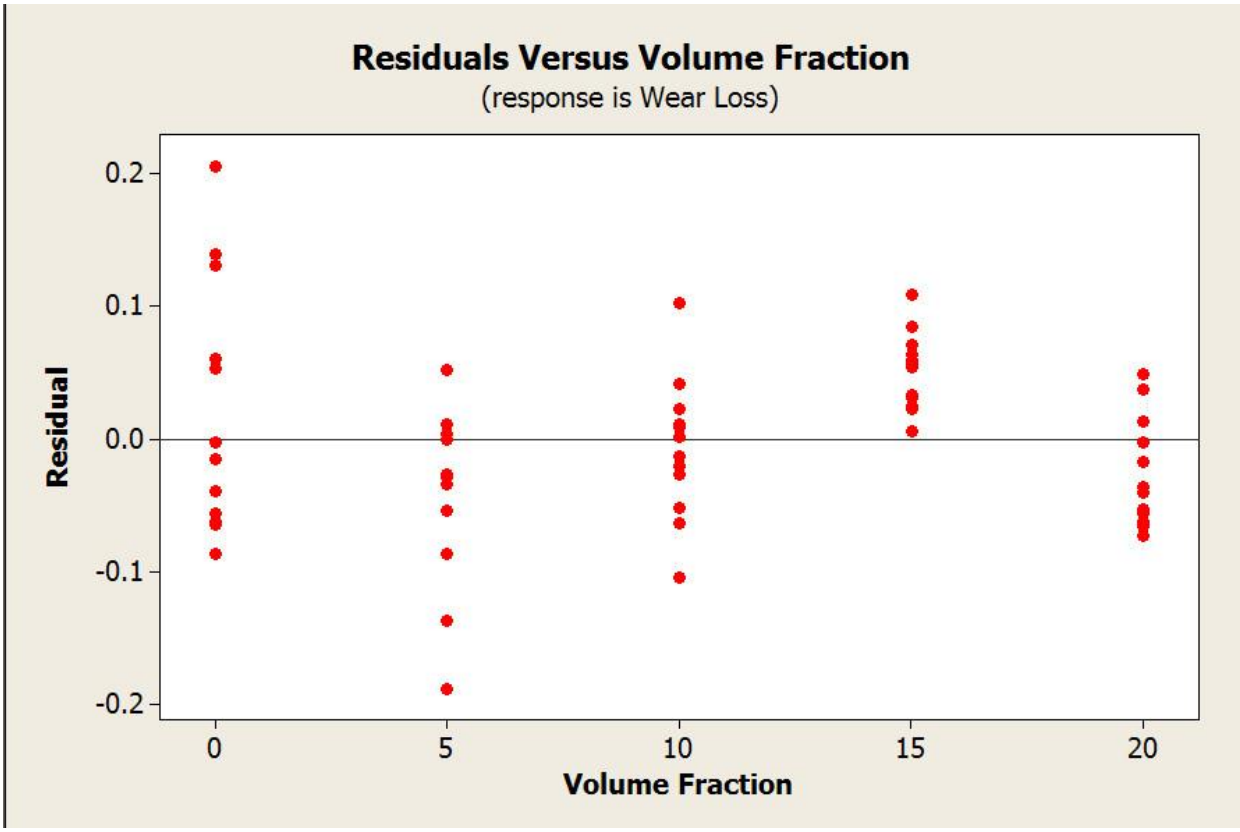
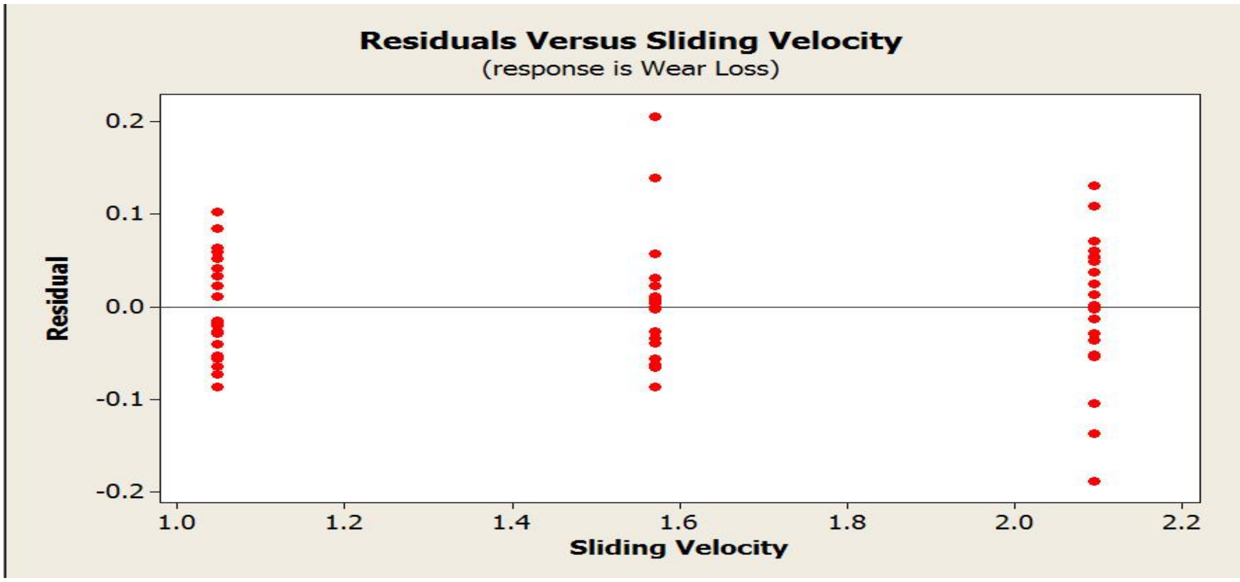


Figure 5.6 (Residuals vs. Sliding Velocity)



Interpretation:

This graph plots the residuals versus another variable. The residuals should fluctuate in a random pattern around the centre line. If the variable is already included in the model, use the plot to determine if you should add a higher-order term of the variable. If the variable is not already included in the model, use the plot to determine if the variable is influencing the response in a systematic way.

This pattern...	Indicates...
I. Pattern in residuals	The variable is influencing the response in a systematic way

******

CHAPTER 6

CONCLUSION

- **The p-value for the Volume Fraction factor is greater than the chosen α-level of 0.05, indicating that the different Volume Fractions do not contribute a significant amount of variability to the Wear Loss.**
- **The p-value for the Sliding Velocity factor (p-value = 0.000) is less than 0.05, indicating that the different Sliding velocities contribute a significant amount of variability to the Wear Loss.**
- **Sliding Velocity variability is the biggest source of inconsistency in the Wear Loss.**
- **The p-value of VF*L is < 0.05 so it's a significant interaction effect. That is, the effect of Volume Fraction on Wear Loss depends on Load. P-value of VF*SV < 0.05 so it is a same case as above. Since p-value of L*SV > 0.05 so this interaction term is not significant.**

- ***COEFFICIENTS*** **:**

  Wear Loss = -0.330542 – 0.042558(VF) + 0.037921(L) + 0.499495(SV) + 0.002357 $(VF)^2$ - 0.000941 $(L)^2$ - 0.065656$(SV)^2$ - 0.000762(VF*L) – 0.006732(VF*SV) + 0.005544(L*SV)

- ***R-squared*:**

  For the wear loss data, 89.43% of the variation in wear loss is explained by model, the predicted R is 84.54%, and the adjusted R is 87.52%.

- **For the Wear Loss data, three observations, number 31, 36 and 57 has a standardized residual of 2.92, 2.15 and -2.83. Therefore, the response surface model does not sufficiently account for the observed level of the response variable, Wear Loss = (0.870, 0.920, and 0.490)**

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