OPTIMIZATION OF WEAR PROCESS PARAMETERS FOR Al-Mg-Mn ALLOY WITH MINOR ADDITIONS OF SCANDIUM AND ZIRCONIUM

A project report submitted
in partial fulfillment of the requirement for the award of the degree of

BACHELOR OF TECHNOLOGY
IN
MECHANICAL ENGINEERING

Submitted by

Y. YUVA KIRAN	**318126520208**
S. BHANU TEJA	**318126520199**
B. CHANDRA MOULI	**318126520173**
G. MOHAN KUMAR	**319126520L44**

Under the guidance of

Dr. SRINIVASA RAO MALLIPUDI
Ph. D., MIE., MISTE.
Assistant Professor
Department of Mechanical Engineering

ANIL NEERUKONDA INSTITUTE OF TECHNOLOGY AND SCIENCES (A)

(Approved by AICTE, Permanently Affiliated to A.U., &
Accredited by NBA and NAAC with 'A' Grade)
Sangivalasa, Bheemunipatnam Mandal, VISAKHAPATNAM - 531162

2022

ANIL NEERUKONDA INSTITUTE OF TECHNOLOGY & SCIENCES (A)
(Permanently affiliated to Andhra University, Approved by AICTE, Accredited by NBA & NAAC) Sangivalasa - 531162.

PRAGNANAM BRAHMA
ANITS

CERTIFICATE

This is to certify that the project report entitled **"OPTIMIZATION OF WEAR PROCESS PARAMETERS FOR Al-Mg-Mn ALLOY WITH MINOR ADDITIONS OF SCANDIUM AND ZIRCONIUM "** has been carried out by

Y. YUVA KIRAN	**318126520208**
S. BHANU TEJA	**318126520199**
B. CHANDRA MOULI	**318126520173**
G. MOHAN KUMAR	**319126520L44**

under the esteemed guidance of **Dr. M. SRINIVASA RAO**, in the partial fulfillment of the requirements for the award of the Degree of Bachelor of Technology in Mechanical Engineering at **ANIL NEERUKONDA INSTITUTE OF TECHNOLOGY & SCIENCES (A)**, Visakhapatnam.

PROJECT GUIDE

(Dr. M. SRINIVASA RAO)
Assistant Professor
Dept. of Mechanical Engg.
ANITS, Sangivalasa
Visakhapatnam.

APPROVED BY:
HEAD OF THE DEPARTMENT

28/5/22

(Dr. B. NAGA RAJU)
Professor
Dept. of Mechanical Engg.
ANITS, Sangivalasa
Visakhapatnam.

PROFESSOR & HEAD
Department of Mechanical Engineering
ANIL NEERUKONDA INSTITUTE OF TECHNOLOGY & SCIENCES
Sangivalasa-531 162, VISAKHAPATNAM Dist. A.P.

THIS PROJECT IS APPROVED BY THE BOARD OF EXAMINERS

INTERNAL EXAMNIER

PROFESSOR & HEAD
Department of Mechanical Engineering
ANIL NEERUKONDA INSTITUTE OF TECHNOLOGY & SCIENCES
Sangivalasa-531 162 VISAKHAPATNAM Dist A.P.

EXTERNAL EXAMINER

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DECLARATION

We, the undersigned, hereby declare that this "**Thesis"** under the title of "**FABRICATION OF TRAFFIC POWERED PROTOTYPE VERTICAL AXIS WIND TURBINE**" **s**ubmitted by me for the award of Degree of "**Bachelor of Technology**" in Mechanical Engineering at ANIL NEERUKONDA INSTITUTE OF TECHNOLOGY & SCIENCES (A), Visakhapatnam, is a record of original research work carried out by us. This work has not been submitted to any University or Institution in India or abroad, for the award of any degree.

Station: Visakhapatnam Date:	**TEAM MEMBERS** **Y. YUVA KIRAN 318126520208** **S. BHANU TEJA 318126520199** **B. CHANDRA MOULI 318126520173** **G. MOHAN KUMAR 319126520L44**

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We express our sincere thanks to **Dr. B. NAGA RAJU,** Professor & Head, Department of Mechanical Engineering for his valuable guidance, suggestions and comprehensive assistance for the project work.

We would like to express my deep gratitude to my project guide **Dr. M. SRINIVASA RAO,** Assistant Professor, Department of Mechanical Engineering, under whose valuable guidance, we were able to complete our project smoothly.

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TEAM MEMBERS

P. UMAMAHESHWARARAO	**316126520249**
K. PAVAN SAI	**316126520241**
K. KUSUMA KUMAR	**316126520277**
S. APPALA CHAITANYA	**316126520215**
K. PAVAN KUMAR	**316126520227**

ABSTRACT

A systematic approach was presented to develop the empirical model for predicting the wear behaviour of Al-Mg-Mn-Sc-Zr alloy which is widely used in ship building industry by incorporating wear process parameters such as applied load, speed, and track diameter. Dry wear test using pin on disc apparatus was carried out considering three-factor three-level Box Behnken design. Response surface methodology (RSM) was applied to developing linear regression model for establishing the relationship between the wear process parameters and wear. Analysis of variance (ANOVA) technique was used to check the adequacy of the developed model. The wear process parameters were also optimized using box behnken design to minimize the wear.Optimal levels obtained at a 5N load, at a speed of 100 rpm, track diameter 50mm for Al-Mg-Mn-Sc-Zr alloy are wear (10.5417) and coefficient of friction (4.6342) respectively.

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NOMENCLATURE

A	Swept area
ACP	Aluminium composite panel
Amp	Ampere
C_p	Coefficient of power
d	Swept diameter
HAWT	Horizontal axis wind turbine
I	Current
K.E	Kinetic energy
m	Mass
M S	Mild steel
P	Electric Power
PVC	Polyvinyl chloride
P_w	Power of the wind
v	Wind velocity
V	Voltage
VAWT	Vertical axis wind turbine
W	Watt
WECS	Wind energy conversion system
ρ	Density

CHAPTER-I

INTRODUCTION

In recent years, aluminium alloys form a very important class of tribo-engineering materials and are invariably used in mechanical components such as gears, cams, bearings, bushes, bearing cages and better wear resistance, where wear performance in nonlubricated condition is a key parameter for the material selection However, aluminium alloys is rarely used as bearing materials in its pure form, because neat aluminium alloys could not satisfy the demands arising from the situations where a combination of good mechanical and tribological properties is required. aluminium alloys with minor additions of transition elements are the most rapidly growing class of materials, due to their good combination of high specific strength and specific modulus, are widely used for variety of engineering applications. This chapter presents an overall view of aluminium alloys. Aluminium alloys are among the most rapidly growing classes of materials and are finding more applications in various fields. The use of aluminium alloys and their composites are on the increase for improved performance in many areas of applications including tribological purposes. This chapter covers the motivation, objectives and scope of the present investigation.

1.1 INTRODUCTION TO ALUMINIUM ALLOYS

1.1.1 CLASSIFICATION OF WROUGHT ALUMINIUMALLOYS

Wrought Aluminium alloys are generally classified as strain-hardening alloys and age-hardening alloys and the detailed classification is shown in Figure 1.1. In Wrought Aluminium alloy designation system, the first digit refers to the main alloying elements, the second digit gives the modification in that alloy, the third and fourth digits give the individual alloy variations and identification of the alloy in that group. The strain-hardening alloys (1xxx, 3xxx, 4xxx and 5xxx alloy series are non-heat treatable). The strength of these alloys may be improved by strain hardening technique. The age-hardening alloys (2xxx, 6xxx and 7xxx alloy series). These alloys improved their properties by heat treatment and quenching followed by natural or artificial aging.

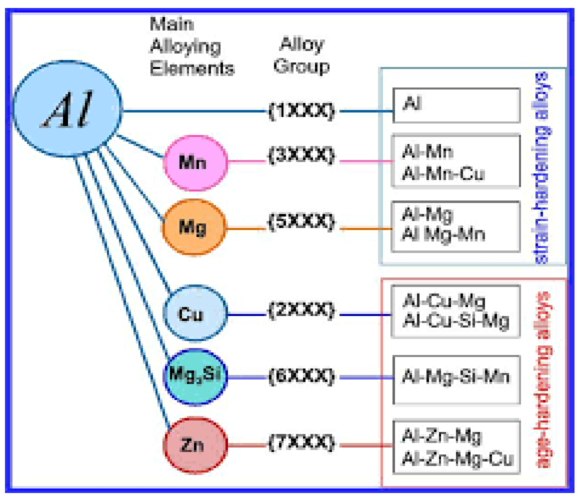


Figure 1.1 Classification of Aluminium alloys

1.1.2 ALUMINIUM ALLOY CHOSEN FOR THEPRESENT STUDY

In this project work, a 5xxx series alloy is chosen for the investigation. This alloy usually contains aluminium (Al), magnesium (Mg), manganese (Mn) as principal alloying constituents and traces of other metals. This alloy attains medium strength and high corrosion resistance among all the non-heat treatable alloys, derives their strength primarily from solid solution strengthening by Mg and Mn. Increase in the Mg content in this series of alloys leads to increase in tensile strength, Mn increases corrosion resistant due to the presence of Al_3Mg_2, Mg_2Si, Al_6(Fe, Mn) intermetallics. These alloys are work-hardenable and can be easily drawn into any shape due to high formability, and exhibits high ductility, good weldability, durability, good finishing characteristics. Thus, these alloys were used in many chemical industries, ship buildings, naval and marine applications. Medium strength is the limitation for these alloys. Al-Mg-Mn alloys are often strengthened by work hardening/stain hardening strengthening, solid solution strengthening, grain refinement strengthening and precipitate strengthening mechanisms. Amongst different strengthening mechanisms for Al-Mg-Mn alloys, Minor-alloying strengthening is an alternative way, which involves the addition of alloying elements such as Ti, Fe, Er, Cr, Mn, Cu, Zn, Ni, Hf, Zr, and Sc as an alloying element. In the present study, Al-Mg-Mn alloy containing the traces of Sc and Zirconium is considered.

1.2 Tribology

Tribology is the science and engineering of interacting surfaces in relative motion. It includes the study and application of the principles of friction, lubrication and wear. Tribology is a branch of mechanical engineering. Most technical universities have a group working on tribology, often as part of their mechanical engineering departments. The limitations in tribological interactions are however no longer mainly determined by mechanical designs, but rather by material limitations so the discipline of tribology now counts at least as many materials engineers, physicists and chemists as it does mechanical engineers. Any product where one material slides or rubs over another is affected by complex tribological interactions, whether lubricated like hip implants and other artificial prostheses, or unlubricated as in high temperature sliding wear in which conventional lubricants cannot be used but in which the formation of compacted oxide layer glazes have been observed to protect against wear. Tribology plays an important role in manufacturing. In metal-forming operations, friction increases tool wear and the power required to work a piece. This results in increased costs due to more frequent tool replacement, loss of tolerance as tool dimensions shift, and greater forces required to shape a piece. A layer of lubricant which eliminates surface contact virtually eliminates tool wear and decreases needed power by one third. Abrasive wear occurs when hard asperities on one surface move across a softer surface under load, penetrate, and remove material from the softer surface, leaving grooves [2]. Most of the abrasive wear problems arise in gear pumps handling industrial fluids, chute liners in power plants, mining, and earth moving equipments. The need for the use of newer materials to combat wear situations has resulted in the emergence of polymer based composite materials. Fiber reinforced polymeric composites are the most rapidly growing class of materials, due to their good combination of high specific strength and specific modulus. They are widely used for variety of engineering applications. The importance of tribological properties convinced many researchers to study the friction and wear behaviour and to improve the wear resistance of polymeric composites. For fiber reinforced polymer matrix composites the process of material removal in dry sliding condition is dominated by four wear mechanisms, viz., matrix wear, fiber sliding wear, fiber fracture and interfacial debonding [3]. 4 Tribologists often classify thermoplastic polymeric materials into three distinct groups according to their friction and wear behaviour. These are: the normal polymers:

low-density polyethylene (LDPE), polypropylene (PP); the amorphous polymers: polyvinyl chloride (PVC), polymethylmethacrylate (PMMA) and thesmooth molecular profile- polymers: polytetrafluoroethylene (PTFE) and ultra high molecular weight polyethylene (UHMWPE). Among them, the better frictional performance of the smooth molecular profile polymers can be explained by the easiness with which the long chain molecules shear across each other [4-5]. The effects of fibrous fillers on wear characteristics of PTFE composites under dry or wet conditions have reported by Wang et al [6].

1.3 Fundamentals of wear

Wear is defined as damage to a solid surface generally involving progressive loss of material due to relative motion between that surface and contacting substance or substances. Main types of wears are abrasive wear, adhesive wear, corrosive wear, erosion wear and fatigue wear, which are commonly observed in practical situation. The process of `wear’ may be variously defined but most generally it is quantitatively measured in terms of the mass, or volume, loss from a sliding or eroding contact. The sequence of events is invariably as follows. Mechanical forces, frictional work, impact forces, contact fatigue stress, cavitation forces and so on induce damage in the contact members. Eventually, or may be also immediately, the surfaces lose mechanical cohesion and debris is produced. Chemical wear has a similar character but on a smaller scale. Subsequently, perhaps immediately, this debris is expelled from the contact zone and the process of wear is observed. When material is removed by contact with hard particles, abrasive wear occurs. The particles either may be present at the surface of a second material (twobody wear) or may exist as loose particles between two surfaces (three-body wear). Adhesive wear is also known as scoring, galling or seizing. It occurs when two solid surfaces slide over one another under pressure. Surface projections or asperities are plastically deformed and eventually welded together by the high local pressure. As sliding continues, these bonds are broken, producing cavities on the surfaces, projections on the second surface, and frequently tiny, abrasive particles, all of which contribute to future wear of surfaces. Often referred to simply as "corrosion" or corrosive wear is deterioration of useful properties in a material due to the reactions 5 with its environment. Surface fatigue is a process by which the surface of a material is weakened by cyclic loading, which is one type of general material fatigue. Wear can also be divided into sliding wear, which occurs in the absence of hard particles, and abrasive wear, which occurs in their presence. Under some conditions sliding wear can generate debris which then causes further wear by abrasion; it must therefore always be borne in mind that the boundary between different types of wear is not a rigid one.

Abrasive wear can be further subdivided into two-body and three-body abrasive wear. Two-body wear is caused by hard protuberances on the counter face, while in three-body wear hard particles are free to roll and slide between two, perhaps dissimilar, sliding surfaces. These types of wear are illustrated below in Figure 1.2.

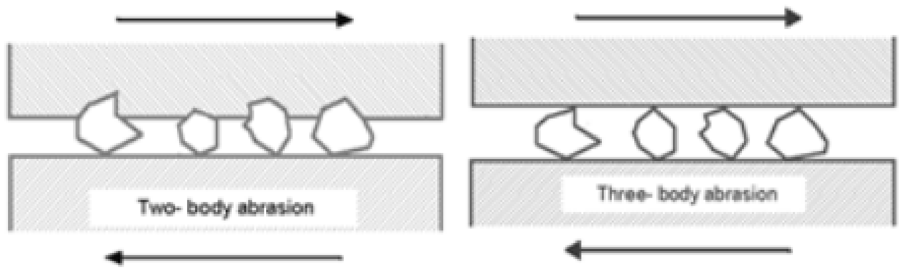


Figure 1.2. Schematic diagram of two body and three body abrasion.

In three body abrasion, the loose abrasive particles abrade the solid surfaces between which they are situated only about 10% of the time, remaining 90% of the time in rolling. Most of the abrasive wear problems which arise in industrial equipment are three body, while two body abrasion is encountered primarily in material removal operation. The rate of material removal in three body abrasions is lower than that of two body abrasion [7]. Abrasive wear is the most important among all the forms of wear because it contributes almost 63% of the total cost of wear [8]. Abrasive wear is caused due to hard particles or hard protuberances that are forced against and move along a solid surface [9]. In two-body abrasion, wear is caused by hard protuberances on one surface which can only slide over the other. Polymer and their composites are finding ever increasing usage for numerous industrial applications such as bearing material, rollers, seals, gears, cams, wheels, clutches etc., [10]. Different types of polymer show different friction and wear behaviour. However, neat polymer is very rarely used as bearing materials and wear-resistant materials because unmodified polymer could not satisfy the demands arising from the situations wherein a combination of 6 good mechanical and tribological properties is required [11]. Among the wear types, abrasive wear situation encountered in vanes and gears, in pumps handling industrial fluids, sewage and abrasive-contaminated water, roll neck bearings in steel mills subjected to heat, shock loading; chute liners abraded by coke, coal and mineral ores; bushes and seals in agricultural and mining equipment, have received increasing attention [12]. The bi-directional fabric reinforcement offers a unique solution to the ever increasing demands on the advanced materials in terms of better performance and ease in processing [13].

1.3.1 Sliding wear

Sliding wear may be defined as ‘wear due to localized bonding between contacting solid surface leading to material transfer between the two surfaces or loss from either surface’. Specific wear rate is the measure of the wear loss per unit distance and per unit load. The coefficient of friction is the ratio of frictional load to the normal load applied. For the applications like gears, bearings and cams, low specific wear rate and low coefficient of friction is essential parameters. But for components like clutches and brakes low specific wear rate and high coefficient of friction is required. However, in both the cases thermal conductivity of the material is essential property. Most commonly used matrix materials are polymeric. The reason for this are two fold. In general the mechanical properties of polymers are inadequate for many structural purposes. In particular their strength and stiffness are low compared to metals and ceramics. These difficulties are overcome by reinforcing other materials with polymers. Secondly the processing of polymer matrix composites need not involve high pressure and does not require high temperature. Also equipments required for manufacturing polymer matrix composites are simpler. For this reason polymer matrix composites developed rapidly and soon became popular for structural applications. Composites are used because overall properties of the composites are superior to those of the individual components for example polymer/ceramic. New requirement and new product has led to drive for more and better polymer composites. Lightweight high performance engineering plastics had replaced metals in many applications as polymers are relatively cheap and large volume structural materials. The wide application of polymer composites ranges from the manufacturing of engineering structures such as tanks, pipes, aircraft interior 7 furnishings and support beams, to the making of leisure and sporting items such as golf clubs and balls, skis, racquets and boats.

1.4 DEISGN OF EXPERIMENTS

Design of Experiments (DOE) is a structured, organized method for determining the relationship between factors affecting a process and the response to that process. Experiments were conducted according to the selected experimental design, followed by data analysis which included regression analysis, model adequacy checking, and determination of optimum conditions.

1.5 DESIGN OF EXPERIMENT TECHNIQUES

The design of experiments techniques are classified based on factors combinations and the most widely used techniques are as follows.

- Factorial Design
- Taguchi Design
- Response Surface Design

Among those, Response surface design of Response Surface Methodology (RSM) is selected for finding the relative significance of various parameters. RSM is a collection of mathematical and statistical methods to evaluate the relationships between independent variables and one or more responses. The RSM enables to evaluate operation variables that may or may not have a significant effect in the main response [Myers et al. (1976)].

The central composite designs, rotatable designs, simplex designs, mixture designs, and other evolutionary operation designs come under this RSM.

The central composite design (CCD) which is a sub-category of RSMis the most efficient design of experiment, and it is widely used in combination with RSM to set up the optimal parameters towards obtaining desired results.A second-order mathematical model can be developed efficiently with CCD. Itis composed of a factorial design, a set of central points, and axial points equidistant to the center point [Myers et al. (1976)] allows the prediction of the second order experimental model with interactive effects of the variables.

The general second order mathematical model (Equation 1.1) to represent response "Y" is given by

$$Y= b_o+ \sum b_i x_i+\sum b_{ii} x_i^2+\sum b_{ij}x_ix_j+ e_r \text{(Eq. 4.1)}$$

Where x_i and x_j are the independent variables, b_o, b_i, b_{ii}, and b_{ij} are the coefficients of intercept, linear, quadratic and interaction variables respectively, Y is the dependent variable or the response, and $e_r$is the error term that accounts for the effects of excluded parameters [Myers et al. (1976)].

Figure 1.1 shows the layout of the CCD for three factors and five levels. Table 1.1 indicates the factors to be studied and the assignment of corresponding levels in coded form on the responseto that process.

Table 1.1 Parametersand corresponding levels (Coded form)

S. No.	Parameters	low	medium	high
01	Parameter 1	-1	0	+1
02	Parameter 2	-1	0	+1
03	Parameter 3	-1	0	+1

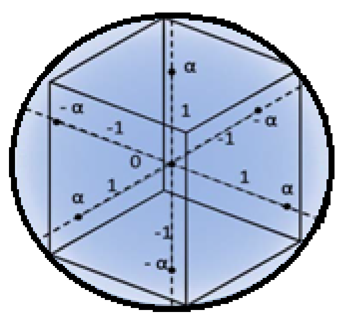


Figure 1.1 Layoutof the central composite design for three variables at five levels

1.6 PLAN OF EXPERIMENTS BASED ON RSM METHOD

For the experimental plan, the RSM method is used for five factors with three levels with a careful understanding of the parameters.

1.6.1 Design of Experimental plan

Knowing the number of parameters and the number of levels, the proper experimental design can be selected using (Minitab statistical software) the available response surface designs with the number of runs as shown in Table 1.2.

Table 1.2 CCD selector

Create Response Surface Design - Display Available Designs

Available Response Surface Designs (with Number of Runs)

Design		Factors 2	3	4	5	6	7	8	9
Central Composite full	unblocked	13	20	31	52	90	152		
	blocked	14	20	30	54	90	160		
Central Composite half	unblocked				32	53	88	154	
	blocked				33	54	90	160	
Central composite quarter	unblocked							90	156
	blocked							90	160
Box-Behnken	unblocked		15	27	46	54	62		
	blocked			27	46	54	62		

Help OK

The name of the appropriate experimental plan can be found by looking at the same column and the row corresponding to the number of parameters and number of levels. Each of the parameters is varied at three levels as shown in Table 1.3. The appropriate BBD for the present research is, therefore the plan is made for 15 experimental runs to be conducted, Table 1.3 shows experimental plan in coded form in which the first column is assigned to the applied load, the second column to the tool rotational speed, the third column to tool traverse speed. The outputs to be studied are hardness, tensile strength, % elongation, bending strength, impact strength.[Lakshminarayanan et al. 2009].

Table 1.3 Selected experimental design matrix (Coded form)

Experiments	**AL**	**RS**	**TS**
1	0	0	0
2	1	0	1
3	-1	0	-1
4	1	1	0
5	-1	1	0
6	0	-1	1
7	-1	0	1
8	1	0	-1
9	0	1	-1
10	1	-1	0
11	0	-1	-1
12	0	0	0
13	0	1	1
14	-1	-1	0
15	0	0	0

Box-Behnken Design, BBD for the response surface methodology, RSM, is specially designed to fit a second-order model, which is the primary interest in most RSM studies. To fit a second-order regression model (quadratic model), the BBD only needs three levels for each factor (figure 1.2), rather than five levels in CCD . The BBD set a mid-level between the original low- and high-level of the factors, avoiding the extreme axial (star) points as in the CCD. Moreover, the BBD uses face points, often more practical, rather than the corner points in CCD. The addition of the mid-level point allows the efficient estimation of the coefficients of a second-order model (Box et al., 2005). The BBD is almost rotatable as the CCD. Moreover, often, the BBD requires a smaller number of experimental runs.

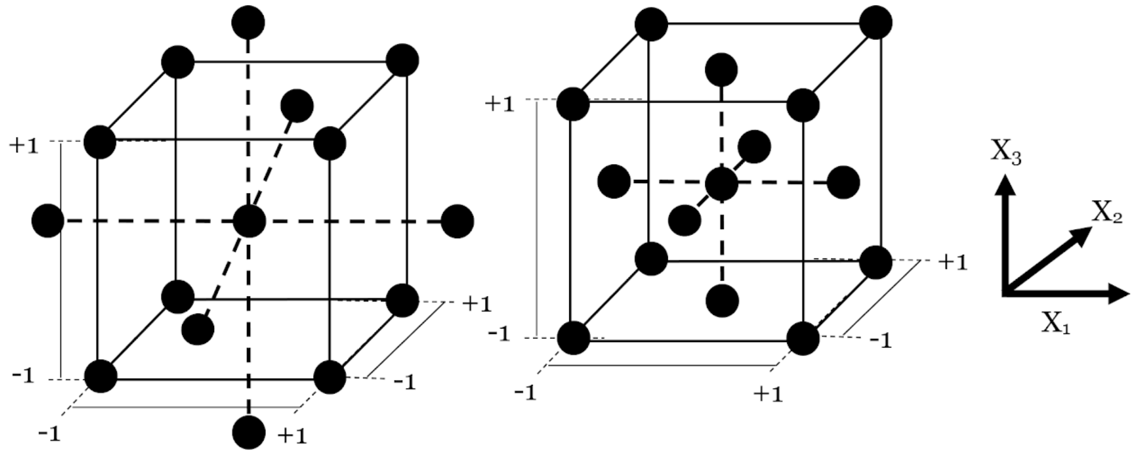


Figure 1.2 Central Composite Design, CCD for Rotatability (left) and Face Center Design (right)

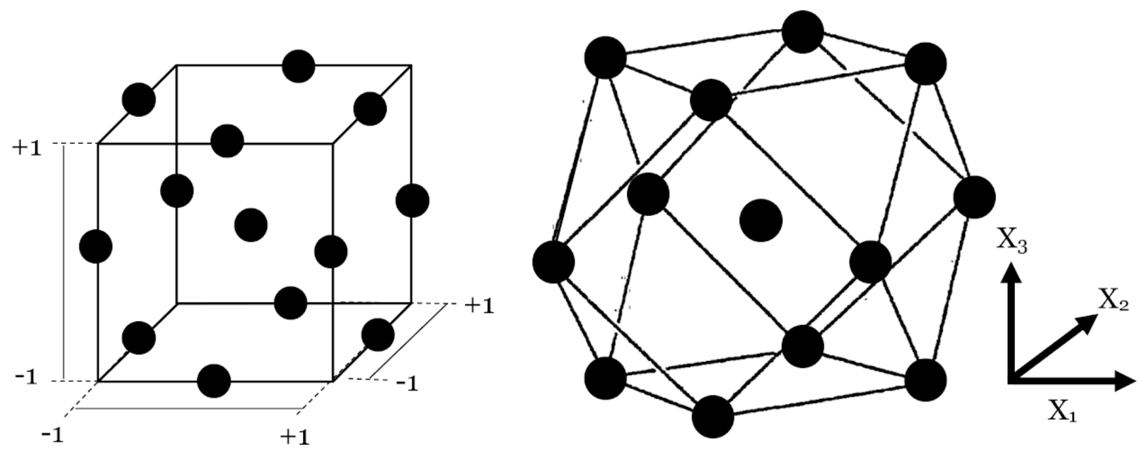


Figure 1.3 Two Representation of the Box-Behnken Design, BBD for RSM.

1.7 DESIRABILITY APPROACH

RSM focuses on the use of desirability approach for single and multi-objective optimization.

The desirability approach concept is to optimize single and multiple equations simultaneously were proposed by Derringer and Suich (1980). The desirability approach is recommended due to its simplicity and availability of software, and it provides flexibility in weighting and giving importance for individual response. Their procedure introduced the concept of desirability functions. This method makes use of an objective function, D(X), called the desirability function and transforms an estimated response Y_i into a scale-free value (d_i) called desirability into a unitless utility bounded by $0< d_i<1$, where a higher d_i value indicates that response value Y_i is more desirable, if $d_i = 0$ this means a completely undesired response [Harington (1965)]. The desirable ranges from zero to one (least to most desirable, respectively). The individual desirability of each response, d_i, was calculated using Eqs. 1.2- 1.6. The shape of the desirability function can be changed for each goal by the weight field ‘‘wt_i.’’ Weights are used to give more emphasis to the upper/lower bounds or to emphasize the target value. In the desirability objective function D(X), each response can be assigned an importance (r), relative to the other responses. The overall desirability function involves in combines individual desirability of all the responses to form a multi-response optimization problem, higher the overall desirability value implies better the quality. In this present study, the responses, wear and coefficient of friction are transformed into appropriate desirability scales according to the following equations (Eq.s 1.2 - 1.6). The factor settings with maximum overall desirability are considered to be the optimal parameter conditions.

For larger-the-better, the desirability will be defined by:

(Eq. 4.2)

For Smaller-the-better, the desirability will be defined by:

(Eq. 4.3)

For target, the desirability will be defined by:

(Eq. 4.4)

If the target within the range, the desirability will be defined by:

(Eq. 4.5)

(Eq. 4.6)

The individual desirability index of all the responses can be combined to form a single value called composite desirability (d_G) and it is given by

(Eq. 4.7)

The higher the composite desirability value implies better the product quality. Therefore, on the basis of the composite desirability (d_G), the parameter effect and the optimum level for each controlled parameter are estimated.

1.8 INTRODUCTION TO MINITAB

Minitab is a statistical package. It was developed at the Pennsylvania state university by researchers Barbara F. Ryan, Thomas A. Ryan Jr., and Brian L. Joiner in 1972. Minitab began as a light version of OMINITAB, statistical analysis research.

Statistical analysis computer application has the advantages of being accurate, reliable and general faster than computing statistics and drawing graphs by hand. Minitab is relatively easy to use once you know a few fundamentals. Minitab is distributed by Minitab Inc., a privately owned company headquartered in state college, Pennsylvania with subsidiaries Coventry, England (Minitab limited), Paris, France (Minitab SARL) and Sydney, Australia (Minitab Pty.).

Today, Minitab is often used in conjunction with the implementation of six sigma, CMMI and other statistics based process improvements methods. Minitab 17, the latest version of the software, is available in 7 languages: English, France, German, Japanese, Korean, Simplified Chinese and Spanish.

Minitab is statistical analysis software. It can be used for learning about statistics as well as statistical research. Statistical analysis computer applications have the advantage of being accurate, reliable, and generally faster than computing statistics and drawing graphs by hand. Minitab is relatively easy to use once you know a few fundamentals.

Minitab Inc. produces two other complement Minitab 17: Quality trainer, a learning package that teaches statistical tools and concepts in the context of quality improvement that integrates with Minitab 17 to simultaneously develop the user's statistical knowledge and ability to use the Minitab software and quality companion 3, an integrated tools for managing six sigma and Lean manufacturing project that allows Minitab data to be combined with management and governance tools and documents.

Minitab has two main types of files, project and worksheets. Worksheets are files that are made up of data; think of a spreadsheet containing variables of data. Projects are made up of the commands, graphs, and worksheets. Every time you save a Minitab project you will be saving graphs, worksheets and commands. However each one of the elements can be saves individually for use in other documents or Minitab projects. Likewise you can print projects and its elements.

1.8.1 Minitab project and worksheets:

Minitab has two main types of files, projects and worksheets. Worksheets are files that are made up of data; think of a spreadsheet containing variables of data. Projects are made up of commands, worksheets and commands. Every time you save a Minitab project, you will be saving graphs, worksheets and commands. However each one of the elements can be saved individually for use in the commands or Minitab projects. Likewise you can print projects and its elements. The menu bar: You can open menus and choose commands. Here you can fine the built in routines. The tool bar: Shortcuts to some Minitab commands.

1.8.2 Two windows in Minitab

- **Session window**: The area that displays the statistical results of your data analysis and can also be used to enter commands.
- **Worksheet window**: A grid of rows and columns used to enter and manipulate the data. NOTE: This area looks like a spreadsheet but will not automatically update the columns when entries are changed Other windows include,
  - **Graph Window**: When you generate graphs, each graph is opened in its own window.

- **Report Window**: Version 17 has the report manager that helps you organize your results in a report.
- **Other Windows**: History and project manager are two windows. See Minitab help for more information on these if needed.

CHAPTER-II

LITERATURE REIVEW

Before starting the project, we had a brief study on various papers related to the wear parameters of Al-Mg-Mn-Sc-Zr Alloy. Several authors portrayed different ideas related to this Alloy. Their views are listed below :

Z.Yin et. al(2000) investigated a series of Al–Mg based alloy plates with thickness of 4 mm containing minor Sc and Zr were prepared. Tensile properties and microstructures of the alloys were studied. The results show that adding 0.2% Sc and 0.1% Zr to Al–5Mg alloy, the strength of the alloy increased by 150 MPa. Strengthening effect is the most outstanding among all minor alloying elements in aluminum alloys. Strength increment caused by adding minor Sc and Zr is attributed mainly to fine grain strengthening, precipitation strengthening of Al3(Sc, Zr) and substructure strengthening.

VUK panenske Brezany et.al (2001) investigated Aluminum alloys containing scandium exhibit specific properties. Scandium is one of the alloying elements that produce a very intensive precipitation hardening effect.

K.L kendig et.al (2002) investigated As a step toward developing an Al-Mg-Sc-Zr alloy for use up to 200 °C, the mechanisms responsible for alloy strengthening were identified for Al-6Mg-2Sc-1Zr (wt%) (Al-6.7Mg-1.2Sc-0.3Zr).

M. Seeman et .al (22 September 2009) In this study, an attempt has been made to model the machinability evaluation through the response surface methodology in machining of homogenized 20% SiCp LM25 Al MMC manufactured through stir cast route. The combined effects of four machining parameters including cutting speed (s), feed rate (f), depth of cut (d), and machining time (t) on the basis of two performance characteristics of flank wear (VBmax) and surface roughness (Ra) were investigated.

Nikulin et.al (2012) investigated the process of grain refinement under severe plastic deformation was examined in an Al–5.4% Mg–0.5% Mn–0.1% Zr alloy, which was subjected to equal-channel angular pressing (ECAP) in the strain interval from 1 to 12 at a temperature of ~300 °C.

M.Vlach et.al (2013) investigated The effects of cold-rolling on thermal, mechanical and electrical properties, microstructure and recrystallization behaviour of the Al-Sc-Zr and Al-Mn-Sc-Zr alloys prepared by powder metallurgy were studied.

C.N Panagopoulos et.al (2013) investigated the wear behavior of 5083 wrought aluminum alloy under the action of corrosive 3˙5% v/v Nacl solution, against stainless steel counter face was studied. Under a constant value of sliding speed, it was observed that the increase in the applied load resulted in a decrease in the friction coefficient of the pair stainless steel/Al 5083.

M.krishnan unni et.al(2014) investigated Aluminum alloys have excellent machining properties compared with other common engineering metals. In this study deals with the

Aluminum alloy 5083, the following process parameter the cutting speed, feed rate, depth of cut for the purpose of analysis.

Samson Jerold manuel et.al (2020) investigated Response surface methodology (RSM) is used to optimize the process parameters in casting, welding and machinability studies of composite materials. Response surface methodology is commonly used to design the experiments and it minimizes the numbers of experiments for specific number of factors and its levels.

Y. Fouad et.al (2011) investigated in the present study, wear test has been performed on wrought magnesium alloy AZ31 samples. The test samples were in different conditions as; in the as cast alloy or after undergoing different surface treatment of the wrought alloy.

Wiliam song et.al (2004) investigated on the wear properties of die cast and sand cast magnesium alloys and aluminum alloys under dry and wet sliding conditions at different loading conditions. While magnesium alloy can be considered as an alternative material in many automotive applications. Pin-on-disk equipment has been used to carry out wear tests in this study. Two magnesium alloys, AS21 and AZ91D, and an aluminum alloy, Al-CA 313, have been used as disks materials in this investigation.

B.S. Ravindranath et.al (2021) Mechanical parts are frequently subjected to friction, resulting in wear of the parts which reduces the components life and leads to the higher power consumption. In the present study, an attempt has been made to optimize the process parameters on pin and disc wear test as per American Society for Testing and

Materials (ASTM) standard Grain size (G)99-05 on 2xxx series alloys – Aluminum Al 2011, Al 2014, and Al 2024. The results reflect that, the parameter disc speed has the greatest influence on the wear loss of the specimen and the material type has the least effect at 95% the confidence level.

CHAPTER-III

OBJECTIVE AND METHODOLOGY

3.1 OBJECTIVE

The research contributions available from the reputed international journals are reviewed on the Al-Mg-Mn alloy and wear and the contributions are discussed in the Chapter-2. Based on the review, still, there is a lacuna in the investigation of wear characteristics of Al-Mg-Mn alloy with additions of transition elements. Therefore, the present research is taken-up on four Al-Mg-Mn alloys and the objectives are outlined below:

1. To study the effect of wear process parameters for Al-Mg-Mn-Sc-Zr alloy based on Box Behenken design.
2. To study the influence of process parameters on the responses of the Al-Mg-Mn-Sc-Zr alloy using RSM and ANOVA.
3. To optimize the optimal wear process parameters using desirability approach inorder to predict the optimal conditions for minimum wear.

3.2 METHODOLOGY

The research methodology adopted for this study, Experimental plan using Box Behenken design and Response surface methodology using desirability approach to optimize the process parameters, the significance of parameters by analysis of variance.

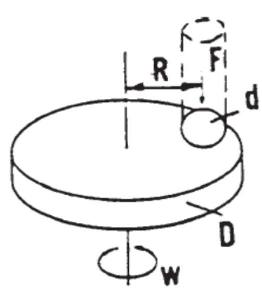
CHAPTER-IV

EXPERIMENTATION

4.1 Wear properties

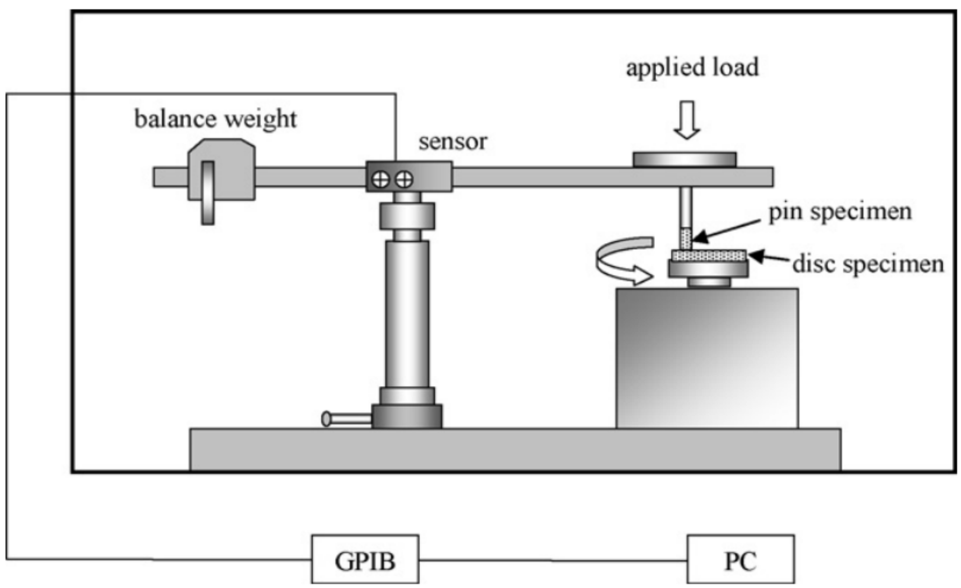
Sliding wear technique by pin–on-disc experimentation Pin-on-disc machine Ducom model LR 20 E(India) made and high precision Mettler electronic balance, Model AG 204 was used to conduct wear test and investigate the coefficient of friction, wear loss and specific wear rate for all the prepared composites according to ASTM G99. This test method covers a laboratory procedure for determining the wear of materials during sliding using a pin-on-disc apparatus. Materials are tested in pairs under nominally non-abrasive conditions. The principal areas of experimental attention in using this type of apparatus to measure wear are described. The coefficient of friction may also be determined. The pin specimen is pressed against the disk at a specified load usually by means of an arm or lever and attached weights. The amount of wear is determined by weighing specimens before and after the test. Wear results are usually obtained by conducting a test for a selected sliding distance and for selected values of load and speed. Scope: This test method covers a laboratory procedure for determining the wear of materials during sliding using a pin-on-disc apparatus. Materials are tested in pairs under nominally non-abrasive conditions. The principal areas of experimental attention in using this type of apparatus to measure wear are described. The coefficient of friction may also be determined.

For the pin-on-disk wear test, two specimens are required. One, a pin with a radius tip, is positioned perpendicular to the other, usually a flat circular disk. A ball, rigidly held, is often used as the pin specimen. The test machine causes either the disk specimen or the pin specimen to revolve about the disk center. In either case, the sliding path is a circle on the disk surface. The plane of the disk may be oriented either horizontally or vertically. The pin specimen is pressed against the disk at a specified load usually by means of an arm or lever and attached weights. In this investigation, pin-on-disc machine was used for evaluating the sliding wear frictional properties of the composites. In this test rig, pivoted liver loaded with dead weight applies the normal load as shown in Figure 2.7. The main advantages of this type of loading method are the less frictional losses and good mechanical advantage in the loading. A pin is pressed against a rotating disc such that the contact surface of the pin will be flat. The cured composite laminates were cut using a diamond tipped cutter to yield wear test coupons of size 8mm diameter. The test samples were then glued using an adhesive to pins of size 8mm diameter and 25mm length. where, F is the normal force on the pin, d is the pin or ball diameter, D is the disk diameter, R is the wear track radius, and w is the rotation velocity of the disk.



Pin on disc experimental parameters

4.2 Method of testing: The test specimens were weighed and initial weights were recorded using a high precision digital electronic balance after thorough cleaning. After recording initial weight, specimen fixed to the holder such that the flat face of the layup come in contact with the rotating hardened steel disc as shown in Figure.2.8. The setup had an arrangement to vary the motor speed and consequently the rpm of the disc. Selecting the suitable track on the disc, sliding distance and rpm, the sliding velocity can be chosen. The final weights were recorded and the wear losses in grams were calculated.



Schematic diagram of pin-on-disc test set-up

Technical specification of the pin-on-disc Machine used for this investigation is:

Speed 3000 RPM (maximum), RPM indicator digital type with proximity sensor

Sliding velocity 14 m/ s (maximum)

Drive system A. C. Motor -Siemens make with A. C. Drive- ABB control

Data acquisition 16 channel ADC card - Dynalog make

Load cells Range 100 N and 200 N (maximum) - Resolution 1N, senstronics make, two numbers, normal load that can be applied using dead weight of 250 N maximum.

Disc dimensions 160 mm diameter and 8 mm thickness. Surface roughness of the disc 25 μm, hardness 62 HRC.

Temperature and heater for disc heating: four thermocouples, temperature heating for pin one element, temperature range up to 400^{0}C

The specific wear rate K_S (g/N-m), was calculated from the equation; $K_S = W / F_N \times d$

where, W is the weight loss in grams, F_N is the normal load in Newton, d is the sliding distance in meters.

The coefficient of friction is calculated from the equation;

$$\mu = F_f / F_N$$

F_f is the frictional force (Newton) and μ is the coefficient of friction.

The Ducom wear and friction monitor – TR 20E series has become the industry standard in wear and friction analysis. The TR 20 Series tribometer is specifically designed for fundamental wear and friction characterization. This instrument consists of a rotating Disk against which a test pin is pressed with a known force. A provision for measurement of compound wear and frictional force is provided. The TR 20E Series comes with the WinDucom software for data acquisition and display of results. The WinDucom instrumentation and data acquisition permits the measurement of: (i) RPM, (ii) wear, (iii) frictional force and (iv) temperature and the detailed specifications the wear tester are given in Table 2.7.

Table 2.7 Equipment specification and specimen size

Parameter	Unit	Min	Max	Remarks
Pin size	mm	3	12	Diameter or diagonal with different holders
Ball diameter	mm	10	12.7	
Disk Size	mm	160 x 8		
Wear Track Diameter	mm	20	145	
Disk Rotation	RPM	200	2000	
Normal Load	N	5	200	In steps of 5 N
Wear	µm	0	2000	
Frictional Force	N	0	200	

Test parameters: Load - values of the force in Newtons at the wearing contact. Speed - the relative sliding speed between the contacting surfaces in m/s and Distance - the accumulated sliding distance in meters. The wear test equipment is shown in figure 4.3(a), 4.3(b) and (c). the specimen holder shown in figure 4.4(a) and 4.4(b).

Figure 4.3(a)

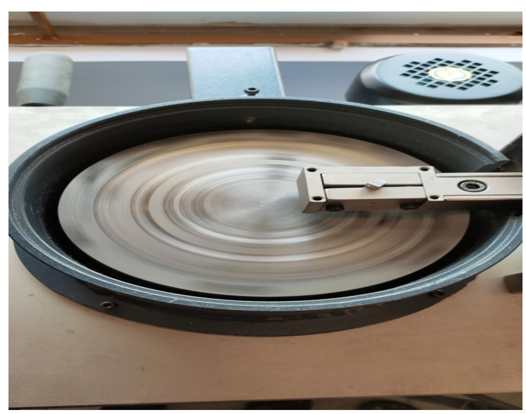


Figure 4.3(b)

Figure 4.3(c)

Figure 4.3(a,b,c) Equipment of Pin on Disc.

Figure 4.4(a)Specimen Holder

Figure 4.4(b)Specimens

4.3 Significance

The amount of wear is determined by weighing both specimens before and after the test. The amount of wear in any system will, in general, depend upon the 68 number of system factors such as the applied load, machine characteristics, sliding speed, sliding distance, the environment, and the material properties. The value of any wear test method lies in predicting the relative ranking of material combinations. Since the pin-on-disk test method does not attempt to duplicate all the conditions that may be experienced in service (for example; lubrication, load, pressure, contact geometry, removal of wear debris, and presence of corrosive environment), there is no insurance that the test will predict the wear rate of a given material under conditions differing from those in the test.

CHAPTER-V

RESULTS AND DISCUSSION

5.1 STUDY ON OPTIMIZATION OF WEAR PROCESS PARAMETERS FOR WEAR AND COEFFIECIENT OF FRICTION

The Box behenken experimental output results relating to wear and coeffiecient of friction for Al-Mg-Mn-Sc-Zr alloys are shown in Table 5.1. The values indicated are the average of three readings (trials).

Table 5.1 Box behenken Experimental design matrix and the responses for experiments

Expt. No.	Load (N)	Speed (rpm)	Track diameter (m)	Experimental		Predicted	
				Wear	Coefficient of friction	Wear (microns)	Coefficient of friction
1	15	300	60	152	5.12	149.62	5.01625
2	5	100	60	7	4.01	59.375	4.11375
3	10	200	60	10	0.17	33.333	2.41667
4	5	200	50	17	3.51	17.375	2.76000
5	10	100	70	38	3.95	38.000	3.76875
6	15	200	50	115	3.58	117.37 5	3.50250
7	10	300	70	107	4.75	109.75 0	4.10375
8	5	200	70	83	2.75	80.625	2.82750
9	10	200	60	80	3.59	33.333	2.41667
10	15	100	60	32	4.00	32.375	3.43125
11	10	100	50	9	3.23	6.250	3.87625
12	15	200	70	81	3.00	80.625	3.75000
13	5	300	60	73	2.10	72.625	2.66875
14	10	200	60	10	3.49	33.333	2.41667
15	10	300	50	115	3.50	115.00 0	3.68125

5.1.1 Development of Mathematical Models

The mathematical model developed by response surface methodology technique was used to predict minimum wear and coefficient of friction in terms of the wear process parameters for Al-Mg-Mn-Sc-Zr alloy. The general second order regression equation to represent responses is given in chapter-1(Equation 3.1).

The experimental results are fitted to the second order quadratic equation. The predicted Eq.5.1, including three factors obtained from the Box behenken experiments,are as follows:

(Eq. 5.1)

Coefficient of friction

The minitab17 statistical software was used to obtain the regression coefficients by applying Box behenken to determine the relationships between response and the process parameters and given in the equation-5.2, and 5.3 for wear and coefficient of friction respectively.

W=-315+ 21.3 L+ 0.324 S+ 11.05 TS- 1.389 L*L- 0.000136 S*S- 0.2273 T*T- 0.00031 L*S+ 0.088 L*T+ 0.00037 S*T (Eq. 5.2)

CoF = 653+ 44.5 L+ 0.568 S+ 27.05 T- 3.216 L*L-0.000284 S*S 0.5645 T*T+ 0.00563 L*S+ 0.100 L*T+ 0.00250 S*T (Eq. 5.3)

5.1.2 Analysis of variance

The analysis of variance (ANOVA) was performed to evaluate the significance of the wear process parameters. Table 5.1, and 5.2 shows the summary of the results of the ANOVA for the wear experiments with the Al-Mg-Mn-Sc-Zr Alloy for wear and coefficient of friction.

The predicted model validation was tested by means of the P-value and the F-value. When the P-value is less than 0.05 (i.e., 95% confidence level) and F-value is higher, implies that the model and independent variables are significant. It was observed that the F-value and P-value for the two responses (wear and coefficient of friction) are equal to 5.79 and 0.000 respectively. The value of R^2 for the predicted model equal to 83.90% and 93.78% for the mechanical properties (wear and coefficient of friction) shows that the predicted model is in good agreement with the experimental data.

Table 5.1 Analysis of variance (ANOVA) for Wear

Source	Sum of squares	Degrees of freedom	F-value	P-value	
model	2608.43	9	5.79	0.006	Significant
L	115.56	1	2.31	0.160	Insignificant
S	27.56	1	0.55	0.475	Insignificant
T	826.56	1	16.51	0.002	Significant
L*R	0.12	1	0.00	0.961	Insignificant
L*T	6.13	1	0.12	0.734	Insignificant
S*T	1.13	1	0.02	0.884	Insignificant
L^2	776.37	1	15.51	0.003	Significant
S^2	741.83	1	14.82	0.003	Significant
T^2	811.69	1	16.22	0.002	Significant
Lack of fit	129.68	5	0.35	0.863	Insignificant
Pure error	500.52	5	-	-	-
Cor Total	3108.95	19	-	-	-
R-squared	83.90%	-	-	-	-
Adj- R Squared	69.41%	-	-	-	-
Pre R-Squared	49.54%	-	-	-	-

Table 5.2 Analysis of variance (ANOVA) for Coefficient of friction

Source	Sum of squares	Degrees of freedom	F-value	P-value	
model	13013.2	9	23.41	0.0001	Significant
L	484.0	1	7.84	0.019	Significant
S	25.0	1	0.40	0.539	Insignificant

T	3660.2	1	59.27	0.000	Significant
L*R	40.5	1	0.66	0.437	Insignificant
L*T	8.0	1	0.13	0.726	Insignificant
S*T	50.0	1	0.81	0.389	Insignificant
L^2	4160.5	1	67.37	0.000	Significant
S^2	3246.8	1	52.57	0.000	Significant
T^2	5008.3	1	81.10	0.000	Significant
Lack of fit	282.2	5	0.84	0.573	Insignificant
Pure error	335.3	5	-	-	-
Cor Total	13630.8	19	-	-	-
R-squared	95.47%	-	-	-	-
Adj- R Squared	91.39%	-	-	-	-
Pre R-Squared	80.13%	-	-	-	-

Normal probability plots for wear and coefficient of friction are shown in Figure 5.1 (a-b). Figure 5.1 and the results for R^2 value indicate good agreement between the calculated and observed results within the range of experiment.

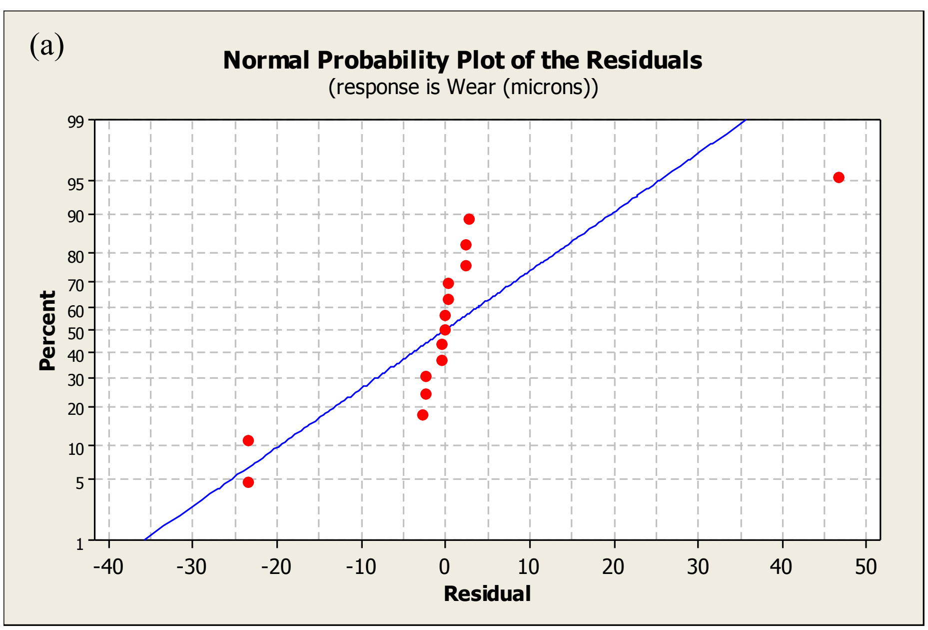


Figure 5.1 (a) Normal probability plots for Wear

(b)

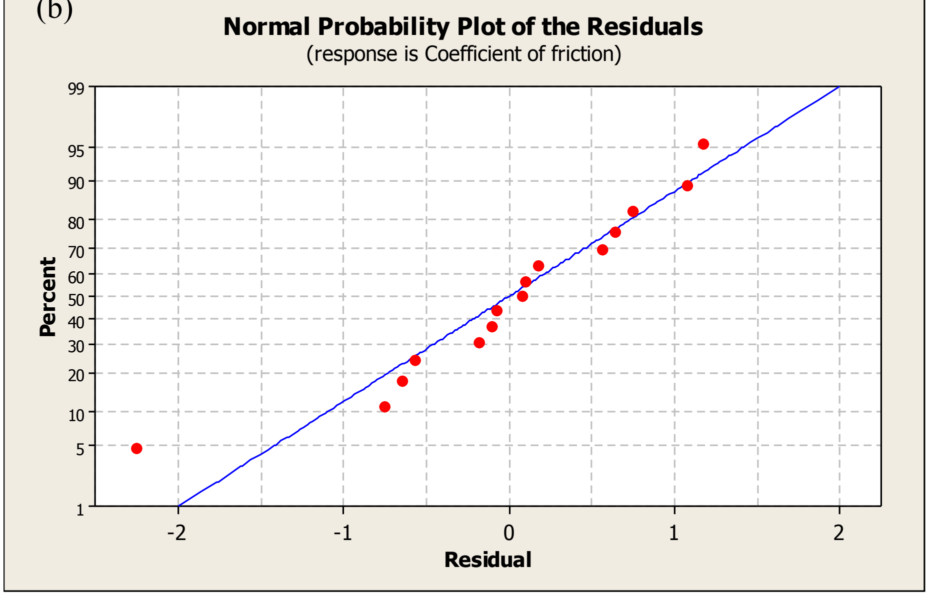


Figure 5.1 (b) Normal probability plots for Coefficient of friction

Figure 5.2(a-b) shows the contour plots for wear and coefficient of friction. Figure 5.2 (a) represented the relation between S*L, T*L and T*S for optimal L (5 N), S (100 rpm) and T (50 mm) process parameters for wear.

(a)

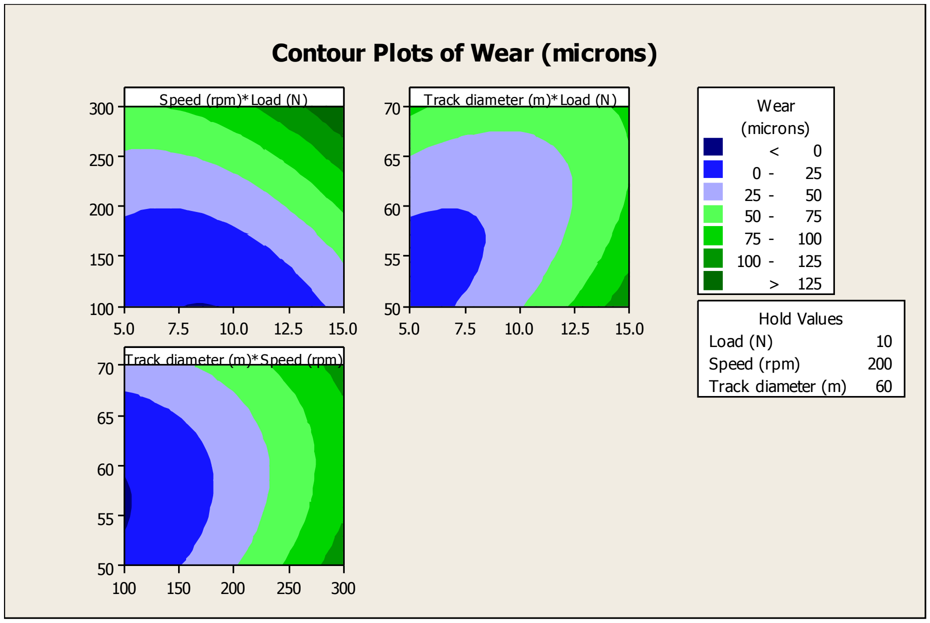


Figure 5.1(a) Contour plots for wear

Figure 5.2 (b) represented the relation between S*L, T*L and T*S for optimal L (5 N), S (100) and T (50) process parameters for coefficient of friction.

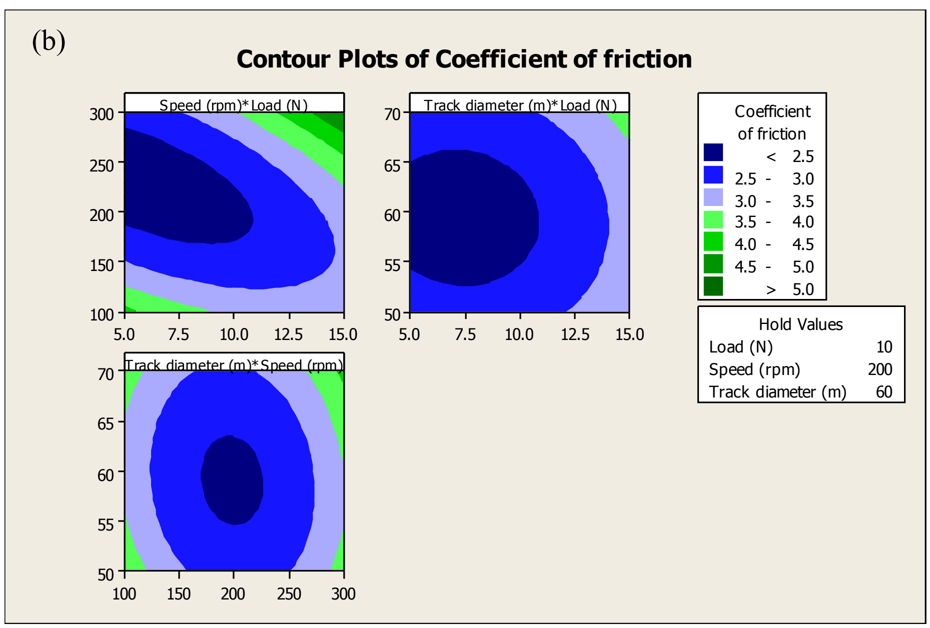


Figure 5.2(b) Contour plots for Ultimate Tensile Strength

The interaction effects between process parameters were less significant when compared to individual effect which was confirmed by circular counters. Figure 5.1(a-b) also confirmed through the ANOVA analysis from the Tables 5.1, and 5.2.

Figure 5.1 shows the three-dimensional response surface plots obtained from RSM, they indicate the optimal response points at the apex. From the response graphs, it is observed that (Figure 5.1(a-b)) the minimum wear (Figure 5.1(a)), coefficient of friction (Figure 5.1(b)), values are obtained at an load of 5 N, speed of 100 rpm, track diameter of 50 mm/min.

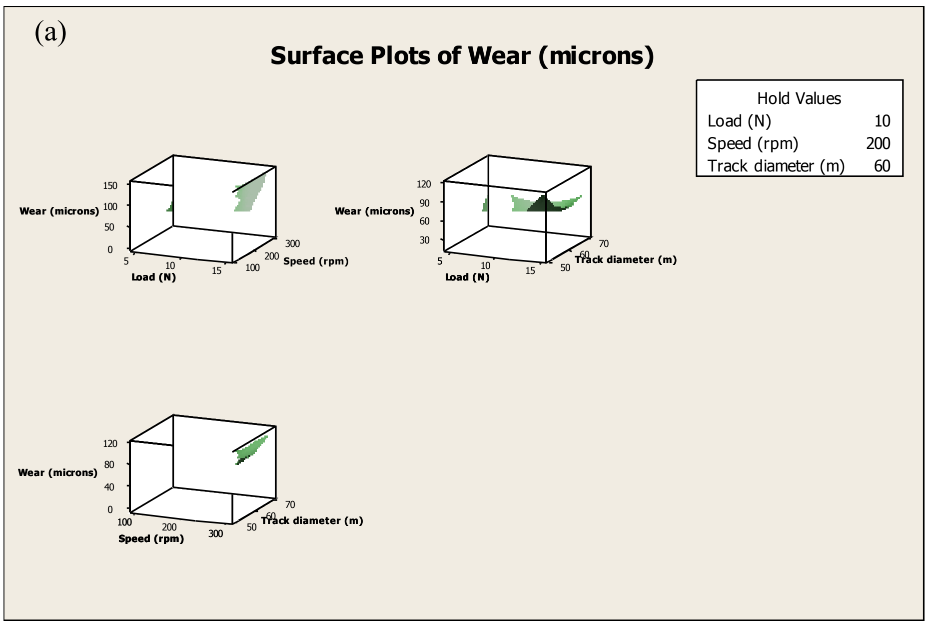


Figure 5.1(a) Response surface plot for Wear

(b)

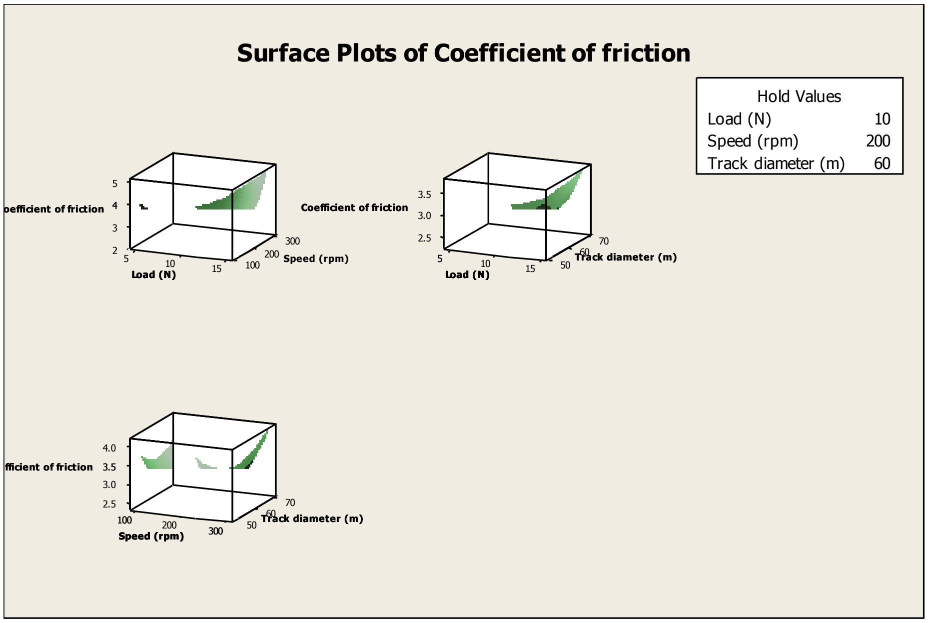


Figure 5.2(a) Response surface plot for Coefficient of friction

5.2 Optimizing parameters

The objective of this work is the minimization of wear and coefficient of friction. Constraints for optimization criteria were adopted by choosing the desired values for each factor and response, and details are presented in Table 5.3.

Table 5.3 Constraints for optimization criteria

Process parameter	Unit	Lower limit	Upper limit
AL	kN	5	15
RS	rpm	100	300
Track diameter	mm/min	50	70

According to this objective, the responses are considered in this study, the larger the better type was selected using desirability approach. The individual desirability and composite desirability were computed for each quality characteristics using the Eq.1.2 and Eq.1.2 respectively presented in the chapter-1 with the aid of desirability approach which is embedded in the minitab17 statistical software. The desirability values varied from 0 to 1. The value closer to 1 had higher influence than others. Considering the composite desirability of minimization of wear and coefficient of friction, the optimal parameter levels obtained was 5 kN load, 100 rpm speed and 50 mm track diameter. The predicted optimized values for each criterion are summarized in Table 5.3. The optimization plots for the criteria used are presented in Figure 5.3 (a-c).

Table 5.4 Predicted optimized values

	Load (N)	**Speed (rpm)**	**Track diamter (mm)**	Wear (Microns)	Coefficient of friction
Minimum (Wear)	5	100	50	10.5417	-
Minimum (Coefficient of friction)	5	100	50		4.0183
Maximum (Wear & Coefficient of friction)	5	100	50	10.5417	4.6342

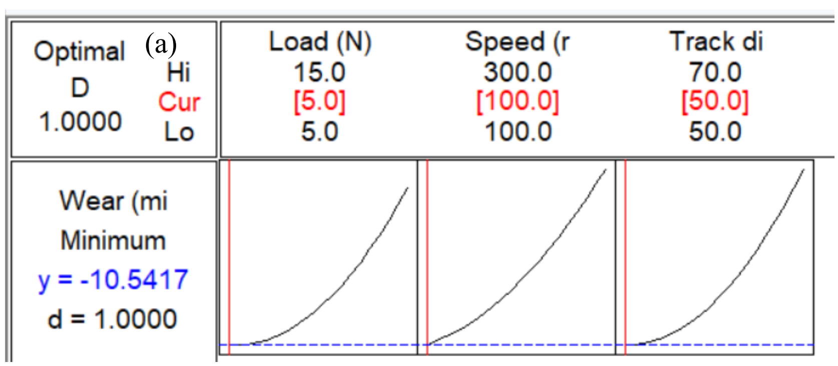


Figure 5.3(a) Optimal plot for Minimum wear

(b)

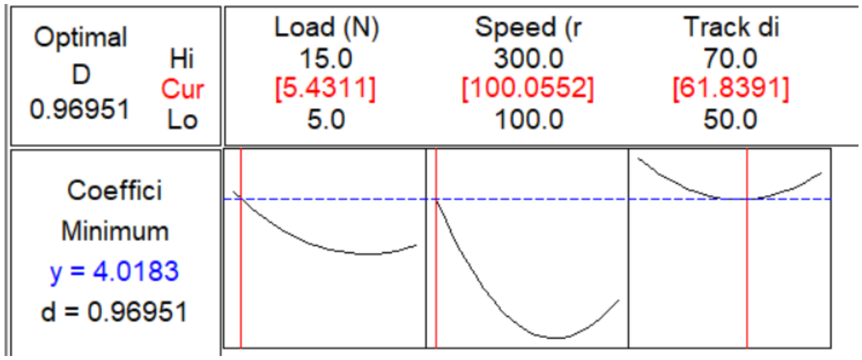


Figure 5.3(b) Optimal plot for Minimum Coefficient of friction

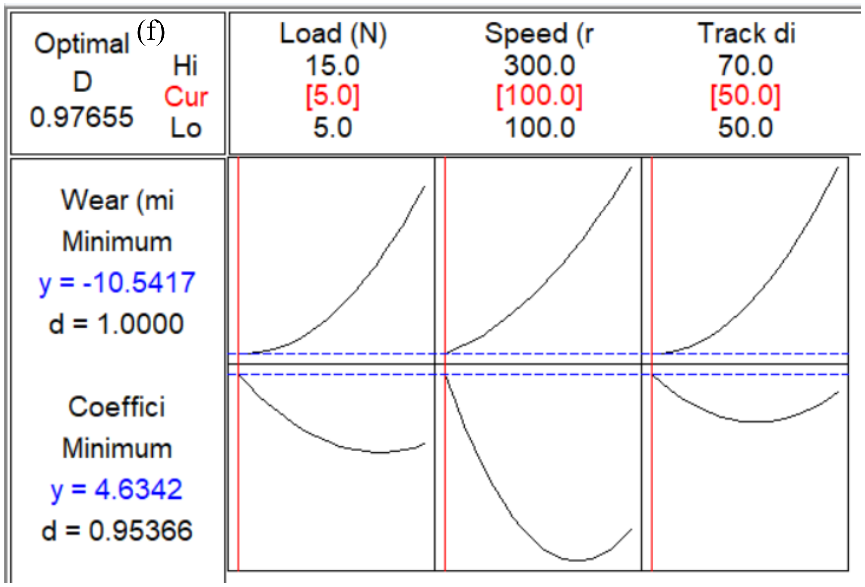


Figure 5.3(c) Optimal plot for Minimum wear and coefficient of friction

5.3 Confirmation test

The optimal parameters obtained through the desirability approach were used to minimization of wear and coefficient of friction. The mathematical models are validated with the confirmation test carried out with the optimal conditions. The predicted and experimental of the fabricated alloy were summarized in Table 5.5.

Table 5.5 Validation of optimized values based on confirmation tests

		AL	RS	TS	Wear	Coefficient of friction
		kN	**rpm**	**mm/min**	**(microns)**	**-**
Minimum (wear and coefficient of friction)	predicted	5	100	50	10.5417	4.6342
Minimum (wear and coefficient of friction)	experimental	5	100	50	9.8	4
Error (%)					9.8	13

CHAPTER VI

CONCLUSION AND FUTURE SCOPE

6.1 CONCLUSION

1. The numerical and graphical optimization methods were successfully applied with the aid of Minitab17 statistical software. The series of calculated R^2 for the considered model were equal to 83.90%, and 93.78% for the responses (Wear and Coefficient of friction), showing a good agreement between the independent variables and the response data.

2. The proposed model by using RSM was in good agreement with a confirmation test.

3. Optimal levels obtained- 5N Applied load; 100 rpm speed; 50 mm track diameter for Al-Mg-Mn-Sc-Zr alloy are wear (10.5417) and coefficient of friction (4.6342), respectively.

6.2 FUTURE SCOPE

- Fatigue, creep and damping properties can be studied for fabricated alloy.

- The work can be extended by the addition of Sc-Zr to other Aluminium alloys

CHAPTER-VII

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7.1 REFERENCES

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