EXPERIMENTAL INVESTIGATION OF WEAR PROPERTIES FOR ALUMINIUM MMCs IN FRICTION STIR WELDED REGION

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IN
MECHANICAL ENGINEERING

By

D. OMMURUGADHASAN

Under the Guidance of

Dr. K. PAJANIRADJA @ KICHENA

Professor

Department of Mechanical Engineering

Pondicherry Engineering College

Puducherry

DEPARTMENT OF MECHANICAL ENGINEERING
PONDICHERRY ENGINEERING COLLEGE
PUDUCHERRY – 605 014
INDIA

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Dedicated

to my family

Dr. K. PAJANIRADJA @ KICHENA
Professor,
Department of Mechanical Engineering,
Pondicherry Engineering College,
Puducherry- 605 014,
INDIA.

BONAFIDE CERTIFICATE

Certified that this thesis entitled **"EXPERIMENTAL INVESTIGATION OF WEAR PROPERTIES FOR ALUMINIUM MMCs IN FRICTION STIR WELDED REGION"** submitted for the award of the Degree of Doctor of Philosophy in Mechanical Engineering of Pondicherry University, Puducherry, is a bonafide in addition to authentic record of the individual work done by **Mr. D. OMMURUGADHASAN,** under my supervision and guidance during the requisite period under the regulation in force. This work is original and this thesis or any part thereof has not been submitted elsewhere for the award of any Degree or Diploma, Associateship of this university or any other university.

Place: Puducherry
Date: 28.08.2018

Dr. K. PAJANIRADJA @ KICHENA
Research Supervisor

DECLARATION

I hereby declare that the work presented in the thesis entitled **"EXPERIMENTAL INVESTIGATION OF WEAR PROPERTIES FOR ALUMINIUM MMCs IN FRICTION STIR WELDED REGION"** Submitted to Pondicherry University for the award of Degree of Doctor of Philosophy is a record of original and independent research work done by me under the Supervision and Guidance of **Dr. K. PAJANIRADJA @ KICHENA,** Professor, Department of Mechanical Engineering, Pondicherry Engineering College, Puducherry, and it has not previously formed the basis for the award of any Degree or Diploma, Fellowship, Associateship or other similar titles to any candidate of any university.

Place: Puducherry **D.OMMURUGADHASAN**

Date: 28.08.2018

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ABSTRACT

Aluminium Metal matrix composites are progressively getting to be plainly famous in car, aviation and hardware ventures, in perspective of their awesome mechanical properties furthermore wear resistance. Metal matrix composites (MMCs) have ascended as a basic class of materials, which are dynamically life form used as of late.

The first part of the research concentrates fabrication of MMCs by stir casting method. In this research work, Al6061T_6 is reinforced with different reinforcement like SiC, TiC and equal weight percentage of SiC and TiC. Also MMCs have been manufactured for various weight percentages like 0%, 5%, 10%, 15% and 20%.

The second part of the research focuses on friction stir welding of Al6061T_6 composites reinforced with different reinforcement like SiC, TiC and equal weight percentage of SiC and TiC. A central composite rotatable four-factor with five-level factorial design has been chosen. By the way of design matrix friction stir welding was carried out. Specimens were extracted from welded region for conducting wear test and response values are recorded.

The third part of the research involves building up numerical models for the wear rate and wears resistance. The result of analysis of variance (ANOVA) shows that the proposed mathematical model can satisfactorily depict the execution inside the breaking points of the variables being contemplated. Analysis of variance (ANOVA) demonstrates that the projected scientific model be able to agreeably portray the execution inside the limits of the factors being considered.

The fourth part of the research concentrates experience the non-dominated sorting genetic algorithm (NSGA-II) can be given more importance in this present study of process parameters for optimization. The elite-preserving operator is being utilized for this algorithm which supports the elite's population by giving them a chance to support the people of coming generation. When compared to other objectives, Optimization problems for multi objective is to make available a set of Pareto optimal solutions that can be very useful.

Further in the research, comparisons are made with the results taken from experimental and optimization values. It is clearly evident from the examination, that NSGA-II provides preferable outcome over that of the RSM and the experimental values. Out of the three different friction stir welded composites used for the experiment, $Al6061T_6$ composite reinforced with Silicon carbide gives minimum wear rate (W) and maximum wear resistance (R).

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LIST OF SYMBOLS AND ABBREVIATIONS

µm	-	Micrometer
% wt.	-	Percentage weight
AMC	-	Aluminium matrix composites
ANOVA	-	Analysis of variance
CCD	-	Central composite design
DOE	-	Design of experiments
mm	-	Millimetre
mm/rev	-	Millimetre per revolution
MMCs	-	Metal matrix composites
N	-	Rotational speed
S	-	Welding speed
F	-	Axial force
P	-	Weight percentage of reinforcement
W	-	Wear rate
R	-	Wear resistance
X1	-	Coded variable of rotational speed
X2	-	Coded variable of welding speed
X3	-	Coded variable of axial force
X4	-	Coded variable of weight percentage of reinforcement
NSGA	-	Non-dominated sorting genetic algorithm
MOGA	-	Multi-objective genetic algorithm

VEGA	-	Vector evaluated genetic algorithm
Rpm	-	Revolution per minute
RSM	-	Response surface methodology
SEM	-	Scanning electron microscope
SiC	-	Silicon carbide
TiC	-	Titanium carbide
XRD	-	X-ray diffraction
SL	-	Semisolid– Liquid
DPS	-	Dual Particle Size
Kgf	-	Kilogram force
GA	-	Genetic Algorithm
NDT	-	Non destructive testing

CHAPTER 1

INTRODUCTION

1.1 Historical Advancement for Friction Stir Welding

During the year 1991, In the Welding Institute (TWI) at Cambridge, friction stir welding (FSW) process was designed. It was further developed and was got patented by The Welding Institute to build up a super, minimum thickness, lighter in weight swap for aluminium combination Al 2219, NASA tested Lockheed Martin Laboratories in 1993, at Baltimore, Maryland and it was utilized on the principal Space Shuttle External Tank. Lockheed Martin, Reynolds Aluminium and the labs at Marshall Space Flight Center in Huntsville, Alabama, were productive in building up another compound recognized like Aluminium Lithium (Al-Li 2195), it can be lessened the heaviness about the External Tank beside 7,500 pounds (3,402 kilograms). At present, the External Tank venture utilizes the novel combination to construct the Shuttle's very good Lightweight Tanks. (Bharat Raj Singh) [11].

Since 1995 in Europe, in the creation of new applications, Friction Stir Welding is being utilized. The German Aerospace focus (DLR), the Institute of Materials was the principal non mechanical research foundation built up in the year 1997. This Institute got the primary TWI permit in Germany and works in the field of friction stir welding of aluminium composites. The FSW is performed on a hardened, numerically controlled bedplate processing machine. The procedure is checked by online temperature, removal and power estimation.

1.2 Mechanism for Friction Stir Welding

The Friction Stir Welding is in point of fact a quite latest joining process as shown in Fig. 1.1 and is a good process for particularly welding aluminium parts. One of parts to be rotated at the time of conventional rotary friction welding process and having practical limitations in Customary formed segments joining, rather in circular cross area and the length is being restricted. The suitable examples are Short tubes or round bars of a similar breadth (Dawes. C. J *et al)* [18].

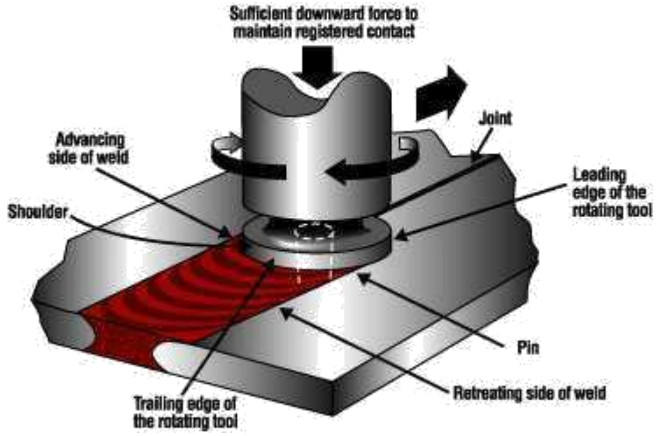


Figure 1.1 Mechanism of Friction Stir Welding

The movement of the parts being joined is also required by the linear reciprocating process. To create the erosion between the two sections a forth motion and straight line back motion was used by the FSW process. Consistency of the parts being joined is not as fundamental with this procedure; be that as it may, movement of the part while welding is basic. For fabricating butt or lap joints extensive variety of lengths and materials thickness is capable in FSW.

FSW can be utilized like a part of an assortment of joint arrangements, including butt welds, divergent thickness butt welds, lap entrance, and lap filet designs as shown in Fig. 1.2 of joint configurations. On the other hand, in the traditional tee fillet joint configuration it cannot be used. It is ordinarily utilized as a part of numerous combination welding applications. This can regularly require overhaul of the item, to take full favourable position of the FSW procedure (Mishra, R.S.et al.) [61].

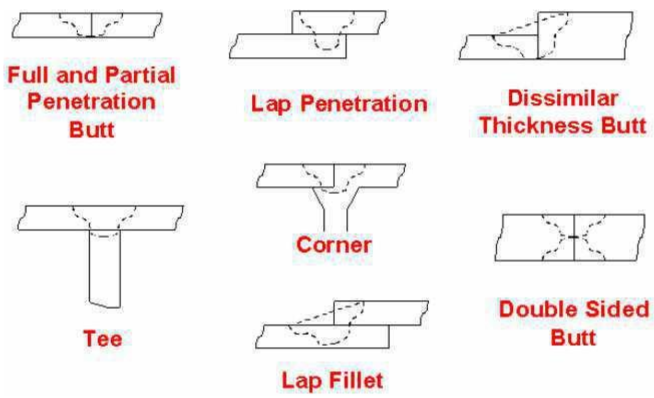


Figure 1.2 Joint configurations of FSW

1.3 Working Principles of FSW

FSW highlights have prompted the use of pioneers for small scale joining of electronic segments; however the procedure is likewise being connected to the manufacture of car segments and accuracy machine device parts in overwhelming segment steel.

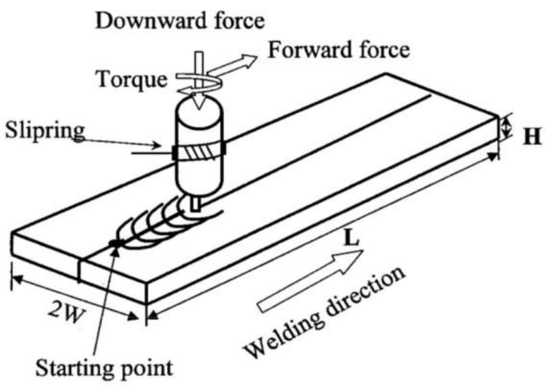


Figure 1.3 Schematic Diagram of FSW

1.4 Theory of Operation

It is schematically explained in Fig .1. 3. And to begin with, the sheets or plates are adjoined along edge to be welded and the pivoting pin is indented into the sheets/plates until the point that the device bear is in full contact with the sheets or plates surface. Once the stick is totally embedded, it is moved with a little mutating edge in the welding heading. Because of the progressing and pivoting impact of the pin along with shoulder of the tool by the side of the crease, a propelling face along with a withdrawing sides are framed along with the mellowed as well as warmed material streams in the region of the pin just before its rear where the material can be combined to make an astounding maximum superiority solid state join.

1.5 Theory of FSW

Hypothesis of FSW a profiled test is pivoted with the tube shaped bore device in friction stir welding and hooked on the joint line it gradually dove amid two bits of metal or cover material that can be butted commonly in Fig .1. 4 (a). The parts must be solidly cinched onto the worktable in a way that keeps the joint countenances from being constrained separated. In the middle of the material of the work piece and the wear safe welding apparatus the frictional warmth is created and is appeared in Fig. 1. 4 (b). This heat creates the most recent smooth exclusive of achieving the dissolving point as well as consents going of the tool by the side of the weld line as appeared in Fig. 1. 4 (c). From the principle edge of the tool to the trailing edge of the device test the plasticized material is moved and in the comfortable contact of the gadget bear and the pin profile it is produced. It leaves a solid stage bond between the two pieces. Huge preferred standpoint of Friction Stir Welding is that it has inside and out less process segments to control. The procedure factors cleanse gas, voltage along with amperage, cable bolster, pass through speed, productive gas and circular segment hole must be controlled in combination welding process. Nonetheless, in Friction Stir Weld there are three process elements to control, turning speed, pass through speed and weight, which are all effortlessly controlled. The diminishment in process inconstancy joined with the expansion in the joint strength gives high degree of reliability and an increased safety margin for the external tank.

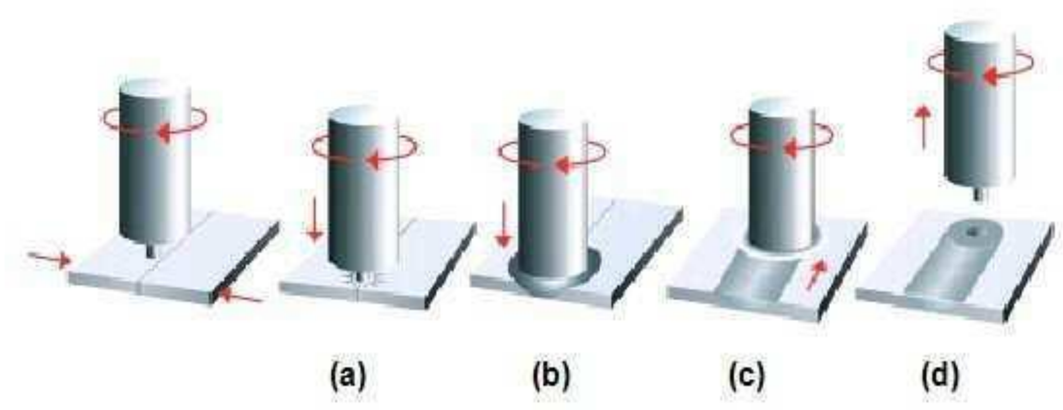


Figure 1.4 Schematic Drawing for Working Processes: (a). Start of joining, (b). Insert joining tool, (c). Joining and (d). Pull away joining tool (end)

1.6 The Force Analysis of FSW

During friction stir welding, there are different parameters effects on the process and on the forces on the pin as shown in Fig. 1.5. These parameters are:

- Material Alloy
- Grain Direction
- Pivot Velocity of Shoulder and Pin (rpm)

- Pin stay Time
- Pilot opening
- Cross rate (mm/min)
- Pins designs

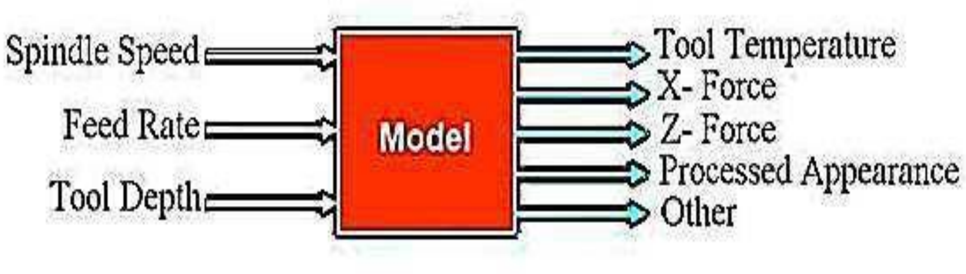


Figure 1.5 Relations between Process Input and Measured Output

These parameters affect on the micro structural changes, resultant mechanical properties and on the forces that effect on the FSW tool (Hattingh. D. G.et al.) [39].

1.7 Type of Forces

During friction stir welding, there are three types of force act on the tool. They are written as shown in Fig. 1.6.

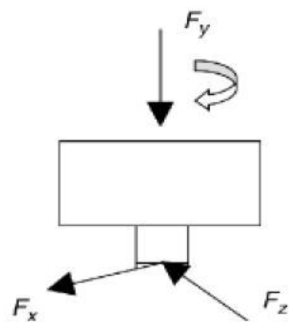


Figure 1.6 Three – axis force on the tool

The longitudinal force (X – force)

The vertical force (Y- force)

The lateral force (Z-axis)

i). The Longitudinal Force (X-force)

The cross force applied parallel to the tool progress along with certain in the explore heading. In view of the fact that this power emerges because of the protection of the material to the movement of the tool it might be ordinary that this power will decrease while the temperature of the material in the region of the tool is extended. The lack of parameters aside from two in influencing the navigate was astounding. Just the material (78%) and grain bearing (2%) contributed, and the unexplained elements were 20%. The outcome demonstrates that in the event that we know the material, the x-force important in the machine configuration can be resolved.

ii). The Vertical Force (Y-force)

A downwards force is basic to maintain the location of the tool by the side of or below than the material surface. Under the load control some of the friction stir welding machines operated for many cases the welding tool is preset in vertical position so that the load will vary at the time of welding. The pin thrust is resolved fundamentally by the material being prepared (57%). The navigate rate contributes 18%. Other contributing parameters are grain bearing, RPM and stay time. The unexplained components are just 15 %.The navigate rate it is trust causes a descending and after that increasing material stream which pushes against the pin. There is no huge cooperation of the variables.

iii). The Lateral Force (Z-axis)

The sidelong power may act inverse to the tool cross bearing moreover is portrayed here as optimistic on the way to the moving side of the technique. A torque can be required to turn the tool, the evaluation of which will depend upon the down power and contact coefficient (sliding friction) or possibly the stream nature of the material in the including locale (staying friction). These forces joined by way of the warm effect shock may well prompt the deformity of the fixture moreover the handled plates with influence the tool wear. These impacts will thusly confuse the development of the leftover stresses in the welding in addition to the expectation of life of the tool.

1.8 Traditional Weld and FSW Weld

In traditional or fusion welding the material get joint in molten state and resolidify, and in FSW, the joint is made in strong state; it never gets in liquid stage as appeared in Fig. 1.7(a) and 1.7(b). Instead, the joint is made under states of extreme plastic twisting.

- The procedure is likewise exceptionally vigorous.
- Not being touchy to ecological conditions, not at all like numerous customary welding forms.
- . It is particularly valid for welding of lower dissolving point materials, for example, aluminium, magnesium, bronze, and copper.
- It likewise yields essentially less contortion than the combination welding forms.
- The huge distinction amongst FSW and combination welding (other than the absence of liquefying) is the capacity to control top temperatures by decision of various welding parameters.

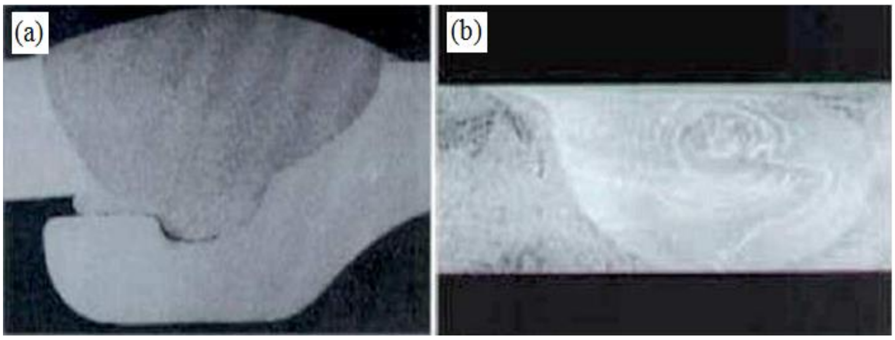


Figure 1.7 (a) Traditional Weld and (b) FSW weld

FSW gives you the Capacity to control the properties of the metal and tailor them for various applications. What's more, it may be conceivable to upgrade rigidity, crack strength, or weakness resistance in light of the specific application.

1.9 Advantages and Disadvantages

The friction stir welding prompts a few points of interest over fusion welding strategies in light of the solid state nature because of the problems among cooling from liquid stage is without delay avoided. Issues, for example, porosity, salute redistribution; hardening splitting is not an issue amid FSW.

In normal, friction stir welding is unfathomably tolerant to varieties in process parameters and materials for creating a low centralization of defects on the other hand friction stir welding is related by number of matchless imperfections. Inadequate weld temperatures, because of low rotational rates or high explore speeds; for example, infer with the intention of the weld material can't suit the broad twisting amid welding. This could cause during lengthy, burrow absconds running by the side of the weld that could be outside of subsurface. Small temperatures may possibly likewise restrict the producing activity for the tool thus decreases the congruity of the bond among the materials on or after every plane of the weld. This imperfection is especially stressing since it is extremely hard to recognize utilizing non-ruinous strategies, for example, X-ray otherwise ultrasonic investigation.

The absence of penetration Imperfection will happen as a result of the crossing point by the side of the base of the weld couldn't be vexed and created by the tool on the off chance that the pin is enough not long or the climbs of the tool out the plate. This is basically a score in the material which can be an intense wellspring of weakness breaks.

1.9.1 Advantages

- Great mechanical properties in the as welded state
- We could weld metal without softening it, keeping up its unique properties regardless of the joining procedure.
- We could join mutually metals those already couldn't be welded.
- We could dispose of the bolts in airframe structures and improve utilization of metal items in all structures by disentangling the assembling procedure, bringing down its cost, and decreasing segment stock by dispensing with parts.
- Enhanced protection because of the nonattendance of poisonous vapour otherwise the liquid material splash.

- Consumables not needed - ordinary steel devices be capable of weld more than 1000m aluminium furthermore no filler otherwise gas shield can be required in favour of aluminium.
- Effortlessly robotized taking place for basic processing machines - bring down setup expenses in addition to not as much of preparing.
- This work in the entire positions (even, vertical, and so on), seeing that there can be no weld pool.
- Commonly great weld form as well as insignificant thickness under/finished coordinating, therefore diminishing the requirement for costly machining in the wake of welding.
- Welding Preparation not usually required.
- Low environmental impact (no fumes).
- Low heat distortion.
- No filler wire required

1.9.2 Disadvantages

- Leave gap gone after tool is drawing in reverse.
- Large downward forces needed by way of overwhelming requirement bracing essential to clutch the plates jointly
- Minimum versatile than manual and curve shapes (issues with thickness assortments and non-coordinate welds).
- Significant resistances.
- Investment is maximum.

1.10 FSW Tools

Tools comprise of a shoulder and a pin which can be necessary with the shoulder or as a different embed conceivably of an alternate material as shown in Fig. 1.8. The outline of the shoulder along with of the pin should be essential on behalf of the weld nature. The tool pin produces the heat as well as mixes the material life form joined however the shoulder likewise has a vital impact by giving extra frictional behaviour and in addition keeping the plasticized material from getting away as of the weld section (Kumar. K et al.) [49]. the plasticized material is removed from the fundamental to the unpredictable side of the tool however is gotten by the shoulder which sets out along the weld to convey a delicate surface wrap up. Without a doubt, unique profile probes required for different materials and different thicknesses. The welding can be created from one side or by welding a large portion of the thickness and afterward to finish the opposite side (Shindo. D. J.et al.) [92].

1.11 Tool Pin

Typically the pin distance across is taken on the way to be proportional to the depth of the welded plates. This satisfies the essential that the head pin shall be adequately little to penetrate the two plates (Vijay, S.J.) [102]. The Device pin length be required to be marginally a smaller amount (with a small amount in 'mm') thickness of the plates, as a result the pin infiltrates the surface as of one side just moreover in the meantime forces the material towards stream in the region of it.

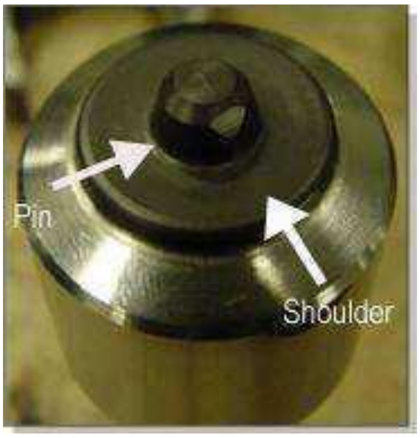


Figure 1.8 Pin and Shoulder of FSW

1.12 Tool Shoulder

The tool shoulder can be like the shape of circular cross section as shown in Fig. 1.8. Because of the warmth scattering from the friction between the shoulder and the surface of the plates (despite the pin action), the material encounters plastic contort and the two plates are consolidated. The tool shoulder length is irrelevant; in any case it must be adequately long to allow its fixation in the turning machine device holder. The shoulder broadness must be most certainly not very substantial with a specific end goal to limit the welding zone line width. At the end of the day, on the off chance that the shoulder width is excessively tremendous, it will influence a wide portion of the plate to be plasticized. The shoulder width is by and large taken as twofold the pin measurement (Madhusudhan. G.et al.) [54].

1.13 Generally Used Tool Materials

Materials, for example, aluminium or magnesium combinations, and aluminium metal matrix composites (AMCs) are generally welded utilizing steel materials. Welding of unrelated materials for both lap and butt configurations steel tools have in addition been used. (Lee et al.) [53] Joined Al– Mg composite by way of low carbon steel into lap joint setup utilizing instrument steel the same as device material exclusive of it's over the top wear by setting the gentler Al– Mg combination over the steel plate and dodging straight get in touch of the tool by means of the steel plate. Figure 1.9 give you an idea about the vital variants of tool shoulder of FSW tool.

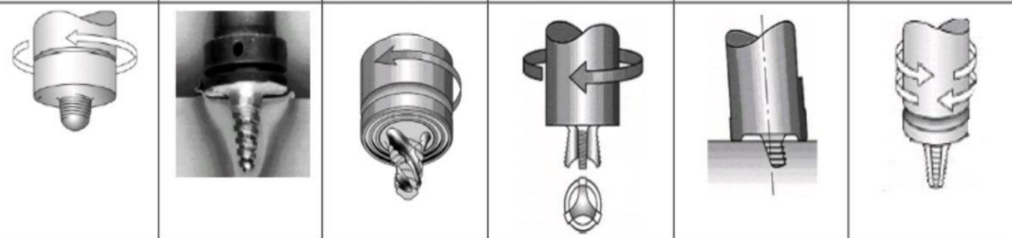
Cylindrical	Whorl^{TM}	MX triflute^{TM}	Flared triflute^{TM}	A-skew^{TM}	Re-stir^{TM}
					
Cylindrical with threads	Tapered with threads	Threaded, tapered with three flutes	Tri-flute with flute ends flared out	Inclined cylindrical with threads	Tapered with threads

Figure 1.9 Basic variants on the Tool Shoulder

During butt joint setup, the tougher work piece can be frequently put on top of the propelling surface in addition to the tool can be somewhat balanced commencing the butt crossing point on the way to the gentler job specimen. Cold worked X155CrMoV12-1 tool steel be utilized to weld the 99.5% unadulterated Cu among CuZn30 metal into butt joint design (Meran and Kovan) [60].

The oil solidified (62 HRC) steel instrument is make the most of to efficiently weld Al 6061+ 20 vol.%Al_2O_3 AMC_9 along with Al 359+20 vol. %SiC AMC. In the welding of soft alloys tool wear is minimum moreover maximum when welding the metal matrix composites for the nearness of hard, grating stages within the composites.

(Edwards. P. Et al.) [23] For FSW of AMCs, a few investigations have demonstrated with the purpose of the tool wears by the side of primary along with gets a self-enhanced shape later than which wear turns out to be significantly less articulated. This self-enhanced last shape, which relies upon the procedure parameters and is by and large smooth without any strings, can lessen wear when used as the fundamental tool shape. Signify wear was found to increase by way of rotational speed as well as decrease at cut down explore speed, which suggests that strategy parameters can be changed in accordance with increment tool life.

(Prado et al.) [74], contended adjacent to the strings require in the tools since the tools kept on creating great worth welds however later than the threading had depleted in addition to gadget had gotten a smooth shape. The tools manufactured by Polycrystalline cubic boron nitride attributable to elevated superiority moreover hardness by the side of lifted temperatures close by high temperature soundness boron nitride is a favoured device material for FSW of hard amalgams, for instance, steels and Ti compounds.

1.14 Applications of FSW

Friction stir welding process have various applications in industry sectors are shipbuilding, aviation, military vehicle, airplane, car, railroad moving stock enterprises and most expected others.

1.14.1 Ship construction and Naval Industries

The shipbuilding and marine ventures are two of the main business areas that have received the procedure for business applications. The procedure is reasonable for the accompanying applications:

- Sheet used for floors, elevations, partitions plus floors
- Aluminium expulsions
- Bodies and superstructures

- Helicopter landing stages
- Naval and convey structures

1.14.2 Space Shuttle

The Space ferry's massive exterior reservoir most recently upgraded by friction stir welding, it is largest element in space ferry and the main component not ready to reuse. The new welding method being showcased to industry uses frictional warming joined with manufacturing strain to deliver high-quality bonds basically free of deformities.

1.14.3 Nuclear plant

As atomic places far and wide become more seasoned there are expanding frequencies of stress consumption breaking (SCC) issues. In PWRs such splitting is notable and frequently connected with reactor pressure vessel parts (eg: essential water SCC at reactor spout areas).

1.14.4 Aerospace Industry

Friction stir welding have numerous possible aerospace purposes. Research in rivet replacement, repair of aging aircraft, fabricated structures, and tooling for assembled structures is undertaken to support the increased adoption of FSW by aerospace companies

The friction stir welding procedure can along these lines be considered for:

- Sections, fuselages, empennages
- Cryogenic fuel reservoirs for space cars
- Aviation fuel reservoirs
- Exterior fling left reservoirs for armed aircraft

1.15 Composites

A composite is a material containing at least two physically or synthetically unique stages. The composite by and large has predominant attributes than those of each of the individual parts. One of the ingredient materials goes about as the matrix and no less than one other constituent material goes about as the reinforcement in the composite. By means of the appearance of new handling procedures, the innovative intrigue along with investigate action to the improvement of metal matrix composites can be expanded quickly as of late (Christman.T et al.) [15].

In correlation by means of unreinforced solid mixes as well as resin composites, MMCs prescribe higher immovability along with quality esteems; bring down coefficient of thermal extension along with the capacity towards be utilized by the side of elevated temperatures (Mubaraki.B et al.)[62]. MMCs which are materials, that can join an extreme metallic framework by way of a hard fired reinforcement to create composite materials with better properties than ordinary metallic amalgams (Barnes.S et al.) [9].

Silicon carbide, titanium carbide, zirconium boride and alumina are the most commonly used reinforcements. Aluminium, Titanium moreover magnesium combinations these can be generally utilized at the same time as the matrix stage. The density for the majority MMCs can be roughly 33% that of steel, bringing about elevated specific strength and firmness. Because of these conceivably alluring properties combined with the capacity to work at high temperatures, MMCs rival super compounds, pottery, plastics and re-outlined steel parts in a few aviation and car applications (Gallab.E.I et al.) [30].

1.15.1 Matrix phase

Matrix is a solid which can be prepared in order to implant and adherently grasp the reinforcement; matrix should not react chemically or metallurgically with the reinforcement.

Part of the matrix material involves the accompanying:

- Disperse the stress to the reinforcement material
- Give the last state of the composite part
- Ties the reinforcements (strands/particulates) together
- Instinctively partisan the reinforcements

- Load convey for the reinforcements
- Shield the reinforcements from surface harm because of scraped spot
- Maximum bonding strength connecting strand and matrix is vital

1.15.2 Reinforcement phase

Reinforcement have high strength, hardened essential segment which is joined into the matrix to accomplish sought after properties. The expression "reinforcement" suggests some property upgrade. Reinforcement may be particle, whisker and fiber.

1.16 Aluminium matrix composites (AMCs)

Aluminium composites encompass a high machinability record and includes massively utilized as a part of aviation and car businesses because of their better properties, for example, higher quality than weight proportion, incredible low-temperature execution, outstanding erosion resistance, substance idleness to usually utilized cutting tools, and so forth. Notwithstanding, the fundamental shortcomings of aluminium combinations are their poor high-temperature execution and wear resistance. To beat these issues, aluminium alloys fortified by earthenware particles, known as metal matrix composites (MMCs), have been produced (Pramanik.A et al.) [75].

A composite material offer designers and engineers the preferred standpoint of fitting structures and materials to meet an assortment of property and execution prerequisites in the changing and requesting situations. This adaptability in configuration joined with unrivalled property-to-weight proportion makes the composite materials an appealing contender for the utilization in various superior and vitality powerful applications in a few businesses going from aviation and military to automotive, recreation and other commercial products. By and by, on the whole composites comprise of a mass material (the matrix) in addition to reinforcement or various likeness thereof, added fundamentally to expand the quality and solidness of the matrix (Teti.R) [101].

In the metal matrix composites (MMCs) aluminium is generally prevalent in like manner. The Al compounds are very appealing because of their low thickness, their capacity to be strengthened by precipitation, their extraordinary erosion protection, high warm in addition to electrical conductivity, and in addition their hoisted damping limit. The transcendent blend of properties was offered by aluminium matrix composites (shape of properties) in such a way, to the point that today no current monolithic material can match.

Throughout the years, AMCs are used as a piece of different assistant, non-essential and utilitarian applications in different engineering sectors. Lower fuel utilization, less clamour as well as lower airborne discharges are the key advantages of AMCs in transportation division. By way of extending stringent biological controls in addition to emphasis on improved mileage, usage of AMCs in transport part will be unavoidable and appealing in the forthcoming years.

For monolithic materials AMCs are anticipated as option and for a few applications the aluminium composites, ferrous amalgams, titanium combination are utilized. It is currently perceived that all together AMCs here replacement for solid materials in building framework to be across the board, there is a convincing need to update the entire framework to put on extra weight and volume reserve funds. Furthermore, with using close net profile framing in addition to particular fortification systems AMCs can offer financially achievable answers for wide assortment of modern applications. Late achievements in business and military uses of AMCs are constructing halfway in light of such inventive changes made in the segment outline.

1.17 Manufacturing of Al composites

Metal matrix composites are stir casted by creating a liquefy of the chose matrix material along with bringing the required reinforcement particles into the liquid matrix, acquiring an appropriate scattering reinforcement method. AMCs can offer financially achievable answers for wide choice of modern applications. Through stirring the imaginative changes made in the segment for late accomplishments of business and military applications of AMCs.

The solidification of the melt is the next step containing dispersed particles in chosen situations to locate the coveted circulation of the scattered stage in the cast matrix. Here, making wettability of aluminium alloy and with the reinforcement particle is the crucial thing. The least complex and most economically utilized strategy is identified since vortex technique otherwise stir-casting technique.

The vortex strategy is one of the better known methodologies used to make and keep up a decent conveyance of the support material in the matrix amalgam. Through this approach, the liquid slurry has been blended overwhelmingly after the melting of the metal matrix material to shape the vortex of the surface of the dissolve, behind that of reinforcement material has been presented along the region of the vortex.

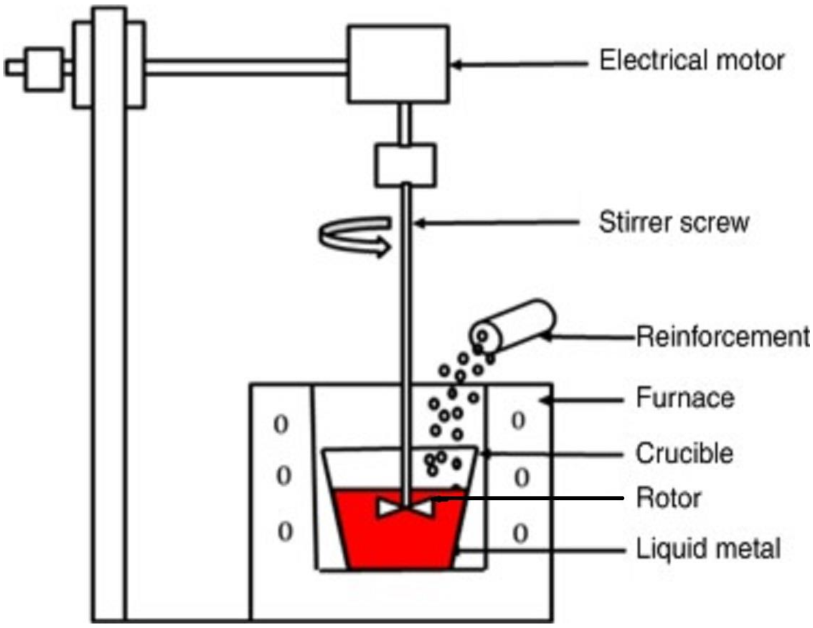


Figure 1.10 Stir casting

Before the casting the stirring is continued for few minutes the improvement of the vortex amid blending is seen to be useful for moving the particles hooked on the matrix soften as the weight distinction between the internal and the external surface of the dissolve sucks the particles hooked on the fluid (Hashim.J et al.) [37]. the vortex procedure includes the presentation of pre-warmed fired particles keen on the vortex of liquid composite made by the pivoting impeller.

Commonly with molten aluminium alloys up to 30% of reinforcement particles is possible to incorporate in the dimension choice of equal to 100 µm. Reinforcement. In the semi-solid matrix alloy at 600ºC the peroxidised particles were added at 900ºC. An argon atmosphere had been kept up finished the dissolve to lessen oxidation. The blend was quickly warmed to 750ºC and the composite slurry was filled a preheated hangeless iron kick the bucket (150ºC) (Hashim.J et al.) [38]. Figure 1.10 is the evidence for the schematic diagram for stir casting.

1.18 Properties of MMCs

The metal matrix composites can accomplish the alluring physical and mechanical properties like hoisted specific modulus, high strength and warm security, contains obvious comprehensively. The distinctive factors domineering the properties of particulate MMCs as well as in addition the effect of the gathering course booked the MMC properties have also been evaluated by a couple of analysts. Change in modulus, quality, exhaustion, crawl in addition to wear resistance relies on the volume portion of reinforcements. In these properties; the versatility is the most supportive and for the most part referred to estimation and is of central essentialness in various applications (Naresh Prasad) [66]. The addition of

Reinforcement hooked on the metal matrix expands the yield strength of the composite. Compressive and rigidities, and the hardness at room and lifted temperatures, are additionally expanded fundamentally, bringing about a change in the composite material's wear resistance. By means of the expansion of the SiC reinforcement the Young's modulus of versatility and the warm extension coefficient are likewise moved forward (Marko.T. et al.) [58]. The Al/ SiC composites exhibit higher 0.2% proof anxiety, rigidity and Young's modulus and lower prolongation and lessening of territory than the throwing aluminium amalgam (Zhenzhong.C. et al.) [109].

1.19 Applications of Aluminium composites

The building materials have enormous walks in view of the fact that 1950s. A few super composites and warmth resistance materials have been produced for different modern applications, particularly aviation/air ship and protection. Car, restorative and game gear businesses pushed progresses in materials further to present new era materials especially having low thickness and light weight with high quality, hardness and firmness. One of the critical of these propelled materials is composites. Composite materials are essential designing materials because of their extraordinary mechanical properties. As cutting edge building materials, metal matrix composites are utilized as a part of numerous applications with the purpose of necessitate high wear resistance, for example, chamber liners, helicopter sharp edges, ventral blades and lower drag prop landing gears in present day military aircraft. Contrasted with the solid compounds, the wear resistance of MMCs is significantly upgraded by the presentation of an optional stage as grating earthenware production hooked on the flexible aluminium matrix.

The aluminium-based MMCs are reinforced Silicon carbide particle reinforced in the middle of the mainly regular MMC and industrially existing ones because of their practical generation (Tamer.O. et al.) [99]. In 1920s aluminium metal matrix composites are broadly examined and are currently used as a piece of waving items, electronic packaging, armours plus auto ventures. They suggest a far reaching collection of mechanical properties depending upon the invention making of the Al - matrix Aluminium composites were broadly utilized in the aeronautic trade. Hyper eutectic Al-Si type of composites, designed for instance, A356 (A1, 7Si, 0.3Mg) to contain $A1_20_3$, ZrO, particles otherwise SiC particles are utilized as a part of the manufacture of car motor segments. The working properties plus Wear resistance of aluminium cast diesel cylinders are improved by the usage of aluminium type of composite piston ring embeds. Aluminium as parent metal composites have moreover been well thought-out as surrogate materials in favour of brings into play in the production of brake rotors, chambers, chamber liners in addition to barrel heads (Deuis. R.L et al.) [19]. A356Al–SiC composites are better wear resistance than the base alloy (Bauri.R et al.) [10].

1.20 Design of experiments (DOE)

An organized, sorted out technique for deciding the connection between various variables is called Design of Experiment (DOE) that affect the procedure and the yield of that procedure, with least number of tests. This technique was first created in the 1920s and 1930, by Sir Ronald A. Fisher, the prestigious mathematician and geneticist.

A systematic planning is design of experiments method furthermore, leading investigations wherein numerous information factors are deliberately changed to examine changes in the yields of a procedure ever, both science and building educational module have underscored one-factor at any given moment tests while the others are held fixed on which one variable (factor) has been altered (Colegrove. P. A et al.) [16].This moves towards is inefficient in addition to the outcomes can be deceiving. However, to find out about and streamline a procedure measurably outlined tests manage the cost of a more viable and productive way. By consolidating the settings of a few factors at the same time in configuration exhibits, it is conceivable to segregate the impacts of each factor exclusively. An outlined analysis generally requires fewer assets for the measure of data got, and the outcomes are more exact since more estimation are utilized to decide the impact of a given factor. Besides, the cooperation's between the components, i.e., the impact of one factor on another can be evaluated.

1.21 Response surface methodology (RSM)

In the direction of plan and look at the investigations the response surface technique has been utilized. It can be a gathering of scientific and measurable strategies were helpful for the demonstrating in addition to investigation of issues in which a response of premium is affected by a few factors as well as the goal is to improve the response. This shall be a successive testing procedure in favour of exact model developing in addition to streamlining. Through leading examinations as well as pertaining regression investigation, a form of the response towards a quantity of free information factors can be acquired. By the view of the model of the reaction, a close ideal point would then be able to be found. RSM is regularly connected in the portrayal and enhancement of procedures (Kansal.H.K et al.) [46].

The goal of utilizing RSM can't be exclusively in the direction of research the response in excess of the whole aspect space, yet additionally on the way to find the district of intrigue everywhere the response achieves its optimum otherwise close optimal esteem. The blend of elements, which gives as well as can be expected, at that point be built up by concentrate deliberately about the response surface method. (Kanagarajan.D et al.) [45].

1.22 Central composite design (CCD)

The most widely used statistical experiment designs in enhancement tests are named response surface designs. Notwithstanding trials by the side of the outrageous level fixing for the factors, response surface plans enclose trials during which at least any of the factors cab be place the investigation go at the midpoint (different levels in the inside of the range may likewise be spoken to).

Coordinate impacts, match savvy collaboration impacts and curvilinear variable impacts information's are provided by these designs. One way to deal with item and process optimization work, gets its name from the utilization of these generally utilized optimization analyze outlines is Response surface methodology. A measurable programming program running on a computer most specialists of RSM now produce their trial plans and dissect their data's.

Sometimes, offer a few assortments of each class even a significant number of these product projects can create many classes of RSM designs. On the other hand, the central composite design has been the most prevalent for many projects of RSM designs because of the accompanying three properties

- A CCD is able to run consecutively. CCD is normally parcelled into two subsets of focuses; straight as well as two-factor connection impacts assessed by the main subset curvature impacts are evaluated by the second subset. At the point when investigation of the information from the principal subset focuses the second subset require not be run and demonstrates the absence of significant curvature effects.
- Central composite designs efforts adequately to give more data about experiment variable impacts and furthermore general test mistake in a less number of runs.
- CCDs are incredibly flexible.

1.23 Multi Objective Optimization utilizing Genetic Algorithm

In single target streamlining, one endeavours to acquire hold of the finest design, which has been regularly the base or most extreme relying upon the optimization issue. If there should arise an occurrence of various goals, there could not stay alive one arrangement, which has been the best concerning all destinations.

Different traditional techniques for getting the answers for multi objective issues are accessible. A few cases are Minimum- Maximum, Weighted amount as well as separate competence methods. These procedures transform the multi target issue hooked on a single objective, through the looking at weights in light of their comparative centrality. This type of techniques experiences the ill effects of a downside that the chief must have an exhaustive learning of positioning of target capacities. Likewise, these strategies fall flat when the target capacities end up plainly irregular (Kuriakose.S et al.) [51]. Genetic Algorithm (GA) as a sort of multi point look conceivably has preference for advancement issues with numerous goals. In any case, GA has been mostly connected to enhancement issues with a solitary goal. The extensions of GAs to multi target improvement are projected for a few behaviours. (Goldberg.D.E) [31]. Genetic algorithm (GA) contains points of interest that it doesn't require any slope data and innate parallelism in looking through the outline space, therefore making it a strong versatile optimization strategy (Rao.S.S) [80].

Some modification for simple GA is required for the method of multi objective optimization. The Non-Dominated Sorting Genetic Algorithm (NSGA) is a type of GA based multi objective arrangement strategy. As a rule, a streamlining issue to be tended to has a few targets to be optimized. The many-sided quality of the issue increments as the quantity of destinations to be optimized in light of the fact that the targets considered are frequently opposing to each other. Such intricate optimization issues have a considerable measure of plausible arrangements. Be that as it may, just a couple of solutions among them are attractive (Tadaliko Murata) [98]. That is, an arrangement of applicant arrangements called non conquered way outs can be gotten for the issue. In view of the fact that numerous solutions are to be gotten as applicant solutions of the issue, two goal genetic algorithm optimization strategy utilized as a part of this examination be a superior, NSGA-II created. (Kalyanmoy Deb) [44].

CHAPTER – 2

LITERATURE SURVEY

2.1 Introduction

The joining techniques for along with technologists friction stir welding (FSW) can be a solid state joining technique which delivered with least price moreover healthy joints of aluminium combinations. In the point of completing inspection job in whichever zone, the first as well as a vital stage are to audit the accessible writing used for the chose point and the exploration issue can be detailed by way of apparent targets. Keeping in mind the end goal to plan the present research issue alongside the procedure that could be embraced for finishing this examination work, the specific audit of the important writing reviewed is exhibited quickly, in following classifications:

2.2 Al metal matrix composites

The research on composites has attempted the usage of aluminium and its alloys reinforced with ceramics for manufacture of Al MMCs. They have normally more applications in wide specialization hence suitable low cost processing method will have to be found. This chapter explains the literatures of the earlier works on pertinent points, for example, a short prologue to material choice, creation strategies for MMCs, mechanical properties of aluminium-based composites, warm examination, acoustic discharge, tribological conduct of aluminium-based composite as well as prediction utilizing response surface methodology. This research study pertains to an outline of the studies taking place the manufacturing types in addition to the properties of MMCs like mechanical, tribological as well as thermal. The adaptability of aluminium makes it as the world's third most normal copiously utilized metal after steel and it comprises 8% of the earth’s crust.

Aluminium is gotten as of the mineral bauxite furthermore is changed over into aluminium oxide (alumina) all the way through the Bayer process. The alumina has been changed over into aluminium metal using electrolytic cells alongside the Hall-Heroult process. Unadulterated aluminium is flexible, pliable, disintegration safe as well as elevated electrical conductivity. It is for the most part used for assembling foil in addition conductor cables. The former applications like proving higher strength, alloying with other elements is necessary. In the engineering field the lightest material is aluminium with the quality in strength to weight ratio superior compared to steel.

Taya. M et al. [100] explained in detail about the materials must contain a mix of predominant properties for example, expanded quality, higher flexible modulus, higher administration temperature, enhanced wear resistance, high electrical and warm conductivity, low coefficient of warm development and high vacuum natural resistance. These properties can be accomplished with the best possible decision of network and appropriate reinforcement by setting up a composite. Composite materials comprise of lattice and fortification. The fundamental capacity of the network is to exchange and convey the heap to the reinforcement or filaments. This exchange of load relies upon the holding between the framework and support, which relies upon the sort of lattice and reinforcement in addition to the manufacture system. The matrix is chosen on the premise of oxidation moreover erosion resistance otherwise different properties.

Albiter. A et al. [4] studied about the matrix material like Al, Ti, Mg, Ni, Cu, Pb and Si, however Al, Ti, Mg are utilized extensively, among which aluminium appears to be the most widely used in different sectors. To design the desired properties, for example, quality, firmness, hardness, wear resistance, warm development etc., a suitable alloy of aluminium can be paired with appropriate reinforcement. real preferences of aluminium metal matrix composites contrasted with unreinforced materials are more prominent quality, enhanced solidness, decreased thickness, enhanced high temperature properties, controlled warm extension coefficient, warm/warm administration, upgraded and custom-made electrical execution, enhanced scraped area and wear resistance, control of mass and enhanced damping abilities.

Yalcin. Y. et al. [106] discussed about the in cooperation of wear rate plus friction coefficient of the A356 composite reductions with expanding SiC molecule content (5-20 vol.%). Be that as it may, examples fortified among 15 plus 20 vol.% SiC when attempted at 5 N associated stack exhibited a development in the contact coefficient. It is assumed that this extension was caused through poor interfacial holding linking the network in addition to SiC elements. Poor holding, related by way of atom separation can develop the particle trade as of the cross section to the WC ball and plate crossing point making vibration.

Bindumadhavan. P. N et al. [12] observed that in A356/SiC composite with Dual Particle Size (DPS) composite (47 and 120 m) showed best wear protection over the composite having quite recently little (47 m) estimated particles. In these DPS composites, greater SiC particles help to pass on a more vital piece of the associated stack, in this manner diminishing the heap on the littler SiC particles and on the base metal. The greater SiC particles moreover help to shield the more diminutive SiC particles from the gouging activity of the rough, in this way helping the littler particles to keep playing out their wear opposing capacity.

Sakthivel. A et al. [85] watched uniform dispersal of particles with little agglomeration of particles close by some porosity in the microstructure of 2618 Al-SiC composites made by Stir casting method. He found that hardness and flexibility of the composites extended with reducing size and growing weight bit of the help particles.

Akhlaghi. F et al. [3] watched that the in Semisolid– Liquid (SL) planning uniform course of SiC particulates and lower porosity content in the midst of the microstructure ponders coordinated on A356/SiC composites conversely with Semisolid-Semisolid (SS) handled specimens, paying little respect to the form pre-warm temperature or the size and measure of the SiC particles.

Sahin. Y et al. [83] observed that the hardness of the MMCs and the framework combination expanded straightly and their densities diminished directly with volume percent boron fiber (0-32 vol.%). The normal wear rate of a 32 vol.% fiber composite in ordinary introduction was decreased by around 84% in examination with matrix alloy. The coefficient of friction steadily expanded through fiber content reaching maximum and decreased for all composite materials.

Kumar. P.R.S et al. [50] noticed that the reinforcement of fly ash elements forces the change temperature Al6061/fly ash Aluminium Matrix Composite (AMC) due to the arrangement of defensive exchange layers of reinforcement particulates and exchanged steel flotsam and jetsam from sliding counter face. Hence, it is essential to evaluate the sliding wear behaviour of Al6061/fly ash AMC at high temperature. It is evident that is one of the most grounded aluminium composites for mechanical use because of its high quality to weight proportion and regular maturing attributes.

Singh. M et al. [94] discussed about the properties of cast aluminium compound sillimanite molecule composite primed by stir casting method. The microstructure of the composites demonstrated sensibly homogeneous dissemination of reinforcement particles and great mechanical holding among the network amalgam. The hardness and wear resistance were seen to be inside and out higher than those of the base compound. The composite was examined that aluminium-sillimanite can be utilized by a wear safe material in the replacement of aluminium alloy.

. Singh. M et al. [94] studied the two body rough wear execution of the cast aluminium compound fortified with 10 wt.% sillimanite. They studied the wear performance of stir cast AMCs having coarse and fine size sillimanite particles at various loads and for different sliding distances. Wear rate of the composites and the grid combination enhanced with the expansion in connected load and rough size. The greater fracturing propensity and inconsistency of earthenware fortifications because of shared impact of higher load as well as coarser abrasives led to the structure of wider and deeper wear grooves. Wear protection of the composite was superior to that of grid compound for better size abrasives, where the pattern toppled for coarser size abrasives.

Eric David Praveen et al. [29] This present examination centers around the impact of Silicon carbide (SiC) particulates on the wear conduct aluminium combination metal framework composites utilizing a factual procedure called Response Surface Methodology (RSM). LM13 aluminium amalgam is fortified with SiC particulates utilizing mix throwing (compocasting) method. The weight division of particles in the Aluminium Metal Matrix Composite (AMMCs) was differed from 0 to 12 wt. % in ventures of 3wt. %. The wear tests were led utilizing four variables and five levels focal central composite design (CCD). Dry sliding wear tests were led by stick on plate mechanical assembly to examine the impact of sliding rate, sliding separation, ordinary load and fortification wt% on the wear rate of composite examples. The outcomes were broke down utilizing examination of difference (ANOVA) for distinguishing the critical elements influencing the execution at 95% certainty interim.

The observational quadratic model connections were built up utilizing RSM to anticipate the impact of wear parameters on the execution parameter (wear rate) with sensibly great exactness. RSM was utilized to improve the wear parameters for a base wear rate. Results demonstrated that ordinary load is the most impacting factor which builds the wear rate and sliding rate is a slightest factor which influences the wear rate. The factual examination is completed utilizing Design Expert 10 programming.

2.3 Al/SiC metal matrix composites

A composite have the arrangement of materials made out of a blend of at least two miniaturized scale constituents in various shape, substance organization and which are essentially insoluble in each other. The motivation to design MMCs is to solidify the metals and ceramic creation i.e. extension of high modulus, great stubborn particles to malleable metal cross section to get tailor made properties. In this paper an effort has been made to consider wear properties with fluctuating weight division of SiC in particle strengthened MMCs made with the help of two stage blending strategy for stir casting system.

Manoj Singla et al. [56] explained about the preparation Al/SiC composites with various weight rates like 5%, 10%, 20% moreover 25% of SiC have been produced by liquid metallurgy procedure. Wear and disintegration characteristics of Al/SiC composites have been dismembered under dry sliding conditions in addition to contrasted and unadulterated aluminium. A sliding wear test have been completed on stick on-circle wear test, with typical heaps of 5, 7, 9 as well as 11 Kgf and with sliding pace of 1.0m/s. the Samples weight lessening was estimated and the assortment of total wear setback with sliding partition has been seen to be straight for both unadulterated aluminium and the composites. It was in like manner watched that the wear rate straightly vacillates with run of the mill stack yet carry down in composites when stood out from that in base material. The arrangement of wear has every one of the reserves of being oxidative for both unadulterated composites and aluminium under the given conditions of load and sliding pace as appeared with scanning electron microscope (SEM) of the messy surfaces.

Habiburrahman. Md et al. [36] The Motivation behind this work is to consider the microstructures, mechanical properties in addition to wear characteristics of as cast silicon carbide (SiC) reinforced aluminium metal matrix composites (AMCs).

AMCs of varying SiC content (0, 5, 10 and 20 wt. %) was manufactured by stir casting. Microstructures, Vickers hardness, versatility along with wear execution of the prepared composites were poor down. The results exhibited that introducing SiC fortresses in aluminium (Al) network extended hardness and inflexibility plus 20 wt. % SiC reinforced AMC showed most noteworthy hardness furthermore inflexibility. Micro structural recognition revealed bundling and non-homogeneous transport of SiC particles in the Al structure. Porosities were seen in microstructures and extended with growing wt. % of SiC strongholds in AMCs. Pin on disc wear test exhibited that bracing Al coordinate with SiC particles extended wear protection.

Suryanarayanan. K et al. [97] discussed about the capability of utilization Al-SiC metal framework composite (MMC) by methods for specific circumstance to the aeronautic trade. At to start with, the required properties are perceived, after which, the work investigates unadulterated aluminium and its criticalness in the business alongside its edges. Utilizing these edges, MMC's were proposed as a potential trade for aluminium and it is seen that the exact arrangement of properties rely upon specific components. Hence these components, for example, reactivity at the interface, volume segment of the strengthening material, kind of the fortifying material and appropriation of the strengthening material are clarified utilizing the current writing. Utilizing the data accessible, the paper clarifies the utilization of Al-SiC MMC in the fuselage skins of superior flying machines. On the other hand it must be noticed that the proposals are exclusively in light of the information accessible and the creator's elucidation of it albeit each endeavour has been made to be as sensible as could be expected under the circumstances.

Lal Krishna. S.K et al. [52] in this study, the design of actuator cylinder by means of 15-5 PH (H-1025) stainless steel is measured. The dilation, weight, time and cost of production of current design are high. The final component while incorporated into the target adds weight as a whole due to its density. The paper absorbed on replacing the existing material with a SiC particle reinforced aluminium metal matrix composite to decrease weight, dilation and fabrication cost of the actuator. To achieve these goals two stage blending strategy for mix throwing method has been received and following property examination has been made. Aluminium alloy 6061 and silicon carbide (500 grit size) was chosen as matrix along with reinforcement material correspondingly. Warmth treatment moreover improves the material properties.

Neelima Devi. C et al. [68] Explained about the regular materials like Steel, Brass, Aluminium and so on won't prevail with no notice. Breaks start and proliferation will happens through in a short length. In recently to defeat this issue, customary materials are supplanted by Aluminium compound materials. Aluminium composite materials make to the best option with its select limit of outlining the materials to give obligatory properties. In this paper elasticity tests have been led by various mass part of SiC (5%, 10%, 15%, and 20%) with Aluminium. The most extreme elasticity has been gotten at 15% SiC proportion. Mechanical and Corrosion execution of Aluminium Silicon Carbide composites are too calculated.

Gurpreet Singh et al. [35] in this paper a parametric investigation of the wear conduct of Aluminium network composites have been completed. AA6082-T6/SiC and AA6082-T6/B4C composites were manufactured utilizing blend throwing system. The level of support was taken as 5, 10, 15 and 20 wt.% for both SiC and B4C particulates. Dry sliding wear tests were led utilizing pin-on-plate contraption at room temperature and process improvement was finished utilizing Response surface philosophy (RSM). Weight rate (wt.%) of fortification, sliding rate, stack and sliding separation were the four procedure parameters considered to investigate these composites wear conduct. Investigation of fluctuation (ANOVA) demonstrated that sliding separation applied the most elevated commitment (60.24 %) to AA6082-T6/SiC wear, trailed by sliding rate (14.28 %), stack (11.88 %) and fortification substance (4.31 %). A similar pattern was found in A6082-T6/B4C composites with somewhat extraordinary commitment esteems, in particular sliding separation (63.28 %), and sliding velocity (14.02 %), stack (10.10 %) and support content (4.05 %). RSM examination uncovered that increments in the fortification substance and sliding velocity lessen the wear rate in the two composites. Then again, increments in stack and sliding separation prompted higher AA6082-T6/SiC and AA6082-T6/B4C composites wear. The two prescient models were approved by directing affirmation tests and guaranteed that the created wear prescient models are exact and can be utilized as prescient devices for wear applications.

2.4 Al/TiC metal matrix composites

Aluminium metal matrix composites (AMCs), strengthened by way of ceramic particulates, have Aluminium matrix composites (AMCs), reinforced with ceramic particulates, have major applications into field of aviation, marine, autos, games and entertainment. Al/TiC particulate composite has improved potential for elevated temperature applications.

Sai Chaitanya Kishorea. D et al. [84] studied about Al6061- TiC composite with 4 wt% TiC was formed by the response of halide salt $K2TiF_6$ and C through the liquid aluminium. SEM and EDX tests were directed to know the nearness of the TiC fortification. Vickers little scale hardness test was done and find to the hardness of Al6061 was improved by the development of TiC. Machinability study was conducted on the in-situ Al6061/TiC MMC to ponder the after effect of cutting rate, feed along with intensity of cut on cutting power and surface unpleasantness by methods for Taguchi L-27 orthogonal array. ANOVA is performed on the gotten results to inspect the part of cutting rate, feed and intensity of cut on cutting force in addition to surface roughness.

Nassimsamer et al. [67] this paper deals about the metal matrix composite acquired through the novel amalgamation route. The coming about composite has been manufactured by an aluminium matrix reinforced by nanometre measured TiC. The normal Al/TiC proportion is 34.6 wt.%. The microstructure contains a personal blend of two areas, an unreinforced territory made of the Al strong arrangement with a low TiC reinforcement substance, and a strengthened region. This composite shows ununiform mechanical properties as to prior micrometer estimated Al– TiC composites and to its most extreme support volume division. The Young's modulus of ∼110 GPa, an extreme rigidity of around 500 MPa and a most extreme lengthening of 6% were found.

Gunderi Siddeshwara Pradeep et al. [34] this paper deals about the fabrication of Al6061–TiC composites by in situ method. The reaction happens with molten Al6061 alloy, potassium hexafluorotitanate salt and pure graphite at a temperature of 900 °C. The in situ composites are compelled to hot delivering at 500 °C in addition uniform strain rate of 0.0115 mm s^{-1} among level of mishapening of 65%. The cast as well as fashioned in situ composites were subjected to grain estimate examine and scanning electron microscopy analysis to think about the appropriation of TiC particles. Mechanical properties like Brinell hardness and pliable properties were inspected to figure the reason for TiC particles on the Al6061 matrix. Microstructure of forged composites exposed uniform dispersion of TiC particles with no forming any lumps at any meticulous regions. Brinell hardness and rigidity of cast and manufactured in situ composites developed with increasing TiC particle. The enhanced mechanical properties were accredited to great scattering of TiC particles, grain enhancement of the matrix and displacement strengthening.

Rai. R N et al. [76] studied the amalgamation and portrayal of in-situ Al-TiC composites reinforced with ceramics was completed. The configuration of offensive TiAl3 particles possibly will be maintained a strategic distance from logical the right functional prerequisite embraced as getting ready Al-TiC composites. It was watched that circulations of fortified particles were homogeneous along the grain limitations. From the observation the normal size of TiC particles was of 0.5 μm. It was additionally noticed that the event of TiC particles in the composite upgrades the yield quality and hardness significantly.

Gopalakrishnan. S et al. [32] discussed enhanced particular quality, high temperature and wear resistance of metal matrix composites (MMC). Aluminium matrix strengthened by way of titanium carbide (Al/TiC) has unrivalled potential. The primary stands up to will be to create this composite in a cost solid way to meet the above needs. In this examination Al/TiC castings with different volume part of TiC were shaped in an argon air by an enhanced mix throwing strategy. Particular quality of the composite has enhanced with higher % of TiC expansion. Dry sliding wear implementation for AMC was destitute down with the help of a pin on disc wear and grinding screen. The present examinations reveal the enhanced particular quality and in addition wear resistance.

Ananda Murthy. H. C et al. [6] Studied the corrosion performance of Al 6061/TiC particulate composites manufactured by stir casting route. The composite explored in chloride medium by means of electro analytical techniques for example Tafel, Cyclic polarization and Impedance measurements. The microstructures were studied by SEM for both Al6061 and reinforced composites be done to know the effect of TiC on the composites for corrosion resistance. The polarization studies make known an expansion in the erosion resistance in composites contrasted by means of the matrix alloy. The corrosion resistance was increased with the addition of TiC.

Naga Prasad Naidu. V et al. [64] This examination is proposed to explore the Machining reaction of Al-TiC_P metal network composites. Aluminium combination is considered as a grid metal composite. The fortifying stage considered is TiC_P Metal grid composites will be manufactured utilizing mix throwing systems. The quantity of process parameters considered in this examination is axle speed, Feed rate, Depth of cut grain size of TiC_P and cutting device material. Analyses will be arranged and directed by DOE (Design of Experiments).The machining reactions considered are surface unpleasantness, cutting power, cutting force and instrument wear. Keeping in mind the end goal to foresee the yield reactions inside the scope of process parameters demonstrating will be finished utilizing reaction surface strategy and man-made reasoning frameworks viz. Fluffy rationale/Neural Networks; Gray social investigation is utilized for advancement of various reaction attributes. At last examination of difference and affirmation test will be done in following stage to approve the created models

2.5 Al/hybrid metal matrix composites

The majority noteworthy kind of hard materials is composite materials with networks of aluminium compounds inferable from an arrangement of their helpful properties. Change of mechanical, specifically tribological properties of cross breed composites were given by the utilization of sure fortify materials, for example, SiC, Al_2O_3, TiC and graphite in clear weight. Present created hybrid composites by means of aluminium matrix have quite higher imperviousness to wear, better particular firmness and raised resistance than tiredness. By the raise of amounts of fashioned components made of half breed composites, diminish of their costs is prompted that even additional extend their applications.

Chaudhury. S.K et al. [14] prepared Al-2Mg-11TiO2 composites all the way through shower framing as well as stir casting technique and compared the frictional and wear conduct of the composites. They watched the lessening wear rate when contrasted with the base combination when tried under the similar conditions. Higher micro hardness at the interface when contrasted with the matrix reflects great interfacial holding. They also found that, addition of TiO_2 particles in the alloy change the wear instrument from absolutely cement to blended method of oxidative and rough wear. The size of the wear flotsam and jetsam expanded with the expansion in stack due to the increased size of the width of grooves. Haul out of TiO_2 particles in the midst of wear caused scratched zone on the cross section surface bringing about serious distortion of particles and platelets. The transform since minimum to rigorous wear was delayed in the composite when contrasted with the combination by way of the increase of load.

Sasimurugan. T et al. [87] studied about the aluminium metal matrix composites are revelation the expanded applications in numerous territories. By the addition of the third segment to the metal matrix create the composite as hybrid. This paper clarifies the examination at first glance harshness attributes of a half and half aluminium metal matrix (Al6061-SiC- Al_2O_3) composite. The exploratory methodologies were completed on a lathe. The composites were set up by the fluid metallurgy method, wherein 3, 6 and 9 wt % of particulates SiC and Al_2O_3 were spread in the base grid. The acquired cast composites were watchfully machined. The attributes that control the surface unpleasantness moreover the surface harshness is increments by method for the expansion of feed rate and it diminishes the surface unpleasantness among the increment of cutting rate.

Niranjan. K et al. [70] investigated the hybrid metal matrix composite (HMMCs) materials were fabricated through stir casting procedure. Growth of Al6061alloy based Hybrid metal matrix composite reinforced by way of 6wt% of SiC in addition to changing steps of graphite by 3wt%, 6wt%, and 9wt%. Investigational study was done to investigate the properties of mechanical similar to hardness, tensile strength, compression strength. As an outcome of hardness reduces with the raise of the part of Gr, tensile strength and compression strength raises with the raise in Gr particulates with the control of SiC particulates.

Suresh. Ps et al. [95] this paper bargains the metal matrix composites fortified by method for graphite particles give enhanced machinability and tribological properties. The present examination try to find the best level of machining parameters for multi execution qualities in turning of Al/SiC/Gr half and half composites using Gray fluffy figuring. The cream composites by strategies for 5%, 7.5% and 10% shared proportionate mass division of SiC/Gr particles were used for the change and their relating flexibility regards are 170, 210, 204 MPa independently. Al−10%(SiC/Gr) blend composite gives enhanced machinability while stood out and composites from 5% and 7.5% of SiC−Gr. Dim fluffy rationale advance toward offers enhanced Gray fluffy reasoning evaluation and has less questions in the yield while differentiated and diminish social system.

Ankush Sachdeva. Et al. [7] This paper clarifies about how the authorities are setting up the material by the mix of different materials called half and half composite material. MMCs have ascended as a get-together of materials fitting for helper, flying, auto, electronic, and warm and wear applications remarkable to their purposes of enthusiasm over the customary materials. The present examination was taken up to research the options of using different fortifications to upgrade the properties of aluminium mix (Al5052) composites. Tests were set up from the aluminium with moving help piece. The mechanical properties considered after the examinations were quality, hardness and extending. The composites were portrayed with the help of, mechanical testing and SEM.

Balakumar. S et al. [8] this paper has been centered on the utilization of fly ash, graphite and copper significantly by strengthening it into aluminium amalgam Al6061 to create a composite by stir casting procedure. By utilizing Taguchi's symmetrical cluster an endeavour has been made to ponder for advancing the rate piece of aluminium composite Al6061 fortified with fly slag, graphite and copper. The mechanical property contemplated is wear opposition and grinding qualities. Taguchi's L4 (23) symmetrical cluster is utilized to design the experimentation and four pieces of aluminium lattice composites were delivered and the examples arranged for testing. The trial results demonstrated noteworthy changes in every structure and wear opposition was moved forward.

Pradeep Devaneyan. S et al. [73] this paper shows the mechanical conduct of aluminium 7075 strengthened with Silicon Carbide (SiC) and Titanium Carbide (TiC) through powder metallurgy course. These examples were delivered by powder metallurgy technique. The cross breed composite was made by Al 7075 amalgam as the network with Silicon Carbide and Titanium Carbide as support. Silicon Carbide and Titanium Carbide are blended in various weight proportions in light of the plan framework defined through a measurable apparatus, in particular, Response Surface Methodology (RSM). Improved mechanical properties have been gotten with 90% of Al 7075, 4% of TiC, and 8% of SiC arrangement in the composite. Coefficient of grinding seems, by all accounts, to be more which has been controlled by ring pressure test.

2.6 Aging of Materials.

The regular aging at room temperature in super saturated solid solution is called natural aging. This procedure is significant for strengthening of amalgams containing aluminium, copper, magnesium and nickel. Regular maturing is dissimilitude with counterfeit maturing, which is done at high temperatures. Common maturing is likewise perceived as low temperature maturing, while simulated maturing is additionally recognized as high-temperature maturing. Normal maturing is a move in the warmth treatment of aluminium compounds in which the metal is isolated from the slake shower and embraced to pick up its full quality at room warm. In manufactured maturing, the metal is kept at a high temperature for it to build its full quality in a shorter timeframe. In a number of aluminium combinations, the precipitation solidifying that outcomes from normal maturing alone creates valuable tempers (T3 and T4 sorts) that are described by high proportions of malleable to-yield quality, high break sturdiness and imperviousness to weariness.

Parvina. N, et al. [72] studied about Al6061/10 wt% SiC composite was set up by the mechanical alloying course. The morphology and in addition the structure of the prepared powder, which change among handling time, was surveyed by means of Scanning electron microscopy (SEM) alongside X-ray diffraction (XRD) strategies, independently. Additionally, the associations among the periods of mechanical alloying (MA), relative thickness and hardness of both crushed and hot ousted materials were investigated. The morphological improvements exhibited that decently equiaxed powders could be mixed after 9 h of preparing. The headway of relative thickness and hardness with preparing time is relied upon to the morphological and littler scale assistant changes constrained on the composite powder. High-relative densities are ordinary of the hot ousted tests. The effect of mechanical alloying process on hardness is more noteworthy contrasted with support particles. The maturing practices of the mechanically alloyed, financially blended in addition to unreinforced Al6061 were taken a gander at. The results showed that MA composites show no developing hardenability.

Martín, et al. [59] investigated Al2618 reinforced with 15% of SiC composite manufactured by stir casting method. The wear resistance level was calculated in the transition temperature range of 20^{o}C to 200^{o}C. In the smooth wear region the wear protection duplicated by way of the development of SiC particles and the transition temperature approximately raised 50^{o}C. The wear resistance will not change for composite or Al2618 alloy in heat treatment like natural or artificial aging.

Ehsani. R et al. [25] within this article, the creation moreover properties of Al 6061/SiC composites, made utilizing a crush throwing strategy, were researched. SiC performs were made by blending SiC powder, having a 16 and 22 m molecule estimate, with colloidal silica as a fastener. The aging behaviour, tensile properties along with crack mechanism of the cast material were considered. The outcomes demonstrate that higher hardness, yield quality, rigidity and Young's modulus can be gotten by the expansion of SiC particles to 6061 Al amalgam, though tractable stretching diminishes. A warm confuse between the metal matrix and the reinforcement was produced, which prompts a lower grain size of the grid with more disengagement density. Diminishing the SiC molecule estimate bring regarding enhanced mechanical properties and a quicker aging reaction. The decohesion of the interface between SiC particles and metal matrix prompted the voids arrangement.

John Banhart et al. [43] the common maturing conduct of unadulterated ternary Al-Mg-Si mixes can be explored by means of estimating hardness, electrical resistivity as well as positron lifetime, and also doing warm investigation and molecule test microscopy. It is discovered that few unmistakable fleeting phases of regular maturing can be recognized in which one of these amounts demonstrates a trademark conduct and that these circumstances match for a considerable lot of these estimations. In the deliberate information the rate of progress has been related with arranged solute flow amid normal maturing for both maturing that happens preceding manufactured maturing (regular pre maturing) and position simulated under maturing (common optional maturing) warm medicines. Controlling elements for solute elements are talked about.

Nieh. G, et al. [69] In the modify that shaped the root for this paper, it was set up that progressions of the micro structural characters of 6061 Aluminium can be created by presenting 23% of boron carbide (B_4C). The microstructure transforms consequently formed were begun to control the maturing energy, a standout amongst the most essential properties of warmth treatable aluminium combinations. An equivalent outcome has also been watched recently for a similar compound strengthened with particulate of SiC.

2.7 Wear behaviours of Composites

Abdulhaqq A, et al. [1] prepared a light weight TiO_2 reinforced composite by scattering titanium dioxide (TiO2) particles into the liquid aluminium. impact of both strengthening particles and porosity substance on the wear and contact of in situ cast composites were assessed It was watched that wear rate in addition to coefficient of friction of the in-situ cast composite decreased with the increasing load and the porosity content and also found to increase with the increasing the TiO_2 content.

Hemanth Kumar., et al. [40] used Taguchi strategy for the concurrent streamlining for the tribological parameters in MMCs. Aluminium MMC (Al-Cu-Mg) compound strengthened with 6 % of titanium dioxide was prepared using stir casting methodology. Dry sliding wears what's more, frictional power of the composite material by the way of different loads in addition to sliding speeds revealed the improved wear behaviour of the composite.

Sanjeev Das, et al. [86] utilized blend throwing course to incorporate zircon sand particles of various sizes and amounts in Al- 4.5Cu alloy melt. Scanning electron micrographs had shown that the coarser particles are more round fit as a fiddle contrasted with the finer ones. Because of the high coefficient of warm development of the particles as compared to the matrix, the solidification in the vicinity of larger size of the reinforced zircon particles was delayed which caused more refinement in grain morphology. XRD example of orchestrated composites demonstrated the nearness of Al, CuAl2 and zircon. Wear resistance enhanced altogether with the expansion of zircon sand particles in Al-4.5Cu compound. The scraped spot resistance of the composite expanded with the expanding measure of molecule and diminishing molecule estimate.

Ali Mazahery et al. [5] considered the rough wear conduct of ZrSiO4 fortified aluminium framework composite (AMCs). The consistency in the circulation of the particles inside the matrix was the salient micro-structural feature which influenced the properties of the particulate AMCs. They found that, superior wear resistance was offered by the composite material as when contrasted with the alloy, regardless of the connected load and zircon molecule volume portion. At the critical load, abrupt increment in wear rate was credited to high frictional warming in this way the confined grip in addition, become softer of the plane by means of counter surface. The results steady with decide that by and large, amalgam strengthened with minerals procure more hardness and show better wear furthermore abrasive resistance.

Ranvir Singh Panwar et al. [79] examined the wear conduct of zircon sand strengthened among LM13 compound composites by the side of raised temperatures. The four composites with 5, 10, 15 along with 20 % reinforced with zircon were developed in the way of stir casting method. The pattern of XRD of the composites revealed great holding between the LM13 composite and zircon sand particles, which was attributed to the formation of Al_2SiO_5 phase at interface due to response of zircon sand and LM13 combination through casting. Zircon sand particles enhance the hardness and wear resistance at a particular load and lowered coefficient of thermal expansion.

Composites by way of more than 10 wt. % of reinforcement show better wear resistance on maximum temperature. Sudden change in the wear rate in the wear graphs at different temperatures marked as the transition temperature, because of the softening of the matrix. Transition temperature was seen to increment with increment in the measure of reinforcement. Micro structural examination of wear tracks and flotsam and jetsam uncovered that both cement and rough wear components were dominant in determining the wear of the composites.

2.8 Modelling of Al composite characteristics

Response surface method (RSM) is an arrangement of scientific and measurable strategies for observational model creating. By vigilant DOE, the purpose at the rear existing is in the direction of propel a response (yield variable) which is organized beside a few free factors (input factors). To distinguish the explanations behind changes in the output reaction and for the input factors changes are made a series of tests were conducted called as experiment. The main purpose of design optimization with the utilization of RSM is lessening the cost of costly examination techniques (e.g. FEA analysis or CFD examination) and their associated numerical commotion.

Suresh.P.V.S et al. [96] received a two phase approach towards advancing for surface unpleasantness. Trial comes about were utilized to fabricate two numerical models for surface unpleasantness by a relapse strategy as per RSM. The second-arrange scientific model got was then taken as a target work and improved with a GA to get the machining conditions for a coveted surface wrap up.

Manonmani et al [57] have observed that RSM gives quantitative estimations to conceivable collaborations between factors in order to get troublesome data utilizing other advancement systems. Identification and evaluation of collaborations between different variables assume a basic part particularly for multivariable streamlining in designing issues and use of RSM in the forecast of qualities process.

Senapathi. A, et al. [91] This paper studied the fabrication of aluminium metal matrix Composite (AMC) by stir casting technique reinforced in the company of treated fly ash in addition to untreated fly ash through the amount of 15%. In plasma reactor the fly ash particles are treated. The comparison made between Al/Treated fly ash composite with Al/Untreated fly ash and Al-Si amalgam. In treated fly cinder composite, from the examination carbon was in treated fly fiery debris composite as graphite which enhanced wear resistance In light of response surface approach (RSM) the experiments are designed. The sliding time, sliding separation and load as info factors while weight reduction and coefficient of contact are output factors are studied.

Elatharasan. et al. [27] This paper deals about the tool rotational speed, welding speed along with significant power accept an important part in friction stir welding for choosing the joint attributes. In this paper the study made on central composite design method and mathematical model was created. To build up the connection between the FSW parameters, three parameters three levels and 20 runs was utilized by response surface methodology. The input parameters are rotational speed, navigate speed and pivotal power and the reactions are elasticity, Yield strength and % of Elongation (%E) were recognized.

2.9 Friction stir welding for Aluminium Composites

FSW is a solid state method; we can perform lengthy weld joints without softening of base materials. FSW gives critical metallurgical points of interest as contrasted and combination welding. The blending and driving activities create a fine-grain structure in the weld area, which yields in high - quality welded joints. To expand the weld quality and to limit welding deserts the study about connection between friction stir welding parameters, warm era and material stream amid welding process (Nami, H et al.) [65].

Elangovan. K et al [26] influenced an endeavour to comprehend the effect of profile of the device to stick besides apparatus bear breadth on Friction Stir Processing zone improvement in joining AA6061. Instruments made with three unmistakable shoulder widths and five one of a kind profile of equipment stick has been used to make the joints by the makers for contemplate. The various gadget profiles used are straight round and empty, square, diminished barrel formed, hung tube molded and triangular. The plan of FSP zone has been penniless down unmistakably.

Scialpi et al [89] the consequence of various geometries of shoulder are studied on the micro structural what's more, mechanical properties of FSW of 6082-T_6 aluminium alloy were analyzed. This paper says about for thin sheets; tolerate by way of intermingle of filet in addition to cavity shaped great joints.

Zhao et al.[108]. In bonding the study made on the impact of pin shape moreover mechanical properties of FSW joined 2014 aluminium compound. From the investigation pin profile influences the stream of the plastic material and the best quality weld was acquired by utilizing the decrease taper tool with screw string.

Hattingh. et al. [39] the thinks about were led on the tool geometry impacted by welding powers and weld rigidity by methods for a tool device. During FSW of 5083 aluminium alloy the forces following up on the gadget, associated torque and temperature were recorded. The optical information lying on the contact between device profile as well as plastic mix zone which controls the perfect instrument assurance for a given game plan of weld conditions is given by force impression.

Reynolds. et al. [81] the formations of stream forms and weld chunk are in weld zone through which FSW are described. The spherical shaped influenced by the instrument plan as well as welding parameters. In material flow the shape of the pin assumes an imperative part as the welding parameters are managed by the tool profile.

Abhishek J. et al. [2] Friction stir welding (FSW) is a moderately new, best in class strong state joining process. This metal joining procedure is gotten from the ordinary rubbing welding. In this setting we have connected FSW system to weld Al-Al, Cu-Cu and Al-Cu couples. We examined the impact of trial parameters like rotational and transverse speed on welding of above metals and ensuing microstructure at interface and mechanical properties particularly hardness and elasticity. We acquired flawless interface and high mechanical quality for every one of the three couples at the rotational speed ranges from 600-1000 rpm and transverse speed from 40-80 mm/min.

2.10 Multi objective optimization (NSGA-II)

Genetic algorithm was foremost determined through John Holland [41] in the mid 1970's, are turning into an imperative device for combinational enhancement, work advancement, and machine learning. GAs is a sort of (I) stochastic pursuit, (ii) multi-point look, (iii) coordinate hunt, and (iv) parallel inquiry. These trademark highlights of GAs contribute vigor of the algorithms. The single objective optimization problems were mainly discussed by genetic algorithms. Keeping in mind the end goal to deal with multi target advancement issues, the target capacities ought to be joined into a scalar wellness work. The trademark highlights of GAs used in Schaffer's work [88] are reached out to multi target optimization issues by Murasa & Ishibuchi [63] and Dev et al [20]. They have described the ability of GAs to address multi target optimization issues.

Jain et al [42] optimized the three most essential ECM process parameters to be specific instrument nourish rate, electrolyte stream speed, and connected voltage with a target to limit geometrical incorrectness subjected to temperature, stifling, and detachment limitations utilizing genuine coded genetic algorithms. The planned advancement display was observed to be excessively mind boggling, making it impossible to unravel utilizing conventional enhancement methods with no estimation. Hence, it was illuminated utilizing genuine coded hereditary calculations which did not require any estimation or linearization of the target capacity and imperatives. They got streamlining comes about were confirmed graphically and from the hypothetical viewpoints. Correlation of the got comes about with that of the past examinations has indicated change as far as geometrical precision.

In a solitary target enhancement, there exists just a single arrangement. Be that as it may, in the event of numerous destinations, there may not exist one plan, which is the best with respect to all objectives. In end handling process, it is difficult to find a singular perfect blend of process parameters for the execution parameters, as the system parameters affect them in an unexpected way. Consequently, there is a requirement for a multi target advancement technique to land at the answers for this issue. Established techniques for taking care of multi target issue experience the ill effects of disadvantage. These strategies change the multi target issue into single goal by allocating a few weights in view of their relative significance. Likewise these traditional techniques fizzle when the capacity ends up noticeably irregular. Since GA is a decent apparatus for illuminating multi target advancement and its works with a populace of focuses, it appears to be normal to utilize multi target GA in end processing procedure to decide the ideal arrangement point from best execution to catch various arrangements all the while. Multi-objective genetic algorithm (MOGA), Vector evaluated genetic algorithm (VEGA), Non dominated sorting genetic algorithm (NSGA-II) are instances of GA based multi target course of action strategies. In the present work, NSGA-II has been used to get the perfect blend of process parameters Rao.S.S [80].

Shajan Kuriakose et al. [51] examined the use of a various regression model to speak to connection amongst information and yield factors and a multi target advancement technique in light of a non commanded arranging hereditary calculation NSGA is used to redesign wire EDM process and a non overpowered course of action set is gotten. The arranging methodology utilizes a wellness task plot which plans non ruled arrangement and utilizations a sharing procedure which jelly assorted variety among the arrangements; additionally none of the courses of action in the pareto perfect set is better than some other plan in the set. The method pro can pick perfect mix of parameters from the pareto perfect course of action set, dependent upon the requirement.

Palanikumar et al [71] explored the enhancement of machining qualities of glass fiber reinforced plastic (GFRP) composites using NSGA-II algorithm. The parameters chosen were cutting rate, feed in addition to depth of cut. The outputs like metal removal rate, tool flank wear in addition to standard surface roughness were analyzed. It can be stated that the greater part of the Pareto perfect spotlights are centered around high cutting rate, low sustain notwithstanding at a high profundity of cut; consequently these can be managed as perfect concentrations for achieving better various exhibitions.

The decision of one arrangement over the others relies upon the procedure specialist's prerequisites. On the off chance that what shall be required can be a higher metal clearing rate, or a predominant surface finish, or a unimportant gadget flank wear, a suitable mix of elements can be chosen in like manner. This technique will build creation rates impressively by diminishing machining time.

Mandal et al [55] have built up a mathematical model by means of artificial neural network (ANN) by way of back propagation algorithm along with furthermore on the way to advance the procedure parameters of wire electro substance machining of C40 Steel they used MOGA and NSGA-II. Different ANN engineering have been well thought-out, moreover 3-10-10-2 is seen to be the best plan, with learning rate and vitality coefficient as 0.6, having mean desire botch is as low as 3.06%and NSGA-II results demonstrates, values got from the improvement methodology are in close simultaneousness with the test regards for pretty much a similar parameter settings.

Vijayan. D et al. [103] in this paper age hardenable aluminium compounds, for example, AA2024 and AA6061 are widely utilized in car, flying machine and marine businesses in light of its high quality to weight proportion and great pliability. At the point when contrasted with combination welding strategies Friction Stir Welding (FSW) is a promising procedure to enhance the nature of the weld joint. FSW process parameters, for example, instrument rotational speed (N), welding speed (F), pivotal load (P) and apparatus stick profiles (Cylindrical, Square and Taper) effectively affect the mechanical properties of FS welded joints fundamentally. The numerical model was produced for the reactions to be specific Ultimate Tensile Strength (UTS) and Tensile Elongation (TE) utilizing Response Surface Method (RSM) and the created scientific model was successfully used to improve the FS welded process parameters utilizing non dominates sorting genetic algorithm II (NSGA-II). The amplified ductile properties of FS welded age hardenable aluminium composites were gotten about 143.3 N/mm2 with its comparing pliable lengthening of 12.53%. It is reasoned that, the NSGA – II is exceptionally valuable in streamlining the procedure parameters of FS Welding and enhancing the nature of the weld joint.

Vo-Duy. T et al. [104] this paper manages the multi-target enhancement issues of covered composite shaft structures. The target work is to limit the heaviness of the entire overlaid composite pillar and boost the characteristic recurrence. Specifically, the concurrent utilization of all the outline factors, for example, fiber volume parts, thickness and fiber introduction points of layers is directed, in which the fiber volume portions are taken as persistent plan factors with the imperative on assembling process while the thickness and fiber introduction edges are considered as discrete factors. The bar structure is subjected to the limitation in the normal recurrence which must be more noteworthy than or equivalent to a foreordained recurrence. With the expectation of complimentary vibration examination of the structure, the limited component technique is utilized with the two hub Bernoulli-Euler pillar component. For taking care of the multi-target improvement issue, the non dominated sorting genetic algorithm II (NSGA-II) is utilized. The unwavering quality and adequacy of the proposed approach are shown through three numerical cases by contrasting the present outcomes and those of past investigations in the writing.

Durga Prasada Rao. et al. [22] The present paper includes exploratory examination and multi-target improvement of mechanical properties of Aluminium 7075-based half and half metal grid composite created by blend throwing process. The composite is fortified with Silicon carbide (SiC) and Titanium dioxide (TiO2) particulates. The mechanical properties that were considered in this work are affected quality, hardness and elasticity. These properties of 7075 Al half and half metal lattice composite are contemplated by performing Charpy affect test, Rockwell hardness test and ductile test, individually. The analyses are led on examples arranged by blending the particulates in various rate mixes, for example, (0, 10), (2.5, 7.5), (5, 5), (7.5, 2.5) and (10, 0) of SiC and TiO2, individually by keeping up the level of 7075 Al consistent at 90 %. In light of the test esteems, second-arrange relapse conditions are fitted between every one of the reaction parameters and the throwing parameters (portion of SiC and division of TiO2) utilizing Minitab 17 programming. The conditions are then improved by characterizing them as the goals of a multi-target streamlining issue (MOOP). A non dominated sorting genetic algorithm (NSGA-II) is utilized to understand the MOOP. A solitary best trade off arrangement is likewise found from the Pareto ideal arrangements gotten by NSGA II.

2.11 Problem Formulation

FSW can be a solid state welding method. FSW has huge budding by means of virtue of the adaptability of its applications and it is normal that it will be effectively and monetarily used in current businesses. Contact blend welding can weld a material irrespective of hardness and is able to sound joints. Good surface integrity is frequently required for metal matrix components. The welding of metal matrix composites with good wear properties is becoming a key technology in engineering applications.

The broad number of past articles exhibits that the showing of the contact mix welding can be seen as an issue of relating the data parameters of the technique with its yield parameters. This can be overseen by techniques for RSM, which is an exploratory showing approach for choosing the association between various process parameters and responses with the diverse needed criteria and looking through the significance of these method parameters on the coupled responses. It is a progressive experimentation framework for building and enhancing the observational model. Affectability examination has been researched to speak to the viability of the preparing parameters on these exact conditions and demonstrated that the distinction in process parameters impacts the wear rate as well as wear resistance.

In FSW process, it is hard to locate a solitary ideal mix of process factors for the effecting parameters, seeing that the technique parameters influence them in an unexpected way. Thus, there is a requirement for a multi target advancement strategy to touch base at the answers for this issue. This work shows about how NSGA-II has been utilized to get the ideal mix of process parameters.

In this research wear rate as well as wear resistance of different Al composites of the a mixture of weight fraction of SiC, TiC, and one and the same weight percentage of SiC along with TiC particles reinforced Al6061T_6 aluminium combination composites which were delivered through a stir casting method are investigated. The average sizes of the reinforcement are 2 to 3μm. It is having very good mechanical properties compared to other engineering materials.

2.12 Objectives of this Research

The following are the goals of the present Research.

1. $Al6061T_6$ alloy with 0, 5, 10, 15 and 20 mass percentages of silicon carbide (SiC), titanium carbide (TiC) and equal weight percentage of SiC and TiC particulate composites, manufacture through stir casting method.

2. The design matrix was prepared. According to the design matrix the friction stir welding was carried out.

3. Advancement of scientific models were prepared for wear rate and wear resistance utilizing Response Surface Methodology (RSM).

4. Identification of most influential input parameters taking place wear rate in addition to wear resistance in the course of response surface methodology (RSM).

5. Optimized input parameters found by RSM for minimum wear rate and maximum wear resistance.

6. Optimization carried out by NSGA- II and found the optimal input factors for minimum wear rate and maximum wear resistance.

7. The optimal input factors derived from RSM and NSGA-II were compared with experimental value and best optimal values are validated.

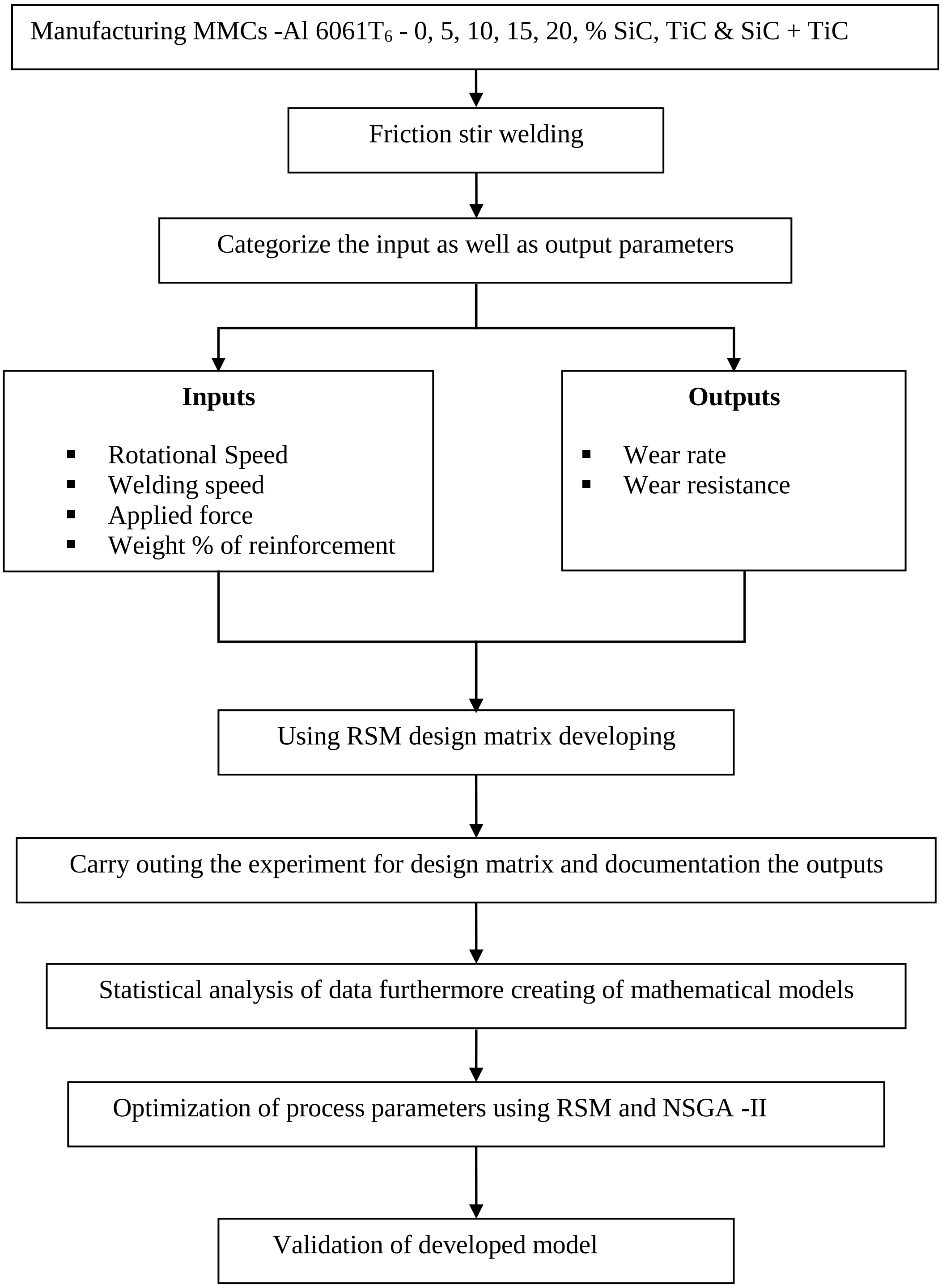


Figure 2.1 Plan of work

CHAPTER 3

EXPERIMENTAL STUDY

3.1 Introduction

In this chapter, details of raw material, reinforcements used for composite preparation and specimen preparation for friction stir welding process and non destructive testing, experimental setup and metallographic studies for the composites are presented.

3.2 Material selection

In this research work the base metal Al6061T_6 was used for composite preparation and reinforcements SiC and TiC were used to manufacture three types of composites as shown in figure 3.1. The MMCs are manufactured for various weight percentage like 0 wt% , 5 wt%, 10 wt%, 15 wt% in addition to 20 wt%. Another combination manufactured for the equal weight percentage of SiC and TiC like 0%wt., 2.5%wt., 5%wt., 7.5%wt. plus 10%wt.

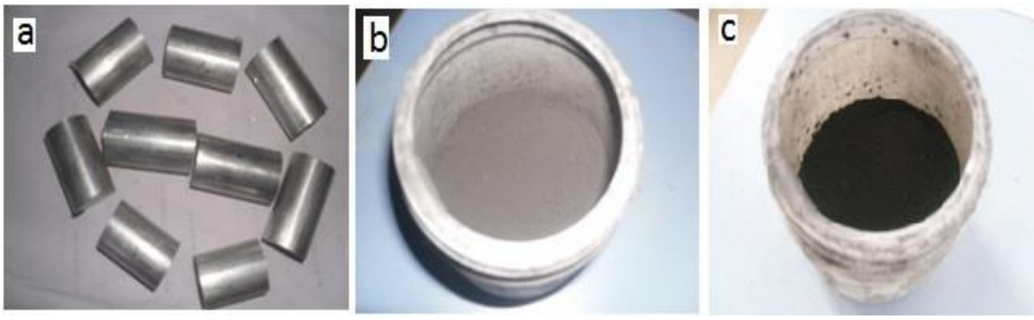


Figure 3.1 Materials for composites: (a) Al6061T_6 alloy (b) Silicon carbide (SiC) (c) Titanium carbide (TiC).

The composition of chemicals in Al6061T_6 alloy specimen can be given in Table 3.1.

Table 3.1 composition of chemicals in Al6061T_6 aluminium alloy (%wt.)

Material	Mg	Si	Fe	Mn	Cu	Cr	Zn	Ni	Ti	Al
Al6061 alloy (%)	0.95	0.54	0.22	0.13	0.17	0.09	0.08	0.02	0.01	Balance

The reinforcements SiC and TiC used for composite preparation with the particle size of 2 to 3 microns.

3.3 Fabrication process

$Al6061T_6$ alloy with different weight rates (0, 5, 10, 15 and 20) of silicon carbide (SiC), titanium carbide (TiC) and equal weight percentage of SiC and TiC particulates composites, manufactured through stir casting. The step by step procedure for stir casting route is shown in Figure 3.2. The base metal was heated to plastic stage in figure 3.1(a), 3.1 (b), then reinforcement added (figure 3.1(c)) and stirred by manually. After that the molten metal stirred for 15 minutes in liquid state for uniform distribution of reinforcement. Degasser added to avoid blow holes in casting. Figure 3.1(d) shows the model of die for specimen preparation. Finally liquid metal poured in die (figure 3.1(e)) and specimens removed (figure3.1 (f)).

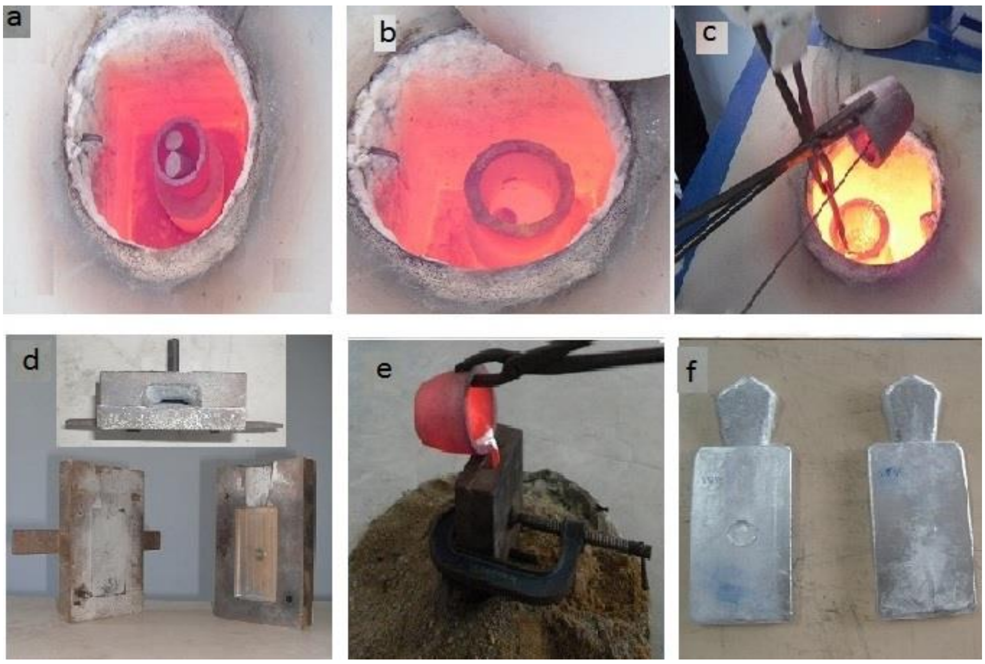


Figure 3.2 Manufacturing of $Al6061T_6$ composites: (a) Heating of $Al6061T_6$ alloy (b) Heating of reinforcement (c) Adding of reinforcement. (d) Die for specimen (e) Liquid Al composite poured in mould (f) Cast pieces.

3.4 Micrographic Studies

After preparing composites by stir casting method, the work pieces were cut into small pieces. Infinitesimal examinations of the examples were completed by means of lend a hand of scanning electron microscope (SEM). Figure 3.3 shows the specimen of 20mm square and SEM of JEOL JSM-6390.

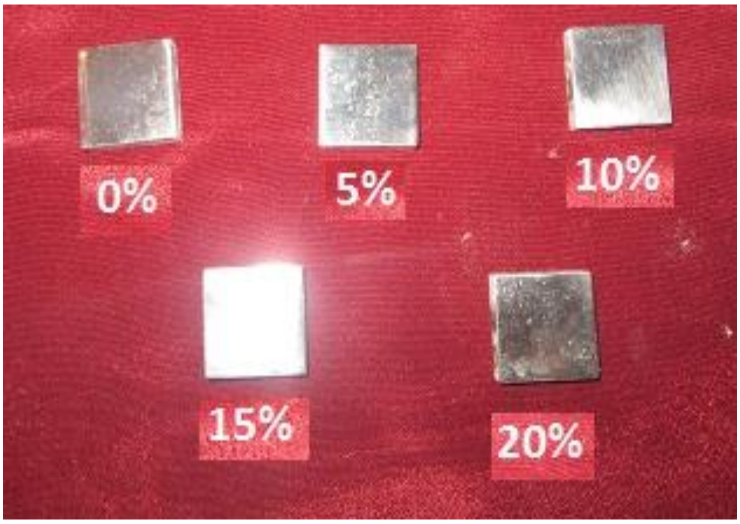


Figure.3.3 Specimen for micrographic study

Figure.3.4 Scanning electron microscope (SEM)

The normal microstructures for the $AL6061T_6$ alloy with different percentage weight of SiC, TiC and equal weight rates of SiC and TiC composites (0,5,10,15 and 20) are shown in Figure 3.5, 3.6 and 3.7 (Edwards. P. D et al.) [24]. from the figures the microstructure examination made and the reinforcement particles distributed uniformly (Christman.T et al.) [15].

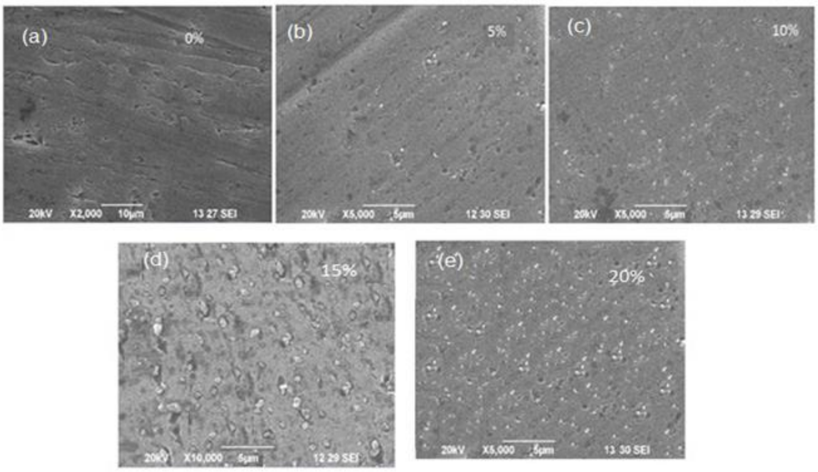


Fig. 3.5 SEM micrographs of Al6061T_6 alloy reinforced with (a) 0% SiC; (b) 5% SiC; (c) 10% SiC; (d) 15% SiC; and (e) 20% SiC.

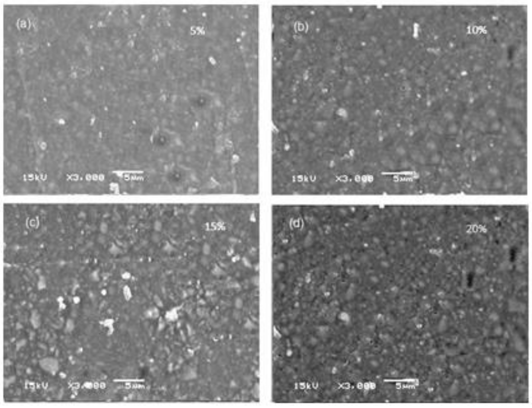


Fig. 3.6 SEM micrographs of Al6061T_6 alloy reinforced with (a) 5% TiC; (b) 10% TiC; (c) 15% TiC; and (d) 20% TiC.

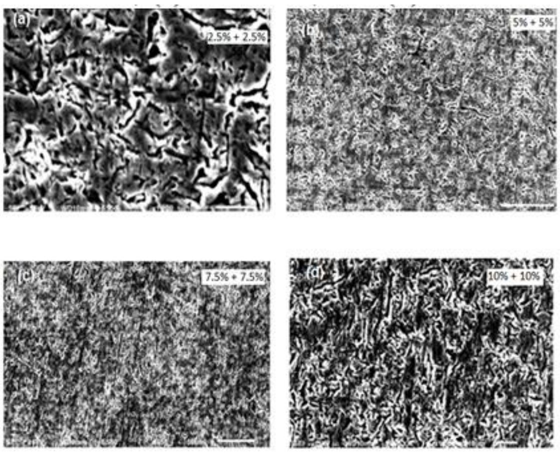


Fig. 3.7 SEM micrographs of Al6061T_6 alloy reinforced with (a) 2.5% SiC + 2.5% TiC (b) 5%SiC + 5% TiC (c) 7.5% SiC + 7.5%TiC and (d) 10% SiC + 10% TiC.

3.5 Non destructive testing

To check the quality of composites a non destructive testing method, ultrasonic test has been carried out for all combination of Al6061T_6 composites and it is presented in table 3.2.

Figure 3.8 Ultrasonic testing

Table 3.2 Ultrasonic test results of Al6061T_6 aluminium composites for various reinforcements with different weight percentages

SL NO	SAMPLE	RESULT
1	Al6061(T6)	No Defect
2	Al6061(T6) + SIC 5%	No Defect
3	Al6061(T6) + SIC 10%	No Defect
4	Al6061(T6) + SIC 15%	No Defect
5	Al6061(T6) + SIC 20%	No Defect
SL NO	**SAMPLE**	**RESULT**
1	Al6061(T6) + TIC 5%	No Defect
2	Al6061(T6) + TIC 10%	No Defect
3	Al6061(T6) + TIC 15%	No Defect
4	Al6061(T6) + TIC 20%	No Defect
SL NO	**SAMPLE**	**RESULT**
1	Al6061(T6) + SIC 2.5% + TIC 2.5%	No Defect
2	Al6061(T6) + SIC 5% + TIC 5%	No Defect
3	Al6061(T6) + SIC 7.5% + TIC 7.5%	No Defect
4	Al6061(T6) + SIC 10% + TIC 10%	No Defect

3.6 Aging study of Al6061T_6composites

The aging effects of Al6061T_6/SiC and Al6061T_6/TiC composites reinforced with different weight percentages were calculated. The tensile strength and hardness number were calculated. The time of 20days and 40days interval was taken for finding the aging effect. The changes in properties are given in table 3.3, 3.4. The properties were slightly increased for the time interval. The increasing rate was reduced when increasing the percentage of reinforcement (Scott MacKenzie. D et al.) [90], (Robert L. Feller) [82].

Table 3.3 Aging effect of Al6061T_6/SiC composites

% SiC	Tensile Strength in Mpa			Vickers hardness number		
	Initially	After 20 days	After 40 days	Initially	After 20 days	After 40 days
0	130	130.05	130.1	148.6	148.7	148.7
5	133	133	133	156.5	156.5	156.5
10	135	135	135	157.8	157.8	157.8
15	139	139.02	139	181.3	181.4	181.4
20	143	143.07	143	189.7	189.7	189.7

Table 3.4 Aging effect of Al6061T_6/TiC composites

% TiC	Tensile Strength in Mpa			Vickers hardness number		
	Initially	After 20 days	After 40 days	Initially	After 20 days	After 40 days
0	130	130.05	130.1	148.6	148.7	148.7
5	130.9	131.01	131	150.8	150.9	150.9
10	132.6	132.61	132.6	152	152	152.6
15	133.4	133.43	133.4	159	159.2	159.2
20	136.05	136.09	136.1	168.1	168.2	168.2

3.7 Specimen Preparation

The different weight percentage of silicon carbide (SiC), titanium carbide (TiC) and equal weight percentage of SiC and TiC particulates, Al6061T_6 composites

(0, 5, 10, 15 furthermore 20) are prepared all the way through stir casting technique. From the cast material the specimen for the friction stir welding has been machined into rectangular specimen of 100 mm × 50 mm × 6 mm.

3.8 Specification of welding tool

The welding tool was manufactured by means of high carbon high chromium steel by way of square tool pin profile. The pin profile also has a important role in the properties of weld joints. The magnitudes of FSW tool is made known within Figure 3.9.

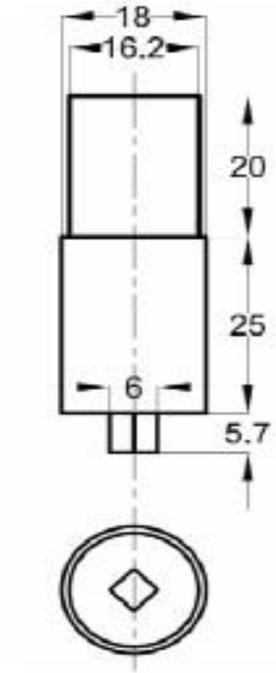


Figure 3.9 Friction stir welding tool

3.9 Friction stir welding (FSW)

Each specimen is welded in a friction stir welding machine MODEL - FSW 3T-300-NC with the following specification Spindle Tapper : ISO 40, Spindle Speed : 3000rpm, Spindle Tilt Angle : +- 5deg, Thrust force (Z axis) : 30KN(max), Travel (Z-axis) : 300mm, Travel (X-axis) : 300mm, Travel (Y-axis) : 100mm, From table to Spindle nose Min/Max 100mm/400mm. The friction stir welding device is shown in Figure 3.10

Figure 3.10 Friction stir welding machine

3.10 Experimentation

Specimens are welded in a friction stir welding machine (Ellis. M.B.D et al.) [28]. the instrument was crashed into the connecting edges of the two plates until the point when the surface of the plates touched by the shoulder with a sufficient power. After a stay time of 15 seconds the device head moves with settled navigate speed (Çam. G) [13]. At the purpose of joint length closes, the instrument is pulled back subsequently, and the same is taken after for various joints as indicated by the design matrix. Figure 3.11 shows the welded plates for Al6061T_6/SiC(a), Al6061T_6/TiC (b) and Al6061T_6/SiC+TiC (c) composites.

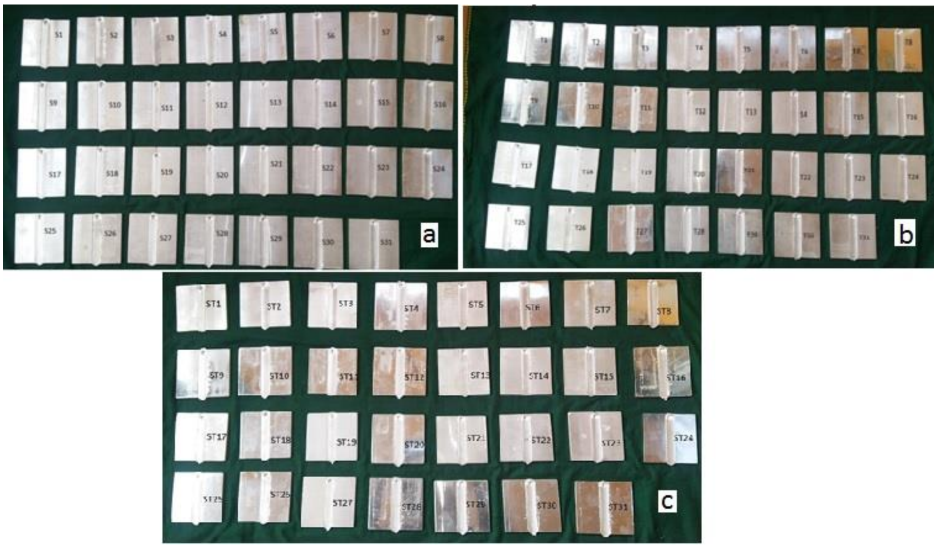


Figure 3.11 Friction stir welded specimen

The chosen procedure parameters among their units in addition to documentations are recorded in Table 3.5

Table 3.5: FSW parameters with their levels

Factor	Unit	Notation	Levels				
			(-2)	**(-1)**	**0**	**(+1)**	**(+2)**
Rotational speed	Rpm	*N*	1000	1075	1150	1225	1300
Welding speed	mm/min	*S*	30	40	50	60	70
Axial Force	KN	*F*	4	5	6	7	8
Reinforcement	%wt.	*P*	0	5	10	15	20

3.11 Design of experiments

In this examination, tests are planned on the premise of the exploratory plan method that has been proposed next to Box and Hunter [17].A 2^k factorial, where k can be the amount of factors, by way of second order rotatable central composite-design was used to upgrade the reliability of results and to decrease the measure of experimentation not including misfortune of precision (here k = 4). This includes nc $=2^k = 16$ corner focuses at +1 level, na $=2^k = 8$ pivotal focuses at $\gamma = +2$, moreover an inside point by the side of zero level rehashed seven times (no to assess mistake). It has been accounted for analyses give a chance to contemplate the individual impacts of each factor as well as their associations [95]. At the point when tests are coordinated factor by factor while changing the level of each factor, the effect of joint effort can't be investigated. Each experiment is performed with controlled process parameters, for example, rotational speed, welding speed, hub power and substance of reinforcement. Table 3.5 gives the levels of different parameters and their levels.

Tests have been completed by outlined setup in light of design of experiments called central composite design (CCD). For the four factors, the outline required 31 tests covering full range of parameters for instance rotational speed, welding speed, axial force in addition to reinforcement content to extract more data for modelling. The tests are conducted for three different composites like $Al6061T_6/SiC$,

$Al6061T_6/TiC$ and $Al6061T_6/SiC+TiC$. The experiments are conducted under dry condition.

The response variables selected for this investigation are wear rate (W) in addition to wear resistance (R). The experiments are conducted as indicated by the required experimentation in light of focal composite second request rotatable plan as Listed in table 3.6. X1, X2, X3, and X4 are the coded estimations of parameters N, S, F, and P individually.

The Test piece was removed as of welded plate of 6 mm x 6 mm x 50 mm measurements. Figure demonstrates the Test piece extraction from welded plates. The wear rate (W) was estimated using DUCOM TR20-LE pin on-disc wear apparatus. Monitor the loss of height utilizing computer aided data acquisition system. The volumetric misfortune was registered through increasing the cross area of the test pin by means of its loss of height.

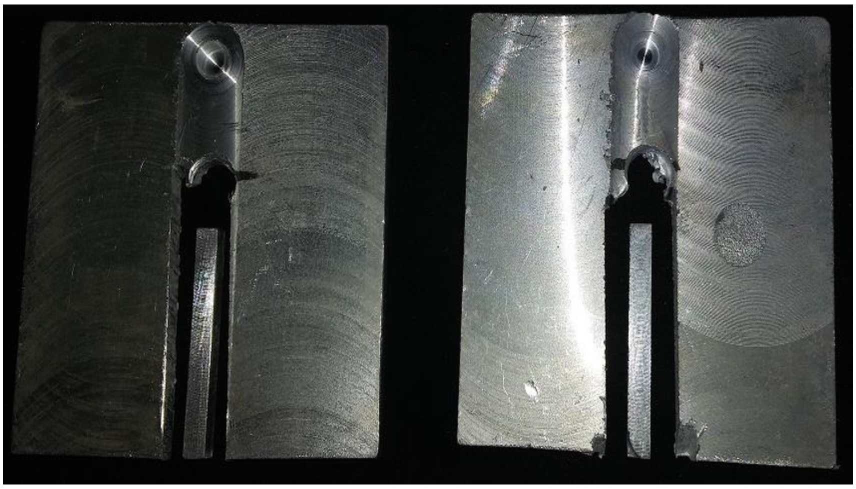


Figure 3.12 Specimen Extracted from welded region

Calculated W and R were as shown below.

W, (mm^3/m) = Volumetric loss / Sliding distance (1)

R, (m/mm^3) = 1 / Wear rate (2)

The experiments are conducted as per CCD, wear rate (W) moreover wear resistance (R) values for all the experiments were presented in Tables 3.6 to 3.8.

Table 3.6 FSW parameters for Al6061T_6/SiC Composite

Exp. No.	Coded factors				Actual factors				Wear rate 'W'($\times 10^{-5}$) (mm^3/m)	Wear resistance 'R'(m/mm^3)
	X_1	X_2	X_3	X_4	*N*	*S*	*F*	*P*		
1	-1	-1	-1	-1	1075	40	5	5	369	271
2	1	-1	-1	-1	1225	40	5	5	358	279
3	-1	1	-1	-1	1075	60	5	5	380	263
4	1	1	-1	-1	1225	60	5	5	366	273
5	-1	-1	1	-1	1075	40	7	5	374	267
6	1	-1	1	-1	1225	40	7	5	382	262
7	-1	1	1	-1	1075	60	7	5	368	272
8	1	1	1	-1	1225	60	7	5	380	263
9	-1	-1	-1	1	1075	40	5	15	233	429
10	1	-1	-1	1	1225	40	5	15	230	435
11	-1	1	-1	1	1075	60	5	15	234	427
12	1	1	-1	1	1225	60	5	15	242	413
13	-1	-1	1	1	1075	40	7	15	221	452
14	1	-1	1	1	1225	40	7	15	246	407
15	-1	1	1	1	1075	60	7	15	212	472
16	1	1	1	1	1225	60	7	15	241	415
17	-2	0	0	0	1000	50	6	10	320	313
18	2	0	0	0	1300	50	6	10	346	289
19	0	-2	0	0	1150	30	6	10	322	311
20	0	2	0	0	1150	70	6	10	317	315
21	0	0	-2	0	1150	50	4	10	319	313
22	0	0	2	0	1150	50	8	10	324	309
23	0	0	0	-2	1150	50	6	0	381	262
24	0	0	0	2	1150	50	6	20	144	694
25	0	0	0	0	1150	50	6	10	286	350
26	0	0	0	0	1150	50	6	10	276	362
27	0	0	0	0	1150	50	6	10	289	346
28	0	0	0	0	1150	50	6	10	311	322
29	0	0	0	0	1150	50	6	10	303	330
30	0	0	0	0	1150	50	6	10	290	345
31	0	0	0	0	1150	50	6	10	274	365

Table 3.7 FSW parameters for Al6061T6/TiC Composite

Exp. No.	Coded factors				Actual factors				Wear rate 'W'($\times 10^{-5}$) (mm^3/m)	Wear resistance 'R'(m/mm^3)
	X_1	X_2	X_3	X_4	N	S	F	P		
1	-1	-1	-1	-1	1075	40	5	5	409	244
2	1	-1	-1	-1	1225	40	5	5	396	253
3	-1	1	-1	-1	1075	60	5	5	410	244
4	1	1	-1	-1	1225	60	5	5	407	246
5	-1	-1	1	-1	1075	40	7	5	415	241
6	1	-1	1	-1	1225	40	7	5	418	239
7	-1	1	1	-1	1075	60	7	5	405	247
8	1	1	1	-1	1225	60	7	5	414	242
9	-1	-1	-1	1	1075	40	5	15	271	369
10	1	-1	-1	1	1225	40	5	15	270	370
11	-1	1	-1	1	1075	60	5	15	273	366
12	1	1	-1	1	1225	60	5	15	284	352
13	-1	-1	1	1	1075	40	7	15	264	379
14	1	-1	1	1	1225	40	7	15	288	347
15	-1	1	1	1	1075	60	7	15	250	400
16	1	1	1	1	1225	60	7	15	281	356
17	-2	0	0	0	1000	50	6	10	361	277
18	2	0	0	0	1300	50	6	10	385	260
19	0	-2	0	0	1150	30	6	10	362	276
20	0	2	0	0	1150	70	6	10	356	281
21	0	0	-2	0	1150	50	4	10	360	278
22	0	0	2	0	1150	50	8	10	366	273
23	0	0	0	-2	1150	50	6	0	381	262
24	0	0	0	2	1150	50	6	20	179	559
25	0	0	0	0	1150	50	6	10	327	306
26	0	0	0	0	1150	50	6	10	315	317
27	0	0	0	0	1150	50	6	10	329	304
28	0	0	0	0	1150	50	6	10	353	283
29	0	0	0	0	1150	50	6	10	343	292
30	0	0	0	0	1150	50	6	10	331	302
31	0	0	0	0	1150	50	6	10	313	319

Table 3.8 FSW parameters for Al6061T$_6$/SiC+TiC Composite

Exp. No.	Coded factors				Actual factors				Wear rate 'W'(×10^{-5}) (mm^3/m)	Wear resistance 'R'(m/mm^3)
	X_1	X_2	X_3	X_4	*N*	*S*	*F*	*P*		
1	-1	-1	-1	-1	1075	40	5	5	388	258
2	1	-1	-1	-1	1225	40	5	5	378	265
3	-1	1	-1	-1	1075	60	5	5	397	252
4	1	1	-1	-1	1225	60	5	5	385	260
5	-1	-1	1	-1	1075	40	7	5	394	254
6	1	-1	1	-1	1225	40	7	5	398	251
7	-1	1	1	-1	1075	60	7	5	382	262
8	1	1	1	-1	1225	60	7	5	397	252
9	-1	-1	-1	1	1075	40	5	15	250	400
10	1	-1	-1	1	1225	40	5	15	251	398
11	-1	1	-1	1	1075	60	5	15	253	395
12	1	1	-1	1	1225	60	5	15	264	379
13	-1	-1	1	1	1075	40	7	15	239	418
14	1	-1	1	1	1225	40	7	15	267	375
15	-1	1	1	1	1075	60	7	15	233	429
16	1	1	1	1	1225	60	7	15	258	388
17	-2	0	0	0	1000	50	6	10	341	293
18	2	0	0	0	1300	50	6	10	363	275
19	0	-2	0	0	1150	30	6	10	343	292
20	0	2	0	0	1150	70	6	10	332	301
21	0	0	-2	0	1150	50	4	10	339	295
22	0	0	2	0	1150	50	8	10	345	290
23	0	0	0	-2	1150	50	6	0	381	261
24	0	0	0	2	1150	50	6	20	159	629
25	0	0	0	0	1150	50	6	10	307	326
26	0	0	0	0	1150	50	6	10	294	340
27	0	0	0	0	1150	50	6	10	305	328
28	0	0	0	0	1150	50	6	10	334	299
29	0	0	0	0	1150	50	6	10	326	307
30	0	0	0	0	1150	50	6	10	313	319
31	0	0	0	0	1150	50	6	10	290	345

3.12 Non destructive testing in FSW region

An NDT test, ultrasonic test was conducted in friction stir welded region of Al6061T_6 composites for different weight percentage of SiC up to 10 wt.% there was no defects in weld region and between 10 wt.% to 20 wt.% of reinforcement of Al6061T6/SiC composites void were developed and shown in table 3.9. Figure shows ultrasonic testing carried out in FSW welded region.

Figure 3.13 Non destructive testing for FSW welded region

The wettability and bonding between the materials are poor when increasing the weight percentage of silicon carbide.

Table 3.9 Ultrasonic test results of Al6061T_6 aluminium weld region for various reinforcements with different weight percentages

SL NO	SAMPLE	RESULT
1	Al6061(T6)	No defect
2	Al6061(T6) + SIC 5%	No defect
3	Al6061(T6) + SIC 10%	Void formation 2.1mm from top
4	Al6061(T6) + SIC 15%	Void formation 3 mm from top
5	Al6061(T6) + SIC 20%	Void formation 3.2 mm from top
SL NO	**SAMPLE**	**RESULT**
1	Al6061(T6) + TIC 5%	No defect
2	Al6061(T6) + TIC 10%	No defect
3	Al6061(T6) + TIC 15%	No defect
4	Al6061(T6) + TIC 20%	Void formation 3.8 mm from top
SL NO	**SAMPLE**	**RESULT**
1	Al6061(T6) + SIC 2.5% + TIC 2.5%	No defect
2	Al6061(T6) + SIC 5% + TIC 5%	No defect
3	Al6061(T6) + SIC 7.5% + TIC 7.5%	Void formation 2.6 mm from top
4	Al6061(T6) + SIC 10% + TIC 10%	Void formation 2.9 mm from top

CHAPTER – 4

MODELING OF FRICTION STIR WELDING CHARACTERISTICS

4.1. Introduction

Aluminium alloys can't be welded by means of gas welding systems on account of poor weldability. Joining of Aluminium compound via Arc moreover Resistance welding by means of Arc and Resistance welding require extraordinary systems in addition to from now on extreme the most sensible procedure for welding of Aluminium composite is Friction Stir Welding Process. Impacts of equipment turn speed, gadget voyages speed, pressure applied and addition of reinforcement on mechanical properties have been examined utilizing plan of investigations system

Friction stir welding is well suitable joining process for Al6061/SiC, Al6061/TiC and Al6061/SiC + TiC composites materials. The friction stir welding includes a substantial number of parameters, which impact the idea of the thing. As a result of this enormous number of parameters and their erratic nature, it is difficult to relate them in a solitary expository model. Expansive trial work is in this manner expected to dissect and improve the procedure number of parameters, which affect the possibility of the thing. Because of this tremendous number of parameters and their inconsistent nature, it is hard to relate them in a single informative model. Far reaching trial work is the minimum trial exertion. The experiment was finished utilizing the technique DOE along with regression analysis. The joined usage of these systems has enabled to make both first and second request models which make it possible to clear up the variability related with each of the mechanical factors (Rajamanickam. N et al.) [77]. an endeavour has been completed to get a perfect setting of process parameters, which may yield perfect W as well as R on the weld region. RSM was used to design and investigate the analyses.

4.2. Procedure for Response Surface methodology (RSM)

It is achievable to speak to self-determining technique parameters during quantitative kind in RSM as:

$$Y = f(X1, X2, X3 \ldots Xn) \pm \varepsilon \qquad \textbf{(4.1)}$$

Where, Y- response (yield), f- response function, ε-experimental error, and X1, X2, X3, . . ., Xn are not depend taking place other parameters.

The normal reaction of Y, a surface can be plotted, perceived seeing that the reaction surface can be gotten. The type of "f" can be obscure and might be extremely confounded. Along these lines, RSM goes for in the vein of "f" through a reasonable lesser requested polynomial within a little district of the free procedure factors. In the event that the reaction can be very much demonstrated by a direct capacity of the autonomous factors, the capacity (Eqn. 4.1) can be developed seeing that:

$$Y = C_0 + C_1X_1 + C_2X_2 + \ldots + C_n X_n \pm \varepsilon \qquad \textbf{(4.2)}$$

In any case, if an arch exists in the framework, at that point a higher request polynomial, for example, the quadratic model (Eqn. 4.3) might be utilized,

$$Y = C_0 + \sum_{i=1}^{n} C_i X_n + \sum_{i=1}^{n} d_i X_i^{\ 2} \pm \varepsilon \qquad (4.3)$$

The reason for choosing second order polynomial equation to know the influence of interaction effect of input factors on responses. The motivation behind utilizing RSM can be not exclusively in the direction of look at the reaction more than the whole factor space, yet in addition in the direction of put the zone of intrigue where the reaction achieves its ideal otherwise close ideal esteem. By concentrate painstakingly the RSM, the mix of components, that will yields as well as can be expected, be built up. In this investigation, 31 experiments are carried out based on CCD. Configuration was produced and broke down utilizing Minitab 15.0 measurable bundle. The levels of each factor were pulled out at the same time as - 2,- 1, 0, 1, 2 in close casing to have a rotatable outline. By fathoming the relapse condition the ideal estimations of the chose factors are obtained and by examining the reaction surface shape plots. The reaction surface approach is a consecutive procedure and its method can be compressed as appeared in Figure 4.1.

The modelling is processed by the following steps (Gunaraj.V et al.) [33]

1) For finding their upper and lower restrains the significant process control variables was identified.

2) Building the design matrix.

3) Conducting the trials according to the design matrix.

4) Storing the response parameters.

5) Developing quadratic models and figuring the regression coefficients.

6) Examining the adequacy of models.

7) Testing the monstrosity of coefficients and getting in contact at the last models.

8) Contours plots were drawn to various process parameters on W and R.

9) Analysis of results.

10) Optimization

11) Summary of results.

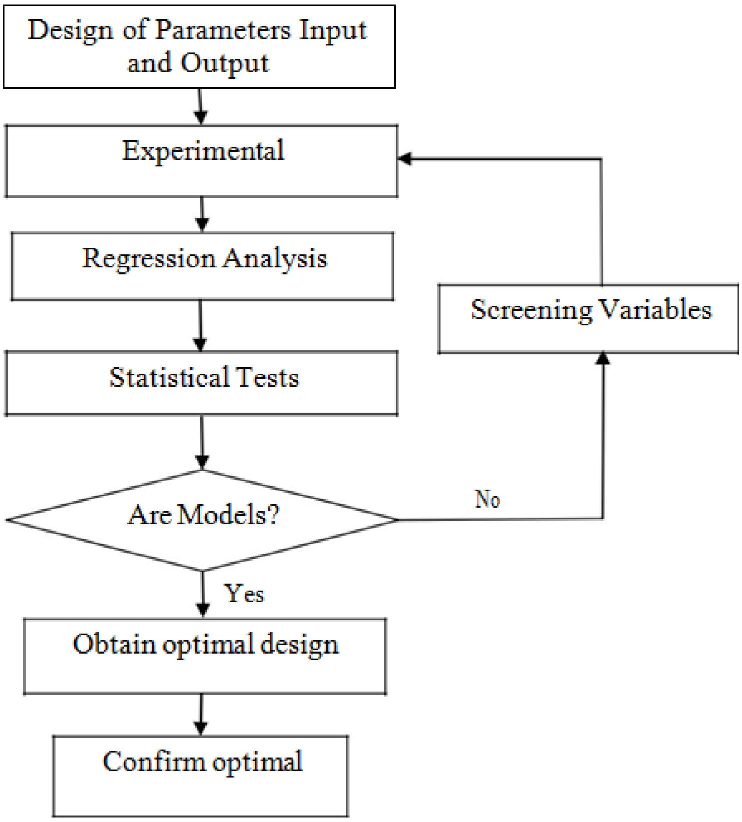


Figure 4.1 Flow chart of response surface methodology

4.3. Modelling of FSW characteristics of Al6061/SiC Composite

The investigations are led through CCD and the normal estimations of wear rate 'W' and wear resistance 'R' by the side of through design matrix are listed in Table 3.6. On behalf of investigation of the information, the examining of integrity of attack of the model can be especially needed. The model sufficiency inspection incorporates analysis for noteworthiness of the relapse show, test for centrality on display coefficients in addition to examination for absence of fit. In favour of this reason, examination of difference (ANOVA) can be executed. The middle values were chosen as the hold value, there may be small variations that occur in the contours plot while changing the hold values to maximum and minimum values (Dinaharan. I et al.) [21].

4.3.1 Modelling for wear rate (W) of Al6061/SiC Composite

RSM as well as DOE systems were initially produced for the model fitting of physical analyses, yet can likewise be connected to numerical investigations. The response should be evaluated is the objective of DOE in the selection criteria.

The ANOVA table for the quadratic model for wear rate (W) is showed up in Table 4.1. The standard rate motivation behind F spread for 95% certainty cut-off is 4.06. From the Table 4.1 the F-value (0.53) for nonappearance of fit is tinier than the standard regard. The other model terms are said to be inconsequential. The assessment of R^2 is more than 99.65 %, which implies that the relapse show gives a splendid illumination of the association between the free (factors) and the response (W). The related P-value for the model is lower than 0.05 (i.e. P = 0.05, or 95% certainty) demonstrates that the model is believed to be factually huge. Figure 4.2 demonstrates the plot of typical likelihood of the residuals for wear rate (W). It can be seen that the residuals are falling on a straight line, which suggests that the mix-ups are regularly appropriated show is genuinely very much fitted with the watched esteems. The displaying condition for wear rate (W) is given in Eqn.4.4

$$\text{Wear rate (W)} = 3568.07 - (4.52X_1) - (5.63X_2) - (145.62X_3) - (14.43X_4) + (0.06X_2^2) + (6.79X_3^2) - (0.32X_4^2) + (0.08X_1 \times X_3) + (0.01X_1 \times X_4) - (0.36X_2 \times X_3) - 0.02X_2 \times X_4) - (0.59X_3 \times X_4) \quad (4.4)$$

Table 4.1 ANOVA for wear rate (W) of Al6061/SiC

Source of variation	Degree of freedom	Sum of squares	Mean sum of squares	*F*- value	P- value
	W	W	W	W	W
Regression	14	114439	8174.23	64.36	0
Linear	4	106123	879.49	6.92	0.002
Square	4	7217	1789.77	14.09	0
Interaction	6	1099	183.16	1.44	0.26
Residual Error	16	2032	127.01		
Lack of fit	10	953	95.33	0.53	
Pure Error	6	1079	179.81		
Total	30	116471			

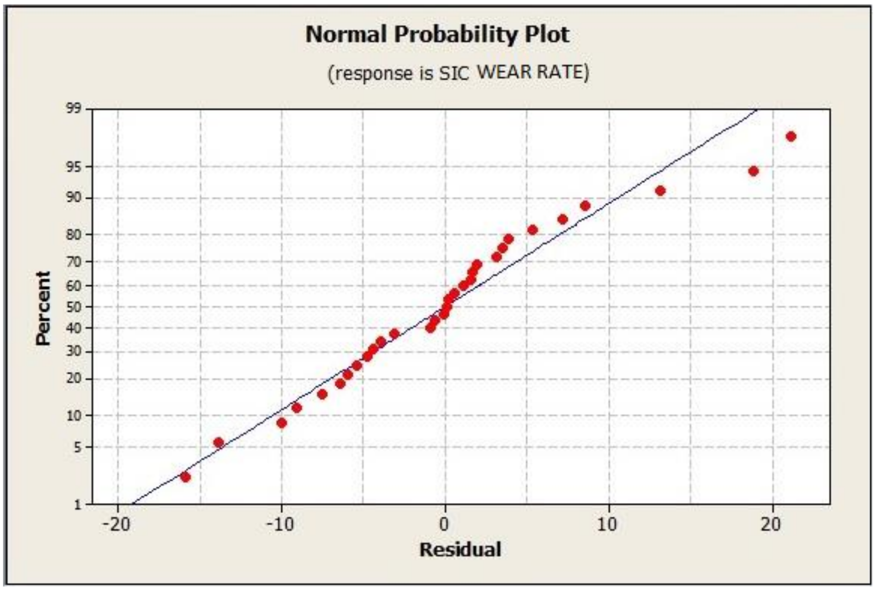


Figure 4.2 Normal probability residuals of wear rate (W) Al6061/SiC

4.3.2 Modelling for wear resistance (R) of Al6061/SiC Composite

ANOVA table on behalf of the quadratic model intended for 'R' can be appeared in Table 4.2. The benchmark rate purpose of F scattering for 95% assurance limit is 4.06. From the Table 4.2 the F-esteem (1. 7) for nonattendance of fit is more diminutive than the benchmark value. The estimation of R^2 for wear resistance is 99.85%, which implies that the regression gives a fantastic clarification of the association between the independent (factors) and the response (R). The related P-regard for the model is lower than 0.05 (i.e., p = 0.05, or 95% assurance), which demonstrates that the model can be considered factually noteworthy. Figure 4.3 shows the ordinary probability plot of the residuals for R. It is watched that the residuals are falling on a straight line, which infers that the mix-ups are routinely coursed and the regression show is really attractive. The showing condition for R is given in Eqn.4.5

Wear resistance (R) = $-3713.12 + (5.57X_1) + (10.08X_2) + (180.30X_3) + (4.95X_4) - (0.08X_2^2) - (8.90X_3^2) + (1.31X_4^2) - (0.09X_1 \times X_3) - (0.02X_1 \times X_4) + (0.49X_2 \times X_3) + (0.02X_2 \times X_4) + (0.71X_3 \times X_4)$ -(4.5)

Table 4.2 ANOVA for wear resistance (R) of Al6061/SiC

Source of variation	Degree of freedom	Sum of squares	Mean sum of squares	*F*- value	P- value
	R	R	R	*R*	R
Regression	14	242104	17293.2	49.16	0
Linear	4	196439	1318.7	3.75	0.025
Square	4	43605	10921.4	31.04	0
Interaction	6	2061	343.5	0.98	0.472
Residual Error	16	5629	351.8		
Lack of fit	10	4164	416.4	1.7	
Pure Error	6	1465	244.2		
Total	30	247733			

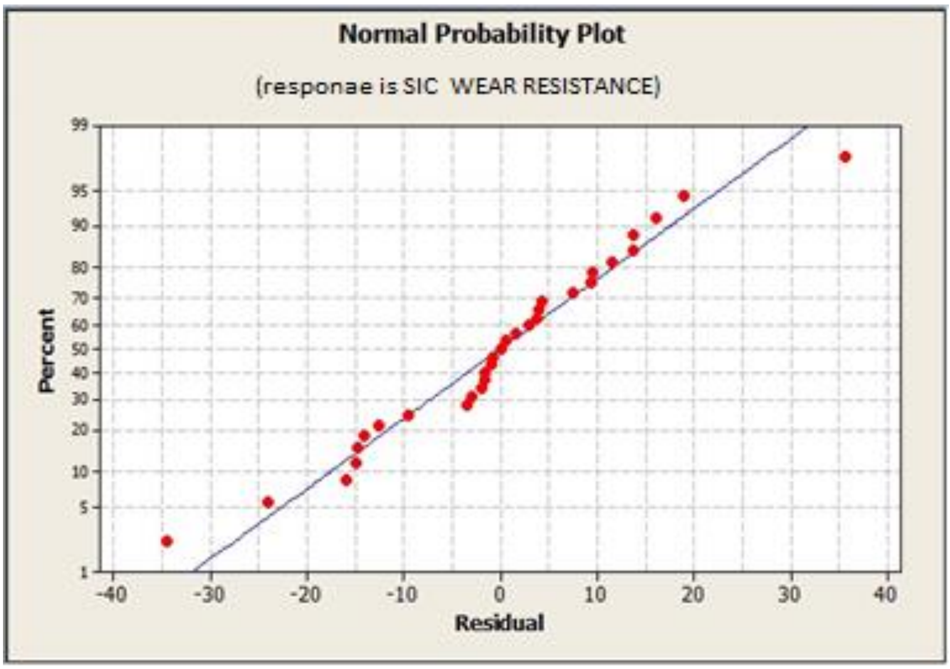


Figure 4.3 Normal probability residuals for wear resistance (R) of Al6061/SiC

The equations 4.4 & 4.5 can be used for the estimation of ‘W’ and ‘R’.

4.4. Modelling of FSW characteristics of Al6061/TiC Composite

4.4.1 Modelling for wear rate (W) of Al6061/TiC Composite

The Analytical models are polynomials with an unknown structure, so the comparing tests are planned just for each specific issue. The same procedure which is followed for Al6061/TiC composite is repeated for wear rate (W), and the outcomes are appeared in Table 4.3. The reinforcement Particle additions have reduced the wear rate and increment the wear resistance of the composites and hence delayed the transition with load from low wear coefficients to high wear coefficients.

The standard rate purpose of F apportionment for 95% assurance keep is 4.06. As of the Table 4. 3 the F-value (0.37) for nonattendance of fit is tinier than the standard value. The estimation of R^2 ascertained in for this model is more than 99.37%, sensible near solidarity, which is worthy. It shows this model provides good relationship between the independent factors moreover the response. Figure 4.4 give you an idea about the normal probability plot for the residuals designed for ‘W’. The end response equation for wear rate (W) is given in Eqn.4.6

$$\text{Wear rate (W)} = 3551.64 - (4.45X_1) - (7.03X_2) - (127.47X_3) - (15.33X_4) + (0.06X_2^2) + (7.00X_3^2) - (0.37X_4^2) + (0.06X_1 \times X_3) + (0.01X_1 \times X_4) - (0.39X_2 \times X_3) - (0.56X_3 \times X_4) \quad (4.6)$$

Table 4.3 ANOVA for wear rate (W) of Al6061/TiC

Source of variation	**Degree of freedom**	**Sum of squares**	**Mean sum of squares**	***F*- value**	**P- value**
	W	**W**	**W**	**W**	**W**
Regression	14	112087	8006.18	64.48	0
Linear	4	103114	841.62	6.78	0.002
Square	4	7890	1972.59	15.89	0
Interaction	6	1082	180.4	1.45	0.256
Residual Error	16	1987	124.17		
Lack of fit	10	764	76.39	0.37	
Pure Error	6	1223	203.81		
Total	30	114073			

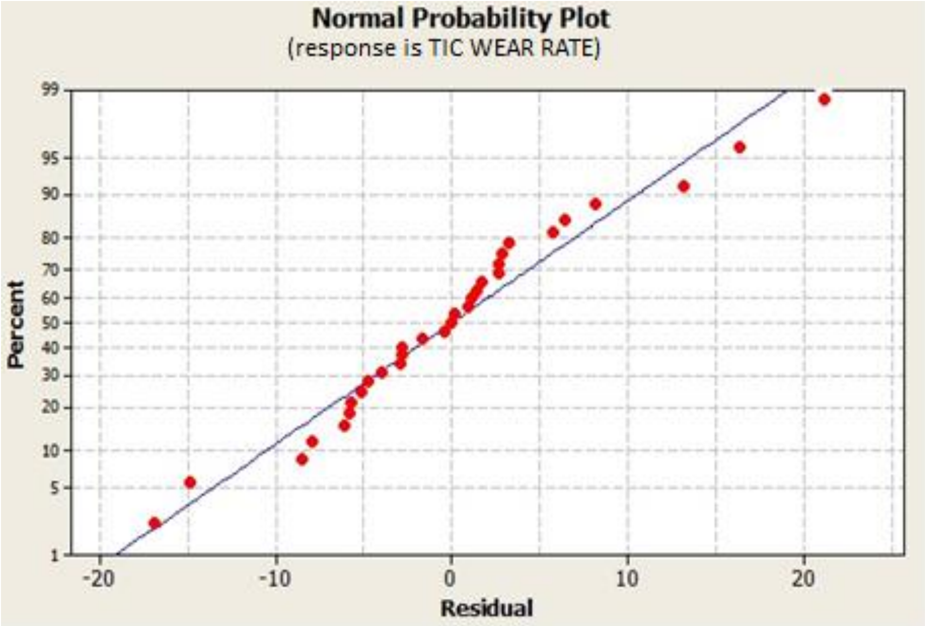


Figure 4.4 Normal probability residuals for wear rate (W) Al6061/TiC

4.4.2 Modelling for wear resistance (R) of Al6061/TiC Composite

The low wear resistance of aluminium alloys has restricted their uses in certain tribological situations. Seizure and wear resistance in aluminium combinations could be considerably enhanced by joining of hard earthenware particulates. Outlining of composite materials with beneficial tribological properties is difficult and is associated with examination of many components.

The similar procedure is applied for wear resistance (R), the outcomes are appeared in Table 4. 4. The R^2-value for the wear resistance (R) is 98.33%, close to 1. The standard rate purpose of F distribution designed for 95% certainty limit can be 4.06. As appeared in Table 4.4 the F-value (1.24) for absence of fit is littler than the standard value. Figure 4.5 shows the ordinary probability plot of the residuals designed for ‘R’. It can be seen that the residuals go down on a straight line inducing that the defects are regularly dispersed. The end response equation for wear resistance (R) is given in Eqn.4.7.

$$\text{Wear Resistance (R)} = -2749.95 + (4.17X_1) + (7.16X_2) + (133.67X_3) + (8.37X_4) - (0.06X_2^2) - (6.87X_3^2) + (0.97X_4^2) - (0.07X_1 \times X_3) - (0.02X_1 \times X_4) + (0.42X_2 \times X_3) + (0.01X_2 \times X_4) + (0.50X_3 \times X_4) \quad (4.7)$$

Table 4.4 ANOVA for wear resistance (R) of Al6061/TiC

Source of variation	Degree of freedom	Sum of squares	Mean sum of squares	*F*- value	P- value
	R	R	R	*R*	R
Regression	14	135231	9659.4	51.17	0
Linear	4	110094	737.9	3.91	0.021
Square	4	23702	5925.5	31.39	0
Interaction	6	1435	239.2	1.27	0.326
Residual Error	16	3020	188.8		
Lack of fit	10	2037	203.7	1.24	
Pure Error	6	983	163.9		
Total	30	138251			

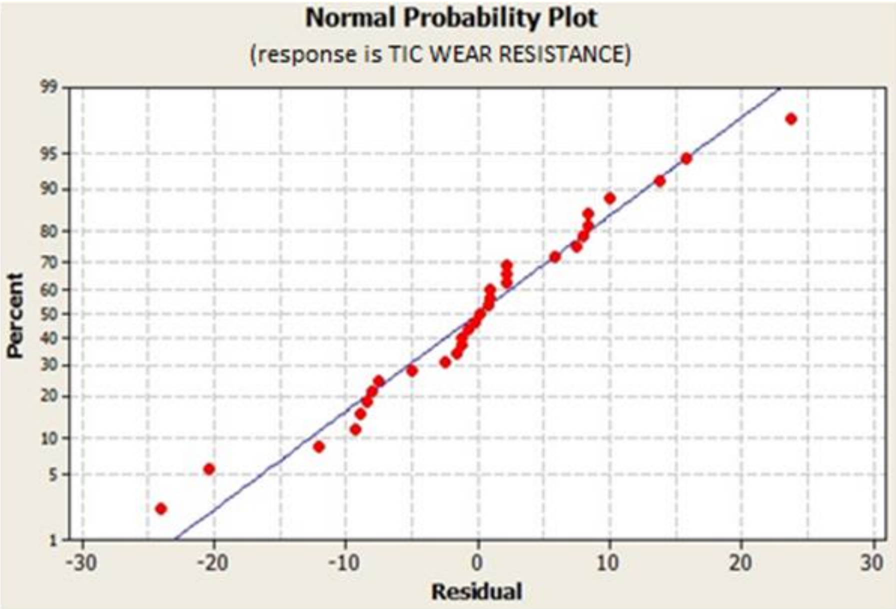


Fig.4.5 Normal probability residuals for wear resistance (R) Al6061/TiC

The equations 4.6 & 4.7 can be used for the estimation of wear rate (W) also wear resistance (R).

4.5 Modelling of friction stir welding characteristics of Al6061/SiC+TiC Composite

4.5.1 Modelling for wear rate (W) of Al6061/SiC+TiC Composite

For checking the sufficiency of the model, the methodology is repeated for wear rate (W) and the results are appeared within Table 4 .5. The standard rate purpose of F dissemination for 95% certainty restrain is 4.06. From the Table 4 .5 the F-value (0.3) designed for absence of fit can be littler compared to the standard value. The estimation of R^2 figured for this model is more than 98.39%, sensible near solidarity, which is worthy. Figure 4.6 shows the standard probability plot about the residuals used for wear rate (W). It can be seen that the residuals are falling on a straight line, which infers that the missteps are routinely coursed and the relapse give you an idea about it can be truly fitted with the watched values. The end reaction condition for wear rate (W) is given in Eqn.4.8

$$\text{Wear rate (W)} = 3551.64 - (4.45X_1) - (7.03X_2) - (127.47X_3) - (15.33X_4) + (0.06X_2^2) + (7.00X_3^2) - (0.37X_4^2) + (0.06X_1 \times X_3) + (0.01X_1 \times X_4) - (0.39X_2 \times X_3) - (0.56X_3 \times X_4) \quad (4.8)$$

Table 4.5 ANOVA for wear rate (W) of Al6061/SiC+TiC

Source of variation	Degree of freedom	Sum of squares	Mean sum of squares	*F*- value	P- value
	W	W	W	W	W
Regression	14	113932	8138.03	56.8	0
Linear	4	105562	833.11	5.81	0.004
Square	4	7298	1824.6	12.73	0
Interaction	6	1071	178.58	1.25	0.335
Residual Error	16	2292	143.28		
Lack of fit	10	762	76.16	0.3	
Pure Error	6	1531	255.14		
Total	30	116225			

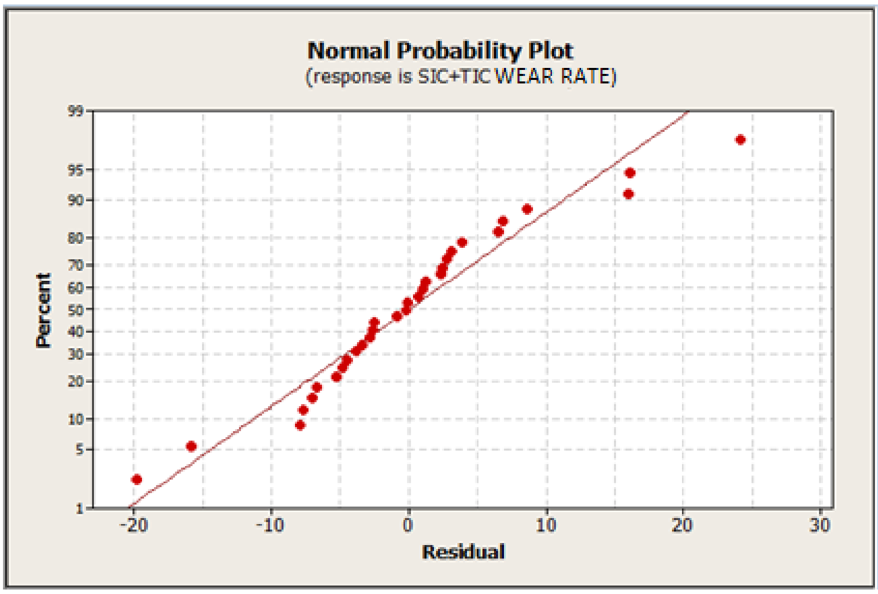


Figure 4.6 Normal probability residuals for wear rate (W) Al6061/SiC+TiC

4.5.2 Modelling for wear resistance (R) of Al6061/SiC+TiC Composite

Hybrid aluminium MMCs reinforced with SiC along with TiC is broadly utilized because of high quality in addition to wear resistance. Frictional conduct of such half and half breed composites is exceptionally basic in picking the perfect mix of SiC and TiC. The sliding contact reaction of mix cast cross breed aluminium composites strengthened with measure up to weight division of SiC and TiC particulates of 2.5%, 5%, 7.5% and 10% fortification is examined.

For model adequacy the similar procedure is repeated for wear resistance (R), and the results are listed in Table 4.6. The standard rate purpose of F distribution designed for 95%confidence point of confinement is 4.06. From the in Table 4.6 the F-value (1. 26) used for absence of fit is littler by compared the standard value. The R^2-value for the surface roughness is 99.14%, close to 1. Fig.4.7 shows the ordinary probability plot of the residuals for 'R'. It can be looked at that the residuals are falling on a straight line, which infers that the bungles are routinely scattered and the backslide demonstrate is really adequate. The end reaction condition of wear resistance (R) is given in Eqn.4.9.

$$\text{Wear Resistance (R)} = -2749.95 + (4.17X_1) + (7.16X_2) + (133.67X_3) + (8.37X_4) - (0.06X_2^2) - (6.87X_3^2) + (0.97X_4^2) - (0.07X_1 \times X_3) - (0.02X_1 \times X_4) + (0.42X_2 \times X_3) + (0.01X_2 \times X_4) + (0.50X_3 \times X_4) \quad (4.9)$$

Table 4.6 ANOVA for wear resistance (R) of Al6061/SiC+TiC

Source of variation	**Degree of freedom**	**Sum of squares**	**Mean sum of squares**	***F*- value**	**P- value**
	R	**R**	**R**	***R***	**R**
Regression	14	184139	13152.8	41.08	0
Linear	4	149310	949.9	2.97	0.052
Square	4	33109	8277.2	25.85	0
Interaction	6	1720	286.7	0.9	0.522
Residual Error	16	5123	320.2		
Lack of fit	10	3469	346.9	1.26	
Pure Error	6	1654	275.6		
Total	30	189262			

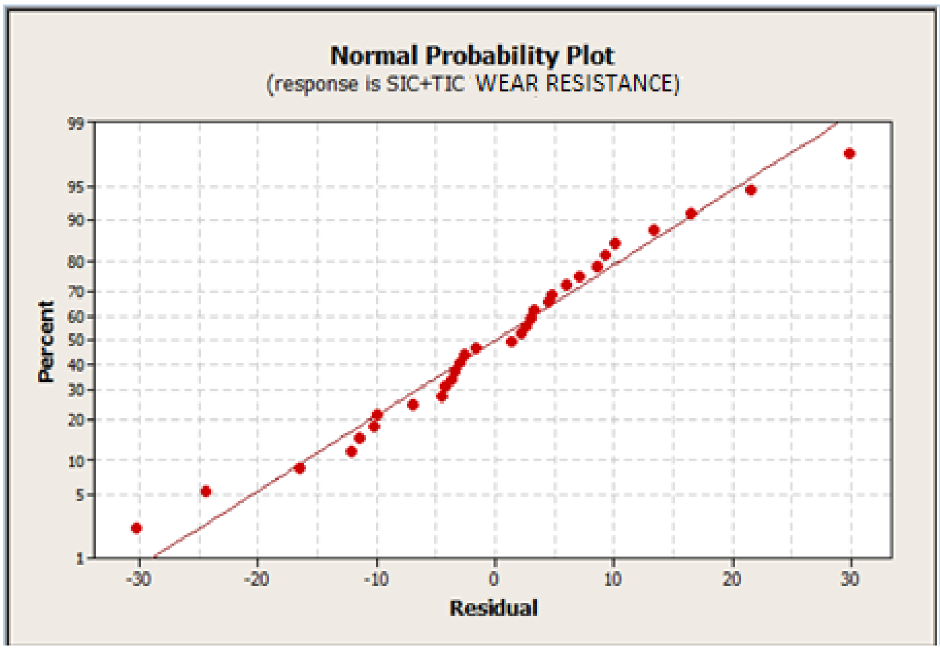


Figure 4.7 Normal probability residuals for wear resistance (R) Al6061/SiC+TiC

The equations 4.8 & 4.9 can be utilized for the estimation of wear rate W and R.

4.6 Validation of the Empirical equations.

To affirm the legitimacy of exact conditions, tests were led. Five set of runs were developed for different process parameters for Al/SiC, Al/TiC and Al/SiC+TiC composites. The results are exposed in table 4.7 to 4.9. The flaws were calculated as ((Experimental value – mathematical model value)/ mathematical model value) X 100. All the results yield the error percentage of (+) or (-) 5%. This confirms the reliability of empirical equations.

Table 4.7 Validation test results for AL6061/SiC composites

SL.NO	N in RPM	S in mm/min	F in KN	P %Wt	Wear rate 'mm^3/m'		Wear Resistance 'm/mm^3'		% error	
					Predicted	Actual	Predicted	Actual	W	R
1	1100	45	6	5	353.74	371.056	280.505	269.501	4.668	4.083
2	1125	55	7	10	294.89	281.656	341.53	355.043	4.699	3.806
3	1175	65	7	15	232.89	235.918	444.687	423.876	1.285	4.91
4	1200	55	5	5	355.54	374.513	278.563	267.013	5.067	4.325
5	1250	45	6.5	10	320.69	337.649	307.995	296.166	5.022	3.994

Table 4.8 Validation test results for AL6061/TiC composites

SL. NO	N in RPM	S in mm/ min	F in	P	Wear rate 'mm^3/m'		Wear Resistance 'm/mm^3'		% error	
			KN	% Wt	Predicted	Actual	Predicted	Actual	W	R
1	1100	45	6	5	386.63	406.7	256.581	245.881	4.935	4.351
2	1125	55	7	10	336.07	321.2	299.459	311.333	4.631	3.814
3	1175	65	7	15	273.66	261.4	376.844	382.555	4.688	1.493
4	1200	55	5	5	389.07	402.54	254.94	248.423	3.347	2.624
5	1250	45	6.5	10	361.56	378.8	273.179	263.992	4.551	3.48

Table 4.9 Validation test results for AL6061/SiC+TiC composites

SL.NO	N in RPM	S in mm/min	F in KN	P %Wt	Wear rate 'mm3/m'		Wear Resistance 'm/mm3'		% error	
					Predicted	Actual	Predicted	Actual	W	R
1	1100	45	6	5	370.07	388.41	268.254	257.46	4.723	4.193
2	1125	55	7	10	314.76	300.193	319.4	333.119	4.851	4.118
3	1175	65	7	15	251.67	254.303	410.554	393.232	1.036	4.405
4	1200	55	5	5	372.07	391.997	266.466	255.104	5.082	4.454
5	1250	45	6.5	10	340.86	358.68	289.566	278.8	4.969	3.862

CHAPTER – 5

OPTIMIZATION OF FRICTION STIR WELDING PARAMETERS

5.1 Introduction

Friction stir welding Machine producers and clients are constantly keen on obtaining better welding quality and higher quality in the welding procedure. The base wear rate in weld locale with wanted quality and insignificant welding abandons make the friction stir welding process less expensive and the welding process more economically feasible and reasonable. However, because of an incredible number of factors and an assortment of materials, ideal welding execution is seldom accomplished. It is important to research how the welding parameters influence the nature of welding. The outcomes will give critical data to accomplish ideal execution in the welding procedure.

Frequently enhancement issues have different destinations. More often than not these targets are clashing (i.e., upgrading one target makes alternate goals be reduced). The GA is a transformative calculation that utilizations hereditary administrators to get ideal arrangements with no suspicions on the subject of the request space. GA works with a masses of achievable game plans and, along these lines, it can be utilized as a part of multi target advancement issues to catch various arrangements all the while (Tadaliko murata) [98]. To locate the agent set of Pareto-perfect arrangements in the earlier decade and past sufficiently GA based multi target enhancement procedures were connected. Evolutionary multi objective optimization (EMO) methods have enough settled their convenience in finding an especially consolidated in addition to all around scattered arrangement of close Pareto ideal solutions for the past 15 years or so. By these investigations and accessible source codes both financially and uninhibitedly, the EMO methodology have been generally connected in different issues comprehending strategies and have acquired a lot of consideration even by the established multi basis interpretation and basic decision making networks. For generation of the Pareto frontier the most widely used method is NSGA-II. The NSGA-II algorithm positions the people in light of predominance.

For keeping decent variety without indicating any extra parameters NSGA-II utilizes elitism and a phenotype swarm correlation administrator (Tadaliko murata) [98].

As seen in the earlier chapters, the present investigation is focused on the friction stir welding of Al6061 composites**,** on the way to observe the influence of tool rotational speed, welding rate, axial force, moreover content of reinforcement particles over technological variables such as wear rate (W) in addition to wear resistance (R). The factors as well as their levels are displayed in the Table 3.2. The use of DOE and regression strategies has empowered to formulate second order polynomial models, which formulate it possible to clear up the vacillation related with each of the mechanical factors examined. Likewise, these models can be utilized for streamlining by which the ideal parameter settings can be gotten for the desired objectives. NSGA-II calculation has been utilized for the streamlining of end processing qualities of Al6061 composites. The goals of the present examination for advancement are minimization of the wear rate (W) moreover maximization of wear resistance (R). An arrangement of non overwhelmed arrangements has been acquired utilizing NSGA-II and as well as can be expected be taken from the available solutions.

5.2 Common procedure of evolutionary multi objective optimization

As expressed some time recently, double objectives in multi target advancement are to locate an arrangement of arrangements as close as conceivable to the Pareto ideal front and at the same time as differing as could reasonably be expected. But the wellness task strategy for various destinations the essential structure of a Pareto based transformative multi target progression resembles that of GA (Suresh. P.V.S et al.)[96]. The stream outline of NSGA-II program can be appeared in Figure 5.1. It begins by means of an irregular starting era. To begin with, the guardians and posterity are consolidated, to shape a string. At the point when the target elements of all strings in an era are computed, the arrangements are characterized into different non overwhelmed fronts.

5.3 NSGA-II algorithm

The steps associated with the arrangement of advancement issue utilizing NSGA-II are compressed as takes after (Jain. N. K et al.)[42].

1. ***Population Initialization*:**

The population shall be instated in light of the issue range and imperatives assuming a few.

2. ***Non Dominated sort*:**

The introduced population will be arranged in view of non-mastery. The quick sort calculation is depicted as beneath

- for every entity p during primary population *P*
- Start *Sp* = 0. This group would include every one of the people so as to be being commanded by p.
- Start *np* = 0. This would subsist the amount of individuals with the purpose of overpower p.
- for every entity *q* in *P*
  - * if *p* commands *q* after that
    - include *q* just before the set *Sp* i.e. *Sp* = *SP* U{q}
  - * also if q overwhelms p next
    - addition the command counteract for *p* i.e. *np* = *np* + 1
- if *np* = 0 i.e. no people overwhelm p. p has a place with the primary front; for singular *p* Set rank of one i.e P*rank* = 1. The primary obverse set refreshed with adding together p towards front one

  i.e *F*1 = *F*1U{q}

  This is finished for each one of the general population on a fundamental level populace P.

  Instate the front counter to one.*i* = 1

  Following can be finished while the i^{th} front can be nonempty i.e. $F_i \neq 0$
- *Q* = 0. The set for securing the general population for $(I + 1)^{th}$ front.

- - for each individual p in front Fi

  * for every individual q in (Sp is the course of action of individuals subjugated by p)

    - *nq* = *nq* -1, decrement the dominance mean individual q.

    - if *nq* = 0 at that point none of the people in the resulting fronts would command q.

  Subsequently set *qrank* = *i* + 1. Revive the set Q with solitary q

  i.e. *Q* = *Q* U *q*.

  - Addition the front counter by one.

  - Now the set Q is the after that front and thus *Fi* = *Q*.

This estimation is better than the principal NSGA since it utilizes the information about the set that an individual command (Sp) and number of individuals that run the individual (np)

3. ***Crowding Distance*:**

Once the non-ruled sort is done the swarming separation is relegated. Since the general population are picked in perspective of rank and swarming separation, each one of the general population in the populace are named a swarming separation esteem swarming separation is doled out front sharp and differentiating the swarming separation between two individuals in different front is vain. The crowing separation is figured as underneath

- For each front Fi, n is the amount of people.

  - instate the detachment to be zero for each one of the general population i.e. Fi(dj) = 0, where j identifies with the jth individual in front Fi.

  - for every target work m

    * Sort the general population in front F_i in light of target m i.e. *I* = *sort* (*Fi*,*m*).

* Assign endless detachment to restrict regards for each individual in

Fi i.e. $I(d1) = \infty$ *and* $I(d_n) = \infty$

* for $k = 2$ to $(n\text{-}1)$

$$I(dk) = I(dk) + \frac{I(k+1).m - I(k-1).m}{f_m^{\max} - f_m^{\min}}$$

I(k).m is the estimation of the m^{th} target capacity of the k^{th} individual in I

The fundamental idea behind the crowing partition is finding the Euclidian division between each individual in a front in perspective of their m goals in the m dimensional hyper space. The general population in the point of confinement are always picked since they have unending partition errand.

4. *Selection*:

Previously the people are arranged in light of non control and with swarming separation relegated; the choice is completed utilizing a swarmed examination administrator (n).

The examination is completed as underneath in view of

(1) Non control rank trick i.e. distinct individuals in front Fi will have their rank as $prank = i$.

(2) crowding distance $Fi(dj)$

. $p <_n q$ if

- $prank < qrank$
- Or if p and q have a place with a analogous front Fi then $Fi(dp) > Fi(dq)$

  i.e. the crowding distance should to be more.

The general population are picked by using a parallel rivalry decision with crowed examination director.

5. ***Genetic Operators*:**

Honest to goodness coded GA's utilization Simulated Binary Crossover (SBX), manager for half breed and polynomial change.

5.1. Simulated Binary Crossover:

Mimicked parallel half and half imitates the twofold mixture found in the paired hybrid saw in nature and is give as underneath.

$$c_{1,k} = \frac{1}{2}\left[(1-\beta_k)p_{1,k} + (1+\beta_k)p_{2,k}\right]$$

$$c_{2,k} = \frac{1}{2}\left[(1+\beta_k)p_{1,k} + (1-\beta_k)p_{2,k}\right]$$

Where c_i,k is the i^{th} child with k^{th} part, p_i,k is the chosen parent and βk (≥0) is an example from an irregular number created having the thickness

$$p(\beta)=\frac{1}{2}(\eta_c+1)\beta^{\eta_c}, if\ 0 \le \beta \le 1$$

$$p(\beta)=\frac{1}{2}(\eta_c+1)\frac{1}{\beta^{\eta_c+2}}, if \beta > 1$$

This circulation can be gotten from a reliably tried unpredictable number u between (0, 1). ηc is the movement list for half and half. That is

$$\beta(u)=(2u)^{\frac{1}{(\eta+1)}}$$

$$\beta(u)=\frac{1}{[2(1-u)]^{\frac{1}{(\eta+1)}}}$$

5.2. Polynomial Mutation:

The polynomial mutation is performed by

$$c_k = p_k + (p_k^u - p_k^l)\,\delta_k$$

Where *ck* and *pk* are child and parent respectively with pk^u being the higher bound on the parent segment, pkl is the lower bound and δk is little assortment which is determined from a polynomial transport by utilizing

$$\delta_k = (2r_k)^{\frac{1}{\eta_m+1}} - 1, \quad \text{if } r_k < 0.5$$

$$\delta_k = 1 - [2(1 - r_k)]^{\frac{1}{\eta_m+1}}, \quad \text{if } r_k \geq 0.5$$

rk is an consistently examined arbitrary number in the vicinity of (0,1) and η_m is mutation distribution index.

6. Recombination and Selection:

The family populace is joined with the present period populace and choice is performed to set the people of the people to come. Since all the past and current best individuals are incorporated the populace, elitism is guaranteed. Population is currently arranged in light of non mastery. The time is filled by each front along these lines until the point that the populace estimate surpasses the present populace measure. In the event that by including each one of the general population in front Fj the masses outperforms N at that point individuals in front Fj are picked in light of their pressing detachment in the plunging demand until the point that the populace estimate is N. The procedure rehashes to produce the resulting eras.

In the present investigation, a non-overwhelmed arranging hereditary calculation, NSGA-II, utilized to advance different exhibitions utilizing the second-order models. The calculation of NSGA-II positioned the people in view of strength. The NSGA-II controls parameters are changed in accordance with acquire the best execution. The parameters utilized are: likelihood of hybrid = 0.9 with circulation list 20, transformation likelihood 0.25, and populace measure 100. It was found that the above control parameter makes better union and scattering of perfect game plans. The 1000 times were made to get the genuine ideal arrangement. For accomplishing better meeting, an era of 1000 is utilized as a part of the investigation. 100 non-commanded arrangements are gotten toward the finish of 1000 era. The 31 out of 100 sets were selected from the 100 non-ruled arrangements. Since none of the courses of action in the non-command set can be totally superior to some other, any of them is the 'better arrangement'. As well as can be expected be chosen in light of individual item necessities, the procedure design should along these lines select the ideal arrangement from the arrangement of accessible arrangements. To have a minimum tool wear rate and maximum wear resistance an appropriate blend of factors were chosen from the 100 non-dominated solutions.

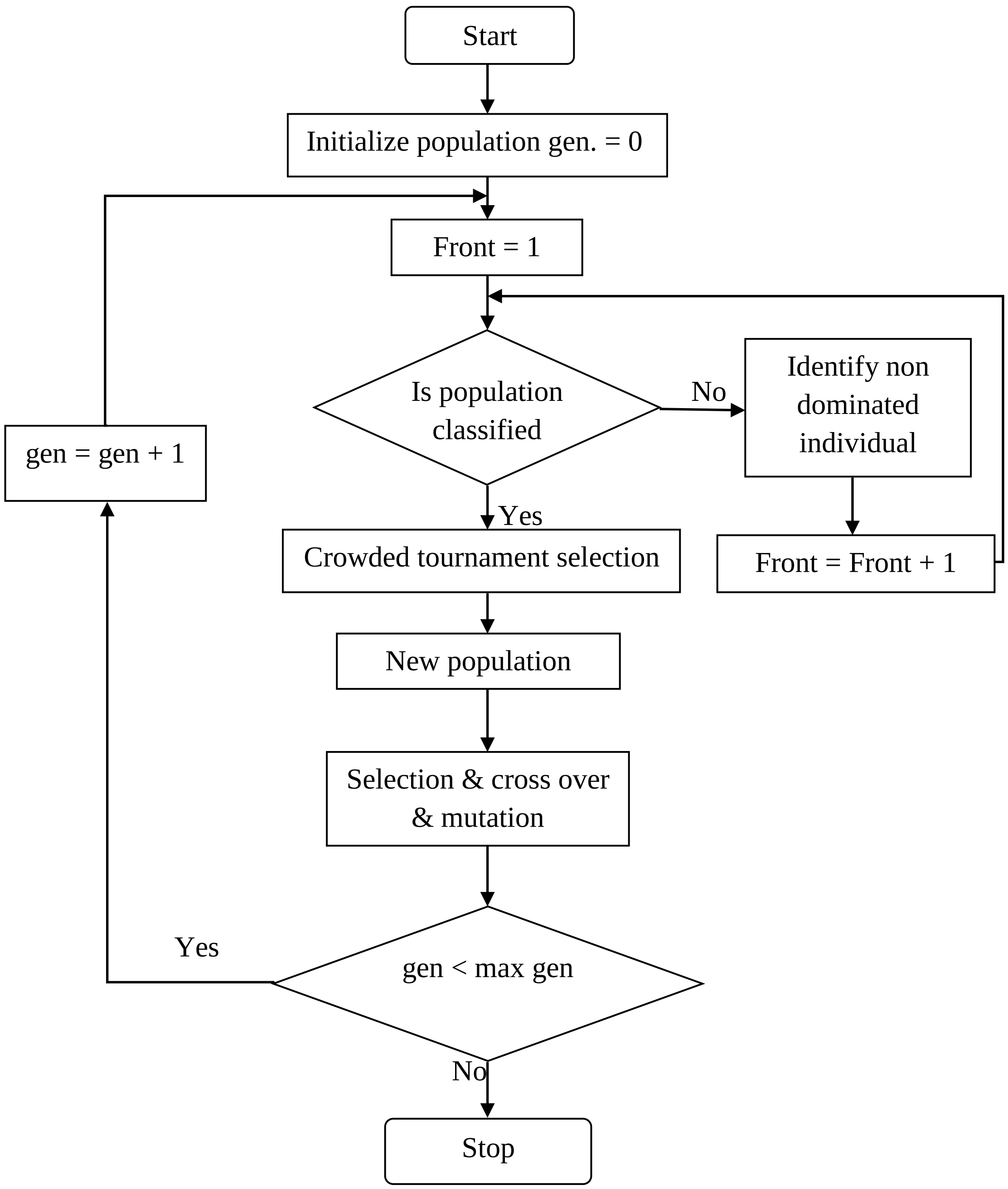


Figure. 5.1. Flow chart for NSGA-II program

CHAPTER – 6

RESULTS AND DISCUSSION

6.1 Introduction

In this research, the investigation is focused on the friction stir welding of $Al6061T_6$ alloy by means of 0%, 5%, 10%, 15% and 20% mass fraction for the reinforcements like silicon carbide (SiC) titanium carbide (TiC) and equal weight percentage 2.5%, 5%, 7.5% and 10% of silicon carbide (SiC) along with titanium carbide (TiC) particulates composites, manufactured by the method of stir casting. The SEM analysis carried out for casting specimens of different weight percentages. A non destructive testing method carried out for checking the quality of composites and friction weld region. The experiments were conducted by means of design of experiments (DOE) as well as regression analysis. The modelling equations are created with the method of response surface design. The contour and surface plots were drawn and the analysis made about the impact of process parameters for wear rate and wear resistance designed for various combinations. RSM and NSGA-II calculation has been utilized for the improvement of friction stir welding process constraints, on the way to acquire minimum wear rate (W) and maximum wear resistance (R). An arrangement of non dominated results has been gotten utilizing NSGA-II and the best result has been taken.

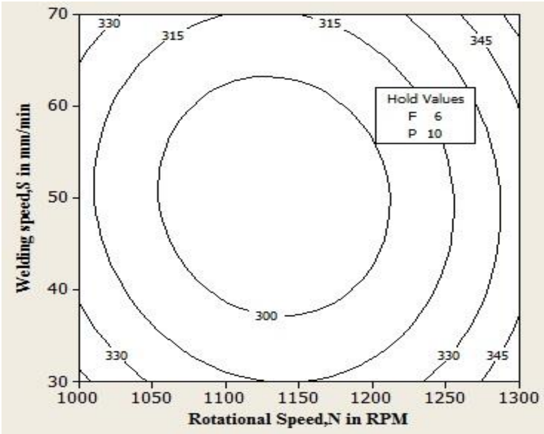
6.2 Analysis of responses for FSW weld region of Al6061/SiC composite

The friction stir welding had been done for Al6061/SiC composite. The thinks about have been made to dissect the impact of the different process parameters on the wear rate (W) and wear resistance (R).

6.2.1 Influence of process parameters for wear rate (W)

From the mathematical models specified through Eq. 4.4.as well as 4.5 created through test perceptions and response surface strategy, ponders have been made to investigate the impact of the different process parameters on the wear rate. The contour plots and surface plots were drawn for different mixes. The number speak to in the plot is wear.

Fig.6.1 and 6.2 demonstrates the impact of tool rotational speed taking place on wear rate of friction stir welded Al6061/SiC composites. The wear rate diminishes as tool rotational speed increments. Additionally increment in tool rotational speed prompts expanded wear rate. Similarly, the wear rate diminishes as welding speed increments additionally increment in welding speed, the wear decrements. Optimum mixing and adequate warmth era is required to create sound joints with fine recrystallized grains. At the point when this condition is accomplished amid welding the joints created will display minimum wear.



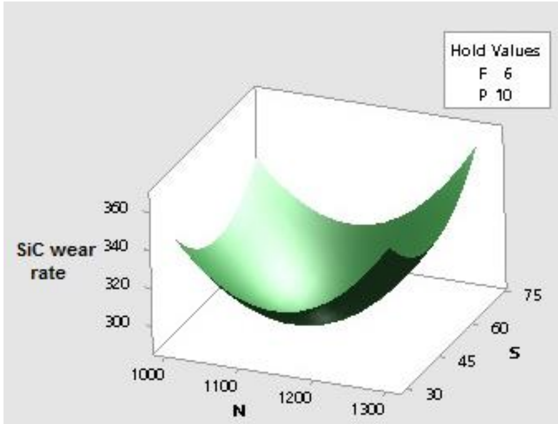


Fig. 6.1 Contour Plot of Wear rate Vs Rotational speed, N in RPM, Welding speed, S in mm/min

Fig. 6.2 Surface Plot of Wear rate Vs Rotational speed, N in RPM, Welding speed, S in mm/min

At minimum rotational speed of the tool the heat production has been low moreover in addition be short of of stirring which leads to high wear rate.(Dinaharan. I et al.) [19]. at higher tool rotational rates the warmth era has been more although discharge too much blended materials. Exorbitant blending causes sporadic stream of plasticized material. Smaller scale level voids show up at higher instrument rotational paces. The frictional warmth produced amid welding influences the grain measure (Karthikeyan, L et al.) [47]. Coarsening of grains happens at higher tool rotational paces which prompts high wear. .(Dinaharan. I et al.) [19]

The welding speed decides the introduction time of this frictional warmth per unit length of weld and along these lines influences the grain development. Ideal introduction time and interpretation of mixed material will prompt great solidification of material with fine grains. Joints experience such condition amid welding will show least wear rate. (Karthikeyan, L et al.) [47].

Fig.6.3 and 6.4 demonstrates the impact of axial force on wear rate of friction stir welded Al6061T6/SiC composites. The wear rate diminishes as axial force increments, additionally increment in axial force, and the wear rate increments. Though, the wear rate diminishes as substance of SiC increments. Additionally increment in substance of SiC, the wear rate additionally diminishes.

Satisfactory axial force surpassing the stream worry of material is required to influence surrender to free joints. Axial force pushes the plasticized material in the weld zone to finish the expulsion procedure. Axial force is additionally in charge of the dive profundity of the pin (Kumar. K et al.) [48].

At the point when axial force increments frictional warmth era additionally increments. Warm is created at bring down axial force which cause improper union of material. Miniaturized scale voids show up at bring down axial force which prompt higher wear rate. The wear rate diminishes with the increase of SiC weight percentage because of expanded nearness of SiC particles in weld zone.

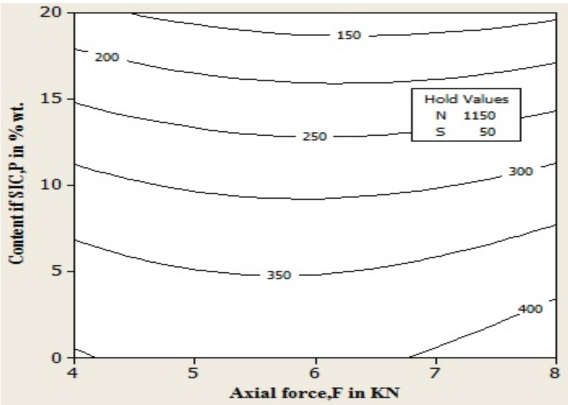


Fig. 6.3 Contour Plot for Wearrate Vs Axial force, F in KN, Content of SIC, P in % wt.

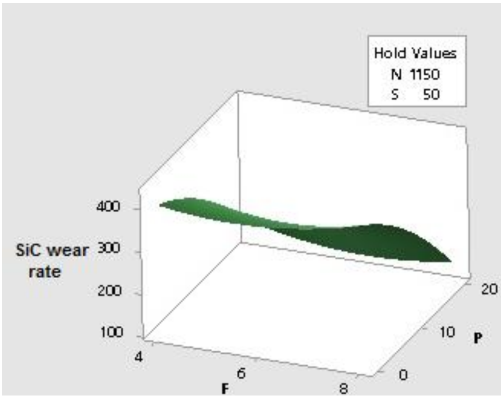


Fig. 6.4 Surface Plot for Wearrate Vs Axial force, F in KN, Content of SIC, P in % wt.

6.2.2 Effect for process parameters lying on wear resistance (R)

Fig. 6.5 and 6.6 demonstrates the impact of tool rotating speed taking place wear resistance for Al6061/SiC composites joined by friction stir welding. The wear resistance raises with the increase of tool rotational speed. Additionally increment inside tool rotating speed prompts diminished wear resistance. Likewise, while the welding speed increases the wear resistance increases. Additionally increment during welding speed prompts diminished wear resistance.

Optimum mixing and adequate warmth era is required to deliver sound joints with very well recrystallized grains. At the point when this condition is accomplished amid welding the joints delivered will show most astounding wear resistance.

The least heat generation can be developed in low speed of tool rotation and also lack of stirring this prompts reduced wear resistance. (Karthikeyan, L et al.) [47]. by the side of upper rotational speeds of tool the developed heat is more but discharge exorbitant blended materials. Over the top mixing causes unpredictable stream of plasticized material. Miniaturized scale level voids show up at higher apparatus rotational paces. The frictional warmth produced amid welding influences in the size of grains. (Dinaharan. I et al.) [19]. Hardening of grain particles happens by the side of higher rotational speed of the tool which prompts low wear resistance. (Karthikeyan, L et al.) [47]

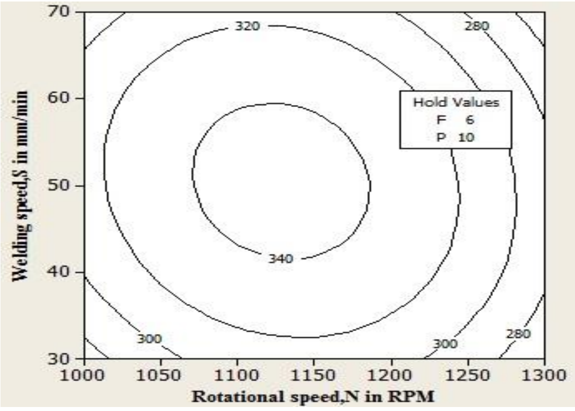


Fig.6.5 Contour Plot of Wear resistance Vs Rotating speed, N in RPM, Welding speed, S in mm/min

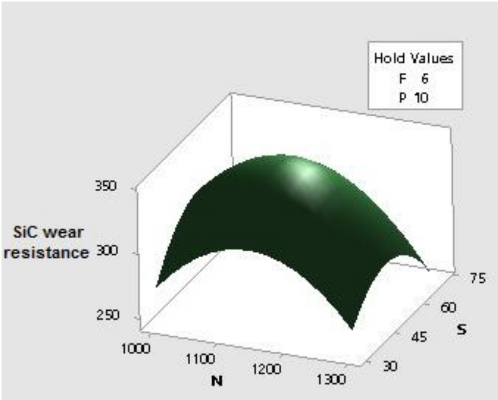


Fig. 6.6 Surface Plot of Wear resistance Vs Rotational speed, N in RPM, Welding speed, S in mm/min

The welding speed clarifies the introduction moment in time of heat due to frictional effect per unit length of weld and accordingly influences the grain development. Ideal presentation time and interpretation of mixed material will prompt great solidification of material by way of fine grains. Joints occurrence such situation amid welding will show elevated wear resistance. (Karthikeyan, L et al.) [47].

Fig.6.7 and 6.8 demonstrates the impact for axial force on top of wear resistance for Al6061T_6/SiC friction stir welded composites. The axial force increases the wear resistance increases. Additionally increment during axial force prompts diminished wear resistance. Though, while the content of SiC increases, the wear resistance increments. Additionally increment into substance of SiC, the wear resistance also increases.

Sufficient axial force surpassing the stream pressure of material be required to influence surrender to free joints. Axial force moves the plasticized material during the weld zone on the way to finish the expulsion procedure. Axial force is likewise in charge of the penetration depth of the pin (Kumar, K et al.) [43].

At the point when axial force increments frictional heat era likewise increments. Poorer heat is produced at bring down axial forces which causes uncalled for solidification of material. Smaller scale voids show up at bring down axial forces which guides towards deprived wear resistance. Higher heat is produced by the side of elevated axial forces which penetrate the tool depth for the welded plate which prompts elevated wear resistance. The increment into wear resistance of welded joints by way of expanded SiC is because of expanded nearness of SiC particles inside the weld region (Ramesh. D et al.) [78].

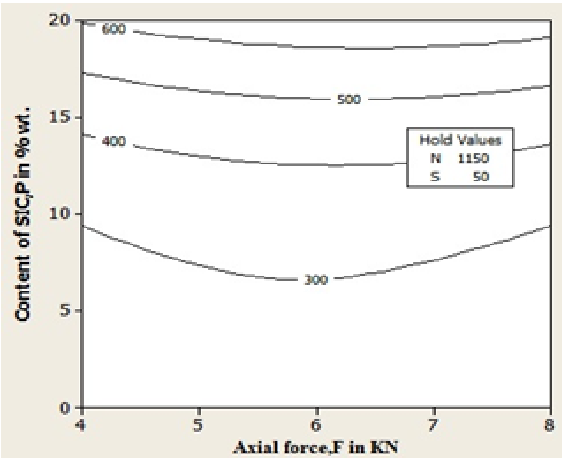


Fig. 6.7 Contour Plot of Wear resistance Vs Axial force, F in KN, Content of SiC, P in % wt.

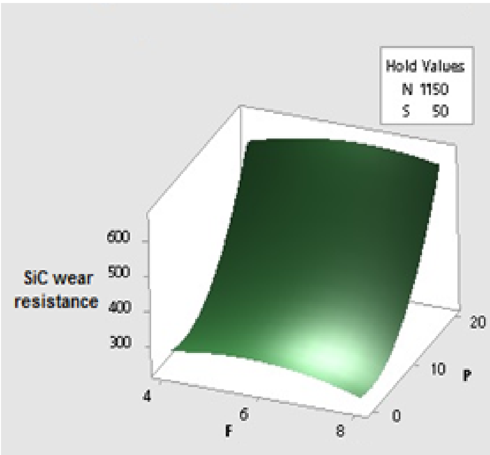


Fig. 6.8 Surface Plot of Wear resistance Vs Axial force, F in KN, Content of SiC, P in % wt.

6.2.3. Optimization of FSW characteristics for Al6061/SiC composite

The second-order response surface equations are given in equations (4.4) & (4.5) is used for correlating the various process variables with the wear rate (W) as well as wear resistance (R) optimality searches can be obtained. For analyzing optimum process parameters RSM and NSGA-II has been carried out.

6.2.3.1 Optimization by Response surface methodology (RSM)

The goal of utilizing RSM can be not exclusively to research the response in excess of the whole factor space, yet in addition to find the area of intrigue where the response achieves its ideal or close optimal esteem. In view of the grew second order response surface conditions for corresponding the different FSW welding process parameters impacts with the wear rate and wear resistance values, the search done for optimality can be achieved. An examination for the optimization for the process parameters has been completed utilizing RSM optimization strategy. Attractive quality for the entire optimization procedure has been computed to demonstrate the achievability of enhancement, i.e. to investigate whether every one of the parameters are inside their working extent or not.

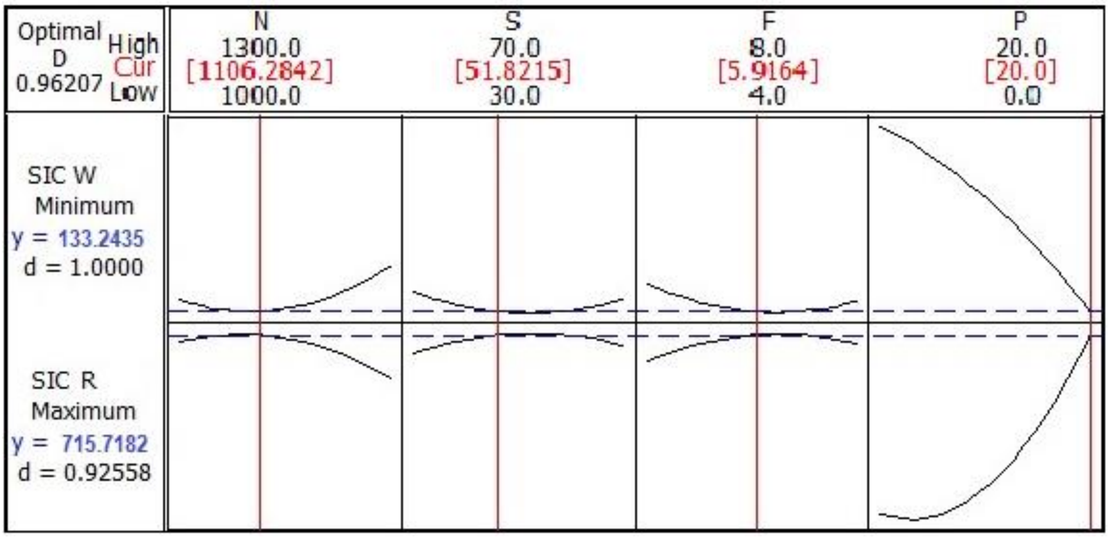


Fig. 6.9 Optimal chart obtained through RSM Al6061/SiC composite

An analysis for the procedure parameters has been completed utilizing RSM optimization system. Attractive quality for the entire procedure streamlining has been figured to demonstrate the achievability of advancement, i.e. to investigate whether every one of the parameters are inside their working extent or not. The objective is to limit the wear rate and boost the wear resistance while both are considered at once. As the composite allure is near one, it know how to be reasoned so as to the parameters are inside their working extent. Improvement plot for the two reactions is shown in fig.6.9 are wear rate (W) = 133.2435 x 10^{-5} mm^3/m and wear resistance (R) = 715.7182 m/mm^3 and the relevant parameters 1106.2842 RPM of rotational speed (N), 51.8215 mm/min of welding speed (S) and 5.9164 KN of axial force (F), and content of silicon carbide (P) 20% respectively.

6.2.3.2 Optimization based NSGA-II for Al6061/SiC

The fig.6.10 demonstrates the development of the pareto-ideal front prompting the last arrangement of answers for Al6061/SiC composites. The 31 out of 100 sets are introduced. In view of the fact that none of the solutions in the pareto-ideal front is totally superior to some other, any of them is a satisfactory solution. The decision of one solution over alternate relies upon the prerequisite of the procedure build. If he requires a minimum wear rate (W) or a maximum wear resistance (R), an appropriate blend of factors can be chosen.

From the trial comes about displayed in table.3.6, the parameters recorded in the test number 24 prompts least wear rate (W) 144 x 10^{-5} mm^3/m and the corresponding wear resistance of 694 m/mm^3, where the 1150 RPM of rotational speed (N), 50 mm/min of welding speed (S), 6 KN of axial force (F), and content of silicon carbide (P) 20% respectively.

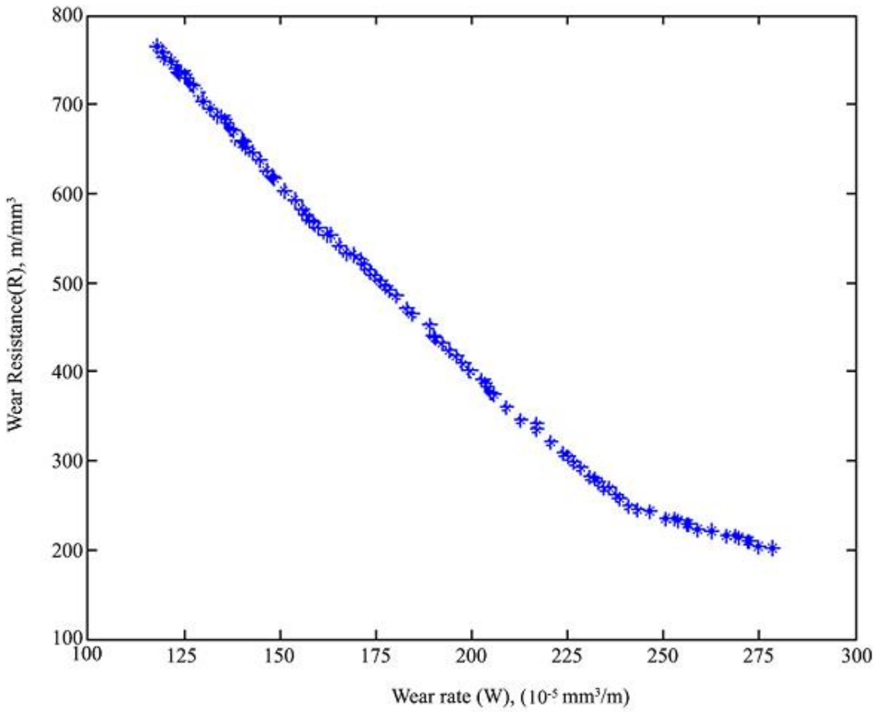


Fig. 6.10 Optimal chart acquired from beginning to end by NSGA-II

By optimizing using NSGA-II, the minimum value of wear rate (w) have be selected beginning the table.6.1, trail no: 15. The wear rate (W) has been 128.101 mm^3/m and the corresponding wear resistance is 718.986 m/mm^3 and the pertinent parameters are 1166.865 RPM of rotational speed (N), 53.619 mm/min of welding speed (S), 5.807 KN of axial force (F), and content of silicon carbide (P) 20%

respectively. The optimized result achieved all the way through RSM was matched up to by way of optimized results achieved via NSGA-II. The wear rate (W) assessment is compared with optimized result gotten through NSGA-II is not as much as RSM. Thus, NSGA-II gives better outcome.

During this investigation, in the wake of deciding the ideal conditions and foreseeing the reactions under these conditions, another trial was composed and directed with the optimum estimations of the friction stir welding parameters. Check of the test comes about at the chose optimum conditions for the instances of wear rate (W) furthermore wear resistance (R) are appeared in table.6.2.

Table 6.1 Optimal combinations of parameters for friction stir welded Al6061/SiC composite

Ex. No.	**Actual factors**				**Wear rate ($\times 10^{-5}$ mm^3/m)**	**Wear resistance (m/mm^3)**
	N in RPM	***S in mm/min***	***F in KN***	***P % of wt.***		
1	1084.462	52.914	7.056	18.925	136.713	666.919
2	1070.765	53.643	6.874	19.289	133.626	684.308
3	1098.087	52.550	6.437	18.561	137.796	648.774
4	1109.016	50.364	6.145	19.472	133.133	683.989
5	1141.803	48.907	6.001	18.743	138.546	645.765
6	1130.874	51.457	5.890	19.357	134.072	673.006
7	1120.675	54.007	6.072	18.957	134.996	669.188
8	1136.338	50.364	5.891	19.107	134.111	661.349
9	1123.675	51.679	5.896	19.675	133.942	688.089
10	1125.918	50.565	5.905	19.191	134.597	661.893
11	1119.340	50.937	6.149	19.219	133.104	671.751
12	1110.720	51.938	6.364	19.453	131.126	685.059
13	1115.341	50.998	6.281	19.494	130.997	686.415
14	1105.851	50.512	6.103	19.094	134.376	667.515
15	**1126.865**	**53.619**	**5.807**	**20.000**	**128.101**	**718.986**
16	1110.723	51.319	6.258	19.645	133.366	693.076
17	1058.969	55.619	6.881	19.754	132.64	705.879
18	1068.265	55.519	7.128	19.881	129.433	711.931
19	1048.956	54.713	7.065	19.901	129.047	713.442
20	1061.314	56.884	6.991	10.901	129.448	712.846
21	1063.88	54.719	7.004	19.969	128.991	716.101
22	1046.983	55.319	7.104	19.976	130.012	709.893
23	1038.419	54.945	6.553	19.997	129.206	717.522
24	1042.439	56.262	7.272	20.000	128.647	718.437
25	1055.427	50.839	7.129	19.854	129.973	717.134
26	1064.831	53.671	6.908	19.900	131.764	709.395

27	1049.674	56.879	7.128	20.000	129.125	712.518
28	1050.547	51.949	7.117	19.997	128.747	716.461
29	1056.790	54.793	7.009	19.899	129.493	713.135
30	1134.340	53.348	6.893	19.999	131.821	704.624
31	1047.947	55.998	7.269	19.796	129.172	718.362

Table 6.2 Validation test results for Al6061/SiC composite

N in RPM	S in mm/min	F in KN	P %Wt	Wear rate 'mm^3/m'		Wear Resistance 'm/mm^3'		% error	
				Predicted	Actual	Predicted	Actual	W	R
1126.865	53.619	5.807	20	128.101	134.502	718.986	743.483	4.996	3.407

The predicted wear rate (W) in addition to wear resistance (R) are compared with the actual wear rate (W) moreover wear resistance (R) and a good agreement was obtained between these friction stir welded properties.

6.3 Analysis of responses for FSW weld region of Al6061/TiC composite

The friction stir welding be conceded out for Al6061/TiC composite. The swot up has been prepared on the way to examine the impact of the different process parameters taking place the wear rate (W) and wear resistance (R).

6.3.1 Impact of process parameters in wear rate (W)

In light of the mathematical models prearranged by Eq. 4.6 as well as 4.7 created all the way through investigational perceptions along with response surface methodology, examines have been completed to break down the impact of the different process parameters for the wear rate as well as wear resistance. The form plots as well as surface plots were drawn in favour of different blends. The number speaks to during the plot be wear rate and wear resistance.

Fig.6.11 and 6.12 demonstrates the impact of rotational speed of on wear rate of friction stir welded Al6061/TiC composites. The wear rate diminishes for rotational speed increments of tool. Additionally increment in rotational speed of tool prompts expanded wear rate. Similarly, the wear rate diminishes as welding speed increments. Increment of welding speed comes about the increase in wear rate. (Dinaharan. I et al.) [19]. optimum mixing along with adequate heat production is compulsory on the way to deliver sound joints by way of fine recrystallized particles.

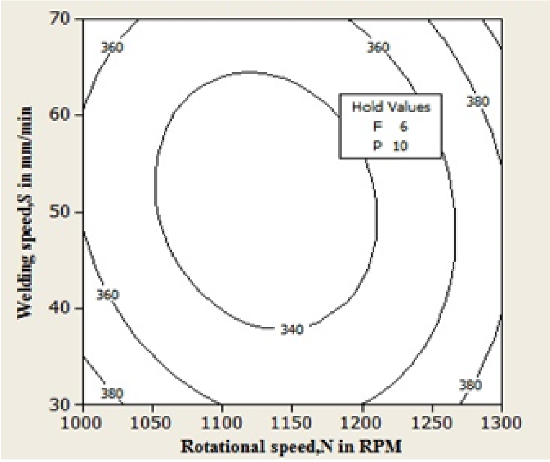


Fig. 6.11 Contour Plot of Wear rate Vs Rotational speed, N in RPM, Welding speed, S in mm/min

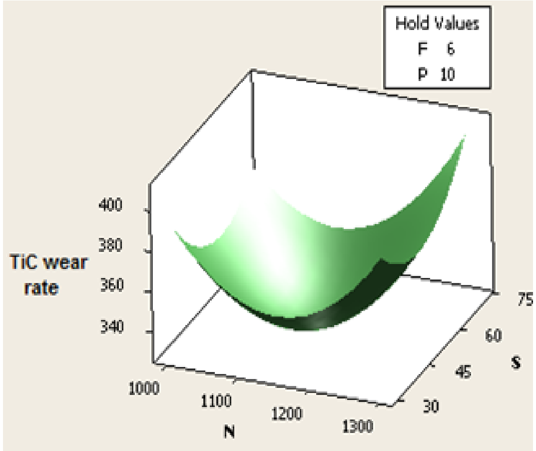


Fig. 6.12 Surface Plot of Wear rate Vs Rotational speed, N in RPM, Welding speed, S in mm/min

By the side of inferior speeds of tool rotation the heat generation can be stumpy and also lack of stirring which leads to high wear rate. (Karthikeyan, L et al.) [47]. by the side of elevated speeds of tool rotation the heat production can be more but discharge unnecessary blended materials. Unnecessary blending causes unpredictable stream of plasticized material. Small scale level voids show up at elevated tool rotational rates. The frictional heat created amid welding influences the grain estimate Kumar, K et al.) [43]. Grain Coarsening happens at elevated tool rotational velocities which prompts high wear. (Karthikeyan, L et al.) [47]

The welding speed decides the contact time for unit length of frictional heat of weld and along these lines influences the grain development. Optimum contact time along with interpretation of blended material will prompt great union of material by way of fine grains. Joints experience for this condition amid welding will display least wear rate.

Fig.6.13 and 6.14 demonstrates the impact of axial force scheduled wear rate of friction stir welded Al6061T6/TiC composites. The wear rate reduced with the increment of axial force, the wear rate increments done with further addition of axial force. Though, the wear rate diminishes as substance of TiC increments. Additionally increment in substance of TiC, the wear rate additionally diminishes.

Satisfactory axial force surpassing the stream stress of material can be obligatory to influence surrender to free joints. Axial force pushes the plasticized material in the weld zone on the way to finish the extrusion process. Axial force is likewise in charge of the pins plunge depth.

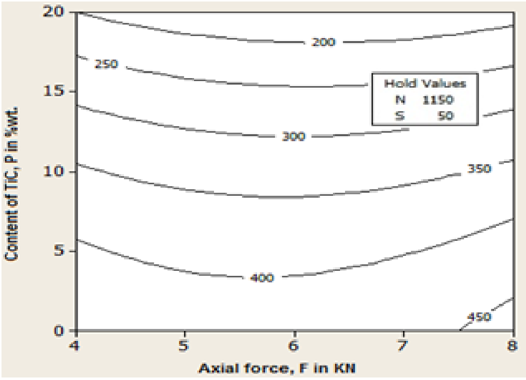


Fig. 6.13 Contour Plot of Wear rate Vs Axial force, F in KN, Content of TIC, P in % wt.

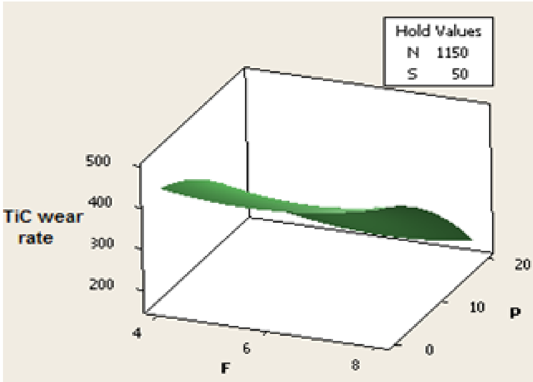


Fig. 6.14 Surface Plot of Wear rate Vs Axial force, F in KN, Content of TIC, P in % wt.

The frictional heat generation raises with the increase of axial force. Poorer heat can be generated by the side of lesser axial forces which causes unseemly material consolidation. In lower axial forces micro voids can appear forces which lead to higher wear rate. When the increase of TiC weight percentage the wear rate can decreases because of expanded nearness of TiC particles in weld zone.

6.3.2 Result for process parameters taking place for wear resistance (R)

Fig.6.15 and 6.16 demonstrates the impact of tool rotational speed taking place on wear resistance of friction stir welded Al6061/TiC composites. The wear resistance boosted due to the increment of tool rotational speed. The wear resistance can be reduced by the way of increase in tool rotational speed. Also, when the welding speed increases the wear resistance increases. The decreased wear resistance can be developed by the way of elevated welding speed.

Optimum blending and adequate heat development is obligatory to create sound joints by way of fine recrystallized grains. At the point when this condition is accomplished amid welding the joints created will show most noteworthy wear resistance.

The heat production can be poor by the side of lesser tool rotational speeds in addition to lack of stirring it can be guides towards reduced wear resistance. By the side of elevated tool rotational speeds the heat generation is more but discharge intemperate blended materials. Over the top mixing causes sporadic stream of plasticized material. Small scale level voids show up at higher rotational speed of tool. The frictional heat created amid welding influences the grain size. Coarsening of grains happens by the side of elevated tool rotational speeds which prompts reduced wear resistance.

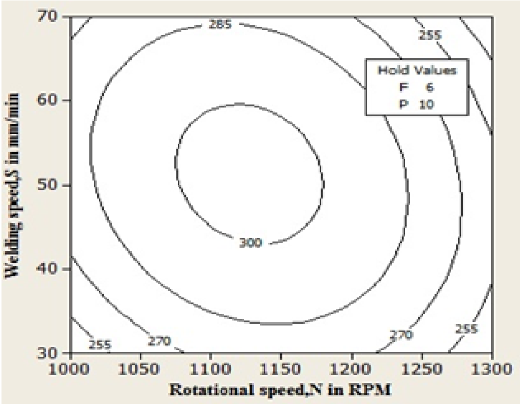


Fig.6.15 Contour Plot of Wear resistance Vs Rotational speed, N in RPM, Welding speed, S in mm/min

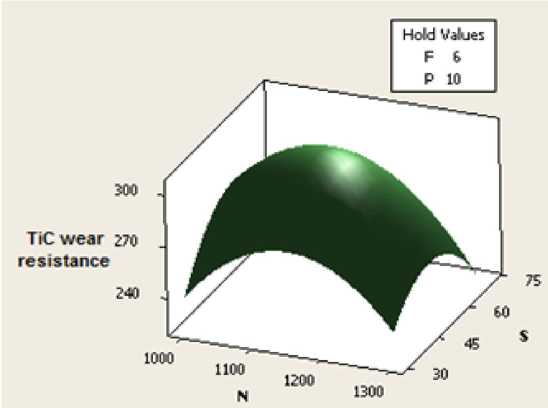


Fig. 6.16 Surface Plot of Wear resistance Vs Rotational speed, N in RPM, Welding speed, S in mm/min

The welding speed decides the presentation time of this frictional heat for every unit length of weld in addition to along these lines influences the grain development. Optimum appearance time and interpretation of blended material will prompt great solidification of material with fine grains. Joints familiarity such situation amid welding will show superior wear resistance. [43].

Fig.6.17 and 6.18 determines achieve of axial force taking place wear resistance for the friction stir welded Al6061T_6/TiC composites. The axial force increases the wear resistance increases. The decreased wear resistance can be developed with the increase of axial force. Whereas, when the content of TiC increases, the wear resistance increases. The wear resistance will increases with the increase of TiC.

Satisfactory axial force surpassing the stream stress of material is required to influence abandon to free joints. Axial force drives the plasticized material in the weld zone to finish the extrusion process. Axial force is additionally in charge of the dive profundity of the pin (Ramesh. D et al.) [78].

At the point when axial force increments frictional heat development additionally increments. Lower heat can be produced at bring down axial force which causes inappropriate union of material. Smaller scale voids show up at bring down axial force which prompts poor wear resistance. Higher heat can be produced at higher axial force which infiltrates the profundity of the tool into the welded plate which prompts higher wear resistance. The increment for wear resistance of welded joints with addition of TiC is because of expanded nearness of TiC particles of the weld region.

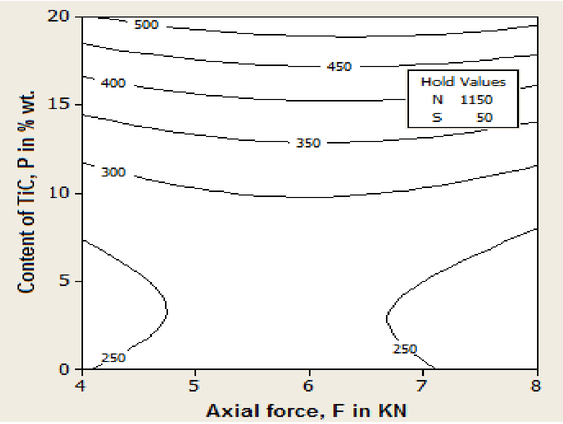


Fig. 6.17 Contour Plot of Wear resistance Vs Axial force, F in KN, Content of TiC, P in % wt.

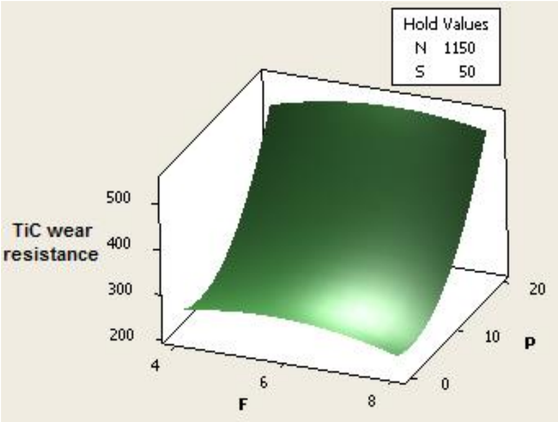


Fig. 6.18 Surface Plot of Wear resistance Vs Axial force, F in KN, Content of TiC, P in % wt.

6.3.3. Optimization of FSW characteristics for Al6061/TiC composite

The second-order response surface equations are given in equations (4.6) & (4.7) is used for correlating the various process variables with the wear rate (W) as well as wear resistance (R) optimality searches can be obtained. For analyzing optimum process parameters RSM and NSGA-II has been carried out.

6.3.3.1 Optimization by the way of Response surface methodology (RSM)

The goal of utilizing RSM isn't just to research the response over the whole factor space, yet additionally to find the district of intrigue where the response achieves its optimum or close optimum esteem. In light of the grew second order response surface equations for connecting the different friction stir welding process parameters impacts for the wear rate and wear resistance values, Optimality inquiry can be gotten. An investigation for the improvement of the process parameters has been done utilizing RSM optimization method. Attractive quality for the entire procedure optimization has been computed to demonstrate the attainability of enhancement, i.e. to investigate whether every one of the parameters are inside their working extent or not.

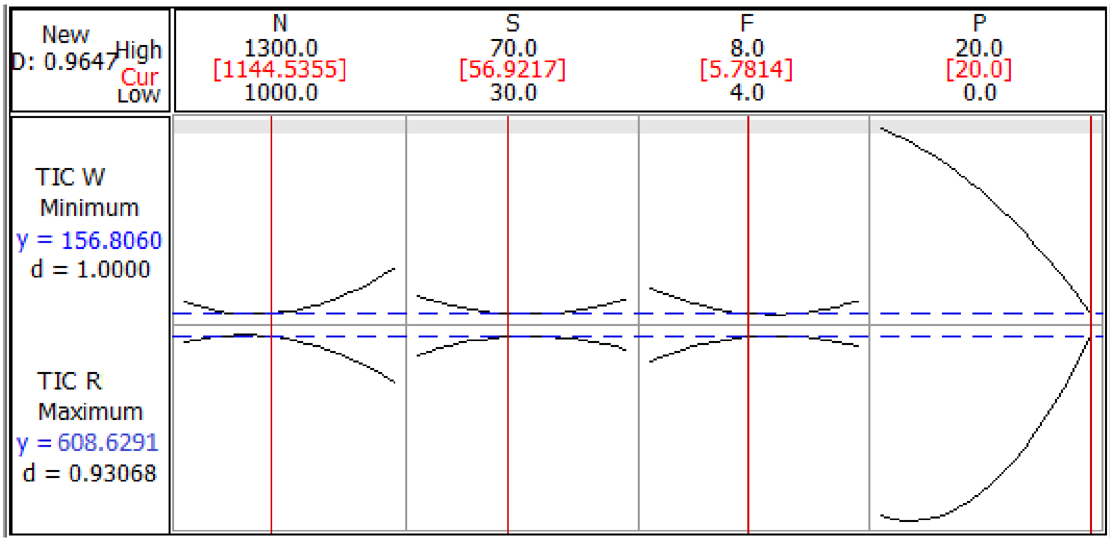


Fig. 6.19 Optimal chart obtained through RSM Al6061/TiC composite

An analysis for the process parameters optimization has been done utilizing the strategy of RSM optimization. Allure for the entire process optimization has been figured to demonstrate the practicality of optimization, i.e. to investigate whether every one of the parameters are inside their working reach or not. The objective is to limit the wear rate and increase the wear resistance at the same time as both are considered at once. When the composite attractive quality is near one**,** it is over and done with that the parameters are contained by their working range. Optimization plot for the both responses can be shown in fig.6.19 are wear rate (W) = 156.8060 x 10^{-5} mm^3/m and wear resistance (R) = 608.6291 m/mm^3 and the relevant parameters 1144.5355 RPM of rotational speed (N), 56.9217 mm/min of welding speed (S), 5.7814 KN of axial force (F), and content of silicon carbide (P) 20% respectively.

6.3.3.2 Optimization based NSGA-II for Al6061/TiC

The fig.6.20 demonstrates the development of the pareto-ideal front prompting the last arrangement of solutions for Al6061/TiC composites. The 31 out of 100 sets are displayed. In view of the fact that not any of the arrangements in the pareto-optimal front is completely superior to some other, any of them is an adequate solution. The solution of one arrangement over alternate relies upon the prerequisite of the process engineer. If he requires a minimum wear rate (W) or a maximum wear resistance (R), an appropriate mix of variables can be chosen.

From the test comes about introduced in table.3.7, the parameters recorded in the trial number 24 prompts least wear rate (W) 179 x 10^{-5} mm^3/m and the corresponding wear resistance of 559 m/mm^3, where the 1150 RPM of rotational speed (N), 50 mm/min of welding speed (S), 6 KN of axial force (F), and content of silicon carbide (P) 20% respectively.

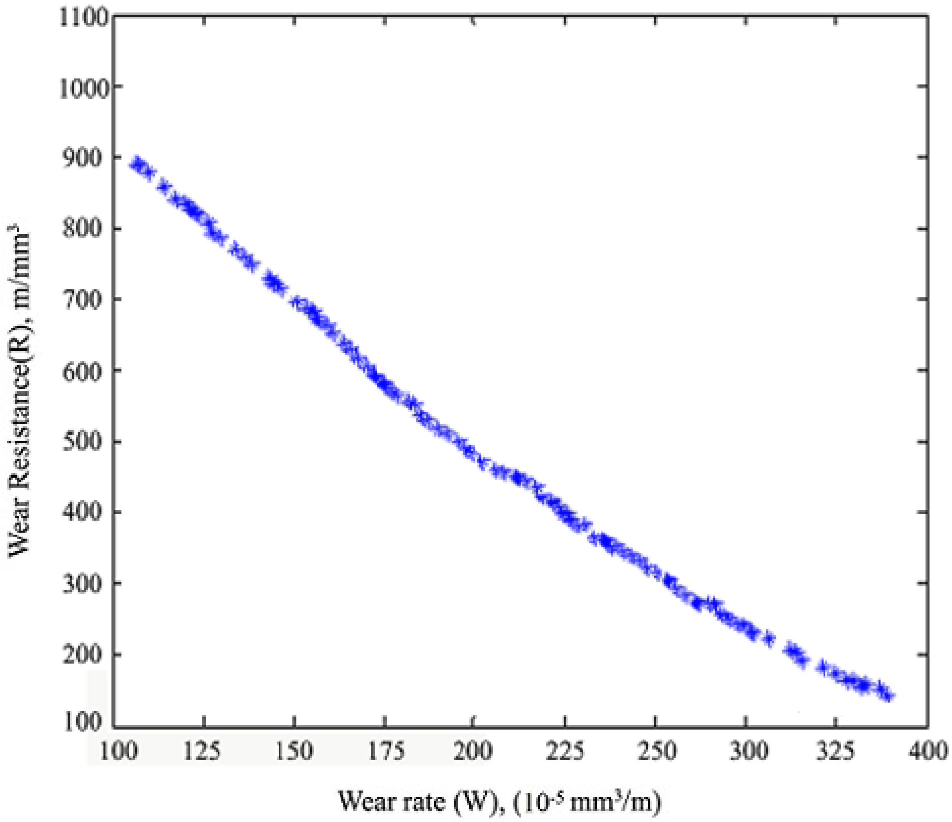


Fig. 6.20 Optimal chart acquired by NSGA-II

By optimizing using NSGA-II, the minimum value of wear rate (w) has been chosen on or after the table.6.3, trail no: 17. The wear rate (W) can be 151.632 mm^3/m and the corresponding wear resistance is 649.879 m/mm^3 and the pertinent parameters are 1131.705 RPM of rotational speed (N), 55.083 mm/min of welding speed (S), 5.797 KN of axial force (F), and content of silicon carbide (P) 20% respectively. The optimized result acquired all the way through RSM was contrasted and upgraded results about got by NSGA-II. The wear rate (W) esteem is compared with optimized result acquired through NSGA-II is not as much as RSM. Thus, NSGA-II bestows better outcome.

In this investigation, in the wake of deciding the optimum conditions and foreseeing the responses beneath these conditions, another trial was composed and led with the optimum estimations of the friction stir welding parameters. Check of the test comes about at the chose optimum conditions for the instances of wear rate (W) along with wear resistance (R) are appeared in table.6.4.

Table 6.3 Optimal combinations of parameters for friction stir welded Al6061/TiC composite

Ex. No.	Actual factors				Wear rate ($\times 10^{-5}$ mm^3/m)	Wear resistance (m/mm^3)
	N in RPM	***S in mm/min***	***F in KN***	***P % of wt.***		
1	1092.13	44.184	6.984	18.431	165.236	581.094
2	1069.33	45.075	6.563	18.997	164.139	575.653
3	1086.16	44.286	6.761	18.981	167.571	568.595
4	1113.44	42.104	6.329	19.121	158.751	599.775
5	1138.29	41.075	6.381	18.101	161.593	589.518
6	1127.65	44.363	6.09	19.345	156.739	626.565
7	1123.34	47.139	6.154	18.643	168.547	566.430
8	1140.66	45.972	6.105	18.927	167.283	570.553
9	1129.949	47.429	5.618	19.569	155.897	631.158
10	1118.824	52.743	6.182	19.238	157.459	604.428
11	1129.008	53.413	6.289	19.318	156.395	614.058
12	1106.328	54.962	6.831	19.518	158.593	621.163
13	1123.487	55.32	6.663	20	154.349	636.577
14	1113.693	56.078	6.236	19.326	155.439	613.219
15	1076.099	59.875	6.703	19.742	157.104	607.191
16	1103.855	57.593	6.317	19.471	156.431	610.067
17	**1131.705**	**55.083**	**5.797**	**20**	**151.632**	**649.879**
18	1075.363	62.617	7.237	19.165	159.219	598.070
19	1054.522	61.861	6.794	19.784	158.371	599.320
20	1069.916	64.118	7.092	18.939	166.459	572.444
21	1056.048	62.165	6.994	19.632	159.231	596.153
22	1042.733	63.161	7.371	18.779	168.829	565.456
23	1048.445	63.091	6.769	19.769	155.992	614.294
24	1051.205	64.864	7.109	20	156.437	646.738
25	1057.903	59.605	6.945	19.762	159.995	593.692
26	1072.065	62.905	7.402	19.769	160.169	592.572
27	1041.414	66.547	6.973	19.385	161.903	588.283
28	1041.817	61.779	7.135	19.457	163.669	583.517
29	1058.968	64.819	6.937	19.598	158.949	598.740
30	1144.736	63.744	6.718	19.928	155.437	632.353
31	1060.165	68.216	7.197	19.459	160.105	594.596

Table 6.4 Validation test results for Al6061/TiC composite

N in RPM	S in mm/min	F in KN	P %Wt	Wear rate 'mm^3/m'		Wear Resistance 'm/mm^3'		% error	
				Predicted	Actual	Predicted	Actual	W	R
1131.705	55.083	5.797	20	151.632	146.739	649.879	681.482	3.227	4.862

The predicted wear rate (W) along with wear resistance (R) are compared with the actual wear rate (W) as well as wear resistance (R) and a good agreement was obtained between these friction stir welded properties.

6.4 Analysis of responses for FSW weld region of Al6061/SiC+TiC composite

The Al6061/SiC+TiC composite plates were butt welded by the method of friction stir welding. The considers have been made to examine the impact of the different process parameters on the wear rate (W) and wear resistance (R).

6.4.1 Process parameters effects taking place for wear rate (W)

By the way of mathematical models prearranged by Eq. 4.8 along with 4.9 created through trial perceptions and response surface methodology, ponders have been made to break down the impact of the different process parameters on the wear rate along with wear resistance. The contour plots moreover surface plots were drawn for different blends. The number speak to in the plot were wear rate and wear resistance.

Fig.6.21 and 6.22 demonstrates the impact of tool rotational speed on wear rate of friction stir welded Al6061/SiC+TiC composites. The wear rate diminishes seeing that tool rotational speed increments. Additionally increment in tool rotational speed prompts expanded wear rate. Similarly, the wear rate diminishes when welding speed increments additionally increment in welding speed, the wear rate also increased. Optimum mixing and adequate heat development can be required to create sound joints by way of fine recrystallized grains. At the point when this condition is accomplished amid welding the joints created will display most elevated wear resistance.

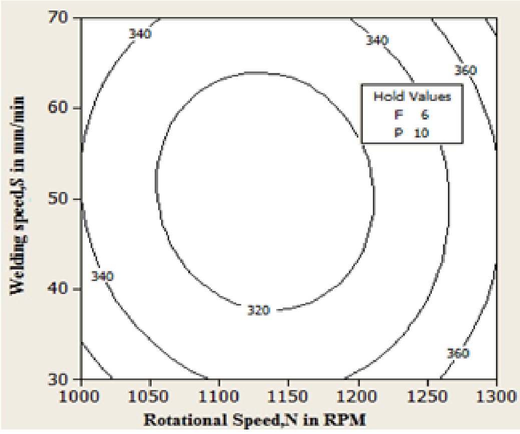


Fig. 6.21 Contour Plot of Wear rate Vs Rotational speed, N in RPM, Welding speed, S in mm/min

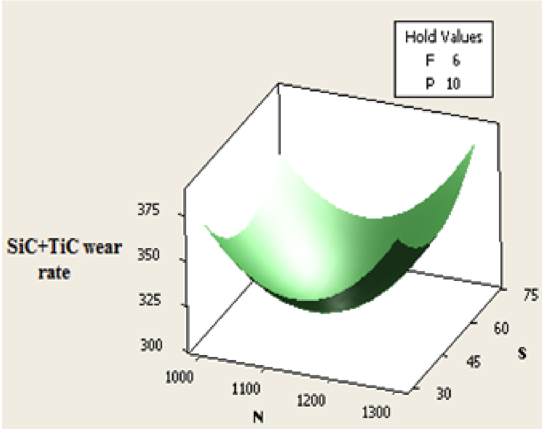


Fig. 6.22 Surface Plot of Wear rate Vs Rotational speed, N in RPM, Welding speed, S in mm/min

The heat generation is poor when tool rotational speeds were least for developing weld joint and also lack of stirring high wear rate can be developed. When the tool rotational speeds were maximum the heat generation is more but excessive stirred materials will be released. Exorbitant blending causes sporadic stream of plasticized material caused by excessive stirring. Smaller scale level voids show up at higher tool rotational paces. The frictional heat created amid welding influences the grain measure (, L et al.) [47]. Coarsening of grains happens at superior tool rotational rates which prompts high wear rate.

The welding speed decides the introduction time of this frictional heat for each unit length of weld with in this manner influences the grain development Optimum presentation time and interpretation of blended material will prompt great combination of material with fine grains. Joints familiarity such condition amid welding will show least wear rate.

Fig.6.23 and 6.24 demonstrates the impact of axial force on top of wear rate of friction stir welded Al6061T6/SiC composites. The wear rate diminishes axial force increments, additionally increment in axial force, the wear rate increments, though, the wear rate diminishes as substance of SiC+TiC increments. Additionally increment in substance of SiC+TiC, the wear rate additionally diminishes.

Satisfactory axial force surpassing the stream stress of material is required to influence absconds to free joints. Axial force drives the plasticized material in the weld zone to finish the extrusion procedure. Axial force is additionally in charge of the pins plunge depth. (Dinaharan. I et al.) [19].

At the point when axial force increments frictional heat generation likewise increments. Lower heat is produced at bring down a axial force which causes ill-advised union of material. Small scale voids show up at bring down axial forces which lead to higher wear rate. The increase of SiC+TiC weight percentage is the reason for decrease in wear rate by way of greater than before presence of SiC+TiC particles inside the weld zone.

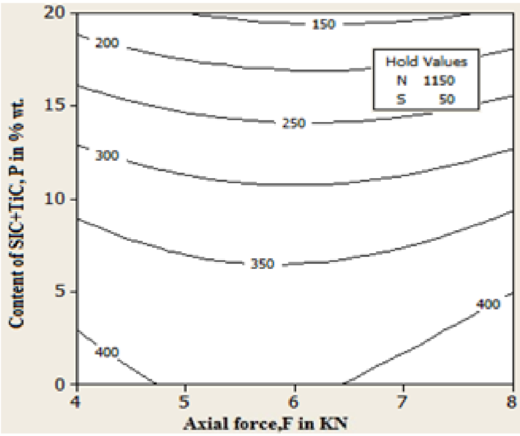


Fig. 6.23 Contour Plot of Wear rate Vs Axial force, F in KN, Content of SIC+TIC, P in % wt.

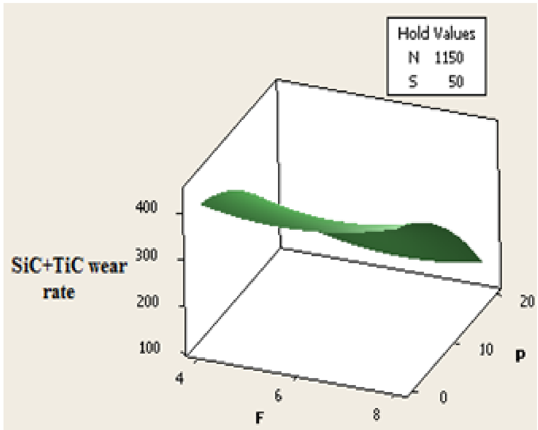


Fig. 6.24 Surface Plot of Wear rate Vs Axial force, F in KN, Content of SIC+TIC P in % wt.

6.4.2 Process parameters causes of wear resistance (R)

Fig.6.24 and 6.26 demonstrates the impact of tool rotational speed on wear protection of friction stir welded Al6061/SiC+TiC composites. The wear resistance increases for the increment of rotational speed of tool. Additional raise of tool rotational speed is the reason for the decrement of wear resistance. Also, when the welding speed increases the wear resistance increases. Increased value for welding speed causes the decrement in wear resistance.

Ideal blending and adequate warmth age is required to create sound joints with fine recrystallized grains. At the point when this condition is accomplished amid welding the joints created will display most noteworthy wear resistance.

The heat generation is low by the side of lesser tool rotational speeds along with also lack of stirring that can be developing the poor wear resistance. For the maximum tool rotational speeds the heat generation is more but discharge too much stirred materials. Extreme mixing creates asymmetrical stream for plasticized material. Miniaturized scale level voids show up at higher tool rotational velocities. The frictional heat created amid welding influences the grain size. Coarsening of grains happens at higher tool rotational speed which prompts deprived wear resistance.

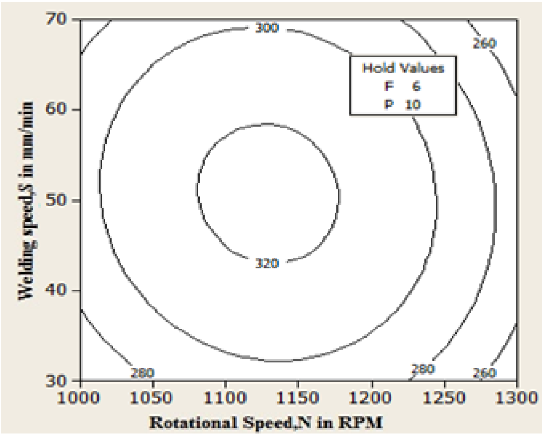


Fig. 6.25 Contour Plot of Wear resistance Vs Rotational speed, N in RPM, Welding speed, S in mm/min

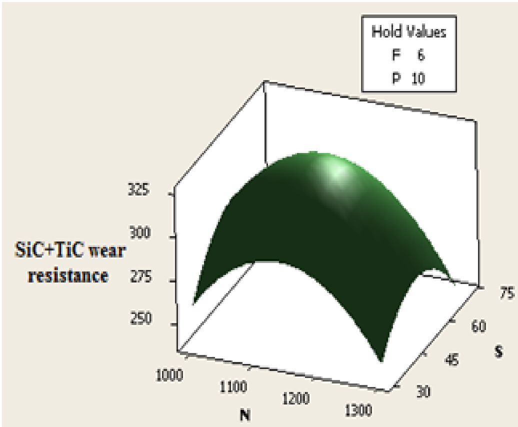


Fig. 6.26 Surface Plot of Wear resistance Vs Rotational speed, N in RPM, Welding speed, S in mm/min

The welding speed decides the presentation time of this frictional heat per unit length of weld and accordingly influences the grain development. Ideal introduction time and interpretation of blended material will prompt great combination of material with fine grains. Joints experience such condition amid welding will show higher wear resistance. (Dinaharan. I et al.) [19].

In Fig.6.27 and 6.28 the cause of axial force happening on wear resistance of friction stir welded Al6061/SiC+TiC composites are shown. The axial force increases the wear resistance increases. The increase of axial force brings the lower wear resistance. Whereas, when the content of SiC+TiC increases, the wear resistance increases. When the content of SiC+TiC added, the wear resistance also increases.

Adequate axial force surpassing the stream stress of material is required to influence dump to free joints. Axial force pushes the plasticized material in the weld zone to finish the Extrusion process. Axial force is likewise in charge of the dive profundity of the pin (Kumar, K et al.) [43].

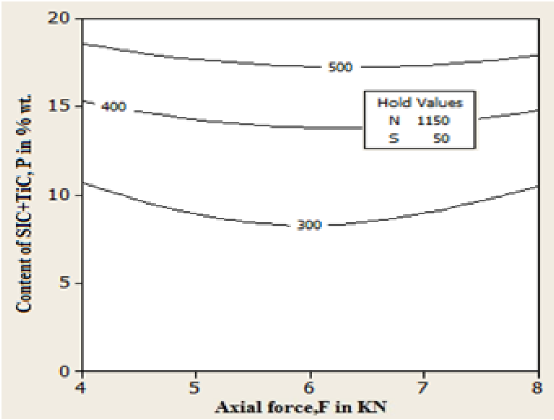


Fig. 6.27 Contour Plot of Wear resistance Vs Axial force, F in KN, Content of SiC+TIC, P in % wt.

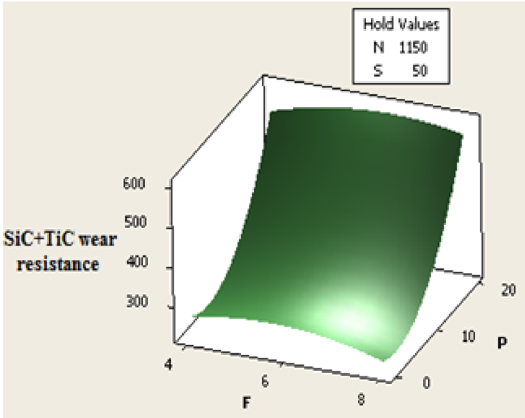


Fig. 6.28 Surface Plot of Wear resistance Vs Axial force, F in KN, Content of SiC+TIC P in % wt.

At the point when axial force increments frictional heat generation additionally increments. Lower warm is produced at bring down pivotal powers which causes inappropriate solidification of material. Miniaturized scale voids show up at bring down axial forces is the reason for poor wear resistance. Higher heat is created at higher axial powers which enter the profundity of the device into the welded plate which prompts higher wear resistance. The increment in wear resistance of welded joints with expanded SiC+TiC is because of expanded nearness of SiC+TiC particles in the weld zone (Ramesh. D et al.) [78].

6.4.3. Optimization of FSW characteristics for Al6061/SiC+TiC composite

The second-order response surface equations be specified here in the equations (4.8) & (4.9) is used for associating the different procedure factors with the wear rate (W) and wear resistance (R) optimality searches can be obtained. For analyzing optimum process parameters RSM and NSGA-II has been carried out.

6.4.3.1 Optimization done by Response surface methodology (RSM)

The objective of using RSM isn't just to explore the reaction over the whole factor space, yet in addition to find the area of intrigue where the reaction achieves its optimum or close optimum esteem. In light of the grew second request reaction surface conditions for corresponding the different grinding mix welding process parameters impacts with the wear rate and wear resistance values, optimality pursuit can be gotten. An investigation for the enhancement of the procedure parameters has been done utilizing RSM improvement system. Attractive quality for the entire procedure enhancement has been computed to demonstrate the plausibility of improvement, i.e. to investigate whether every one of the parameters are inside their working extent or not.

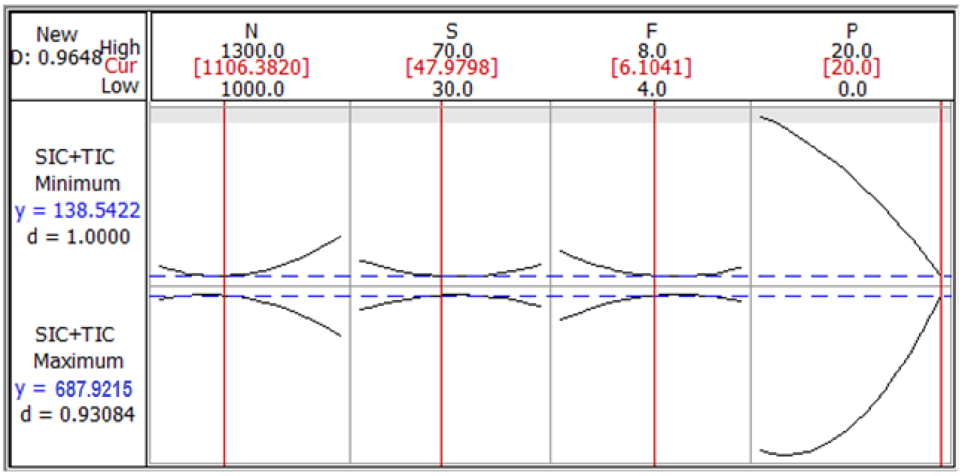


Fig. 6.29 Optimal chart obtained through RSM Al6061/SiC composite

An analysis for the enhancement of the procedure parameters has been done utilizing RSM streamlining strategy. Attractive quality for the entire procedure enhancement has been computed to demonstrate the possibility of streamlining, i.e. to investigate whether every one of the parameters are inside their working extent or not. The objective is to limit the wear rate and boost the wear resistance while both are considered at once. As the composite allure is near one, it can be inferred that the parameters are inside their working extent. optimization plot for the two reactions is shown in fig.6.29 are wear rate (W) = 138.5422 x 10^{-5} mm^3/m and wear resistance (R) = 687.9215 m/mm^3 and the relevant parameters rotational speed (N) of 1106.3820 RPM, welding speed (S) value of 47.9798 mm/min, axial force (F) value of 6.1041 KN, and equal wt.% content of silicon carbide and titanium carbide(P) 10% & 10% respectively.

6.4.3.2 Optimization based NSGA-II for Al6061/SiC+TiC

The fig.6.30 demonstrates the development of the pareto-ideal front prompting the last arrangement of answers for Al6061/SiC+TiC composites. The 31 out of 100 sets are displayed. Since none of the arrangements in the pareto-ideal front is totally superior to some other, any of them is an adequate arrangement. The decision of one arrangement over alternate relies upon the prerequisite of the procedure engineer. If he requires a minimum wear rate (W) or a maximum wear resistance (R), an appropriate blend of factors can be chosen.

From the trial comes about exhibited in table.3.8, the parameters recorded in the analysis number 24 prompts least wear rate (W) 159 x 10^{-5} mm^3/m and the corresponding wear resistance of 629 m/mm^3, where the rotational speed (N) is 1150 RPM, welding speed (S) can be 50 mm/min, axial force (F) value is 6 KN, and content of silicon carbide (P) 20% respectively.

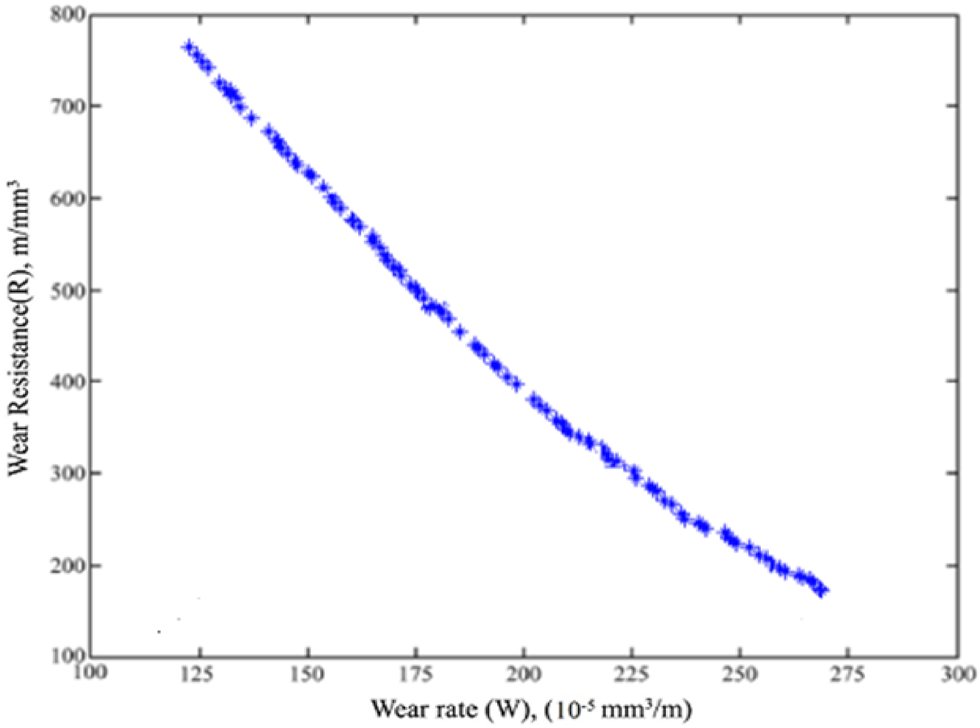


Fig. 6.30 Optimal chart obtained through NSGA-II

By optimizing using NSGA-II, the minimum value of wear rate (W) can be taken from the table.6.5, trail no: 21. The wear rate (W) can be 136.827 mm^3/m and the corresponding wear resistance is 669.492 m/mm^3 and the pertinent parameters are 1136.372 RPM of rotational speed (N), 54.826 mm/min of welding speed (S), 5.904 KN of axial force (F), and content of silicon carbide (P) 20% respectively. The optimized solution developed by the way of RSM was matched up to by means of optimized results got by NSGA-II. The wear rate (W) value is compared with optimized result acquired through NSGA-II is not as much as RSM. Subsequently, NSGA-II gives better outcome.

In this investigation, in the wake of deciding the ideal conditions and foreseeing the reactions under these conditions, another trial was outlined and led with the ideal estimations of the rubbing mix welding parameters. Check of the test comes about at the chose ideal conditions for the instances of wear rate (W) and wear protection (R) are appeared in table.6.6.

Table 6.5 Optimal combinations of parameters for friction stir welded Al6061/SiC+TiC composite

Ex. No.	Actual factors				Wear rate ($\times 10^{-5}$ mm^3/m)	Wear resistance (m/mm^3)
	N in RPM	*S in mm/min*	*F in KN*	*P % of wt.*		
1	1079.183	53.819	6.989	18.874	145.738	604.158
2	1081.179	54.549	6.672	18.975	143.571	608.203
3	1109.162	51.639	6.519	18.882	149.692	623.382
4	1107.382	51.429	6.003	19373	140.643	663.732
5	1934.548	55.382	6.973	18.996	147.713	617.802
6	1128.837	59.348	5.979	19.328	139.953	636.966
7	1119.045	55.397	6.452	18.839	146.485	592.269
8	1213.802	50.294	6.342	19.006	144.796	596.752
9	1093.381	49.382	5.694	19.792	139.794	640.412
10	1128.724	51.318	5.827	19.091	143.591	634.049
11	1121.475	51.938	6.296	19.352	139.311	638.369
12	1128.492	53.427	6.638	19.197	139.023	629.508
13	1174.419	51.469	6.376	20.000	137.154	646.845
14	1104.399	51.336	6.217	19.803	139.416	642.302
15	1071.628	54.279	6.432	19.899	137.217	635.484
16	1127.382	52.428	5.818	19.798	139.405	654.222
17	1097.276	57.361	6.714	19.993	137.132	667.403
18	1072.517	54.658	6.938	19.792	138.424	627.029
19	1056.386	55.473	6.578	19.931	138.305	630.392
20	1059.326	53.956	7.008	18.999	142.647	612.394
21	**1069.647**	**55.237**	**6.974**	**20.000**	**136.827**	**669.492**
22	1179.347	61.547	6.872	19.749	144.102	609.345
23	1083.381	56.376	6.631	19.991	137.117	640.021
24	1129.473	57.548	5.945	20.000	137.923	638.198
25	1134.817	51.572	6.879	19.013	139.633	623.982
26	1119.327	54.726	6.197	19.093	140.485	623.303
27	1057.361	55.728	7.051	19.152	139.788	616.617
28	1101.194	56.294	7.095	19.005	140.822	609.952
29	1127.427	56.251	6.083	19.989	138.378	628.095
30	1131.738	54.534	6.674	19.999	138.267	642.310
31	1092.235	57.417	6.916	19.813	139.200	623.553

Table 6.6 Validation test results for Al6061/SiC+TiC composite

N in RPM	S in mm/min	F in KN	P %Wt	Wear rate 'mm^3/m'		Wear Resistance 'm/mm^3'		% error	
				Predicted	Actual	Predicted	Actual	W	R
1136.372	54.826	5.904	20	136.827	142.639	669.492	701.071	4.248	4.717

The predicted wear rate (W) in addition to wear resistance (R) is compared with the actual wear rate (W) along with wear resistance (R) and a good agreement was obtained between these friction stir welded properties.

6.5 Summary

The composites were stir casted for Al6061T_6 alloy with 0, 5, 10, 15 and 20 weight percentages of silicon carbide (SiC) moreover titanium carbide (TiC) particulates and equal weight percentage of SiC and TiC particulates. Specimen plates prepared for the size 100mm X 50mm X 6mm. plates were butt welded and specimens were extracted from weld region of size 6mm X 6mm X 50mm. RSM, considers have been done to break down the impact of the different procedure factors on wear rate (W) and wear resistance (R). Friction stir welding process parameters have been enhanced by utilizing RSM and Non dominated Sorting Genetic Algorithm (NSGA-II) for minimize the wear rate (W) as well as maximize the wear resistance (R).

1. The impact of various process parameters on contact blend welding execution criteria are shown however shape plots and surface plots of wear rate (W) and wear resistance (R) for Al6061T_6 composites with SiC, TiC and equal weight percentage of SiC & TiC. It can be understandable as of the response contour plots and surface plots, at lower tool rotational speed; wear rate is less extent, when Increase in tool rotational speed, an increment in wear rate is watched which could be because of the creation of heat due to frictional effect between FSW tool and specimen plates. The stirring and mixing are done by tool rotation. Sufficient heat generation and optimum stirring needed for to produce quality joints. In minimum rotational speed wear rate is minimum due to poor stirring. When the stirring speed is more than the optimum level a bulk deposition of reinforcement occurs which leads high wear rate and poor wear resistance.
2. The impact of a range of process parameters taking place friction stir welding performance criteria are exhibited though contour plots and surface plots of wear rate (W) and wear resistance (R) for Al6061T_6 composites with SiC, TiC and equal weight percentage of SiC & TiC. It is clear from the response contour plots and surface plots, at the lower welding speed, translation of tool is influenced by the welding speed which moves the stirred material from front to back and vice versa and completes the welding. Heat generates between

tool shoulder and work piece due to friction. The grain growth affected by frictional heat and exposure time determined by welding speed. Fine grains and good consolidation of material is lead by optimum level of translation of stirred material and exposure time. The higher wear resistance joints developed in optimum level of translation of stirred material and exposure time.

3. The process parameters can be involved on top of friction stir welding performance criteria are exhibited though contour plots and surface plots of wear rate (W) and wear resistance (R) for Al6061T_6 composites with SiC, TiC and equal weight percentage of SiC & TiC. Good bonding occurs in weld region when the surfaces is developed in the close of inter atomic forces. Required axial force exceeding the flow stress of material is needed to develop quality weld joints. The plasticized composite material in the weld region to complete the extrusion process induced by axial force. Penetration depth of pin depend the axial force. Sufficient extrusion and optimum frictional heat required to produce quality weld joints. Frictional heat increases when axial force increases. Improper consolidation of material occurs in lower axial force which leads poor wear resistance also lead for micro voids. Higher axial force will result higher wear rate and poor wear resistance by high frictional heat.
4. In the friction stir welding process parameters performance criteria are exhibited though contour plots and surface plots of wear rate (W) and wear resistance (R) for Al6061T_6 composites with SiC, TiC and equal weight percentage of SiC & TiC. The wear rate decreases with increase of reinforcement particles with excellent wear properties. Wear resistance increases with the addition of reinforcement particles of higher hardness.
5. Optimized results of three different Al6061T_6 composites based on RSM and NSGA-II is given in the Table 6.10. From the table it was found that wear rate (W) value of RSM was compared with NSGA-II. NSGA-II provides lesser wear rate (W) value. Hence, NSGA-II imparts better result.
6. The validation tests were conducted for Al6061T_6 alloy using three different reinforcements. The predicted welding responses were contrasted and the genuine reactions and a decent agreement were gotten between these reactions. It can be watched that the computed blunder is inside the permissible limit is given in Table 6.7.

Table 6.7 Optimum parameters designed for friction stir welding of Al6061 composites

Sl. No	Composite type	Results obtained	Rotational speed, N in RPM	Welding speed, S in mm/min	Axial force, F in KN	Reinforcement, P in wt %.	Wear rate (W) x10^{-5} mm^3/m	Wear resistance (R), m/mm^3
1	Al6061T_6/ SiC	Experimental	1150.000	50.000	6.000	20.000	144.000	694.000
		RSM	1106.284	51.826	5.916	20.000	133.243	715.718
		NSGA-II	1126.865	53.619	5.807	20.000	128.101	718.986
2	Al6061T_6/ TiC	Experimental	1150.000	50.000	6.000	20.000	179.000	559.000
		RSM	1144.535	56.922	5.781	20.000	156.806	608.629
		NSGA-II	1131.705	55.083	5.797	20.000	151.632	649.879
3	Al6061T_6/ SiC+TiC	Experimental	1150.000	50.000	6.000	20.000	159.000	629.000
		RSM	1106.382	47.979	6.104	20.000	138.542	687.921
		NSGA-II	1136.372	54.826	5.904	20.000	136.827	669.492

Table 6.8 Validation test results for friction stir welded Al6061 composites

Sl. No	Composite type	Rotational speed, N in RPM	Welding speed, S in mm/min	Axial force, F in KN	Reinforcement, P in wt %.	Wear rate (W) x10^{-5} mm^3/m			Wear resistance (R), m/mm^3		
						predicted	Actual	%Error	predicted	Actual	%Error
1	Al6061T_6/ SiC	1126.865	53.619	5.807	20	128.101	134.502	4.996	718.986	743.483	3.407
	Al6061T_6/ TiC	1131.705	55.083	5.797	20	151.632	146.739	3.227	649.879	681.482	4.862
	Al6061T_6/ SiC+TiC	1136.372	54.826	5.904	20	136.827	142.639	4.248	669.492	701.071	4.717

CHAPTER - 7

CONCLUSIONS

In this work, RSM and NSGA-II approaches are proposed for selecting the most preferred set of parameters for optimal wear properties on friction stir welding of Al6061T_6/SiC metal matrix composite. The selection criterion for parameters is based on outputs of friction stir welding, namely, wear rate (W) and wear resistance (R). The following can be concluded from the present investigation:

1. Al6061T_6 alloy with 0, 5, 10, 15 and 20 mass percentages of silicon carbide (SiC) and titanium carbide (TiC) particulates composites, and equal weight percentage of SiC and TiC of 2.5, 5, 7.5, and 10 are manufactured through stir casting method. The composites were examined by using non destructive testing method of ultrasonic testing to find the quality of composites and found there are no defects for all combination of composites.

2. Friction stir welding has been carried out for Al6061T_6 composites reinforced with different reinforcement like SiC, TiC and equal weight percentage of SiC and TiC. In the weld region a non destructive testing method of ultrasonic testing was carried to find the quality of weld joint and found there were voids developed for Al6061/SiC weld region 10%, 15% and 20% of reinforcement composites. For Al6061/TiC weld region void developed in 20% of reinforcement composite joints. In AL6061/SiC+TiC weld region void developed in 15% and 20% of reinforcement level.

3. Mathematical models were developed for friction stir welding of Al6061T_6 composites reinforced with different reinforcement like SiC, TiC and equal weight percentage of SiC and TiC for associating the intelligent and higher-arrange impacts of the different process parameters on the dominating welding criteria, i.e. the wear rate (W) and wear resistance (R).

4. The normal probability plot of the residuals designed for wear rate (W) in addition to wear resistance (R) were drawn for Al6061T_6 composites reinforced with different reinforcements like SiC, TiC and equal weight

percentage of SiC and TiC, and observed that the residuals are falling on a straight line, which means that the errors are normally distributed and the regression model is fairly adequate.

5. It is observed that the Welding Speed along with percentage of silicon carbide were bring into being to have greater influence on wear rate (W) and wear resistance (R) in FSW of Al6061T_6 metal matrix composites, followed by Rotational Speed and pressure applied has less influence on wear rate (W) and wear resistance (R).

6. The NSGA-II optimization values of the various Al6061T_6 composites shows that the wear resistance (R) marginally increases with minimum wear rate (W) compared with experimental data. It was found that, when wear rate (W) and wear resistance (R) values of RSM was compared with NSGA-II, NSGA-II provides minimum wear rate (W) and maximum wear resistance (R). Hence, NSGA-II imparts better result.

7. The validation tests were conducted and matched up to with the actual wear properties a fine conformity was attained among these wear properties. It can be observed that the calculated error can be within the permissible limit. It can be watched that the computed mistake is inside as far as possible.

SCOPE FOR FUTURE RESEARCH

1. This research may be extended to study the effects of addition reinforcements on Al6061T_6 alloy. The study will be extended for analyzing the wear properties in weld region for different reinforcements and combination of reinforcements with equal weight percentages.
2. Al6061T_6 composites are developed for alternating of aluminium alloy materials that can perform better with good wear characteristics.
3. Al6061T_6 composites are believed to offer very high strength, hardness, wear resistance, and many new properties that could greatly enhance the joint of the friction stir welding.

   It would be interesting to examine the friction stir welding of Al6061T_6 composites and how the process parameters affect the wear resistance of the weld region and minimize the wear.

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LIST OF PUBLICATIONS / PRESENTATIONS

Publications in International / National Journals:

1. Ommurugadhasan. D, Palaniradja. K, Arokiadass. R., **“Wear Rate Modelling and Analysis of Friction Stir Welding of Al6061 / SIC composite”,** International journal of Mechanical and Production Engineering, Volume 5, Issue 1, January 2017
2. Ommurugadhasan. D, Palaniradja. K, Arokiadass. R.,**” Prediction and Optimization of Friction Stir Welding Parameters of Al6061/TiC Metal Matrix Composites”,** International journal of advances in Mechanical and Civil Engineering, Volume 4, Issue 1, Feb 2017

3. Ommurugadhasan. D, Palaniradja. K, Arokiadass. R., **“Prediction of Wear Rate and Wear Resistance Model on Friction Stir Welded Al6061/SiCp Metal Matrix Composites – RSM Approach”** Advances in Natural and Applied Sciences, Volume 11, Issue 4, April 2017

Presentations in International Conference:

1. Ommurugadhasan. D, Palaniradja. K, Arokiadass. R.,**” Modelling and Analysis of FSW Welded Region Wear of Al6061/TIC Composite”,** National Conference on Research and Development in Science Engineering and Technology.

VITAE

D. Ommurugadhasan is currently working as Associate professor and Head of the Department in St Annes College of Engineering and Technology, panruti.

He received his Master of Engineering in Engineering Design with First Class from Government College of Technology (2005), Coimbatore, Tamilnadu, India and he completed his Bachelor of Engineering in Mechanical Department from Thanthai Periyar Government Institute of Technology, Vellore, University of Madras (2000), Tamilnadu, India.

He has total experience of more than 16 years as Lecturer, Senior lecturer, Assistant Professor and Associate Professor in the Department of Mechanical Engineering at various Colleges like Mailam Engineering College, Easwari Engineering College, Dr.S.J.S. Paul Memorial College of Engineering and Technology and St Annes College of Engineering and Technology. His area of interest includes design related subjects, Material science and Metallurgy. He has guided number of UG project work.

Research interests include Response surface methodology, Taguchi techniques.