

**CHARACTERISTIC STUDY ON DEPOSITION OF ALUMINIUM ALLOY
6063 OVER EN8 MEDIUM CARBON STEEL BY FORCE CONVECTION
MODE FRICTION SURFACING**

Submitted in partial fulfillment of the requirements for the award of

Bachelor of Engineering degree in

Automobile Engineering

By

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DEPARTMENT OF AUTOMOBILE ENGINEERING

SCHOOL OF MECHANICAL ENGINEERING

SATHYABAMA

INSTITUTE OF SCIENCE AND TECHNOLOGY

(DEEMED TO BE UNIVERSITY)

Accredited with Grade “A” by NAAC JEPPIAR NAGAR, RAJIV GANDHI

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MAY-2022



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DEPARTMENT OF AUTOMOBILE ENGINEERING

BONA FIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of DEEPAN.S (Register No.38860003) and GUNA.P (Register No.38860006) who carried out the project entitled “**CHARACTERISTIC STUDY ON DEPOSITION OF ALUMINIUM ALLOY 6063 OVER EN8 MEDIUM CARBON STEEL BY FORCED CONVECTION MODE FRICTION SURFACING**” under my supervision from October 2021 to May 2022.

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We, Deepan S (**Register Number 38860003**), Guna P (**Register Number 38860701**) hereby declare that the project report entitled Characteristic study on deposition of aluminium alloy 6063 over en8 medium carbon steel by forced convection mode friction surfacing done by me under the guidance of Dr. Dillip Kumar Sahoo, M.E.(Ph.D). at Sathyabama institute of science and technology, is submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering degree in Automobile.

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ABSTRACT

The present experimental work investigated the shows the performance criteria regarding material transfer efficiencies of friction surfaced Aluminum alloy 6063 over medium carbon steel substrate. Friction surfacing was carried out by different combination of process parameters and characterization of coating and bonding strength were evaluated. Performance criteria regarding the deposition efficiency, joining efficiency and coating efficiency with respect to primary process parameters were established for the coatings. The mechanical strength of the coating was analyzed by micro hardness, bending and shear test. The microstructural attributes and interfacial characteristics of the coatings were analyzed by using high amplification FE-SEM image, which disseminate the presence of delicate gritty martensitic features at interface. The XRD analysis showed the existence of oxygen, chromium, and cobalt at interface, which indicate the emergence of oxide compounds which leads to acceptable metallurgical bonding between the materials. RSM and ANN methodology is used to optimize the process parameters and the output parameters.

Keywords: Friction surfacing, Micro Hardness, Bending, FE-SEM, XRD, RSM, ANN.

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LIST OF ABBREVIATIONS

FS	FRICTION SURFACING
FC	FORCED CONVECTION
AA 6063	ALUMINIUM ALLOY 6063
ANN	ARTIFICIAL NEURAL NETWORK
SEM	SCANNING ELECTRON MICROSCOPE
XRD	X-RAY DIFFRACTION
SPHA	SUBSTRATE PREHEATING APPROACH
CNC	COMPUTER NUMERICAL CONTROL
VMC	VERTICAL MILLING CENTER
RSM	RESPONSE SURFACE METHODOLOGY
ANOVA	ANALYSIS OF VARIANCE
CT	COATING THICKNESS
CW	COATING WIDTH
BS	BENDING STRENGTH
TS	TENSILE STRENGTH
PSI	POUND-FORCE PER SQUARE INCH

CHAPTER 1

INTRODUCTION

1.1 FRICTION SURFACING:

Friction surfacing (FS) is a solid-state technology with increasing applications in the context of localized surface engineering. FS has mostly been studied to produce fine-grained coatings with outstanding wear and corrosion characteristics. Because no bulk melting occurs, this procedure enables the dissimilar connecting of materials that would normally be incompatible or impossible to deposit using fusion-based methods. Several studies have also highlighted its energy efficiency and minimal environmental effect as important benefits when compared to other alternative technologies. Repair of worn or damaged surfaces by building up or crack sealing are two of the most common uses. It has also been used to improve surface qualities in certain areas of component and tool manufacture. FS has deposited a diverse range of material combinations, primarily alloy and stainless steels. Aluminium, magnesium, and titanium alloys have also been studied, with the goal of producing metal matrix composite.

Starting with a brief introduction, this paper provides a full overview of thermomechanical and microstructural alterations, as well as process modelling methodologies. The material combinations studied thus far, as well as the influence of process factors, are discussed. The key technological and equipment improvements are discussed, including computational optimization models, surface preparation, gas protection, post-processing procedures, pre-heating, and cooling. A comparison of friction surfacing to conventional electric arc, laser, and thermal spraying-based methods is also presented, as with an assessment of the material deposition rate and specific energy consumption. A view on future research and development is presented based on existing process benefits and shortcomings.

Friction surfacing offers tremendous promise for more industrial applications and is being explored as a viable alternative to traditional coating methods. The current review article gives a comprehensive overview of the principles of FS as well as the most recent technological breakthroughs, laying the theoretical and technical groundwork for fresh researchers and industry practitioners looking for novel coating options.

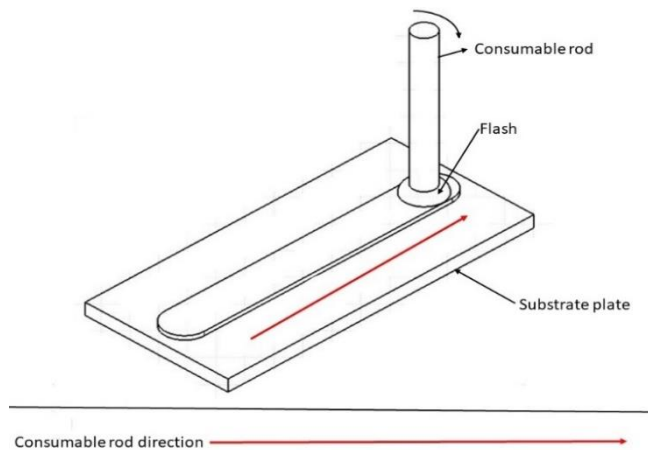


Fig 1.1 Working principle of Friction surfacing model

1.1.1 Four different experimental setups have been developed:

The friction coating was allowed to cool at various pressures, and the inert gas is delivered to the coated face by Pound-force per square inch (psi). The coating was allowed to cool at atmospheric air pressure in the first step, then pressures of 30 psi, 60 psi, and 90 psi were applied and measured in the second stage. The process parametric relationship between aluminium alloy 6063 coated over en8 medium carbon steel by friction surfacing was investigated, and it was discovered that the coating thickness dropped as the coating width rose. Furthermore, both coating qualities become superior at the highest torques.

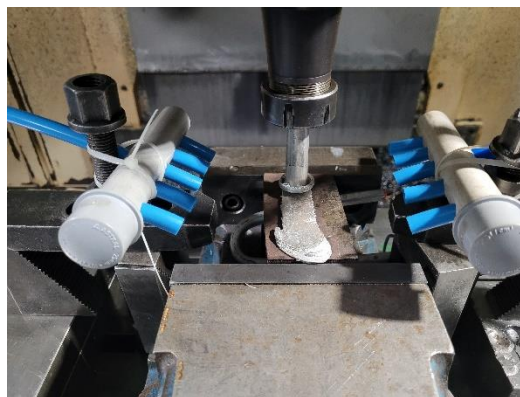


Fig 1.2 Gas nozzle setup for coating area

1.2 OPTIMIZATION PROCESS:

Friction Surfacing has improved fracture toughness, greater wear resistance, higher stiffness, and lesser distortion with fluctuation in operating temperature thanks to its interlocking microstructure. Friction Surfacing is ideal for applications requiring increased specific modulus, strength, creep resistance, corrosion resistance, and

enhanced wear characteristics because of its unique mix of desired qualities. ANN was trained to predict two responses and end as combined into an objective function using weights. Deep learning emerged as an expeditiously growing research field that explores the performance in a wide range of areas like machine translation, image segmentation, speech recognition, and object recognition. Deep learning began from ANN which is a branch of an ML. Most deep learning methods imply the neural network architecture that which some time represented a deep neural network. In this paperwork, the effect of tool rotation speed, Transverse speed, and axial force on the weld produced through FSW were investigated. Friction surfacing coating of aluminium 6063 alloys over medium carbon steel has been done through FSSW. All the parameters are taken at three levels to study the nature of the parameter's effect. Tensile strength has been calculated for the welds generated with a different experimental run. An analysis has been done with the analysis of variance (ANOVA) based Taguchi method to determine the effect of different parameters on the tensile strength of the weld. Taguchi L9 orthogonal array has been used to reduce the number of experiments. The results were analysed by using ANOVA statistical tools. to find the optimum machining conditions to get good high tensile strength. The effect of tool Transverse speed, tool rotational speed, and axial force on tensile strength of AA6063 aluminum joints produced using the friction stir spot welding process was studied. It found that the tool having square profile results in better joint efficiency than the tool having another profile. Artificial neural networks are becoming increasingly relevant in the field of metal processing. This research focuses on computer-assisted ANN models for predicting the tensile and shear strength of tool steel M2 deposits generated by friction surfaces. Due to the limits of the experimental study, the simulation was conducted using the uttermost and at least 33 33-factor configurations of the 23 23-factor signs used in the experimental work. The tensile and shear strength of the friction surfacetoolsteelM2sediments were predicted using a Genetic Approach neural network (GANN). Artificial neural networks (ANNs) may be utilized in a variety of engineering applications to overcome the inadequacies of traditional methods by leveraging input data to acquire essential knowledge. The present work deals with the parameter optimization using the Hybrid Taguchi-Grey relation process and artificial neural network on the successfully coated Aluminium 6063 over EN8 Medium carbon steel.

CHAPTER 2

LITERATURE SURVEY

[1] Voutchkov, I., Jaworski, B., Vitanov, V. I., & Bedford, G. M. (2001). An integrated approach to friction surfacing process optimization. Surface and coatings technology, 141(1), 26-33

This paper discusses the procedures for data collection, management and optimization of the friction surfacing process. Experimental set-up and characteristics of measuring equipment are found to match the requirements for accurate and unbiased data signals. The main friction surfacing parameters are identified and the first stage of the optimization process is achieved by visually assessing the coatings and introducing the *substrate speed vs. force* map. The optimum value from this first stage forms a region around the middle of a trapezium-shaped area whose borders are found experimentally. Data collected for the second stage were analyzed using the least squares method which were applied to find the coefficients of a second order regression model. Advantages of applying artificial intelligence methods to friction surfacing modelling are also described and the higher accuracy achieved using neural networks demonstrated.

[2] Vitanov, V. I., Voutchkov, I. I., & Bedford, G. M. (2000). Decision support system to optimise the Frictec (friction surfacing) process. Journal of materials processing technology, 107(1-3), 236-242.

This paper presents recent work that builds on an earlier paper by the authors, which introduced a novel approach to the selection of the optimum process parameters for friction surfacing, using a combination of rule based and modelling techniques. In the current paper the process optimization is considered as a three-stage process. The first stage involves the optimization of the process parameters required to cause the friction surfacing process to work smoothly and produce a well-formed coating. The experimental methods used to record the process parameters and the methods used to create an interactive database are described. A method of presenting the acquired data in a useful graphical form is explained and is shown to be an integral part in the rapid completion of stage one. The second and third stages, which involve bond strength and the bond strength/coating thickness relationship, are briefly explained in the context of commercial applications.

[3] Vitanov, V. I., Voutchkov, I. I., & Bedford, G. M. (2001). Neurofuzzy approach to process parameter selection for friction surfacing applications. Surface and coatings technology, 140(3), 256-262. Friction surfacing is an advanced manufacturing process, which has been successfully developed and commercialized over the past decade. The process is used for corrosion and wear resistant coatings and for reclamation of worn engineering components. At present, the selection of process parameters for new coating materials or substrate geometries experimentally requires lengthy development work. The major requirement is for the flexibility to enable rapid changes of process parameters in order to develop new applications, with variations of materials and geometries in a cost effective and reliable manner. Further improvement requires development of appropriate mathematical models of the process, which will facilitate the introduction of optimization techniques for efficient experimental work as well as the introduction of real time feedback adaptive control. This paper considers the use of combined artificial intelligence and modelling techniques. It includes a new frame of a Neurofuzzy-model based Decision Support System — FricExpert, which is aimed at speeding up the parameter selection process and to assist in obtaining values for cost effective development. Derived models can then be readily used for optimization techniques, discussed in our earlier work.

[4]Chandrasekaran, M., Batchelor, A. W., & Jana, S. (1997). Friction surfacing of metal coatings on steel and aluminum substrate. Journal of Materials Processing Technology, 72(3), 446-452.

It was found that tool steel and inconel were efficiently deposited onto steel to form a dense strong coating while aluminum was only deposited at high contact pressures. Titanium could not be deposited under the tested conditions. Stainless steel, mild steel and inconel could be deposited onto aluminum substrates to form dense coatings, however only SS displayed a lack of intermetallic compound formation with Al. Melting of Al by frictional heat was observed and this led to the formation of brittle and therefore undesirable intermetallic compounds at the interface of the coating. X-ray microscope investigations of the coatings confirmed that the structure of the coating is a continuous series of discrete layers inclined at a shallow angle to the phase of the substrate.

[5] Chandrasekaran, M., Batchelor, A.W. & Jana, S. Study of the interfacial phenomena during friction surfacing of aluminium with steels. Journal of Materials Science 32, 6055–6062(1997).

Friction surfacing was carried out with stainless steel 304 and mild steel 1020 consumables on to an aluminium 5083 substrate in an argon atmosphere. Mild steel bonded well with the substrate and there was evidence of interfacial compound formation whereas in the case of stainless-steel consumable there was no evidence of mixing and the coating was found to have a rolled structure on the surface. No clear evidence of mechanical interlock was obtained for stainless steel on aluminium. In both cases a nominal contact pressure as high as 21.8 MPa was required to obtain a good coating. For the mild steel coating there was evidence of transfer of aluminium on to the coating and the matrix had a shear crack along the matrix/coating interface.

[6] Rafi, H. K., Ram, G. J., Phanikumar, G., & Rao, K. P. (2010, June). Friction surfacing of austenitic stainless steel on low carbon steel: Studies on the effects of traverse speed. In Proceedings of the World Congress on Engineering(Vol.2).

In this work, the effect of traverse speed on coating characteristics have been investigated for friction surfacing of stainless steel type 310 on low carbon steel. The results show the significance of traverse speed in producing coatings with good bond integrity/interfacial bond strength.

[7] Khalid Rafi, H., Balasubramaniam, K., Phanikumar, G., & Prasad Rao, K. (2011). Thermal profiling using infrared thermography in friction surfacing. Metallurgical and Materials transactions A, 42(11), 3425-3429.

Infrared (IR) thermography was used to measure thermal profiles in the coating, consumable rod, and substrate during friction surfacing. A sudden raise followed by a steady state in thermal profile was observed and attributed to viscous heat dissipation during plastic deformation. The retreating side of the coating experienced higher temperature compared to the advancing side, indicating that the hot plasticized metal is carried from the advancing side to the retreating side.

[8] Vijaya Kumar, B., Madhusudhan Reddy, G., & Mohandas, T. (2014). Identification of suitable process parameters for friction surfacing of mild steel with AA6063 aluminium alloy. *The International Journal of Advanced Manufacturing Technology*, 74(1), 433-443.

The present study is aimed at identifying suitable process parameters for friction surfacing of IS2062 mild steel with AA6063 aluminium alloy and obtain relationships between the input parameters and the process response that can be used for sound coating with adequate strength and ductility. Factorial experimental design technique was used to investigate and select the parameter combination to achieve adequate strength and ductility. Mechatrode rotational speed, axial load and substrate traverse speed was observed to be the most significant factors on the process response.

[9] Nixon, R. G. S., Mohanty, B. S., & Bhaskar, G. B. (2018). Effect of process parameters on physical measurements of AISI316 stainless steel coating on EN24 in friction surfacing. *Materials and Manufacturing Processes*, 33(7), 778-785.

They made an investigation on their present work to obtain the solid-state coating of AISI316 stainless steel over EN24 medium carbon steel by friction surfacing process. Spindle speed, axial force, and table traverse speed were perceived to be the supreme aspects for bonding integrity. It was observed that the depth of the coating (C_t) lessened as the coating width (C_w) increased. The impact of process parameters on physical geometry of the coating was explored by experimentation based on desirability approach. The coefficients of correlation for coating width (0.94) and thickness (0.99) are extremely high. The coatings exhibited martensitic microstructure with fine grain size and without carbide particles which substantiates the effectiveness of good bonding. The optimal process parameters were identified by response surface methodology as 2.26 mm/s of T_s , 7.20 kN of AL , and 1447.17 rpm of RoS and also the output values are observed as $C_t = 2.10$ mm and $C_w = 17.21$ mm.

[10]Govardhan, D., K. Sammaiah, K. G. K. Murti, and G. Madhusudhan Reddy. "Evaluation of bond quality for stainless steel-carbon steel friction surfaced deposits." *Materials Today: Proceedings* 2,no. 4-5 (2015): 3511-3519.DOI:[10.1016/j.matpr.2015.07.327](https://doi.org/10.1016/j.matpr.2015.07.327)

This paper is an attempt to give review details of the variants of friction surfacing techniques, bonding mechanism, factors selection of process parameters to apply on different combinations of materials and confirming the same with experimental test results. Effect of process parameters on the responses like width, height, surface roughness, tensile strength shear strength and ratio of tensile strength and shear strength are discussed in details.

[11]Jujare, T., Kumar, A., Kailas, S. V., & Bhat, K. U. (2014). Friction surfacing of mild steel by copper: a feasibility study. *Procedia Materials Science*, 5, 1300-1307.

This work reports on the feasibility of deposition of copper on the mild steel using friction surfacing method. Commercial mild steel was chosen as the substrate and commercial pure copper as the consumable rod. Friction surfacing was attempted by varying the parameters, namely, rotational speed as 1250, 1500 and 1750 rpm and scan speed as 20, 30 and 40 mm/minute. A constant, 2 kN load was used as axial load. Good deposition was obtained under certain combination of process parameters. Deposition was characterized using optical microscopy, scanning electron microscopy, energy dispersive spectroscopy and x-ray diffractometry. Formation of copper deposit on the mild steel substrate is discussed.

[12] Puli, R., & Ram, G. J. (2012). Corrosion performance of AISI 316L friction surfaced coatings. *Corrosion Science*, 62, 95-103.

In this work, the corrosion behavior of AISI 316L stainless steel coatings made using friction surfacing and manual metal arc welding processes was comparatively evaluated. Friction surfaced coatings exhibited superior general and pitting corrosion resistance compared to manual metal arc coatings, while both the coatings were found to be immune to intergranular corrosion. Compared to alloy 316L bulk material, friction surfaced coatings showed better pitting corrosion resistance, but considerably lower general corrosion resistance.

[13] Li, H., Qin, W., Galloway, A., & Toumpis, A. (2019). Friction surfacing of aluminium alloy 5083 on DH36 steel plate. *Metals*, 9(4), 479.

In this work, friction surfacing (FS) of AA5083 on a DH36 steel substrate was experimentally studied. The process parameters such as rotation speed, travel speed and feed rate are of great significance to the success of the FS process. Seven friction surfaced plates with different combinations of parameters were examined. Optical microscopy, SEM and EDS were used to analyse the characteristics of the microstructure and composition of the interface between the surface and the substrate. The results show that the deposition surface quality decreased as the feed rate, travel speed and axial force increased. However, the bond strength increased with higher feed rate, higher rotation speed and lower travel speed. Elemental diffusion of Fe to AA5083 was established, and the intermetallic compound FeAl_3 was produced in the interface.

[14] Seidi, E., & Miller, S. F. (2021). Lateral friction surfacing: experimental and metallurgical analysis of different aluminum alloy depositions. *Journal of Materials Research and Technology*, 15, 5948-5967.

In this approach, frictional heat and plastic deformation result in deposition of consumable material from the radial surface of a tool onto a substrate. This paper presents a comprehensive assessment of lateral friction surfacing of AA2011, AA6061, and AA7075 aluminum alloys, with particular focus on the impacts of process parameters on the coating properties. The influence of process variables such as tool rotational speeds, normal applied forces, and type of consumable materials was investigated on the process temperature, physical, and metallurgical characteristics of the deposits using optical microscopy, infrared thermography, scanning electron microscopy, and EDS.

[15] Kramer de Macedo, M. L., Pinheiro, G. A., dos Santos, J. F., & Strohaecker, T. R. (2010). Deposit by friction surfacing and its applications. *Welding International*, 24(6), 422-431.

This work will present the state of the art of deposition by means of the friction surfacing process, the influences of the deposition parameters and some applications of the process. In second part, some results for a study being conducted with deposition of three different consumable rods (materials for ABNT 8620, ABNT 4140,

and AISI 310 steel rods) in a substrate of ABNT 1070 carbon steel will be presented, using as deposit parameters a rotational rod speed of 3500 rpm, traverse speeds of 8.5–17 mm/s, and axial pressure of 1.03 and 1.38 MPa. The deposits were characterized by visual analysis, macrograph analysis, micrograph analysis, micro hardness profile, and push-off test. The results so far were considered to be satisfactory, showing that the technique can be employed to repair surfaces of components in high carbon steels and for deposition of similar and dissimilar materials. However, the optimum parameters for the process must still be studied.

[16] Reddy, G. M., Rao, K. S., & Mohandas, T. (2009). Friction surfacing: novel technique for metal matrix composite coating on aluminium–silicon alloy. *Surface Engineering*, 25(1), 25-30.

The present work pertains to the study of wear and corrosion resistance of surface coating of SiC_p reinforced AA 2124 aluminium alloy composite onto the surface of aluminium alloy A356. To improve wear and corrosion resistance of A356 Al–Si alloy, SiC_p reinforced composite was coated on A356 Al–Si alloy substrate by friction surfacing technique. The coating was characterized by metallography, dry sliding wear and potentiodynamic polarization testing. The present study revealed that aluminium alloys could be friction surfaced with metal matrix composites. The coating exhibited excellent wear resistance, which is attributed to the formation of strong metallurgical bond with the substrate. The coating was also found to have adequate corrosion resistance. The study assumes special significance as deposition of metal matrix composites utilizing friction surfacing is reported for the first time.

[17] Reddy, G. M., Prasad, K. S., Rao, K. S., & Mohandas, T. (2011). Friction surfacing of titanium alloy with aluminium metal matrix composite. *Surface Engineering*, 27(2), 92-98.

Present work pertains to investigation carried out on solid state surfacing of titanium alloy Ti–6Al–4V with AA2124SiC_p metal matrix composite by friction surfacing. The coating was characterized by metallography and dry sliding wear. For the first time it was found that titanium alloy could be friction surfaced with metal matrix composites. The surface coating exhibited the wear properties to many-fold than that of the titanium substrate. Significant improvement in the wear resistance of titanium alloy may be attributed to the interdiffusion of elements and the formation of nanocrystalline layer of the alloy at the interface.

[18] Stegmüller, M. J., Grant, R. J., & Schindele, P. (2019). Quantification of the interfacial roughness when coating stainless steel onto aluminium by friction surfacing. *Surface and Coatings Technology*, 375, 22-33.

In this method of using a rotating consumable friction rod supplemented by inductive heating was employed to produce conditions necessary for a sound bond between a stainless steel coating and an aluminium substrate. The rotational speed of and load on the coating rod influenced the bond strength significantly with low rotational speeds and high load values producing a good bond quality; however, cavitations at the coating-substrate interface showed a detrimental effect on the bond quality. Mechanical interlocking could be identified from images of longitudinal cross-sectional slices which were recorded using optical microscopy. An image recognition software tool was used to generate an interfacial roughness profile graph which described the coating-substrate interface. Additional filtering of the profile graph showed the depth of mechanical interlocking of the stainless-steel coating into the aluminium substrate with the degree of this interlocking quantified by roughness values calculated from the profile graph. Large roughness values can be related to high coating push-off strengths (up to 107 MPa), and also were a result of low rotational speeds and high load values during friction surfacing. Dovetail shaped mechanical interlocks identified in the profile produced both high push-off and shear strength when compared with wedge-shaped interlocks; which, overall, provided good shear strengths up to 126 MPa.

[19] Bararpour, S. M., Aval, H. J., & Jamaati, R. (2019). Modeling and experimental investigation on friction surfacing of aluminum alloys. *Journal of alloys and compounds*, 805, 57-68.

In this method AA5083 and AA5052 alloys were utilized as consumable rod and substrate, respectively, in Friction Surfacing (FS) process and a three-dimensional finite element software known as ABAQUS was employed to anticipate the materials thermo-mechanical behavior over this procedure. At that point, in order to investigate the mechanical and microstructures characteristics of the coated samples, the experimental observations and model predictions have been implemented. The results clarified that the strain rate and temperature values are not high at the interface of the substrate and coating layer, also, we observed their maximum values in a layer nearby the upper surface of the coating in the advancing side (AS). Regardless of the irregular

strain rate and temperature profiles, there are no important differences in the microstructure of the materials detected in the center of the cross-sections in the direction of advancing and retreating sides (RS). It should be noted that the grain structure is not influenced by the strain energy effect which is kept in the coating layer all through the FS procedure. Moreover, we can consider the grain structure recrystallization as a contributing factor in improving the material strength of the coating which is anticipated to be proportional to the grain size in reverse.

[20] Sugandhi, V., & Ravishankar, V. (2012). Optimization of friction surfacing process parameters for aa1100 aluminum alloy coating with mild steel substrate using response surface methodology (RSM) technique. Modern Applied Science, 6(2), 69.

This paper focuses on the development of empirical relationship for the prediction of coating width, coating thickness of friction surfaced materials. Experimental part of the study is based on five level central composite designs of three process parameters. To investigate the effects of input parameters on coating width and coating thickness, an empirical relationship is constructed by multiple regression analysis. Optimization of the model is carried out to study the coating width and thickness using design-expert software. Deposit geometry measurements for all the specimens space carried out and compared with the relative impact of input parameters on coating width and thickness to verify the measurement errors on the values of the uncertainty in estimated parameters. The results obtained show that the developed empirical relationship can be applied to estimate the effectiveness of process parameters for a given coating width and thickness.

[21] Anand, K., Barik, B. K., Tamilmannan, K., & Sathiya, P. (2015). Artificial neural network modeling studies to predict the friction welding process parameters of Incoloy 800H joints. Engineering Science and Technology, an International Journal, 18(3), 394-407.

The present study focuses on friction welding process parameter optimization using a hybrid technique of ANN and different optimization algorithms. This optimization techniques are not only for the effective process modelling, but also to illustrate the correlation between the input and output responses of the friction welding of Incoloy 800H. In addition, the focus is also to obtain optimal strength and hardness of joints with minimum burn off length. ANN based approaches could model this welding process of INCOLOY 800H in both forward and reverse directions efficiently, which

are required for the automation of the same. Five different training algorithms were used to train ANN for both forward and reverse mapping and ANN tuned force approach was used for optimization. The paper makes a robust comparison of the performances of the five algorithms employing standard statistical indices. The results showed that GANN with 4-9-3 for forward and 4-7-3 for reverse mapping arrangement could outperform the other four approaches in most of the cases but not in all. Experiments on tensile strength (TS), microhardness (H) and burn off length (BOL) of the joints were performed with optimized parameter. It is concluded that this ANN model with genetic algorithm may provide good ability to predict the friction welding process parameters to weld Incoloy 800H.

CHAPTER 3

AIM AND OBJECTIVE

3.1. AIM:

The main goal of this research is to use friction surfacing to create a very strong parameters such as axial load, traverse speed, rotational speed (RPM), and gas pressure are used to analyse the deposition of aluminium over mild steel. Then there's the strength, microhardness, and corrosion properties to consider.

3.2. SCOPE:

The main goal of this research is to use friction surfacing to create a very strong solid-state coating between en8 mild steel and aluminium alloy AA 6063. Process parameters such as axial load, traverse speed, rotational speed (RPM), and gas pressure are used to analyse the deposition of aluminium over mild steel. Then there's the strength, microhardness, and corrosion properties to consider.

There are several tests to be conducted in the mechanical testing the sample was tested under the condition of bend test, hardness test, and tensile test to find the property of the material and in the microhardness test like SEM image and XRD to find the efficiency of the coating. The composition can be found out using the SEM and XRD whereas the strength can be determined by the Bending and tensile test. The specified inert gas is used at various pressures to get various samples in order to determine the optimal result pressure for this technique (SPHA).

3.3. EXPERIMENTAL METHODOLOGY:

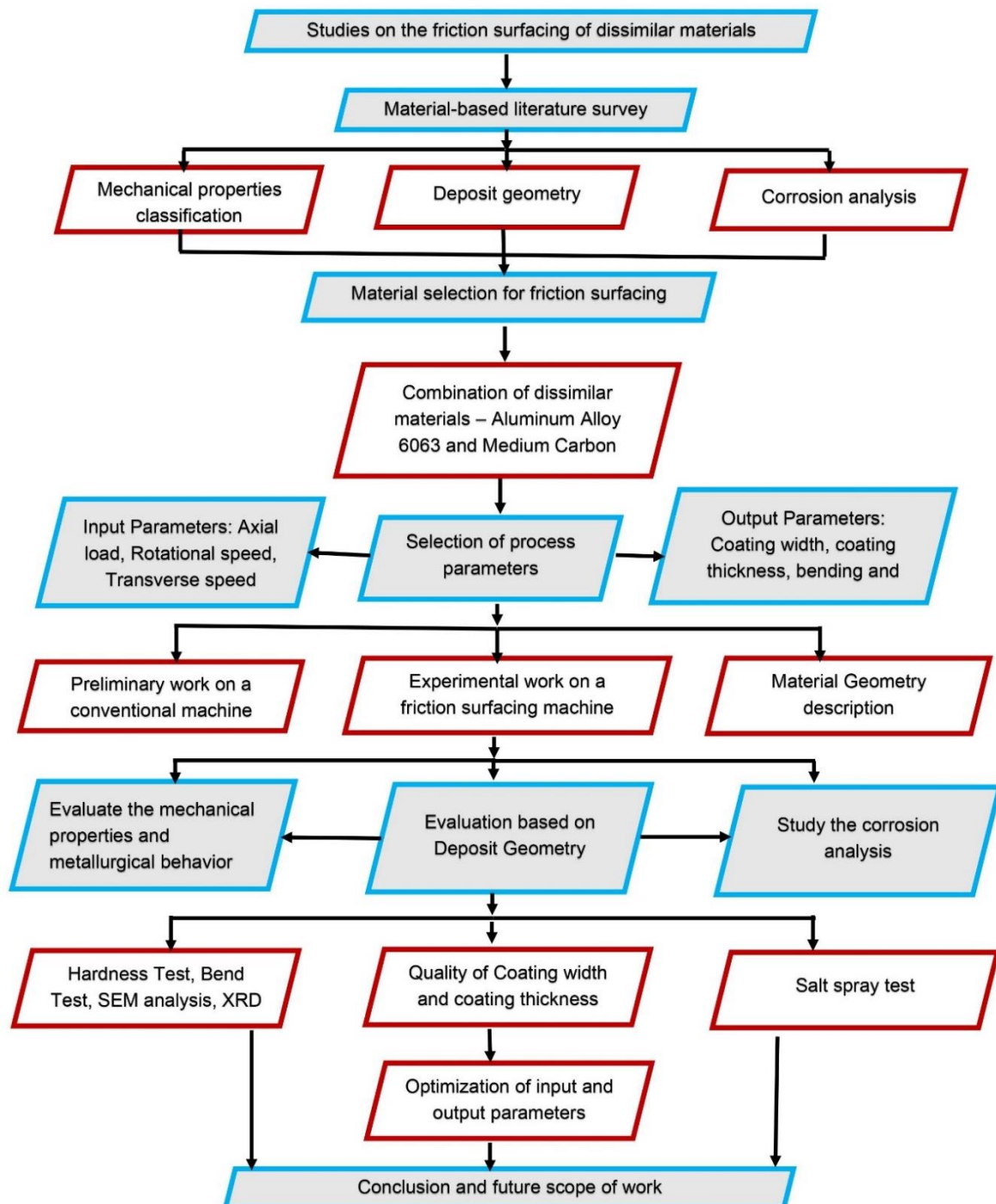


Fig 3.1 Experimental Methodology

CHAPTER 4

MATERIAL AND EXPERIMENTAL PROCESS

4.1. MATERIALS AND METHODS:

The milling machine serves as a friction surfacing machine, allowing the tool to cover the plain surface simply and swiftly. The substrate plate is heated both before and after the procedure with an electric iron heating source. By using programmable coding, the CNC machine applies pneumatic pressure to the substrate plate to coat it. Precipitated hardening aluminum alloy AA6063 was utilized for the coating material, which gives higher strength and corrosion resistance. A revolving rod with a diameter of 18 mm and a length of 100 mm was used for the trials. The testing was carried out on the wrought substrate material EN8, which had dimensions of 150x100x6 mm and provided artificial aging qualities owing to the precipitation hardening impact of the Mn Si partition. The chemical composition of the as-received EN8 carbon steel and AA6063 material is reported.

4.2. MATERIAL PREPARATION:

A consumable rod measuring $\varnothing 19 \text{ mm} \times 100 \text{ mm}$ (AA 6063) and a substrate plate measuring $30\text{mm} \times 6\text{mm} \times 100\text{mm}$ (EN8 medium carbon steel). Then a 750 W electric iron heating coil was employed to protect the substrate plate from touching the milling machine bed. And there's a variable pressure gauge for the gas supply to the process. Before starting the FS process, a milling machine was used to remove a thin layer of 0.5 mm thickness from the substrate material to provide a level and even surface for smooth and close contact with the consumable rod and to prevent oxidation on the substrate surface.

4.3. ALUMINIUM AA 6063:

The alloying components magnesium and silicon make up AA 6063, which is an aluminium alloy. The Aluminium Association maintains the standard that controls its composition. It is heat treatable and weldable and has typically acceptable mechanical qualities. It resembles the British aluminium alloy HE9 in appearance. The alloying elements of 6061 and 6063 are identical. 6061 aluminium contains more silicon, copper, and chromium than 6063 aluminium and can have up to quadruple the iron content. 6061 contains more of each alloying element than 6063 in general.

Magnesium, silicon, chromium, manganese, titanium, zinc, iron, and aluminium are all included in the AA 6063 aluminium alloy. AA 6063 has a good corrosion resistance because of its increased aluminium content.

Table 4.1. Chemical composition of Aluminium alloy AA 6063

Material	Mg	Si	Cr	Mn	Ti	Zn	Fe	Al
% Of composition	0.56	0.47	0.1	0.1	0.1	0.1	0.35	Balance

4.4. EN8 MEDIUM CARBON STEEL:

EN8 is an unalloyed medium carbon steel that is used in applications that demand better qualities than mild steel but don't justify the purchase of a steel alloy due to expense. By using flame or induction hardening techniques, EN8 may be heat treated to provide an excellent surface hardness and moderate wear resistance. Because of the thermo-mechanical rolling process, EN8: unalloyed medium carbon steel has a higher strength than regular bright mild steel. EN8 is a high-strength steel that may be used for a wide range of technical applications.

Shafts, studs, bolts, connecting rods, screws, and rollers made of EN8 and EN24 steel are widely used in the vehicle industry, however, they have poor corrosion resistance. The EN8 medium carbon steel contains carbon, manganese, phosphorus, sulphur, silicon, nickel, and iron.

Table 4.2. Chemical composition of EN8 medium carbon steel

Material	C	Mn	P	S	Si	Ni	Fe
% Of composition	0.35	0.60	0.05	0.05	0.11	0.01	Balance

Before beginning the operation, the mild steel was cleaned with a cutting tool in the friction surfacing machine to eliminate any early rust particles. The plate was then secured in the VMC machine, and the process's beginning and finishing positions were coded in the machine.

4.5. SUBSTRATE PREHEATING (SPHA):

In this experimental study, an induction unit (5 kW output power) was employed to preheat the substrate plate. The substrate temperature was maintained at the constant of 200°C which is nearly equal to the recrystallization temp of aluminium 6063. After preheating the substrate, the aluminium rod was passed onto the substrate with downward axial force. The preheating time for carbon-steel substrate was approximately 80 secs and the initial dwell time was around of 12 secs before the commencement of transverse speed.

4.6. INERT GAS SUPPLY:

In this method, the nitrogen gas N₂ is employed as the inert gas. The connecting pipe is linked to the gas cylinder and then to the pressure regulator so that the pressure differential in the setup may be varied while the coating process is in progress. There were four distinct pressures used: 0 psi, 30 psi, 60 psi, and 90 psi.

4.7. FRICTION SURFACING PROCESS PARAMETERS:

Table 4.3. Process parameters

FACTORS	LEVEL		
Samples	1	2	3
Rotational Speed (R.P.M)	2000	2500	3000
Axial Force (KN)	4	5	6
Traverse Speed (mm/min)	75	150	225



Fig 4.1. STM Vertical milling machine

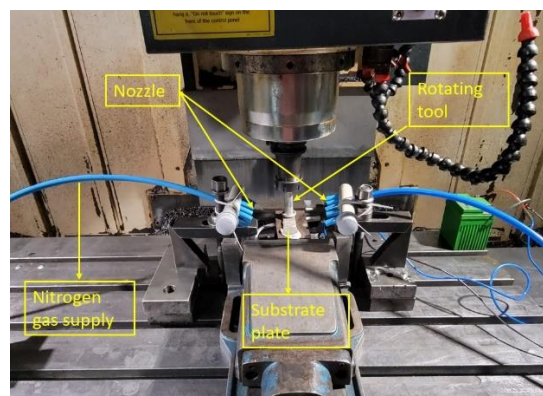


Fig 4.2. Experimental setup image FS process

4.8. MODELLING DIAGRAMS:

The Catia program was used to create the model of the setup. The air passage holes were made to a diameter of 6mm, with 8mm between each gap and an air passage count of 8. The graphic was developed to differentiate the four parametric utilized in the forced convection approach. The setup was 40 mm from the point of contact, and the procedure was carried out without any pressure at first, then with three distinct types of pressure applied at 30 psi, 60 psi, and 90 psi. Nitrogen is essential in the production of stainless steel.

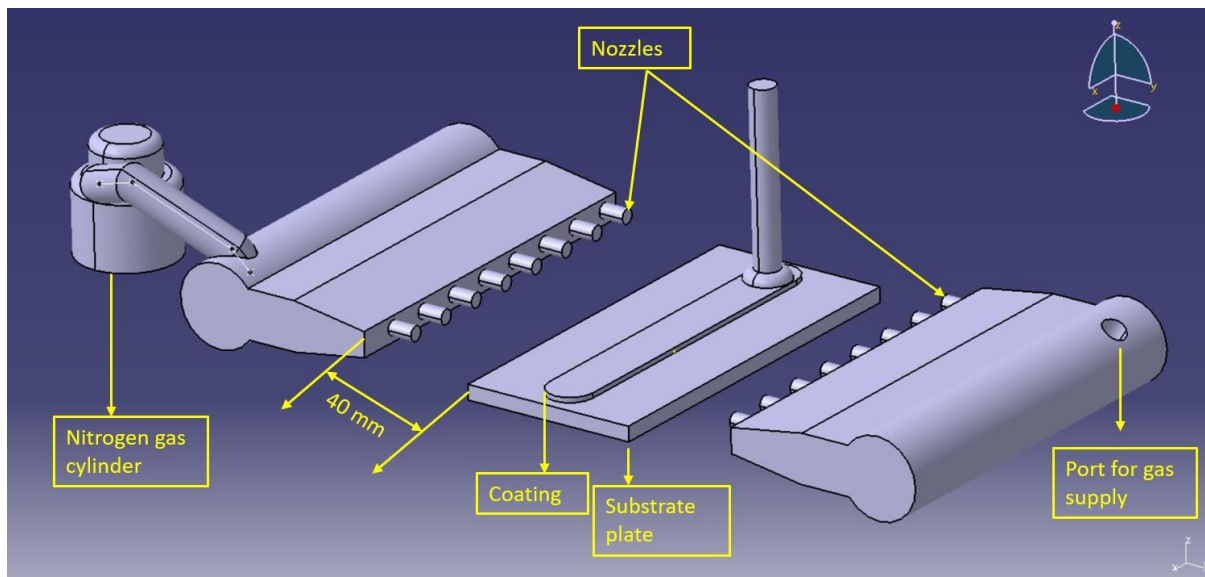
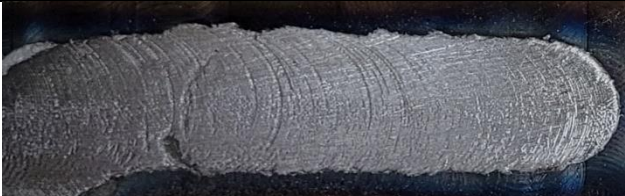


Fig 4.3. Software modeling for Friction surfacing process

4.9. COATING CHARACTERIZATION:

Table 4.4. Specimens derived from various parametric combinations

Parameters	Specimens	Observation
A=4 B=2000 C=75		No cracks were observed
A=4 B=2500 C=150		No cracks were observed
A=4 B=3000 C=225		No cracks were observed
A=5 B=2000 C=150		No cracks were observed
A=5 B=2500 C=225		No cracks were observed
A=5 B=3000 C=75		No cracks were observed
A=6 B=2000 C=225		No cracks were observed
A=6 B=2500 C=75		No cracks were observed
A=6 B=3000 C=150		No cracks were observed

Whereas the A is defined as the axial force, the B is defined as the rotational speed of the spindle, and the c is defined as the traverse speed.

4.10. COATING PARAMETERS:

Table 4.5. Forced convection at 0 psi

Sample no.	Axial force (KN)	Rotational speed (R.P.M)	Transverse speed(mm/min)	Substrate Temperature (°c)	Coating Width (mm)	Coating Thickness (mm)	Temperature (°c)
A1	4	2000	75	200°c	22.74	1.85	450°c
A2	4	2500	150	200°c	23.35	1.64	480°c
A3	4	3000	225	200°c	21.33	1.79	528°c
A4	5	2000	150	200°c	24.16	1.95	460°c
A5	5	2500	225	200°c	24.25	2.33	477°c
A6	5	3000	75	200°c	24.22	1.97	498°c
A7	6	2000	225	200°c	24.29	1.90	470°c
A8	6	2500	75	200°c	20.60	2.40	544°c
A9	6	3000	150	200°c	21.67	2.33	580°c

Table 4.6. Forced convection at 30 psi

Sample no.	Axial force (KN)	Rotational speed (R.P.M)	Transverse speed(mm/min)	Substrate Temperature (°c)	Coating Width (mm)	Coating Thickness (mm)	Temperature (°c)
B1	4	2000	75	200°c	23.17	1.54	460°c
B2	4	2500	150	200°c	22.03	2.44	480°c
B3	4	3000	225	200°c	21.65	2.47	540°c
B4	5	2000	150	200°c	20.60	1.88	499°c
B5	5	2500	225	200°c	23.22	1.69	550°c
B6	5	3000	75	200°c	21.11	1.72	499°c
B7	6	2000	225	200°c	20.45	1.55	440°c
B8	6	2500	75	200°c	23.40	2.22	499°c
B9	6	3000	150	200°c	22.12	1.77	550°c

Table 4.7. Forced convection at 60 psi

Sample no.	Axial force (KN)	Rotational speed (R.P.M)	Transverse speed(mm/min)	Substrate Temperature (°C)	Coating Width (mm)	Coating Thickness (mm)	Temperature (°C)
C1	4	2000	75	200°C	21.20	2.02	466°C
C2	4	2500	150	200°C	22.61	2.33	488°C
C3	4	3000	225	200°C	22.47	1.86	528°C
C4	5	2000	150	200°C	20.90	1.66	470°C
C5	5	2500	225	200°C	21.36	2.37	504°C
C6	5	3000	75	200°C	21.09	2.33	560°C
C7	6	2000	225	200°C	22.31	2.55	471°C
C8	6	2500	75	200°C	20.99	2.44	518°C
C9	6	3000	150	200°C	21.66	2.50	575°C

4.8. Forced convection at 90 psi

Sample no.	Axial force (KN)	Rotational speed (R.P.M)	Transverse speed(mm/min)	Substrate Temperature (°C)	Coating Width (mm)	Coating Thickness (mm)	Temperature (°C)
D1	4	2000	75	200°C	20.65	2.03	455°C
D2	4	2500	150	200°C	20.34	2.55	484°C
D3	4	3000	225	200°C	21.22	1.66	520°C
D4	5	2000	150	200°C	22.11	1.77	499°C
D5	5	2500	225	200°C	20.36	1.99	522°C
D6	5	3000	75	200°C	20.44	1.44	560°C
D7	6	2000	225	200°C	19.87	2.29	460°C
D8	6	2500	75	200°C	20.22	2.54	488°C
D9	6	3000	150	200°C	22.16	2.67	530°C

CHAPTER 5

RESULT AND DISCUSSION

5.1. PRIMARY INSPECTION:

Following deposition, the deposit's quality is assessed on the shop floor. These are for qualitative investigation in order to determine if the deposit is acceptable or not. For evaluating bonding and quality of friction surfaced deposits, NDT procedures include appearance and adhesion tests like lifting, impact, and chisel and hammer tests are used.

5.2. VISUAL INSPECTION:

The medium carbon steel plate was visually examined for any bends or cracks in the surface, ensuring that no undeformed coating would be applied throughout the process. If any corrosion particles are present on the plate, they must be removed using the cutting tool at a depth of 0.2mm. Each tool must be cut to the exact size and the aluminium alloy AA 6063 must be straight. When measuring thickness, remember to consider the depth of the plated being cleaned.

5.3. MEASUREMENT OF DEPOSIT DIMENSIONS:

For four types of treatment combinations, the deposit breadth, thickness, and coating roughness are not the same. The breadth and thickness of the deposit are greater at the start of each treatment combination and stay steady throughout the procedure. Because of the software set to elevate the spindle due to feed rate, the tool is automatically disengaged from the substrate plate at the end of the procedure. In comparison to the remaining length, the deposit's width is tiny. The roughness of the surface is also consistent over its length. As the surplus length and breadth are removed, there will be a greater quantity of length and width. The deposit is separated into eight equal sections over the remaining length.

5.4. MECHANICAL CHARACTERIZATION:

The friction surfaced samples were subjected to several testing techniques in this mechanical characterization procedure to demonstrate that the coating and the base plate had an intermolecular link. As a result, it is put through a variety of tests like hardness, bending, and tensile.

5.4.1. Rockwell Microhardness test:

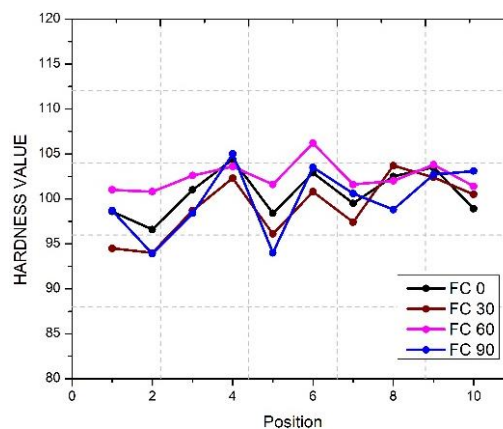
The sample was sliced into two parametric, 1. Vertical and 2. Traverse material and the hardness test was done between the interface of the sample. The Ball intender was placed in the hardness machine, and a steady load of 10 Kgf was applied to the sample at various locations. From the supplied samples, the average hardness was 110.46 HV and 91.46 HV. This might be due to improved microstructure growth and molecular interlocking at a relatively high temperature, followed by a quick cooling rate after the FS operation. The rotational speed and axial force applied to the consumable rod have also been observed to have a significant influence on the increase in surface hardness at the contact.

5.4.1.1. Longitudinal hardness test:

By using a slow-cutting technique, the coated sample was sliced with a smooth surface by the cutting machine. This material was vertically sliced into two halves.



Fig 5.1. Half-cut material for Vertical hardness test



Graph 5.1. graph obtained from values of vertical material hardness test

Table 5.1. Hardness values obtained from Longitudinal material.

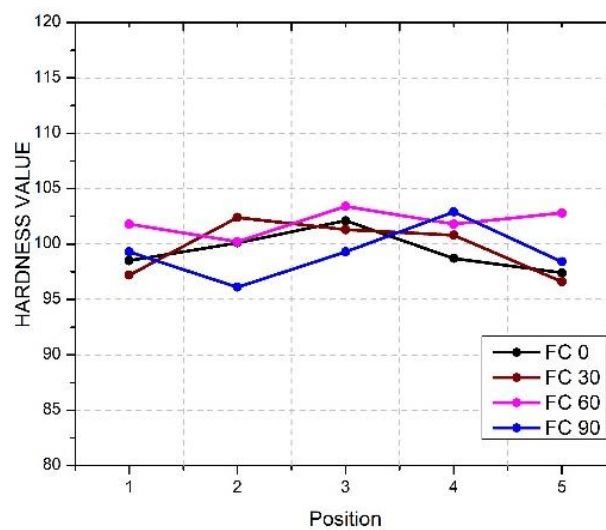
POSITION	FC 0	FC 30	FC 60	FC 90
1	98.6	94.5	101	98.7
2	96.6	94	100.8	93.9
3	101	98.7	102.6	98.4
4	104.4	102.3	103.6	105
5	98.4	96.1	101.6	94
6	102.9	100.8	106.2	103.5
7	99.5	97.4	101.6	100.6
8	102.5	103.7	102	98.8
9	103.5	102.4	103.8	102.7
10	98.9	100.5	101.4	103.1

5.4.1.2. Traverse hardness test:

The provided sample was sliced horizontally between the coated surface using the Cutter machine.



Fig 5.2. Traverse cut material for hardness test



Graph 5.2. graph obtained from values of traverse material hardness test

Table 5.2. Hardness values obtained from traverse material.

POSITION	FC 0	FC 30	FC 60	FC 90
1	98.5	97.2	101.8	99.3
2	100.1	102.4	100.2	96.1
3	102.1	101.3	103.4	99.3
4	98.7	100.8	101.8	102.9
5	97.4	96.6	102.8	98.4



Fig 5.3. Rockwell microhardness testing machine.

5.4.2. Bend test:

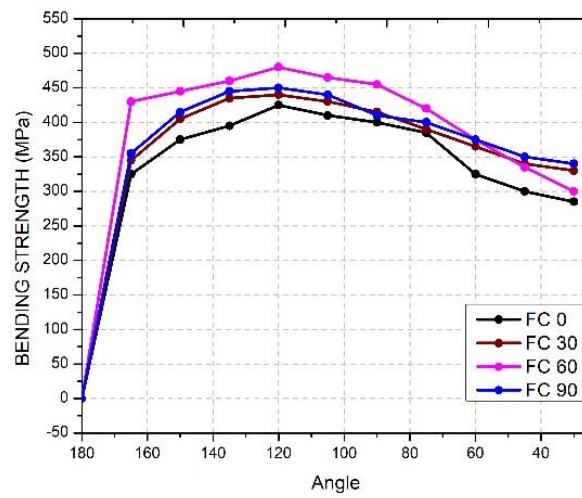
After deleting the unbounded edges, the materials produced from both Friction Surfacing techniques were chosen for face and root bend tests. The preparation of test samples and procedures have been monitored according to IS 1599 (2012) standards. The applied stress versus bending angle which showed that the maximum bending strength was achieved with the value of 459 Mpa with 120° bend angle whereas in the case of SPHA approach the maximum bending strength was achieved at 478MPa with 120° bend angle. ASTM A370-21 is used to test and assess the mechanical characteristics of steel, stainless steel, and related alloy products. Because various steels are utilized for diverse reasons, it is critical that they be tested and characterized. The test was conducted at a room temperature of 27 °c.

5.4.2.1. Root bend:

The coated sample was placed in the machine the face of the sample the coated side was placed facing the V- tool and the force is applied. There is no removal of coating.



Fig 5.4. Root bend sample material



Graph 5.3. Graph obtained from root bend test values

Table 5.3. Values for root bend test

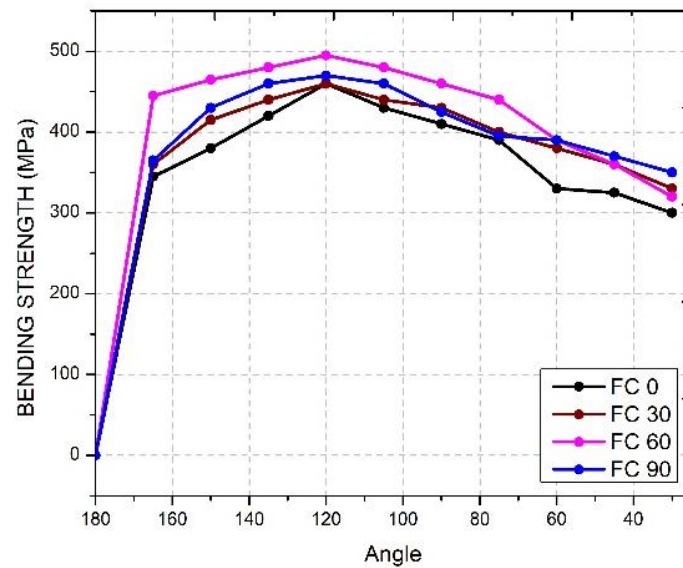
ANGLE	FC 0	FC 30	FC 60	FC 90
180	0	0	0	0
165	325	345	430	355
150	375	405	445	415
135	395	435	460	445
120	425	440	480	450
105	410	430	465	440
90	400	415	455	410
75	385	390	420	400
60	325	365	375	375
45	300	340	335	350
30	285	330	300	340

5.4.2.2. Face bend:

The coated sample was placed backside facing the V-Tool and the force is applied. There is no removal of coating.



Fig 5.5. Face bend sample material



Graph 5.4. graph obtained from face bend test values

Table 5.4. Values for face bend test

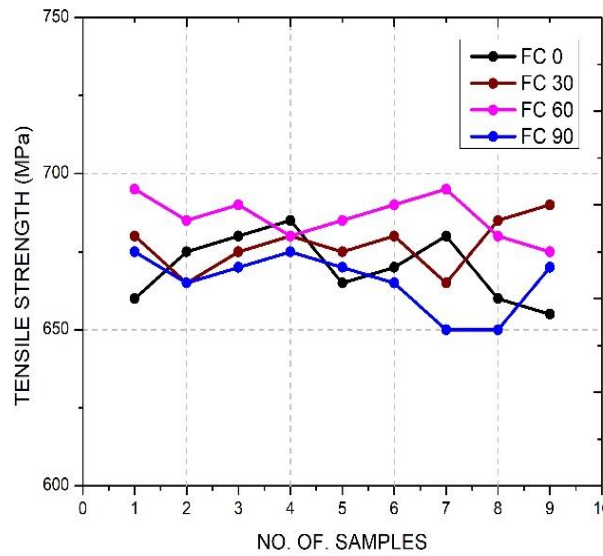
ANGLE	FC 0		FC 30	FC 60	FC 90
180	0		0	0	0
165	345		360	445	365
150	380		415	465	430
135	420		440	480	460
120	460		460	495	470
105	430		440	480	460
90	410		430	460	425
75	390		400	440	395
60	330		380	390	390
45	325		360	360	370
30	300		330	320	350

5.4.2.3. Tensile Test:

The ram tensile test has been carried out on a 100 KN INSTRON UTM testing machine by employing continuous load till the bond fails. In the case of CA approach, the bonding strength has been observed was 72 MPa while 132 MPa was observed in the sample obtained from SPHA. So, it can be concluded that the samples obtained from SPHA process have better bonding mechanism than the samples from the CA approach which seems to indicate proper mechanical interlocking at the coating interface. The sample was test at room temperature of 27°C.



Fig 5.6. A – Before tensile test B – After tensile test



Graph 5.5. Graph obtained from tensile test values

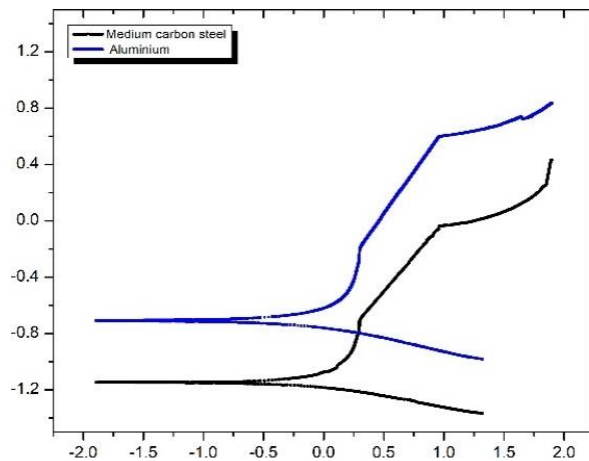
Table 5.5. Tensile values obtained from I sectional sample

NO.OF. SAMPLES	FC 0	FC 30	FC 60	FC 90
1	660	680	695	675
2	675	665	685	665
3	680	675	690	670
4	685	680	680	675
5	665	675	685	670
6	670	680	690	665
7	680	665	695	650
8	660	685	680	650
9	655	690	675	670

5.5. CHEMICAL ANALYSIS:

5.5.1. Polarization corrosion test:

In general, various metallic materials have varied polarization properties, which are determined by the material's open circuit potential, break down potential, and passivation potential. The observation of these electrochemical characteristics determines a material's corrosion factor. To do this, a dependable and well-functioning corrosion system is necessary. A polarization scan allows for the extrapolation of the kinetic and corrosion parameters of a metal substrate. During a scan, the oxidation or reduction of an electroactive species can be limited by charge transfer and the movement of reactants or products. These factors are all encapsulated by the polarization scan; therefore, having a system that produces a reliable and repeatable polarization scan across multiple cycle is of great importance.



Graph 5.6. Graph for Polarization corrosion test

5.5.2. Salt spray test:

The aluminium is heated towards its melting point in the friction surfacing process, and the bonding takes place on the Medium carbon steel substrate owing to friction. The Aluminium deposit may be exposed to corrosion attack after it is cooled to room temperature, depending on the cooling rate. As a result, it is critical to assess the deposit's corrosion resistance.

5.5.2.1. Test parameters:

Chamber temperature: 33.5 – 34.5 °c

pH value: 5.60 – 5.70

The volume of salt solution collected: 1.25 – 1.75 ml/hr

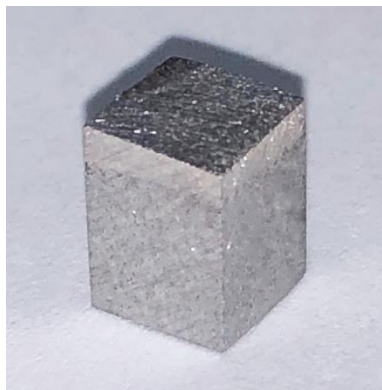
Concentration of solution: 5 – 5.45% of Nacl

Air pressure: 12 to 16 psi

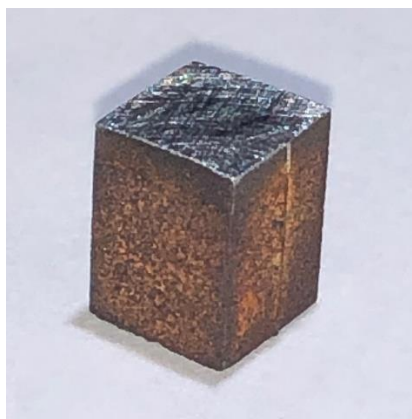
Components loading

In the chamber position: 30 °

Observation: No rust formed after 200Hrs.



a.



b.

Fig 5.7. a – Before corrosion test, b – After corrosion test.

5.6. MICROSTRUCTURAL ANALYSIS:

The chemical and micro analysis is performed to determine the corrosion behaviour, bonding nature, and interface composition of the coating. This is discovered by SEM, XRD, and corrosion testing. Four samples S2, S5, S7, S9 from different parameters is taken for testing.

5.6.1. Scanning electron microscope:

The given sample was cut into a small cross-sectional area of 5mm sq. A small cubical was formed in the SEM analysis the sample was placed under the microscope at interface of the aluminium and medium carbon steel. The SEM microscope of 20 μ was used to see the interface of the material. The images were showing the layer and there is a good formation is obtained in the FC 60. The samples A,B,C, and D represent the samples of different samples obtained.

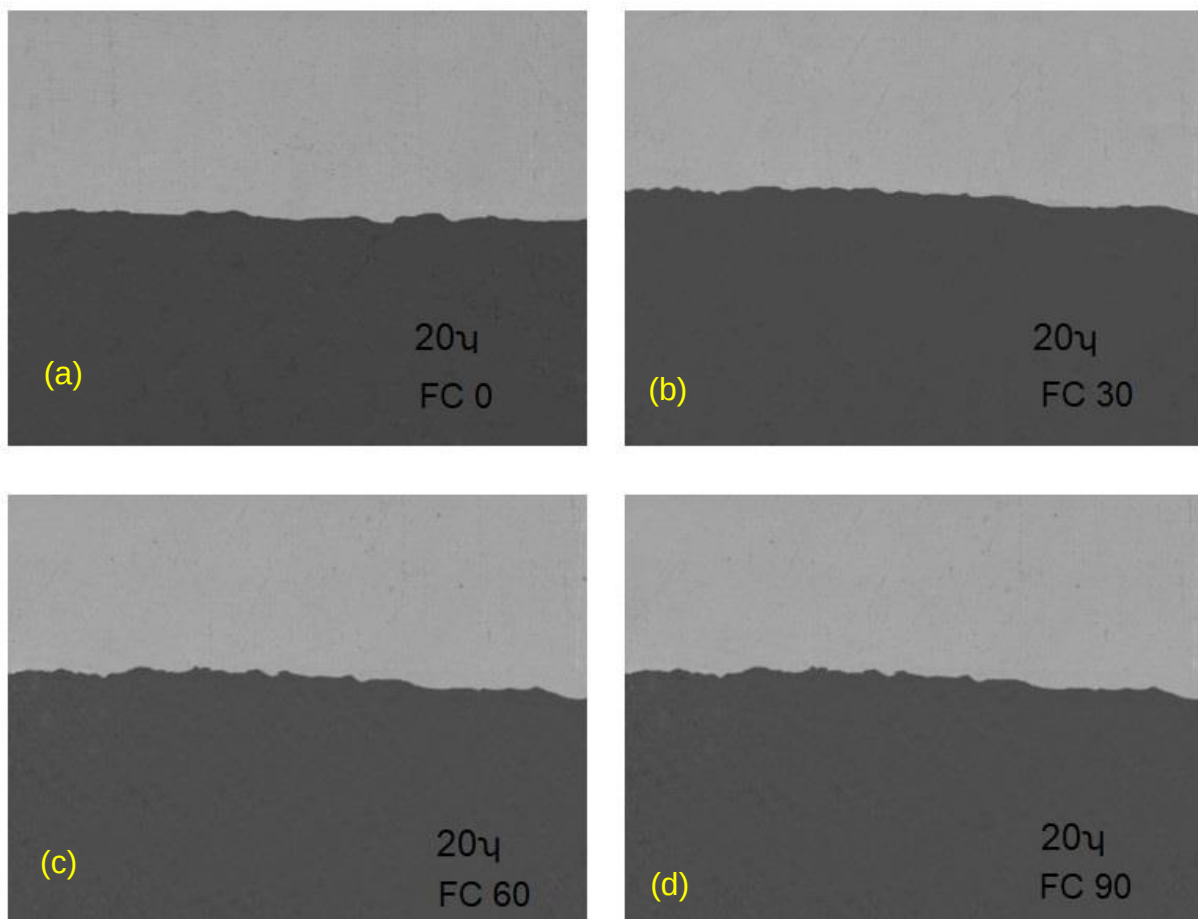


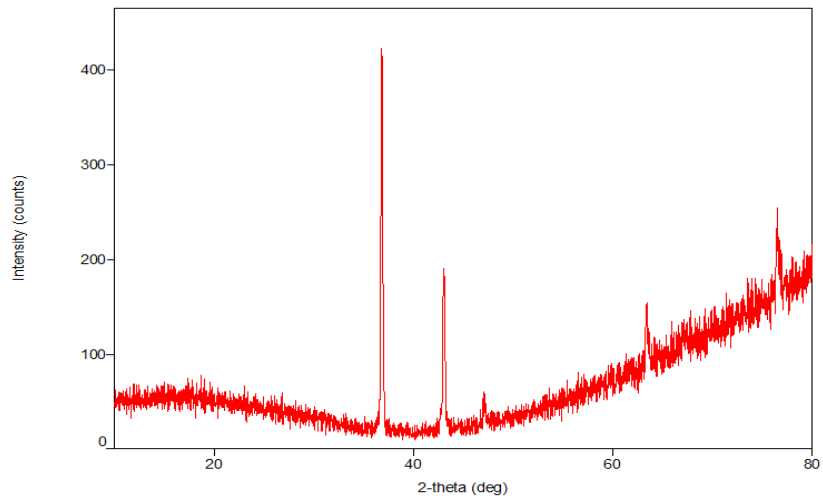
Fig 5.8. SEM photos of samples a, b, c, and d at the coating interface.

5.6.2. X-Ray diffraction (XRD):

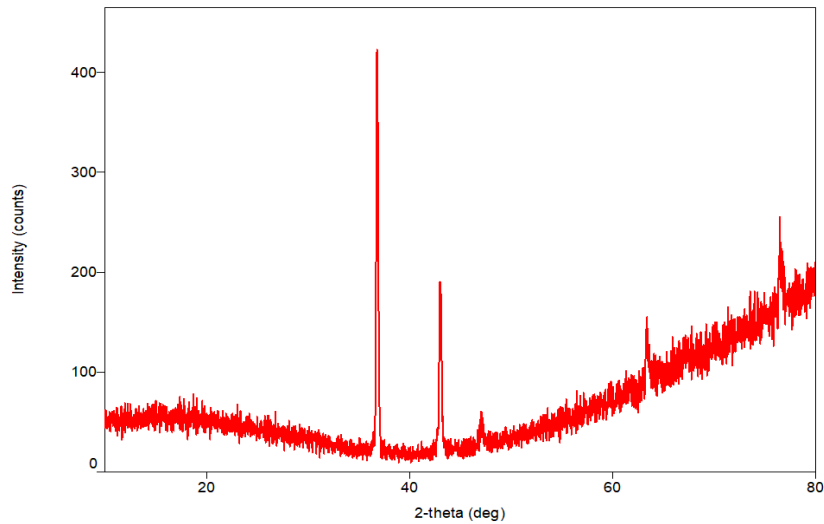
For two trials, the XRD investigation is performed on AA 6063 coated Mild steel. The peaks in the graph represent the bonding structure of the AA 6063 and EN8 medium carbon steels in the XRD method. When the temperature drops below 550°, α -ferrite forms, aiding in the corrosion resistance of Aluminium over mild steel. In the fig 5.7. A and B Represents the different side of the sample.

Table 5.6. X-Ray diffraction Parameters

X-Ray	30 kV, 12 mA	Scan speed / Duration time	8.0000 deg./min.
Goniometer	None	Step width	0.0200 deg.
Attachment	None	Scan axis	2Theta/Theta
Filter	None	Scan range	10.0000 - 80.0000 deg.
CBO selection slit	None	Incident slit	None
Diffracted beam mono.	None	Length limiting slit	None
Detector	SC-70	Receiving slit #1	None
Scan mode	CONTINUOUS	Receiving slit #2	None



(a)



(b)

Graph 5.7. (a) XRD-Sample1

(b)XRD-sample2

5.7. OPTIMIZATION:

To produce optimum outcomes, the Response surface method (RSM) and Artificial neural network (ANN) were used to examine the optimization of process parameters and output data. The parameters have been tabulated, and graphs have been drawn. Table 1 depicts a comparison of experimental value with RSM and ANN for an output value of CW, Table 1 depicts a comparison of experimental value with RSM and ANN for an output value of CT, Table 2 depicts a comparison of experimental value with RSM and ANN for an output value of BS, and Table 2 depicts a comparison of experimental value with RSM and ANN for an output value of TS.

5.7.1. Response Surface Methodology:

A combination of statistical and mathematical tools for modeling and evaluating engineering issues is known as response surface methodology. The major goal of this approach is to optimize the response surface, which is impacted by a variety of process factors. The link between the controlled input parameters and the resulting response surfaces is also quantified using the response surface technique.

RSM was employed to develop the method for optimizing and predicting the coating width, coating thickness, tensile strength, and bending strength in friction welding of Aluminium alloy 6063 under the Box-Behnken design of the experiment. The equation below explains the relationship of the three independent variables, i.e., Axial force(AF), Rotational speed(RS), and Transverse speed(TS), and output variables, i.e., coating width(CW), coating thickness(CT), tensile strength (TS), and Bending Strength(BS) of Friction surfaced Material. Heating pressure had maximum effect on the tensile strength because it was responsible for the amount of heat generated at the joining surfaces, i.e., if less heating pressure was applied, then adhesion would not be proper which would further decrease the tensile strength, and similarly, if heating pressure was more, then sufficient adhesion could be obtained which would increase the tensile strength

Coating width, CW= $22.603 + 0.259 AF - 0.215 RF + 0.224 TS - 0.244 AF^2 + 0.058 RS^2 - 0.559 TS^2 - 0.222 AF*RS + 0.045 AF*TS - 0.877 RS*TS$.

Coating Thickness, CT= $2.190 + 0.095 AF - 0.034 RS - 0.176 TS - 0.325 AF*AF - 0.237 RS^2 + 0.013 TS^2 - 0.028 AF*RS - 0.117 AF*TS + 0.195 RS*TS$.

Bending Strength, BS= $421.7 - 3.1 AF + 15.6 RS + 25.0 TS + 12.3 AF^2 - 37.7 RS^2 + 23.5 TS^2 - 1.3AF*RS - 5.0 AF*TS + 25.0 RS*TS$.

Tensile strength, TS= $683.33 - 0.63 AF - 4.38 RS + 10.00 TS + 3.96 AF^2 - 11.04 RS^2 + 0.21 TS^2 - 1.25 AF*RS - 7.50 AF*TS - 2.50 RS*TS$.

Table 5.7. a, b, c, d represents the Anova table for coating width, coating thickness, bending and Tensile strength.

a. Anova table with values for coating width:

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	5.9468	0.66076	0.25	0.966
Linear	3	1.3059	0.43531	0.16	0.916
Axial Force	1	0.5356	0.53561	0.20	0.672
Rotational speed	1	0.3698	0.36980	0.14	0.725
Transverse speed	1	0.4005	0.40051	0.15	0.714
Square	3	1.3547	0.45158	0.17	0.912
Axial Force*Axial Force	1	0.2201	0.22013	0.08	0.785
Rotational speed* Rotational speed	1	0.0126	0.01256	0.00	0.948
Transverse speed* Transverse speed	1	1.1545	1.15446	0.43	0.539
2-Way Interaction	3	3.2861	1.09538	0.41	0.752
Axial Force*Rotational speed	1	0.1980	0.19802	0.07	0.796
Axial Force*Transverse speed	1	0.0081	0.00810	0.00	0.958
Rotational speed* Transverse speed	1	3.0800	3.08002	1.16	0.331
Error	5	13.2965	2.65931		
Lack-of-Fit	3	5.0821	1.69403	0.41	0.764
Pure Error	2	8.2145	4.10723		
Total	14	19.2434			

b. Anova table with values for coating thickness:

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	1.10826	0.123140	0.93	0.567
Linear	3	0.32982	0.109942	0.83	0.533
Axial Force	1	0.07220	0.072200	0.54	0.494
Rotational speed	1	0.00911	0.009112	0.07	0.804
Transverse speed	1	0.24851	0.248512	1.87	0.230
Square	3	0.56808	0.189361	1.42	0.339
Axial Force*Axial Force	1	0.39000	0.390000	2.93	0.147
Rotational speed* Rotational speed	1	0.20827	0.208269	1.57	0.266
Transverse speed* Transverse speed	1	0.00058	0.000577	0.00	0.950
2-Way Interaction	3	0.21035	0.070117	0.53	0.682
Axial Force*Rotational speed	1	0.00303	0.003025	0.02	0.886
Axial Force*Transverse speed	1	0.05522	0.055225	0.42	0.548
Rotational speed* Transverse speed	1	0.15210	0.152100	1.14	0.334
Error	5	0.66447	0.132895		
Lack-of-Fit	3	0.26527	0.088425	0.44	0.748
Pure Error	2	0.39920	0.199600		
Total	14	1.77273			

c. Anova table with values for bending strength:

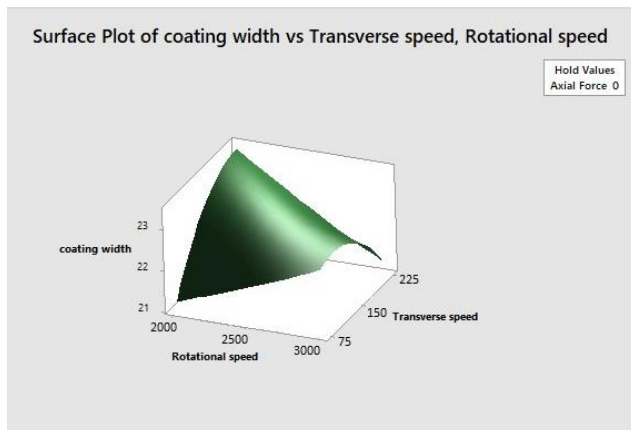
Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	18145.4	2016.16	0.84	0.612
Linear	3	7031.3	2343.75	0.98	0.472
Axial Force	1	78.1	78.13	0.03	0.864
Rotational speed	1	1953.1	1953.13	0.82	0.407
Transverse speed	1	5000.0	5000.00	2.09	0.208
Square	3	8507.9	2835.97	1.19	0.403
Axial Force*Axial Force	1	557.9	557.85	0.23	0.649
Rotational speed* Rotational speed	1	5250.2	5250.16	2.20	0.198
Transverse speed*Transverse speed	1	2046.3	2046.31	0.86	0.397
2-Way Interaction	3	2606.3	868.75	0.36	0.783
Axial Force*Rotational speed	1	6.2	6.25	0.00	0.961
Axial Force*Transverse speed	1	100.0	100.00	0.04	0.846
Rotational speed* Transverse speed	1	2500.0	2500.00	1.05	0.353
Error	5	11947.9	2389.58		
Lack-of-Fit	3	11431.2	3810.42	14.75	0.064
Pure Error	2	516.7	258.33		
Total	14	30093.3			

d. Anova table with values for tensile strength:

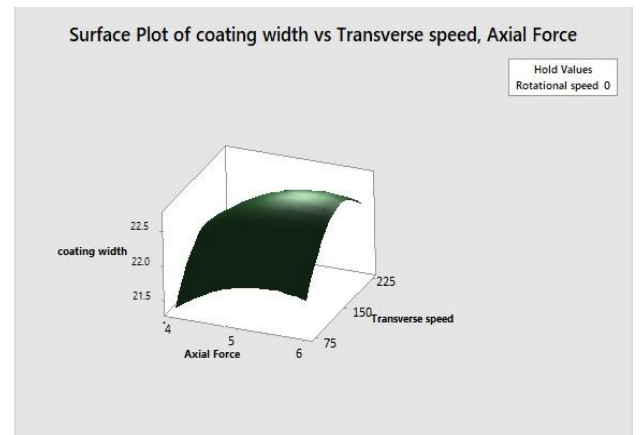
Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	1750.42	194.491	1.86	0.256
Linear	3	956.25	318.750	3.05	0.131
Axial Force	1	3.12	3.125	0.03	0.870
Rotational speed	1	153.12	153.125	1.46	0.280
Transverse speed	1	800.00	800.000	7.65	0.040
Square	3	537.92	179.306	1.71	0.279
Axial Force*Axial Force	1	57.85	57.853	0.55	0.490
Rotational speed*Rotational speed	1	450.16	450.160	4.30	0.093
Transverse speed*Transverse speed	1	0.16	0.160	0.00	0.970
2-Way Interaction	3	256.25	85.417	0.82	0.538
Axial Force*Rotational speed	1	6.25	6.250	0.06	0.817
Axial Force*Transverse speed	1	225.00	225.000	2.15	0.202
Rotational speed*Transverse speed	1	25.00	25.000	0.24	0.646
Error	5	522.92	104.583		
Lack-of-Fit	3	6.25	2.083	0.01	0.999
Pure Error	2	516.67	258.333		
Total	14	2273.33			

5.7.2. Surface graphs:

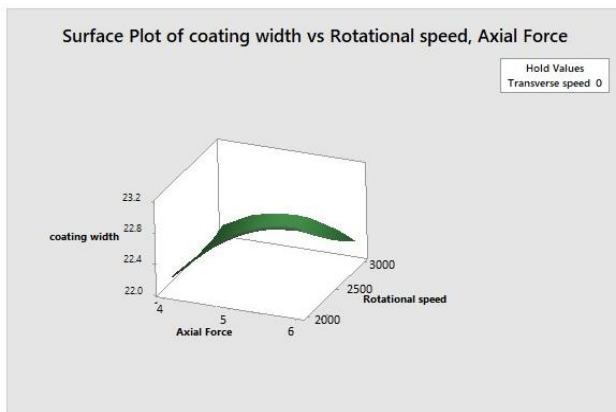
Surface Graph are used to determine the best combinations of two sets of data. The colors and patterns, like on a topographic map, show places with similar value ranges. Make sure that both the categories and the data series are numeric values when creating a Surface chart. Straight lines are used to connect neighboring spots to construct the plot. Surface plots can be used to visualize matrices that are too big to represent numerically, as well as to graph functions with two variables. surface (X, Y, Z) generates a basic three-dimensional surface map. The function depicts the matrix Z values as heights above a grid in the x-y plane given by X and Y. The color of the surface changes with the heights indicated by Z. fig (a) represents the surface plot between coating width and transverse speed in comparison with rotation speed, fig (b) represents the surface plot between coating width and transverse speed with comparison with axial force, fig (c) represents the surface plot between coating width and rotational speed with axial force, fig (d) represents the surface plot between coating thickness and transverse speed with rotational speed, fig (e) represents the surface plot between the coating thickness and traverse speed with axial force, fig (f) represents the surface plot between the coating thickness and rotational speed with axial force, fig (g) represents the surface plot between bending strength and traverse speed with rotational speed, fig (h) represents the surface plot between bending strength and traverse speed with axial force, fig (i) represents the surface plot between bending strength and rotational speed with axial force, fig (j) represents the surface plot between tensile strength and traverse speed and rotational force, fig (k) represents the surface plot between tensile strength and traverse speed with axial force, fig (l) represents the surface plot between tensile strength and rotational speed with axial force.



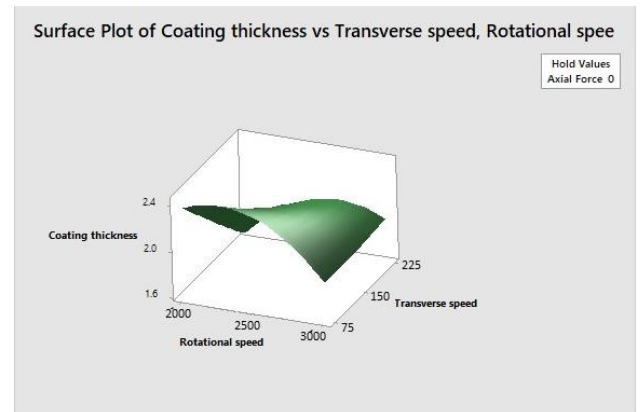
(a)



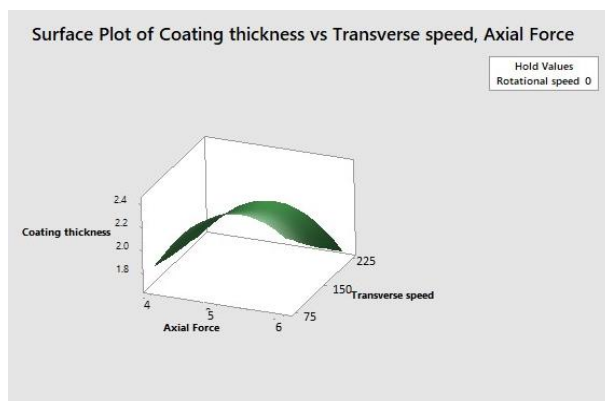
(b)



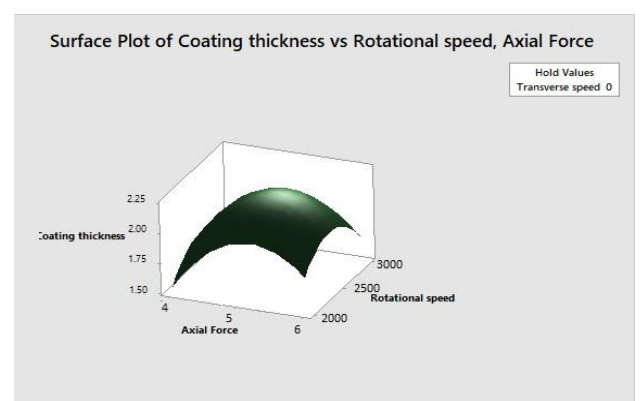
(c)



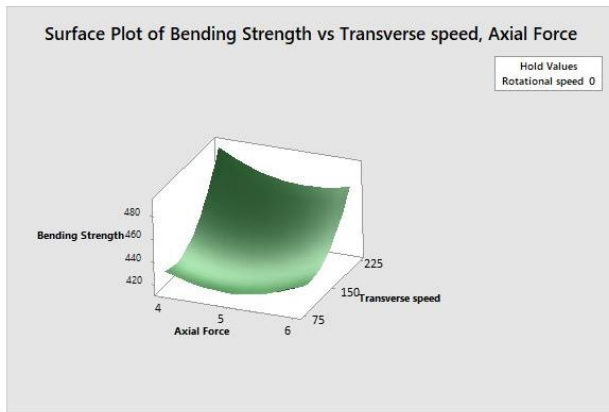
(d)



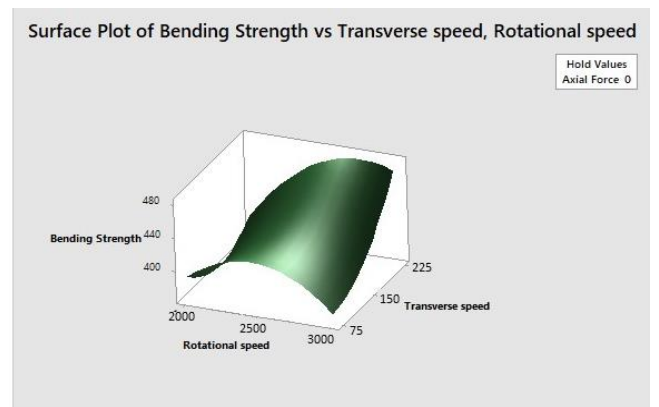
(e)



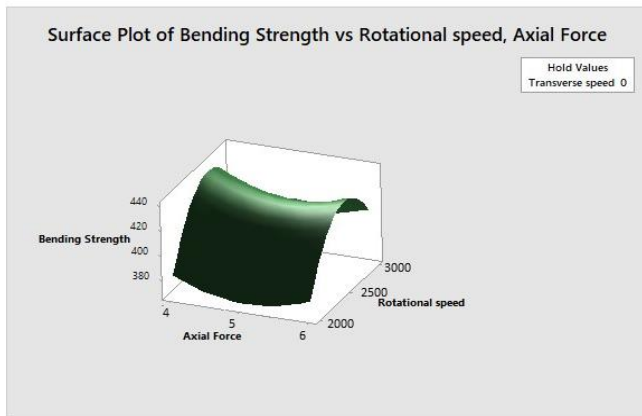
(f)



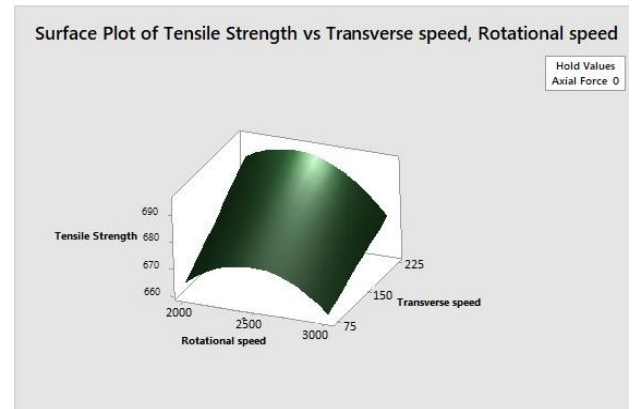
(g)



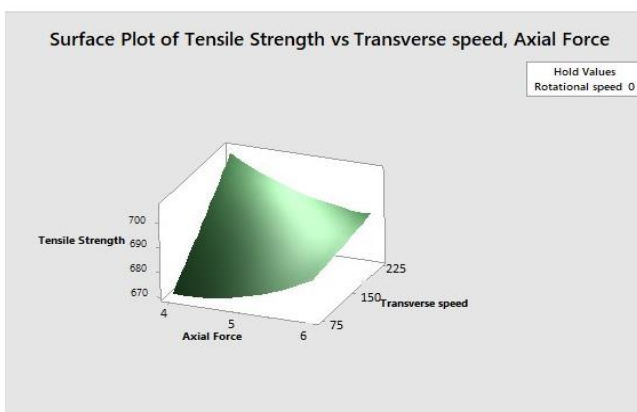
(h)



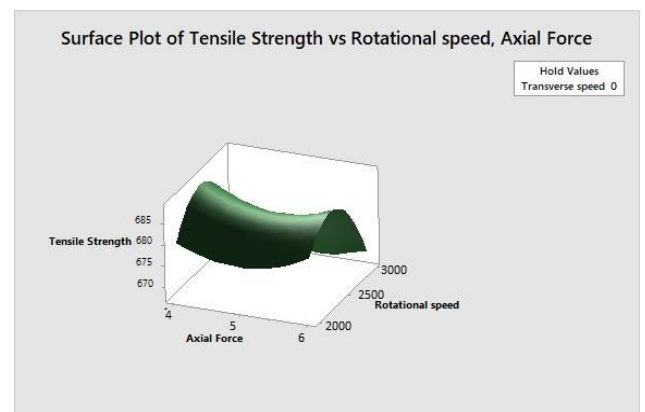
(i)



(j)



(k)



(l)

Fig 5.9. Surface plots for Coating width, thickness, Bending strength and Tensile strength with respect to Traverse speed, axial force, and Rotational speed

5.7.3. Box Behnken:

The Box-Behnken design is an independent quadratic design. Because it does not contain an embedded factorial or fractional factorial design. The treatment combinations in this design are located at the midpoints of the process space's edges and in the middle. These designs are rotatable (or almost rotatable), and three layers of each factor are required. In comparison to central composite designs, the designs have limited orthogonal blocking capabilities.

The geometry of this design indicates a sphere within the process space, with the sphere's surface protruding through each face and the sphere's surface tangential to the space's midway.

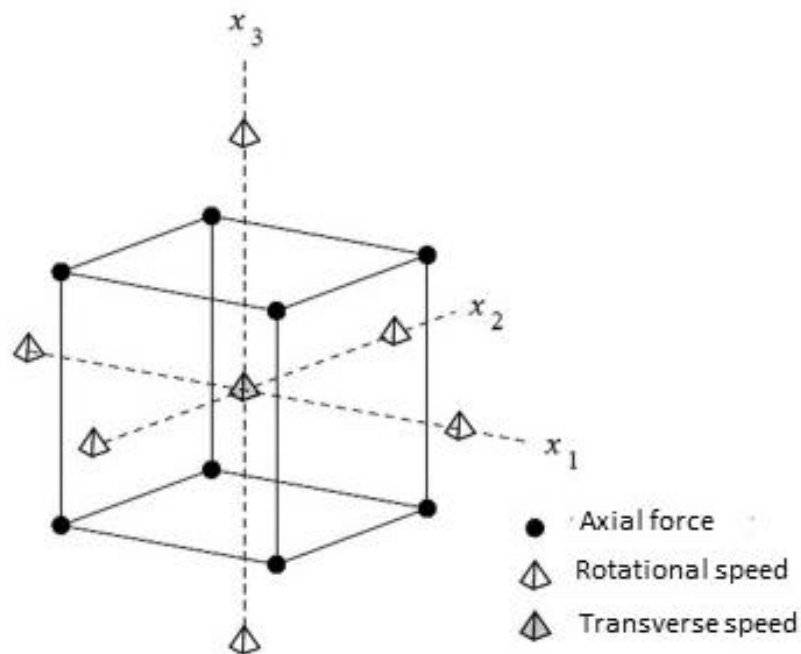


Fig 5.10. Box-Behnken design

5.8. ARTIFICIAL NEURAL NETWORK:

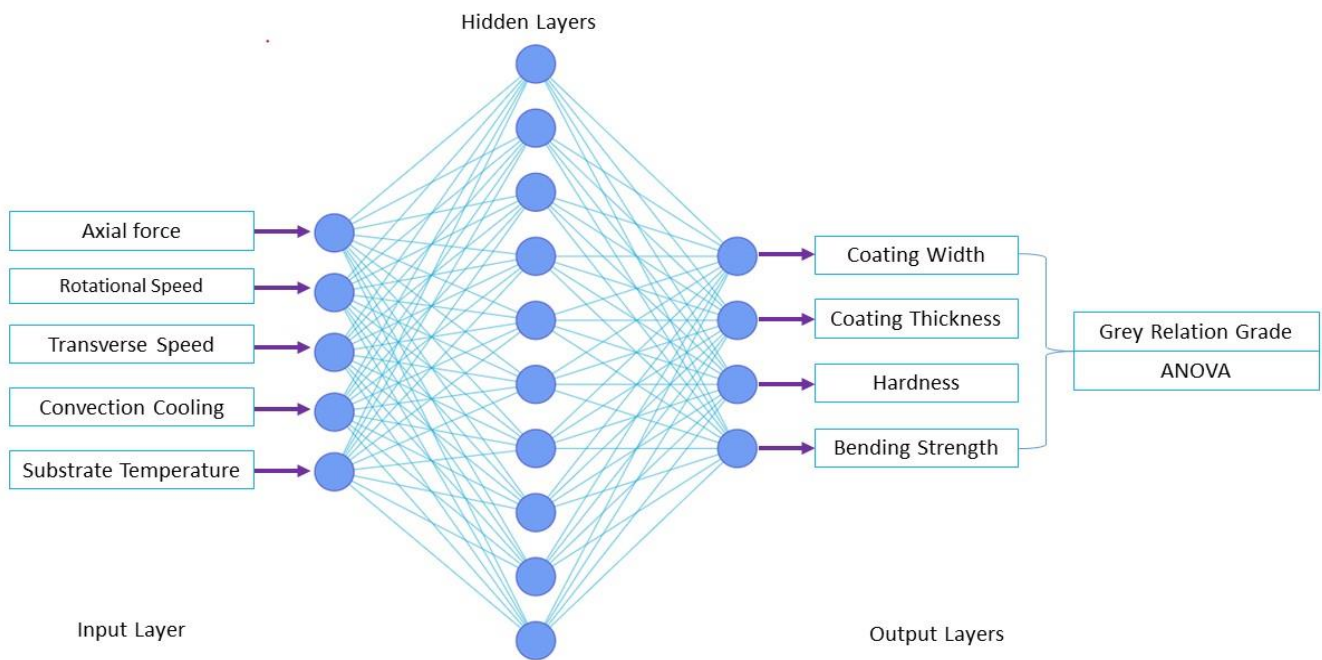


Fig 5.11. Schematics of Artificial neural network (ANN) layers

An artificial neural network (ANN) is a computational model that mimics the operation of a biological network made up of neurons. In a variety of applications, ANN is frequently used to simulate complicated nonlinear functions. The input, hidden, and output layers are the three layers of a multilayer perceptron ANN system. All of the input factors are found in the input layer. The hidden layers process the information from the input layer, which is subsequently followed by the output layer (Fig 5.14). The ANN approach was utilized to optimize the process parameters used in friction welding utilizing inputs acquired from trials conducted on AA1106 in a functioning state. As a result, the process was optimized, and the optimal value for the process was discovered, as well as the maximum tensile strength and the maximum bending strength.

Experimental design matrix and output response

Table 5.8. Observed Value and Calculated Values with Errors for Bending strength and Tensile strength

Exp. matrix	Obs. BS (Mpa)	Cal. BS (Mpa)	Error BS (Mpa)	Obs. TS (Mpa)	Cal. TS (Mpa)	Error TS (Mpa)
Training data						
1	325	325.4	-0.36	660	661.5	1.49
2	345	346.6	-1.58	680	680.3	-0.27
3	345	344.9	0.15	680	679.3	0.68
4	445	444.5	0.55	685	684.6	0.36
5	415	414.3	0.68	665	664.3	0.73
6	415	416.5	-1.53	665	665	0.03
7	460	459.6	0.37	690	689.3	0.68
8	445	446.2	-1.22	670	671.5	-1.45
9	445	444.3	0.75	670	670.4	-0.44
10	480	479.6	0.37	705	704.7	0.34
11	450	449.7	0.22	675	674.2	0.77
12	450	449.2	0.78	675	674.8	0.25
13	410	409.8	0.23	695	694.9	0.15
14	440	439.7	0.35	690	691.4	-1.44
15	440	440.9	-0.94	690	691.8	-1.77
16	455	456.3	-1.32	725	725.6	-0.63
17	440	441.2	-1.24	725	726.3	-1.27
18	440	439.6	0.38	695	696.6	-1.58
19	420	419.3	0.75	730	729.3	0.67
20	400	399.5	0.52	720	719.8	0.23
21	400	399.6	0.38	720	719.3	0.75
22	375	374.3	0.75	750	749.2	0.78
23	400	401.7	-1.65	725	724.1	0.89
24	400	401.2	-1.22	725	724.5	0.52
Testing Data						
25	385	384.54	0.46	710	710.62	-0.38

26	390	390.89	-0.89	750	749.33	0.77
27	400	399.52	0.48	690	689.22	0.88
28	325	324.7	-0.26	740	739.6	0.45
29	365	363.2	1.85	740	741.7	-1.66
30	340	338.9	1.11	740	739.3	0.68

Table 5.9. Observed Value and Calculated Values with Errors for Coating Width and Coating Thickness

Exp. matrix	Obs. CW (mm)	Cal. CW (mm)	Error CW (mm)	Obs. CT (mm)	Cal. CT (mm)	Error CT (mm)
Training data						
1	22.74	21.83	0.91	1.85	2.1	-0.25
2	23.17	22.48	0.69	1.54	1.89	-0.35
3	23.17	22.67	0.5	1.54	1.2	0.34
4	22.61	21.38	1.23	2.33	1.54	0.79
5	20.34	20.14	0.2	2.55	1.87	0.68
6	20.34	20.78	-0.44	2.55	1.96	0.59
7	22.47	23.22	-0.75	1.86	2.36	-0.5
8	21.22	22.39	-1.17	1.66	2.1	-0.44
9	21.22	20.96	0.26	1.66	2.1	-0.44
10	20.9	21.59	-0.69	1.66	1.37	0.29
11	22.11	21.66	0.45	1.77	1.36	0.41
12	22.11	21.69	0.42	1.77	1.7	0.07
13	24.25	25.65	1.58	2.33	1.58	0.75
14	23.22	24.14	-0.92	1.69	2.35	-0.66
15	23.22	23.94	-0.72	1.69	2.15	-0.46
16	21.09	20.54	0.55	2.33	1.69	0.64
17	20.44	21.67	-1.23	1.44	2.45	-1.01
18	20.44	21.77	-1.33	1.44	0.96	0.48
19	22.31	21.36	0.95	2.55	1.24	1.31
20	19.87	20.87	-1	2.29	1.89	0.4

21	19.87	18.36	1.51	2.29	1.45	0.84
22	20.99	21.35	-0.36	2.44	1.77	0.67
23	20.24	21.54	-1.3	2.54	1.67	0.87
24	20.24	20.02	0.22	2.54	2.22	0.32
Testing data						
25	21.12	21.50	-0.38	2.32	2.82	-0.50
26	20.64	21.10	-0.46	2.56	2.16	0.30
27	21.47	22.37	-0.90	2.84	2.44	0.40
28	21.67	20.44	0.23	2.33	2.89	-0.56
29	22.12	21.97	0.15	1.77	1.33	0.44
30	22.12	21.65	0.47	1.77	1.44	0.33

The friction surfacing process was modelled in a genetic algorithm-tuned neural network (GANN) to predict the output(s) or response(s) for a given set of input parameters. Three input parameters, namely Axial Force (AF), Rotational Speed (RS), and Transverse Speed (TS) were considered for the forward model. Four responses, namely Coating Width (CW), Coating Thickness (CT), Bending Strength (BS), and Tensile Strength (TS) were predicted as outputs of the forward model. Three desired responses were fed as inputs to the model and the outputs were obtained in terms of the process parameters to be set to achieve the desired set of responses. The mapping of the process in the reverse direction might be required for its automation. The main objectives of ANN are to develop methods and models from experiments and examples for solving problems, usually solved by conventional techniques. ANN is a quite efficient learning tool for the generalization of deformation behaviour characteristics, and a computing tool with high precision for the constitutive relationships between inputs and outputs by simulating the working process of biological neurons with network structures. Generally, it consists of an input layer, output layer and mostly used one hidden layer. To train the network transfer or activation function is used. In the present study, the parameters for learning were decided by detailed parametric studies and the 'tanh' activation function was used for both hidden and output layers. The 30 responses obtained from the experiment were divided into two sets of 24, and 6 for training, and testing respectively which were done by the option available in the software.

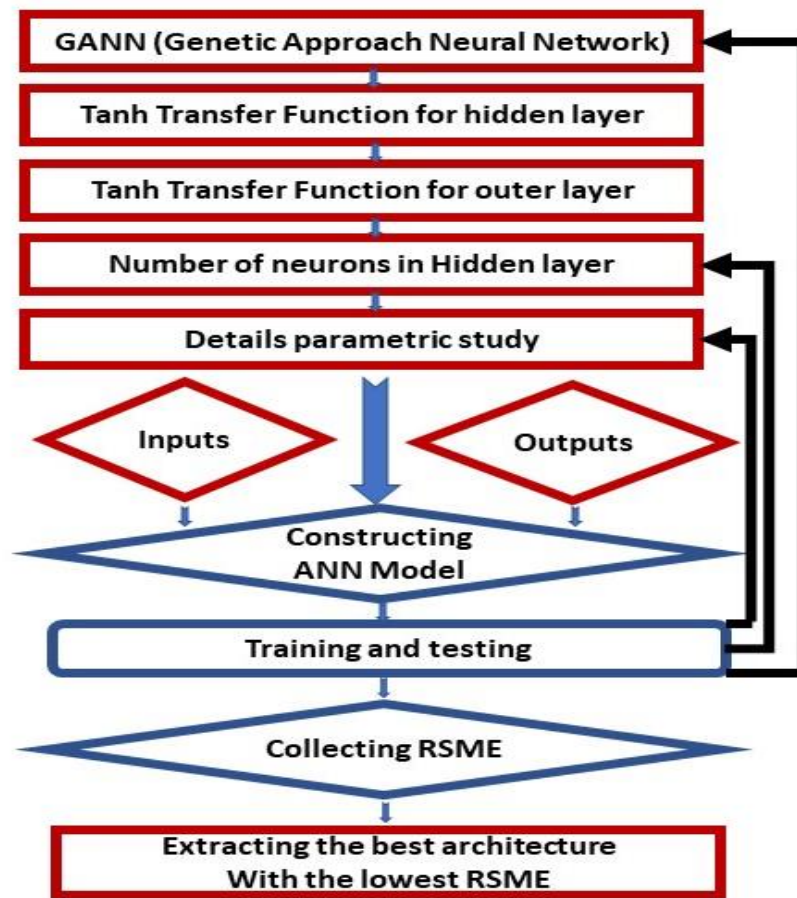


Fig 5.12 Represents the types of ANN systems

Numbers of artificial neurons combined through weights, which are also described as coefficients and adjustable factors are present in an ANN model, so ANN is considered a system with parameters. The weighted sum of the inputs constitutes the activation of the neuron. The activation signal is passed through the transfer function to produce a single output of the neuron. Coefficients optimization in training continues until prediction errors are minimized, and the system gets accuracy with a specified level. New input data or information can be given to the network when it is trained and tested. Nowadays, several metaheuristic algorithms have been proposed to solve the optimization problem. Such search algorithms include genetic algorithm (GA), ant colony optimization (ACO), and particle swarm optimization (PSO). Since the MLP neural network was used for modelling and optimization, the optimization procedure in this research is called neural network-based multi-objective optimization. The best-

developed model by ANN is used to optimize of process parameters of the friction welding of AA6063 using the ANN tuned force approach. The flow chart for optimization is shown.

5.9. GENETIC ALGORITHM:

In the present work, we used an evolution of Genetic Algorithms (GA). The flow chart for the genetic algorithm. A schematic view of a GA-ANN system in which a Genetic Algorithm (GA) was used to evolve an optimal neural network system through the batch mode of training. The ANN parameters used in this model are transfer function, connecting weights, and bias values which were optimized using a GA. The statistical index root means square error (RMSE) was used to calculate the fitness of the GA string. The GA tried to evolve an optimized ANN system through several generations using fitness information calculated by detailed parametric studies.

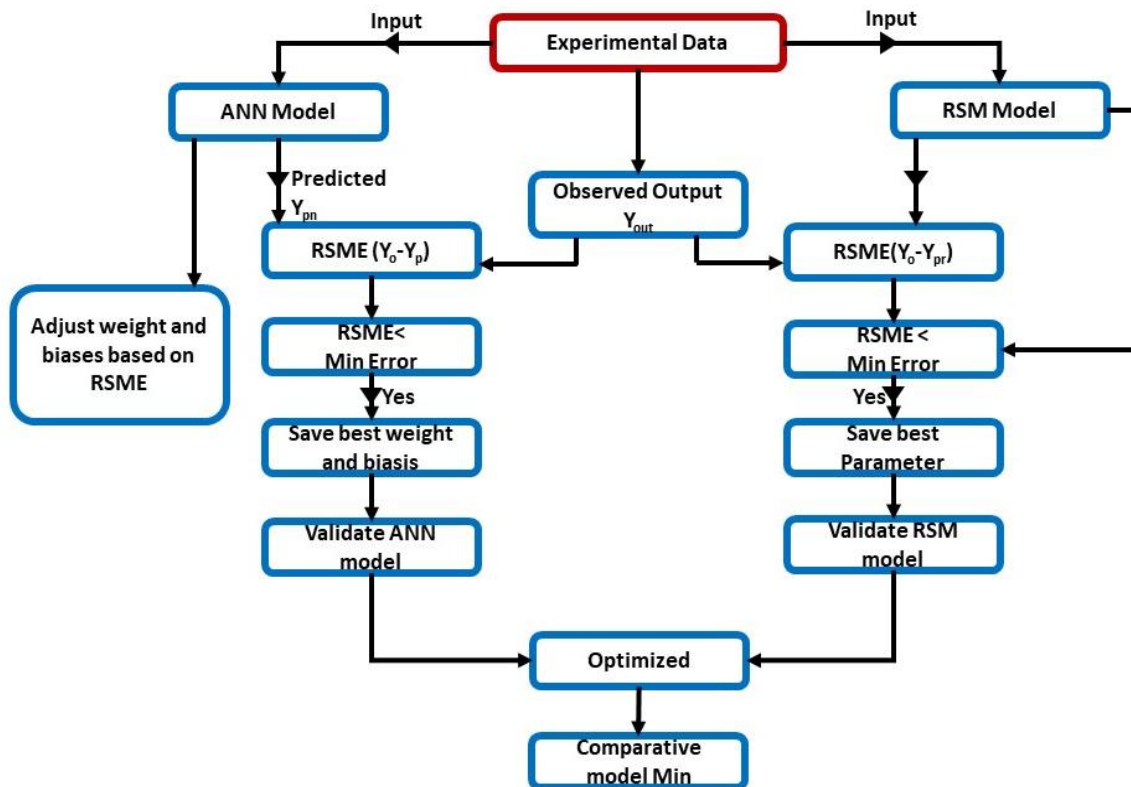
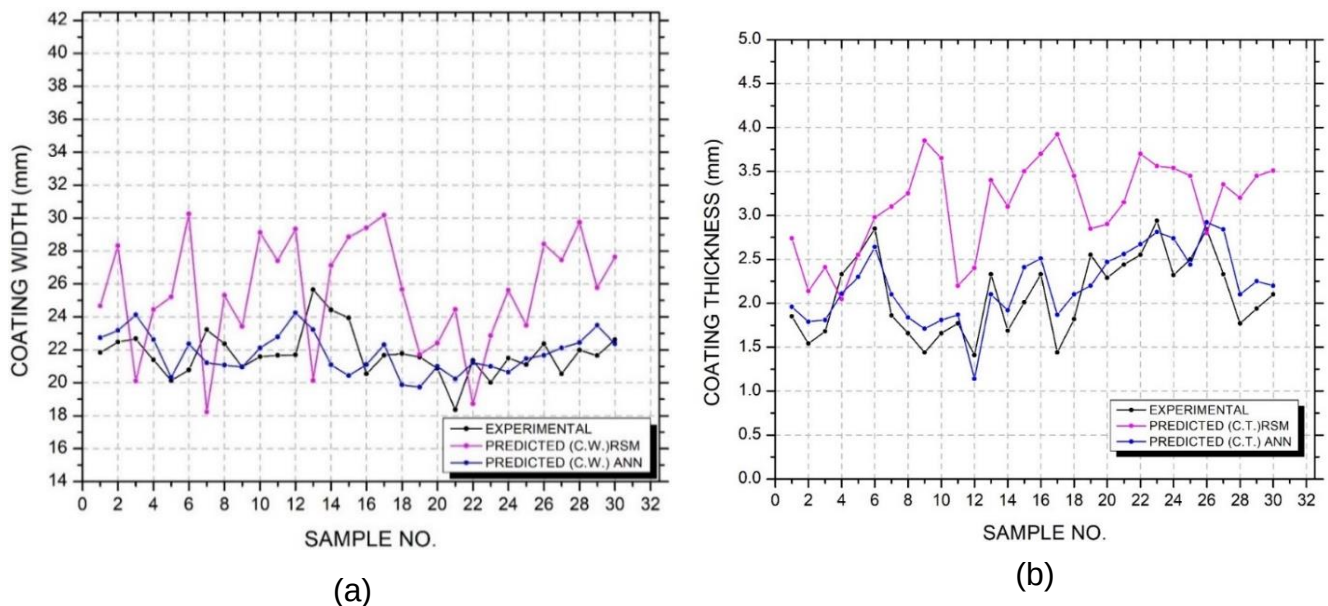


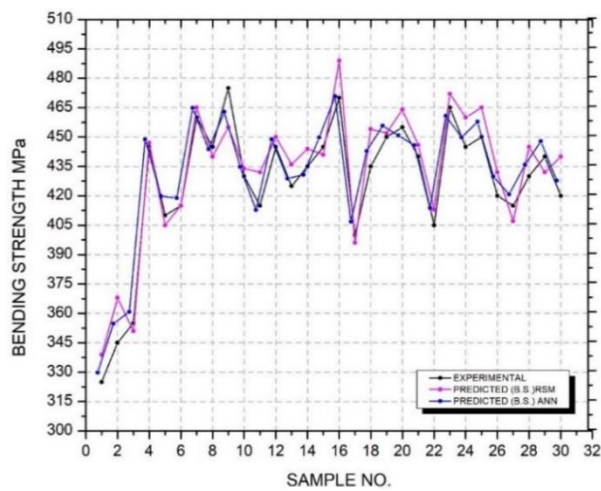
Fig 5.13 Schematic representation of experimental data for ANN and RSM model

5.10 COMPARISON OF RSM AND ANN MODELS:

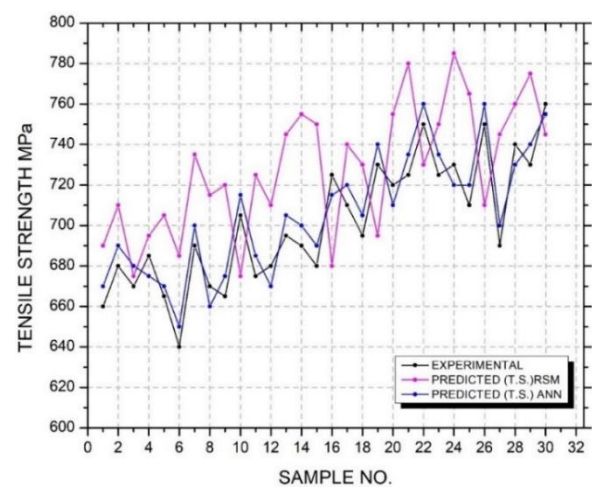
In this work, a comparison of the capabilities of both the techniques (ANN and RSM) was made, and the estimation was examined. To accomplish this task, ANN and RSM techniques were used for predicting responses at experimental points (Box Behnken design). Then, the actual values were compared with anticipated values gathered from RSM and ANN. For comparison of ANN and RSM, root-mean-squared error (RMSE) and absolute average deviation (AAD) were used. The actual and predicted values for the Box Behnken are presented in Fig 5.13.



Graph 5.8: a and b: shows the comparison between actual and predicted values (RSM and ANN) of Coating width and Coating thickness



(c)



(d)

Graph 5.9: c and d shows the comparison between actual and predicted values (RSM and ANN) of bending strength and tensile

Table 5.10 Comparison of predicted values for C.W and C.T

Axial Force (KN)	Rotational speed (RPM)	Transverse speed (RPM)	Experimental Coating width (mm)	Experimental Coating thickness (mm)	Predicted Coating width (mm)		Predicted Coating thickness (mm)	
					RSM	ANN	RSM	ANN
4	2000	75	325	660	24.67	22.74	2.74	1.96
4	2000	75	345	680	28.32	23.17	2.14	1.79
4	2000	75	345	680	20.11	24.12	2.41	1.81
4	2500	150	445	685	24.43	22.62	2.05	2.11
4	2500	150	415	665	25.21	20.34	2.55	2.3
4	2500	150	415	665	30.26	22.37	2.98	2.64
4	3000	225	460	690	18.22	21.22	3.1	2.1
4	3000	225	445	670	25.3	21.07	3.25	1.84
4	3000	225	445	670	23.42	20.95	3.85	1.71
5	2000	150	480	705	29.11	22.11	3.65	1.81
5	2000	150	450	675	27.4	22.78	2.2	1.87
5	2000	150	450	675	29.33	24.25	2.4	1.14
5	2500	225	410	695	20.14	23.22	3.4	2.1
5	2500	225	440	690	27.12	21.09	3.1	1.92
5	2500	225	440	690	28.86	20.44	3.5	2.41
5	3000	75	455	725	29.42	21.1	3.7	2.51
5	3000	75	440	725	30.18	22.31	3.92	1.87
5	3000	75	440	695	25.67	19.87	3.45	2.1
6	2000	225	420	730	21.72	19.74	2.85	2.2
6	2000	225	400	720	22.42	20.99	2.9	2.47
6	2000	225	400	720	24.45	20.24	3.15	2.56

6	2500	75	375	750	18.72	21.22	3.7	2.67
6	2500	75	400	725	22.87	21	3.56	2.81
6	2500	75	400	725	25.62	20.64	3.54	2.74
6	3000	150	325	710	23.49	21.46	3.45	2.44
6	3000	150	365	750	28.42	21.67	2.8	2.92
6	3000	150	340	690	27.45	22.12	3.35	2.84
6	3000	75	335	740	29.74	22.45	3.2	2.1
6	3000	75	445	730	25.77	23.48	3.45	2.25
6	3000	75	405	750	27.64	22.36	3.51	1.96

Table 5.11 Comparison of predicted values for B.S and T.S

Axial Force (KN)	Rotational speed (RPM)	Transverse speed (RPM)	Experimental Bending Strength (Mpa)	Experimental Tensile Strength (Mpa)	Predicted bending strength (Mpa)		Predicted Tensile strength (Mpa)	
					RSM	ANN	RSM	ANN
4	2000	75	325	660	339	329	690	670
4	2000	75	345	680	368	354	710	690
4	2000	75	345	680	351	360	675	680
4	2500	150	445	685	447	448	695	675
4	2500	150	415	665	405	419	705	670
4	2500	150	415	665	415	418	685	650
4	3000	225	460	690	465	464	735	700
4	3000	225	445	670	440	443	715	660
4	3000	225	445	670	455	462	720	675
5	2000	150	480	705	434	434	675	715
5	2000	150	450	675	432	412	725	685
5	2000	150	450	675	450	448	710	670
5	2500	225	410	695	436	428	745	705
5	2500	225	440	690	444	430	755	700
5	2500	225	440	690	441	449	750	690
5	3000	75	455	725	489	470	680	715
5	3000	75	440	725	396	406	740	720
5	3000	75	440	695	454	442	730	705
6	2000	225	420	730	452	455	695	740
6	2000	225	400	720	464	450	755	710
6	2000	225	400	720	446	445	780	735
6	2500	75	375	750	413	413	730	760
6	2500	75	400	725	472	460	750	735
6	2500	75	400	725	460	449	785	720
6	3000	150	325	710	465	457	765	720
6	3000	150	365	750	432	429	710	760
6	3000	150	340	690	407	420	745	700
6	3000	75	335	740	445	435	760	730
6	3000	75	445	730	432	447	775	740
6	3000	75	405	750	440	427	745	755

CHAPTER 6

CONCLUSION

Experiments were carried out for a single-layer coating of Aluminium 6063 alloy over EN8 medium carbon steel in substrate preheating approach (SPHA) of FS process. Main parametric relations of input and output parameters like Coating width, coating thickness, Bending strength, Tensile strength and Hardness strength.

1. By Friction surfacing the Coating of Aluminium alloy 6063 over EN8 medium carbon steel is executed.
2. Vickers Microhardness testing is used to determine the hardness of the mechtrode, substrate, and interface. The interface hardness is greater than the substrate and mechtrode, ensuring that the coating has a good bonding characteristic.
3. The coating is bent to 120° angles in the bending test to determine the material's tensile strength as well as its ductility and durability. During the test, the coatings did not shatter or peel off at any angles, indicating that the material can withstand 7.5 tonnes of force. However, because to inadequate interlocking, there seems to be material peeling or cracking at maximum stress. This indicates that the material is soft and that the settings need to be adjusted.
4. Tensile test was conducted on the material to determine the maximum tensile load the bonding can withstand. The test indicates that the material withstands a load of 165KN it indicates better bonding strength between the metals.
5. The corrosion test is carried out to determine the corrosion behaviour of the substrate, mechtrode, and interface, with good results at the coating material's interface.
6. The FE-SEM study is used to determine the microstructural structure at the coating contact. It was discovered that the intermolecular interaction between Aluminium alloy and EN8 medium carbon steel is strong, and dynamic recrystallization took place without any gaps or carbon formation.
7. Finally, from the above results, it is concluded that the coating between Aluminium alloy 6063 and EN8 medium carbon steel has coated successfully. Thus, it is convenient to use effectively the Aluminium 6063 rod to produce single track crack free coating over by friction surfacing process.

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