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Study and Analysis of Spot Welding of Dissimilar Material 1008 Low Carbon Steel-5052 Aluminum Alloy

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Abstract: Resistance spot welding is one of the oldest of the electric welding processes in use by industries today. The weld is made by a combination of heat, pressure, and time. As the name resistance welding implies, it is the resistance of the material to be welded to current flow that causes a localized heating in the part. Resistance spot welding is mostly used to weld various sheet metal products. Typically the sheets are in the 0.5-3.0 mm thickness range. The resistance spot welding of dissimilar materials is generally more challenging than that of similar materials due to differences in the physical, chemical and mechanical properties of the base metals. The influence of the primary welding parameters affects the heat input such as, peak current on the morphology, micro hardness and tensile shear load bearing capacity of weldment. Database regarding dissimilar materials resistance spot welding is very limited hence much research work is going on this field by various researchers, but most of work is on low thickness material typically 1mm to 2 mm. This work is an attempt to reveals aspects of the resistance spot welding of dissimilar materials of higher thickness typically 3mm. In this work resistance spot welding is performed on two different metal steels named low carbon steel, high strength low alloy steel with variation in current rating keeping of the parameters as constant. Although the bearing force of joint shows a linear relation with current rating but at higher current rating poor joint appearance is obtained also cavities are formed in joint.

I. INTRODUCTION

In the current scenario, there has been so many researches done and still going on in the field of welding technology. Countless works are been carried on in the recent times in the different streams of welding with consideration of so many factors from each and every bit of materials and tools used during the process by changing the properties and values and usages etc. Let's start with the basic introduction along from the history to the various types of the current research work importance will be discussed in this introduction section.

Welding is a process of joining the metal pieces by the application of heat on them. Welding is one of the least expensive process and widely used now a day in manufacturing sectors. Welding joints different metals by means of a number of processes in which heat is supplied either electrically or by mean of a gas torch over the materials. Different welding processes are used in the manufacturing of the Automobiles bodies, structural works, tanks, and general mechanical repair work. In the production and manufacturing industries, welding is used in refineries and pipeline fabrication. Now through all these thoughts, it may be called as the secondary manufacturing process.

A. Classification Of Welding Processes

They are different types of welding identifications are made and they have been as many as around 35 different welding and brazing process and several soldering methods, in use by the industry each day. There are so many various ways of classifying the welding based on different assets and they may be classified on the basis of source of heat (process, uses, flames, arc etc.)

II. LITERATURE REVIEW

A. Reviews on Significances Of RSW Welding Process

Marashi *et al.* (2007) founded that the spot weld strength in the pull out failure mode is controlled by the strength and fusion zone size of galvanized steel side. Their results stated that the fusion zone size and failure mode are the most critical factors in the weld quality in terms of peak load and energy absorption governed by various parameters. The spot weld strength in the pullout failure mode is controlled by the strength and fusion zone size of the galvanized steel side. Higher hardness leads to pullout failure mode during the tensile shear test.

Hatsuhiko OIKAWA *et al.* (2007) had an investigation made in order to get high reliability in the welded joints of automobile components using suitable welding current ranges. For RSW process the outcome new welding techniques like Laser welding is been focused as a new trend with various problems, so RSW is better in this perspective, because of the higher strength level of steel sheets are going to be used for which RSW would be the better choice.

Patel *et al.* (2011) focused on dissimilar spot welds of magnesium- aluminum alloy using spot welding process. They observed that the layer of the intermetallic compound consists of $Al_{12}M_{17}$ formed at the weld center were the hardness becomes higher. The output was that the hardness of IMC's is significantly higher than that of base metal as confirmation made by three different methods such as EDS, XRD and micro-hardness test. Due to the intermetallic layer thickness, there were predominant crakes in the reaction layers.

Ranfeng Qiu *et al.* (2010) studied the interfacial characteristic of RSW steel-aluminum alloy joint. They conducted that the width of the discontinuous reaction layer formed in the weld increases with weld current and the thickness increases as approaching the center of the weld.

Qiu *et al.* (2008) observed reaction blocks in aluminum near the welding interface as estimated in hexagonal AlFeCr having a=2.451nm and c=0.758nm based on HRTEM and SADP. The inference obtained is a two layers pf reaction structures were found, a mixed layer of FE_2Al_5 and $FeAl_3$, besides the A5052 and the approximate 35nm thick $FeAl_2$ and unusual structures of reaction blocks in Al near the welding interface were observed by them.

Vural *et al.* (2006) analyses the fatigue strength of RSW galvanized steel sheets and austenitic stainless steel AIS5052 sheets joined using a lap joint. They selected material combinations and nugget diameter as parameters. Either observation was their endurance limit of similar steel sheet combinations is higher than that of different steel sheets combinations as a result of unbalance between sheets occurs during the spot welding operations of steel sheets having different material properties especially welded using electrical resistance.

Cho & Rhee (2003) studied the nugget formation mechanism and its effects on the RSW welding process parameters which observed using a digital high-speed camera. The formation and growth were observed at 1000frames/sec and the shape of the heat generation during the initial stages was observed, as it progressed. The yellow-red heat zone directly related to the nugget was generated at the center of the weld. The dynamic resistance was affected by the change in length and area for the current flow rather than the temperature after saturation.

Alenius *et al.* (2006) explored the mechanical properties of spot welded dissimilar joints for stainless steel and galvanized steels. The failure load of the specimen's was around 72-78% of that of the lap shear specimen. Their conclusive evidence were that the failure types were plug failure in both the cases.

The lap shear strength of dissimilar metal joints depends on the strength and thickness of non-stainless steel. They observed that dissimilar metals susceptible to hydrogen embrittlement in chlorine solution at room temperature and same in stainless steel joints when it was galvanically coupled to zinc.

Penner *et al.* (2014) made a study on dissimilar RSW of aluminum to magnesium with zinc coated steel interlayer's. The mechanical properties and microstructure of the welds were analyzed. Their conclusive evidence were that the Zn coated steel interlayer was utilized to prevent mixing odd Al and Mg alloys resulting in the much higher strength of the welds, and the joining mechanism took place at Al/steel and Mg/steel interfaces.

Sun *et al.* (2004) deal about the RSW of Aluminum alloy to Steel with transition material, from process to performance in which a cold rolled clad material was introduced as a transition to aid the resistance welding process. Their experimental results obtained shows that the nugget formation process was examined using consecutive metrological cross-sectioning and two distinct fusions zones formed during spot welding.

The static, dynamic and fatigue performance of these welds were examined and compared.

Weihua Zhang *et al.* (2013) conducted the interfacial microstructures and mechanical property examination on RSW joint of high strength steel and an aluminum alloy of 4047 AlSi12 interlayer and the effect of interlayers were studied. The results obtained from the study shows that the increasing thickness of interlayer the nugget diameter has shown a decreasing tendency and the thickness of the intermetallic compound layer decreased under optimized welding parameters.

The tensile shear load of the welded joint experienced an increased tendency first and then it shows a decreased tendency with increasing inner layer thickness.

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III. OBJECTIVES AND METHODOLOGIES

The primary objective of this work is to ensure the feasibility in welding of AIS5052-AIS5052, AISI1020-AISI1020, AIS5052-AISI1020, AISI1020-AL similar and dissimilar joints by ERSW process. Similarly, this research work also concentrates on identifying suitable RSW weld process parameters for obtaining better mechanical and nugget dimensions for weldments using RSM and ANOVA tools. The individual investigation includes

A. An experimental investigation has been carried out on welding of AIS5052, AISI1020 and AA1008 similar joints using ERSW process by varying the weld pressure and keeping weld time and current as constant.
B. To ensure the quality of similar and dissimilar ERSW joints, mechanical tests such as Tensile Shear Fracture Load (TSFL) and microhardness test were carried out. Similarly, the metallurgical test such as Scanning Electron Microscope (SEM), EDAX, Micro &Macro Examinations was conducted. The factography examination was carried out on the failed tensile test samples.
C. The corrosion test was carried out on the ERSW joints using potentiodynamic polarization.
D. In order to investigate the effect of ERSW weld process parameters on welding of AIS5052, AISI1020, and AA1008 dissimilar joints. The weld trails were conducted by varying
E. welding current (55W- 65W), Time (1.5 sec to 2.5 sec) and pressure (3.3 to 3.7kgf).
F. To optimize the RSW weld input process parameters such as current, voltage and pressure on the welding of dissimilar AIS5052, AISI1020, and AA1008 joints was carried out using RSM. Based on the input data obtained from RSM model the weld trails were conducted. The welded samples were subjected to TSFL and microhardness test. The nugget diameter was measured by video captured model (VCM) for all the joints. Similarly the metallurgical test EDAX, SEM etc. and the factography test was also carried out on dissimilar joints.
G. To predict the better ERSW weld process parameters for welding of dissimilar AIS5052, AISI1020, and AA1008 joints was carried out using ANOVA model for obtaining good mechanical properties and nugget diameter.
H. To validate the optimized process parameters confirmation test was conducted and experimentally obtained results were compared with the RSM and ANOVA results.
I. Similarly, the corrosion test was conducted on the samples welded at the optimum condition and the obtained results were compared with the results unoptimized weld samples for ERSW joints.
J. From the detailed literature review on ERSW welding process on optimization and prediction of its process parameters for different materials. The major problem had been identified and presented as a detailed workflow chart as given in three phases presented in Figure 3.1 (a), 3.1 (b), 3.1 (c) and the entire workflow chart given in 3.1 (d).

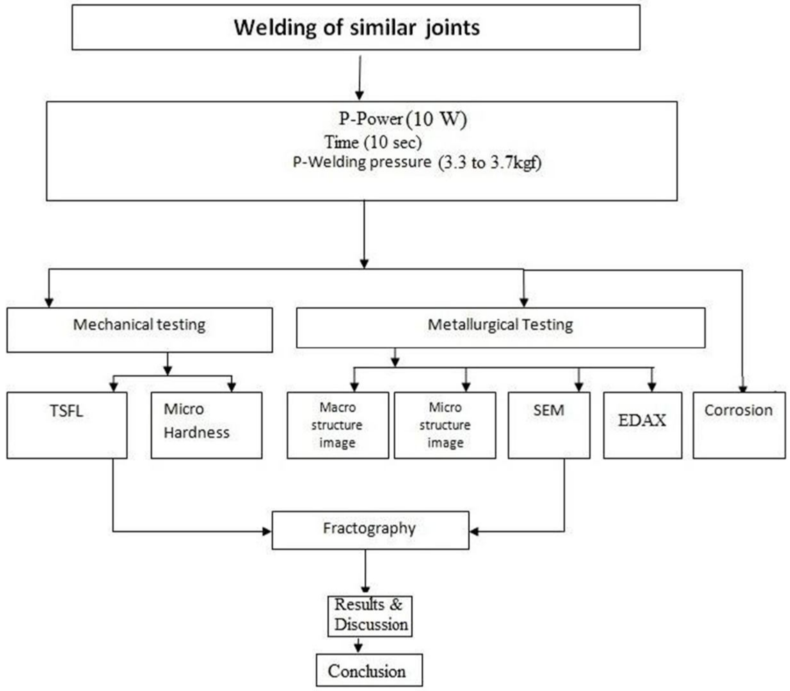

Figure 3.1(a) Schematic workflow chart phase-1

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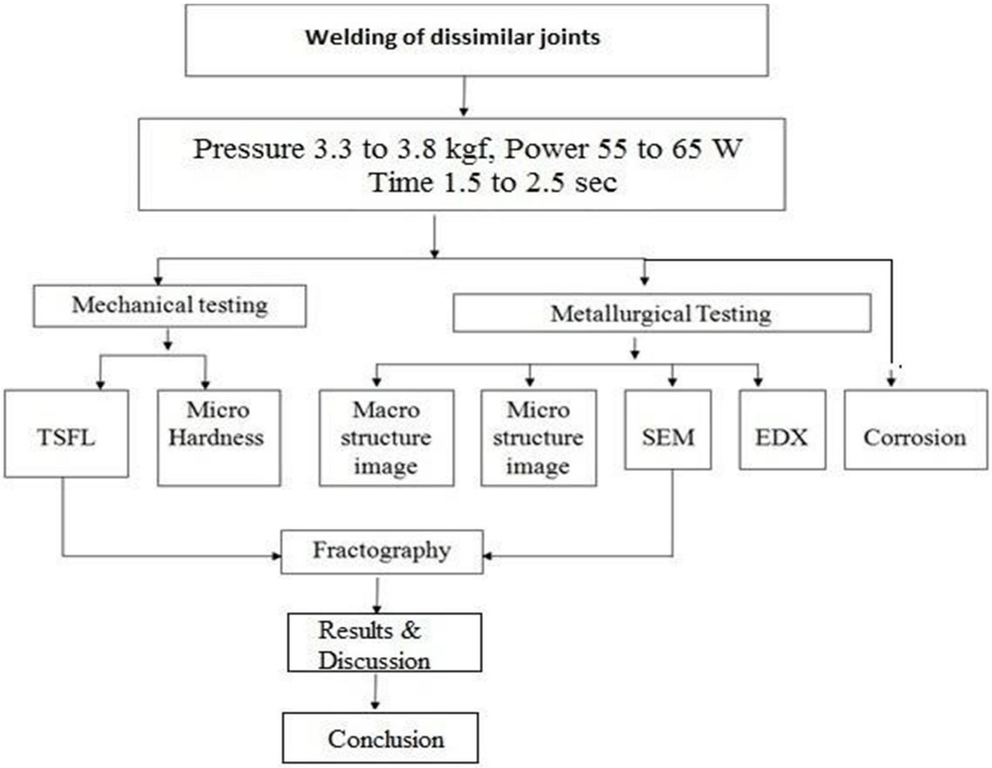

Figure 3.1(b) Schematic workflow chart phase-II

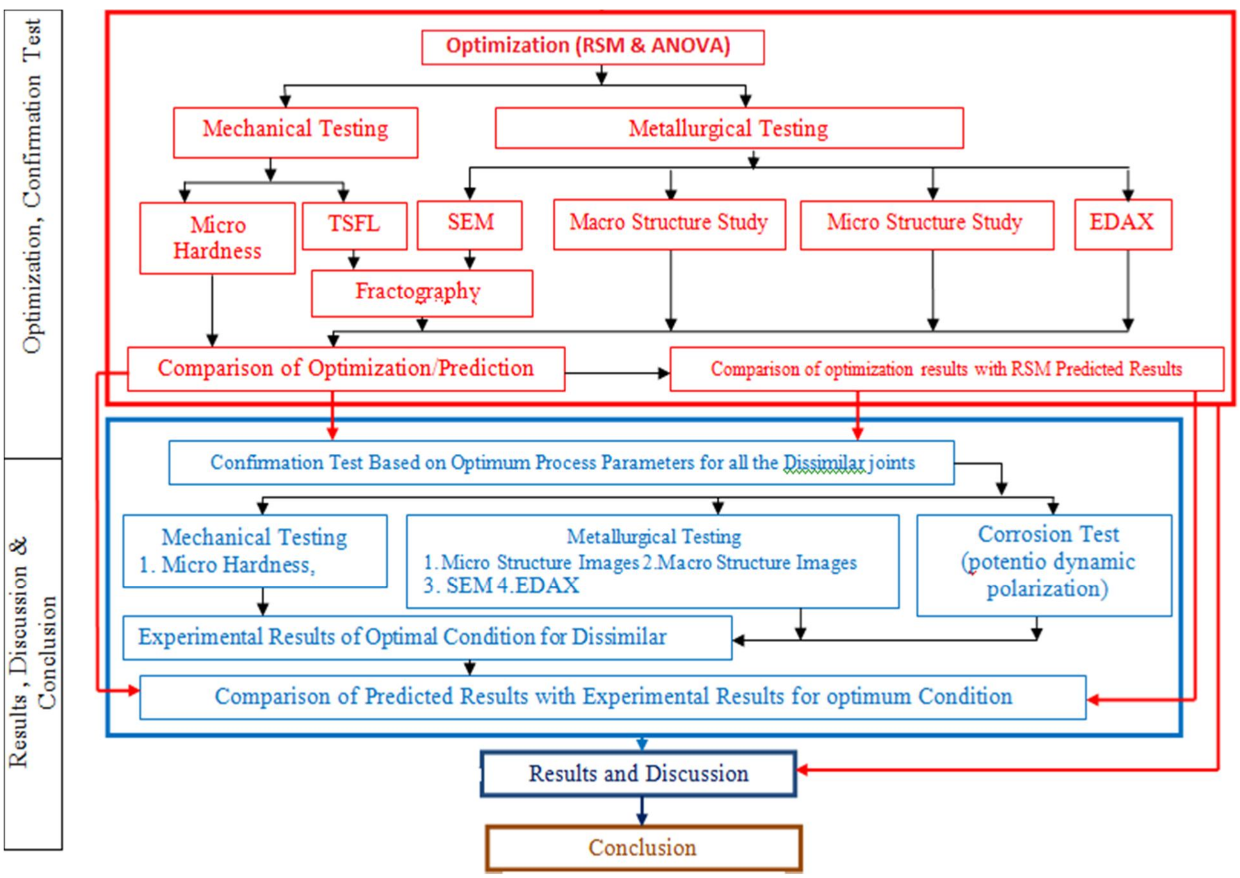

Figure 3.1(c) Schematic workflow chart phase-III

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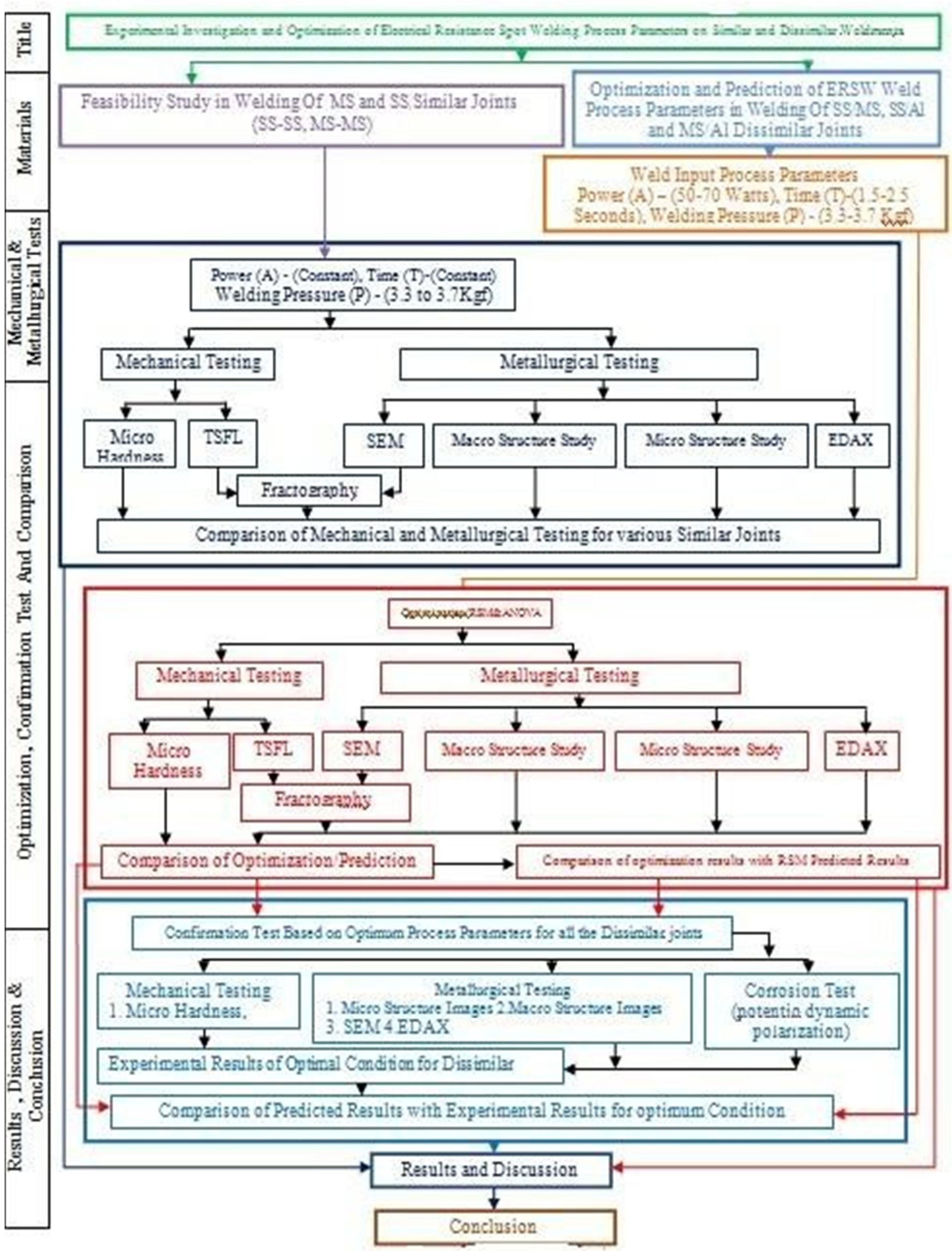

Figure 3.1(d) Schematic workflow chart

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IV. METHODOLOGY

The total and complete experimental methodology is described in the form of the workflow chart in this section and illustrated in Figures 3.1(a), 3.1(b), 3.1(c) and 3.1 (d). The sequence of the methodology which was followed in the present investigation is given below:

A. Initially, the base material was prepared from the AIS5052, AISI1020, and AA1008, for welding of similar and dissimilar joints using ERS Welding process.
B. Welding of similar joints was carried out by keeping pressure and time as constant and the pressure was varied from to 3.9 kgf.
C. Then the welded samples are tested using the radiographic test to check and confirm that the samples contain no defect on them.
D. According to the various ASTM standards the TSFL and microhardness test samples were prepared from welded joints and tested.
E. The metallographic test like micro, macro, SEM and EDAX were carried out on the welded samples to study the structural changes happened in the grains during welding in the nugget zone.
F. Factography test was carried out on the failed TSFL samples to study the mode of failure occurred.
G. A corrosion test was conducted on the ERSW joints using potentiodynamic polarization to analyze the effect of corrosion on the welded joints.
H. Similarly, welding of dissimilar joints was carried out at various RSW weld parameter such as current (50A-30kA), voltage (50-70W) and pressure (3.4 to 3.9kgf) and the mechanical, metallurgical, factography and corrosion tests were conducted for the dissimilar joints.
I. In order to identify the optimum ERSW weld process parameters, the RSM model was used.
J. The RSM model was developed based on Central Composite Rotatable Design (CCRD) for optimization of the three important process parameters such as power time andpressure.
K. Similarly, the welded sample was initially tested using radiographic test for the confirmation of defect-free joints. The various mechanical test's such as TSFL and Microhardness test was carried out on all the samples prepared based on various ASTM standards from the ERSW welded joints.
L. The metallographic test such as SEM, EDAX, micro, and macro was conducted on the welded samples and the factography test was carried out TSFL on fractured samples.
M. The prediction of ERSW weld process parameters was carried out using ANOVA model.
N. A corrosion test was carried out on the samples welded at optimum process parameters and obtained results were compared with the non-optimized corrosion test results.

V. EXPERIMENTAL METHODS AND MATERIALS

Based on the inference from the objectives and methodologies discussed in the third chapter, the experimental methods to be deployed and followed are framed and discussed in an elaborate manner. This current chapter emphasizes the material selection and the base materials preparations for welding. It further discusses in depth about the welding machine, welding procedure followed and the welding process parameters incorporated in this research work.
The different mechanical testing machines used for various tests like the TSFL and microhardness test and their necessary appropriate ASTM standards are used for the preparation of the sample's has been put forth in this chapter. This chapter also discussed in detail the necessary metallurgical testing machines used for this research work required to analyze like the macro, micro, SEM and EDAX tests.

A. Materials Selection

In this work AISI 304 (SS), AISI 1020 (MS) and AA 1008 (Al) was selected as base materials for this investigation because they are widely used in automobile and household applications.

In this work, AISI 304 (SS), AISI 1020 (MS) and AA 1008 (Al)
selected as base materials for this investigation because of they are widely applied in different engineering industries and their corresponding chemical composition and mechanical properties are tested and tabulated in Tables 4.1 and 4.2 respectively.

Table 4.1 Chemical Compositions of the Selected Base Materials

Materials	Weight %											
	C	Fe	Mn	P	S	Cr	Ni	Si	Al	Cu	Mg	Zn
AISI1020	0.17-0.23	99.08-99.53	0.30-0.60	≤0.040	≤0.05	-	-	-	-	-	-	-
AIS5052	0.08	66.3-74	2	0.045	0.03	18-20	8-10.5	1	-	-	-	-
AA1008	-	0.5	0.3-0.9	-	-	0.1	-	0.5	90-94	4-5	1-2	.25

Table 4.2 Mechanical Properties of the Selected Base Materials

Materials	Properties				
	Tensile Strength, Ultimate (MPa)	Modulus of Elasticity (GPa)	Bulk Modulus (GPa)	Poissons Ratio	Shear Modulus (GPa)
AISI1020	394.72	200	140	0.290	80.0
AIS5052	505	193-200	-	0.29	86
AA1008	324	73.1	-	0.33	28

B. ERSW Welding Machine

The joining of metal sheets was carried out in Resistance spot welding machine with the configuration of pedestal type inverter base medium frequency DC machine (Model PACI TECH-ERSW) of capacity 90kV. It has the flexibility of welding sheets up to 6 mm thickness with a maximum current of 20 kVA capacities. The photographs views of the ERSW welding machine deployed for this investigations were shown in figure 4.1.

Figure 4.1 Photographic View of the ERSW machine deployed in this study

C. Weld Process Parameters

The weld process parameters selected for feasibility trails and optimization in welding of AISI 304 and AISI 1020 AA1008 similar and dissimilar joints was discussed detailed in this section below.

1) *Selected ERSW Process Parameters for Trail Experiments:* The feasibility study was conducted by varying the weld pressure and keeping the weld time and current as constant for AISI 304 and AISI 102 similar joints. The parameters selected for the feasibility study was discussed in section.
2) *ERSW Process Parameters for Optimization and Prediction Techniques:* The optimization and prediction of ERSW process parameters were carried out on AISI5052-AISI1020, AISI1020-AA1008, and AIS5052-AA1008 dissimilar joints by varying the welding current (55-65W), Time (1.5 to 2.5 sec) and pressure (3.4 to 3.9kgf). The parameter range was selected from the results obtained from the feasibility study experiments as explained in section 4.3.1 and based on a literature survey.

D. Mechanical Testing

The mechanical properties of the ERSW welded joints were identified by conducting TSFL and Microhardness tests on the specimens prepared from the ERSW welded joints according to various ASTM standards.

1) *TSFL Test:* The TSFL specimens were prepared from the welded joints based on ISO14273 standards as given in Figure 4.2. The TSFL test was conducted using UTM of 20kVA as given in Figure 4.3.

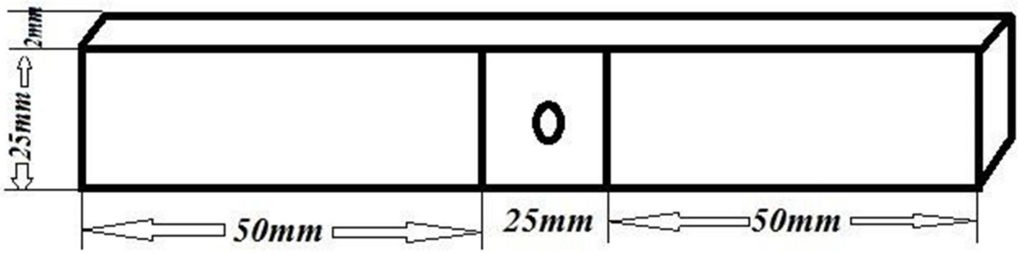

Figure 4.2 Specimen Dimensions (all dimensions are in mm)

Figure 4.3 TSFL machine

2) *Micro Hardness Test:* The microhardness test samples were prepared from the ERSW weld samples based on the ASTM standards as shown in Figure (4.5). Figure 4.6 shows the base and nugget zone of the welded samples. The microhardness test was carried out by using a Micro Vickers Hardness Tester machine by applying a 1Kg load shown in Figure 4.5.

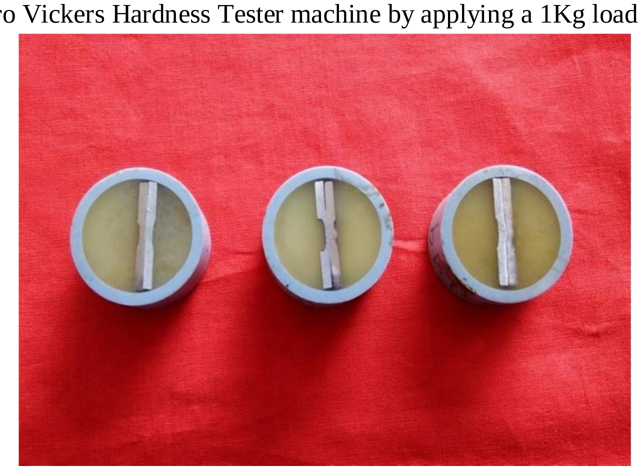

Figure 4.4 Hardness sample

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a) Machine Name: Micro Vickers Hardness Tester
b) Testing load range: 10 grams to 1 Kg Load Make: Wilson Wolpert – Germany
c) Vernier caliper least count: 0.01 mm
d) Available Hardness testing Scale: HV, HRA, HRC, 15N, 30Netc.

Figure 4.5 Micro Vickers Hardness TesterMachine

E. Metallurgical Testing

The metallurgical investigation was carried out on the specimen prepared from ERSW welded joints using an optical microscope and scanning electron microscope for analyzing the structural changes occurred in the weld nugget zone. The factography test was carried out on a failed TSFL sample using SEM in order to identify the mode of failure and the result was correlated with mechanical properties. The EDAX test was carried out on the nugget zone in order to examine the elemental changes occurred during welding.

The optical microscope was used for macro and micro was shown in Figure 4.6. The SEM and EDAX test conducted by using SEM machine shown in Figure 4.7.

Figure 4.6 Photographic image of Optical Microscope

Figure 4.7 Photographic image of Scanning Electron Microscope (SEM)

F. Potentio Dynamic Polarisation Test

The corrosion test was carried out using potentiodynamic polarization methods and the corresponding experimental setup as shown in Figure 4.8. The corrosion samples were prepared from the joints welded at the optimized condition for dissimilar joints and on the similar joints welded at high weld pressure according to the specification of potentiodynamic polarization the sample dimensions are 10mm × 10mm and the nugget zone has been polished by mirror polished method, which is shown in Figure 4.9

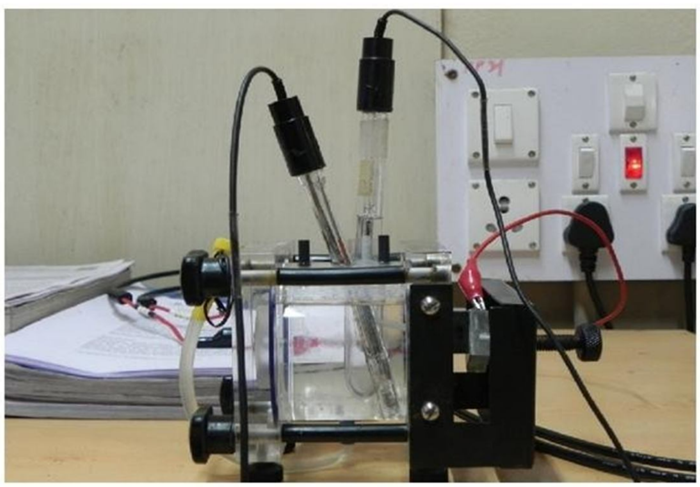

Figure 4.8 Experimental setup for potentiodynamic polarization test

Figure 4.9 Samples of Corrosion Test

VI. SUMMARY

This chapter describes in details about the selected various material, weld procedures and various mechanical metallurgical and corrosion test methods are employed in this work. This chapter also discussed in detail about the ERSW weld machine and the various weld input process parameters identified for experimental works. This chapter also explains various ASTM standards employed in the preparation of the sample test in this work, the next chapter describes in details about various weld process parameters selected for similar and dissimilar joints.

A. *Mechanical and Metallurgical Investigation of AIS5052 –AIS5052 similar Joints*

This section discusses in detail about the results obtained from TSFL, microhardness, nugget diameter and corrosion test for AIS5052- AIS5052 similar joints.

B. *Analysis of TSFL and hardness*

The TSFL test samples were prepared from ERSW welded joints according to ISO14273 standard as shown in Figure 7.1, then the samples were tested using Instron 250 kN. The failed TSFL specimens are shown in Figure 7.2. From the Figure 7.2, it is identified that all the samples are failed at the weld nugget region.

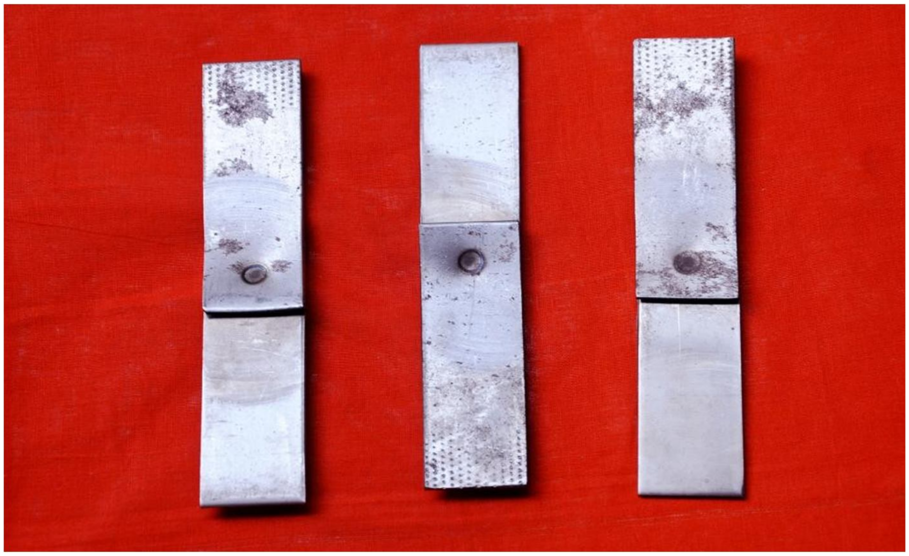

Figure 7.1 Photographic view of TSFL test samples of AIS5052 Similar joints before testing

Figure 7.2 Photographic image of TSFL tested samples of AIS5052 –AIS5052 similar welded joints after testing.

The TSFL test results for the samples welded at three different weld pressure are shown in Figure 7.3.

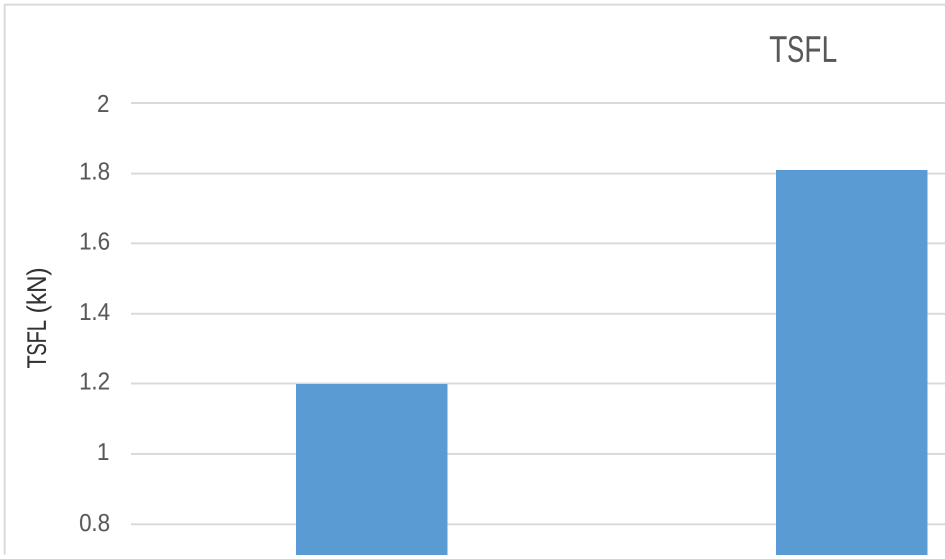

Figure 7.3 TSFL test results for the samples welded at three different weld pressure conditions for AIS5052 Similar joints.

From the Figure 7.3, it is noted that the maximum TSFL was obtained for the sample welded at the weld pressure 3.7kgf.
The results obtained from the TSFL and microhardness tests were given in Table 7.1.

Table 7.1 Results obtained from TSFL and microhardness tests for AIS5052 similar joints

Sample No	Weld Parameters			TSFL (kN)	Micro Hardness (VHN)
	Power (W)	Time (seconds)	Pressure (kgf)		
AIS5052–AIS5052-1	15	10	3.3	1.20	214.8
AIS5052–AIS5052-2	15	10	3.5	1.81	215.2
AIS5052–AIS5052-3	15	10	3.7	1.85	220.2

From the Table 7.1, it is clearly identified that increase in weld pressure increases the TSFL strength.
Similarly, the microhardness samples were prepared from the ERSW joints welded at three different weld pressure and it was etched by sodium hydroxide solution as shown in Figure 7.4 (a).

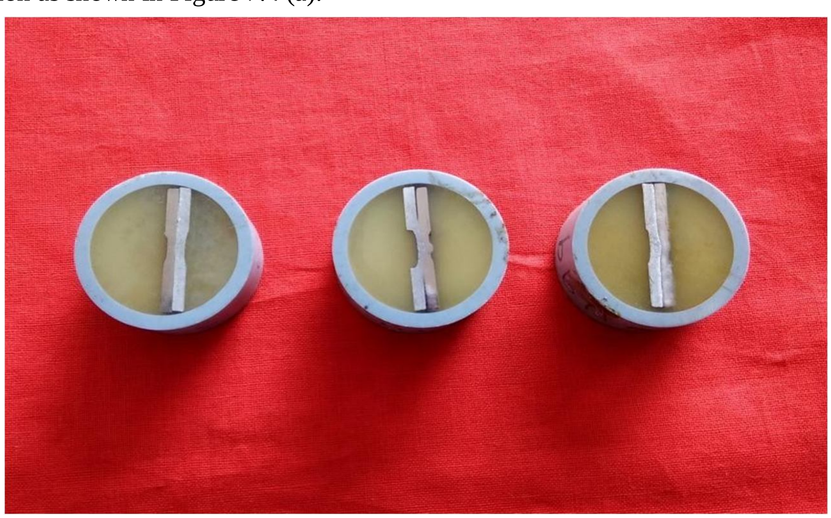

Figure 7.4 (a) Photographic view of microhardness samples of AIS5052 similar joints

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The hardness test was conducted using a Vickers microhardness tester for a load of 1 kg. The results obtained from the test are shown in Figure 7.4 (b).

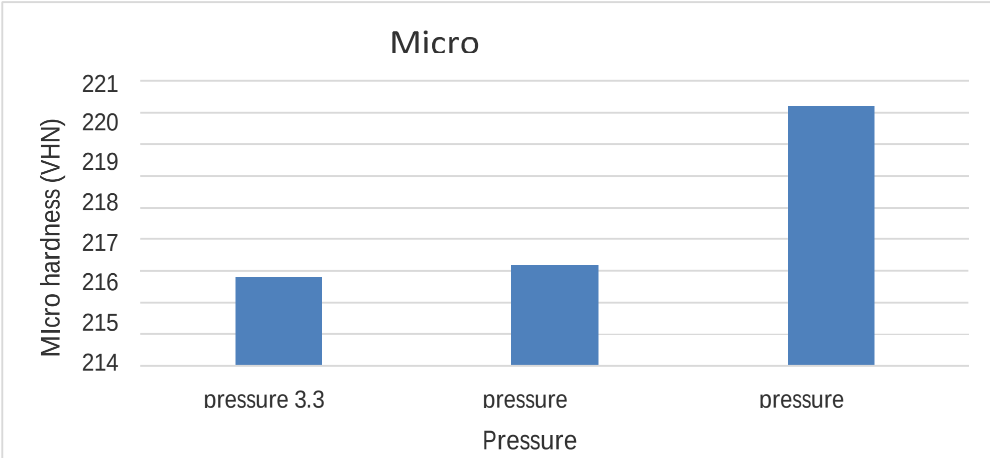


Figure 7.4(b) Microhardness test result for the samples welded at various weld pressures

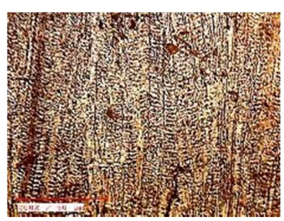
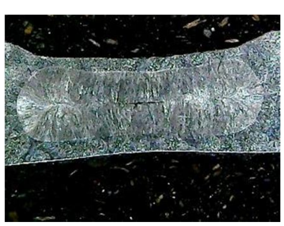
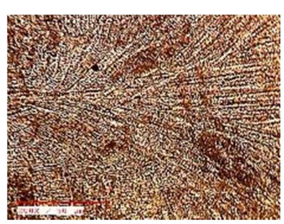
From the Figure 7.4(b) it is identified that maximum hardness values were obtained for the sample welded at the maximum weld pressure of 3.7kgf. Therefore, it was observed that the hardness values are directly proportional to the weld pressure as tabulated in Table 7.1.

C. Analysis of Metallurgical Results

The macro, micro, SEM, EDAX and factography analysis test was carried out on the AIS5052- AIS5052 joints and the results are discussed in the section below.

D. Macro, Microstructural and nugget dimension examinations

The macro and microstructural examinations were carried out on AIS5052- AIS5052 joints welded at different weld pressure 3.3 kgf, 3.5 kgf and 3.7kgf and their corresponding images are shown in Figure 7.5(a) to (f).

Pressure (kgf)	Macro Image	Micro Image	Nugget Diameter (mm)
3.3	 (a)	 (d)	3.8
3.5	 (b)	 (e)	4.2

3.7	 (c)	 (f)	4.9

Figure 7.5 (a) to (f) shows the Macro-micro image and Nugget diameter of the AIS5052

E. AIS5052 similar joints welded at various weld pressure

The macrostructural images show that the sample welded at the weld pressure 3.7kgf is having defect free nugget and no holes were identified. Similarly, while comparing the nugget zone macro structures it is identified that the sample welded at pressure 3.3kgf possess small holes, which clearly reveals that the sample welded at the weld pressure 3.7kgf weld pressure is better as shown in figure 7.5 (a), 7.5 (b) & 7.5 (c). The same result was proved in the TSFL, hardness and nugget diameter examinations.

The microstructural study shows that the sample welded at a pressure of 3.7kgf is having very fine grains when compared with the samples welded at the pressure at 3.3kgf and 3.5 kgf as shown in Figure 7.5 (d, e & f). The microstructural images show the occurrence of course austenite and ferrite mode. In addition to that, the presence of high chromium content in AIS5052 promotes more ferrite content. The presence of dendritic ferrite on the nugget zone was also identified and this dendrite ferrite was almost normal to weld interface as presented in the above Figure 7.5(d, e & f).

The nugget diameter was measured using a video measurement system (VMS) 2010F and the measured values of the nugget diameter of the samples welded at three different weld pressure are tabulated in Figure 7.5. From the nugget diameter values, it is identified that the maximum nugget diameter was obtained for the sample welded at maximum weld pressure of 3.7kgf.

VII. CONCLUSION

A. The experimental investigation may also be carried out on the welded joints under fatigue, creep and high-temperature applications.

B. The other optimization techniques such as ANN, Genetic Algorithm, Taguchi method can be applied for optimization and prediction of the weld input process parameters.

C. The various simulation software such as ANSYS, SYSWELD can be applied for simulation of an ERSW process parameter in identifying the temperature distribution and the same can be compared with the experimental results.

D. The comparison study may be conducted by changing the various electrode material in ERSW process.

E. The comparative study may be carried out by conducting welding using various another weld process such as laser welding, electron beam welding, friction stir welding etc on and AIS5052-AISI102 AA1008 compared with the ERSW process.

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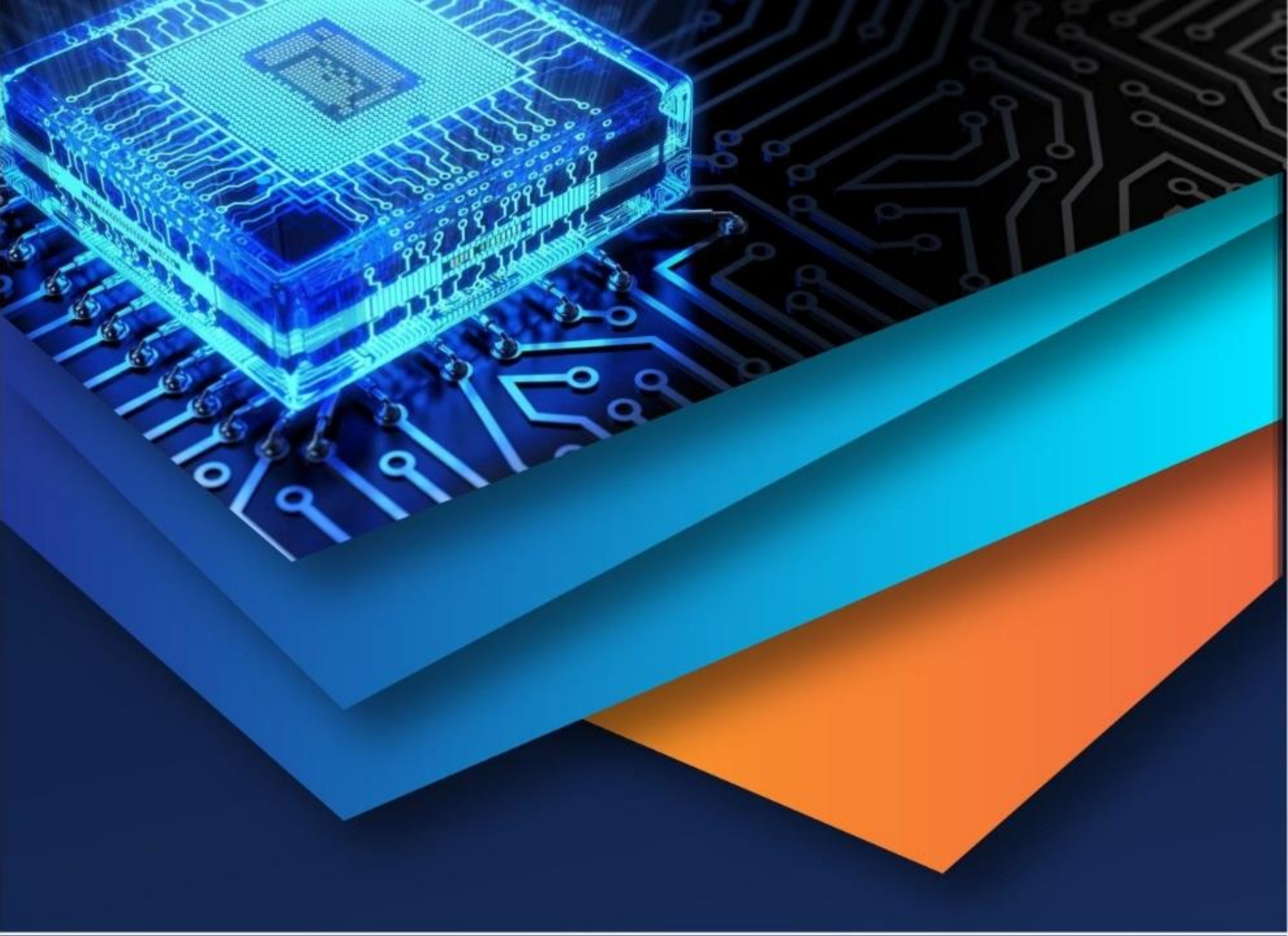

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