Study of Variation in Parameters and its effects on Spot welding of Advanced High Strength Steel

A Major Project thesis submitted

In partial fulfillment for the requirement of the degree of

Master of Engineering
In
Production & Industrial Engineering

Submitted By
PANKAJ KUMAR
(ROLL NO.2K13/PIE/15)
Session 2013-2015

Under The Guidance Of
Dr. A.K. MADAN

DEPARTMENT OF MENCHANICAL & PRODUCTION ENGINEERING
DELHI TECHNOLOGICAL UNIVERSITY, DELHI
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Candidate's Declaration

I hereby certify that the work which is being presented in the dissertation entitled **"Study of variation in parameters and its effects on Spot welding of Advanced High Strength Steel"**, in partial fulfillment of the requirements for the award of the degree of Master of Engineering in Production Engineering, submitted in the Department of Mechanical Engineering, Delhi Technological University (Formerly Delhi College of Engineering), New Delhi is an authentic record of my own work carried out under the supervision of Dr. A.K. Madan, Associate Professor of Mechanical Engineering Department, Delhi Technological University, Delhi.

I have not submitted the matter embodied in this dissertation for the award of any other degree.

PANKAJ KUMAR
2K13/PIE/15

Acknowledgement

This is to acknowledge all those people who gave me an opportunity to work on this project. My sincere regards to **Dr. A. K. Madan, Associate professor,** Delhi Technological University, for providing me this stupendous opportunity of working in this area. Again, I would like to thank **my project guide Dr. A. K. Madan** for his efforts and ideas that helped me incalculably during the course of my work. I also sincerely thank for his timely help and guidance throughout the project. The project was a great challenge for me and without the help and support of mentors it would not have been possible to go about this task.

I again wish to place on my records my heartful thanks and gratitude to all the senior students and my classmates at Delhi Technological University without whose sincere help, guidance, encouragement and cooperation this project could not have been successfully completed.

Finally my sincere thanks go to my parents for their blessings and my family who gave me strength love and care to carry out this work successfully.

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Abstract

Resistance Spot welding process have been focus of research in the fields of sheet metal manufacturing form last many years. In this process, an electrical current flows through resistive circuit to generate enough heat between two pieces of sheet metal so that the metal reaches molten stage. The resistance to the flow of current is provided by the work piece. The maximum heat is generated at the point of maximum resistance.

In the present work, macro structural characteristics of resistance spot welding joints of the two dissimilar thickness dual phase steel having dissimilar thickness and dissimilar phase were described in terms of melting rate, indentation rate, nugget diameter and indentation diameter. The results revealed that the melting rate of the DP600 side was higher than that of the DP780 side and the indentation rate of the DP600 side was lower than that of the DP780 side of the welded joints. The base metal lap order had the important effect on nugget diameter, and the DP780/DP600 spot welded joints tended to get the larger nugget diameter than DP600/DP780 spot welded joints with the same process parameters. The indentation diameters of DP600 and DP780 sides depended on the electrode geometry and force.

The reason for most spot weld capability method is to insure that, for given material, a weld piece of satisfactory size can be achieved. There are three recognized parameters of resistance spot welding – weld current, cycle duration and forging pressure which impacts the material size. Because of variety of these parameters, there is additionally impact on the mechanical properties spot weld joint. The experimental work is done to study the effects of variation of parameters on nugget diameter and properties in resistance spot welding process for a particular isotropic material. The tests are led on isotropic material and its different physical and warm properties were know

Experiments alone neither can easily study the separate effects of various factors involved in the resistance spot welding process, nor can they accurately predict the complex behavior of coupled electrical, mechanical and thermal processes during the spot welding procedure. Moreover, they are often limited in scope because of the restricted operational capabilities with regard to the available hardware. Also, the scope is reduced due to excessive time and cost associated with experimental procedures, which involve many influential parameters. FEM is numerical based approach and considered to be efficient tool for solving field problems. In comparison to the analytical analysis, one important merit of this model is that it can be easily applied to a model, which includes the non-uniform material properties and/or complex boundaries.

Keywords: Advanced High Strength Steel (AHSS), DP780, DP600, Spot Welding, Parameters, FEM, ANSYS

CHAPTER 1

INTRODUCTION

Advanced high-strength steels (AHSS) combine strength and ductility by phase transformation and solution strengthening and achieve a strength-to-weight ratio for lightweight applications in the automobile industry [1,2]. Dual phase (DP) steel is one of the most common AHSS due to the good formability and ductility with relatively high strength, continuous yielding followed by rapid work hardening, a low yield to tensile strain ratio and non-aging behavior at ambient temperature [3–5]. In order to maximize efficiency and performance, the dissimilar material combinations are very widely used in automotive industry [6]. The adoption of dissimilar metal combinations provides possibilities for the flexible design of the products using each material efficiently.

Because of its light weight and ease of manufacturing, sheet metal is commonly used in industry. For effective application, rapid and low cost, joining processes are necessary for various kinds of sheet metal. From this point of view, the resistance spot welding process is very attractive joining method, since it is relatively simple in principle and requires minimum operator skill.

FEM has become powerful tool for numerical solution to a wide range of engineering problems. With aid of statistical design and advances in computer technology, FEM can provide quick and accurate solution to complex problem with relative ease. Using this numerical procedure, the uncertainties associated with experiments can be avoided and cost can be significantly reduced. Therefore, FEM is employed to analyze spot welded joint.

1.1 OBJECTIVES OF PROJECT

The objective of the project is to gain the knowledge within the field of spot welding and FEM. The following objectives are specified:

- To study the spot welding experimentally and by aid of computer simulation.
- To find the effect of variation in parameters in spot welding process.
- To study the effect of application of heat and load to work material.

1.2 PROBLEM STATEMENT

1. Experimental relation of parameters in the process:
    - To study the effect of melting rate on welding current; electrode force and welding time.
    - To study the effect of indentation rate on welding current; electrode force and welding time.
    - To study the effect of nugget diameter and indentation diameter on welding current; electrode force and welding time.
2. Find the stress distribution and temperature variations during the process of resistance spot welding.

1.3 PLAN OF WORK

AHSS DP780 and DP600 are used as test material in the project for spot welding analysis. This material is used frequently in automobile industry due to its high strength and light weight. JIS standard is followed to prepare Lap joint with help of resistance spot welding process. Spot Welding is done with Microprocessor Controlled IT (Integrated Transformer) spot weld gun at an Automobile industry. Variation in properties such as welding time, welding current, electrode force is studied by varying various parameters. The value of current and cycle time is varied and weld properties are noted down with specific instruments. FEM is done with ANSYS 9.0 software. Modeling is done with AUTOCAD software and then the model is imported to

ANSYS for the analysis. A simple axis symmetric model is assumed and real time boundary conditions are given in the FEM tool for the analysis.

CHAPTER 2

LITERATURE REVIEW

Resistance spot welding is a process that has been widely used in sheet metal fabrication, with advantages of high speed suitability of automation and inclusion in high production assembly lines with the other fabricating operations. This chapter deals with the principle and theoretical background of spot welding process. Also some light is given on the recent work in this area.

Resistance spot welding is an important method in automobile manufacturing till today and a typical vehicle could need 3000– 7000 spot welds [7,8]. Quality and performance of the resistance spot welds are very important to the durability and safety design of vehicles [9]. The quality of the spot-weld was examined by destructive tests to determine whether a satisfactory weld had been produced, such as quasi-static tensile test and dynamic cycle test. Pal and Bhowmick [10] studied the high cycle fatigue behavior of DP780 steel sheet and found that DP780 spot-weld joints had almost similar fatigue behavior at low load high cycle and high load low cycle. Khan et al. [11] studied the hardness profile of dissimilar HSLA350/DP600 resistance spot welds and found that the hardness in the fusion zone (FZ) was higher than that in the base metal (BM) due to the formation of lath martensite.

Hernandez et al. [12] studied the mechanical properties of dissimilar DP600/DP780 spot-weld joints and found that HAZ softening promoted a pullout failure mode and fracture occurred first in the DP780.

The macro characteristics of spot welded joint also have important influence on quality and performance. Increasing independent depth led to stress concentration and provided the potential location for shear–tensile failure [13]. Nugget diameter affects the tensile–shear strength of the spot welded joints.

However, there are few literatures about macro characteristics of spot-welded joints.

Considering the facts above, the aim of this research is to study the macro characteristics of dissimilar thickness dual phase steel RSW joints including melting rate, indentation rate, nugget diameter and indentation diameter. The effects of process parameters and BM lap orders on the spot welded joint macro characteristics are discussed.

2.1 Resistance Spot Welding

Resistance spot welding was invented in 1877 by Eiihu Thomson and has been widely used since then as manufacturing process in process for joining sheet metal. A resistance welding machine is designed to pass electrical current through the parts to be joined, bringing these components to plastic state. Once in this state, a mechanical force is required to forge the parts together. This process if applied correctly, will produce a weld nugget that is stronger than the base metal. The correct application of electrode force will eliminate metal expulsion (flash) and minimize electrode wear. Even when joining galvanized steel, a clean strong joint can be accomplished without the usual sparks seen in most resistance welding process. Fused properly, the resistance welding process is the fastest and most economical process of joining sheet metals [1]. The basic joint is primarily accomplished through forging of plastic state material. To reach this ideal state, a proper balance between force and heat must be obtained. Since heat is created between parts being joined by the voltage drop across the electrical resistance (nugget area), a higher force will lower this resistance and thus reduce the effective heat. Reduction of force will raise this resistance to provide higher heat, but at same time lower the forging action of the machine. The balance between these two factors is important.

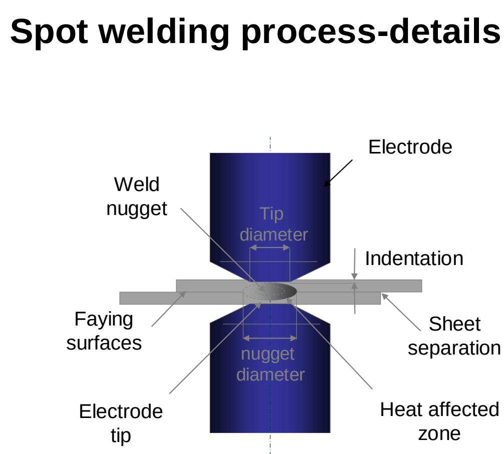


Figure 2.1: Spot welding process details

2.2 Parameters affecting Resistance Spot Welding

The principle of resistance welding is the Joule heating law where the heat *Q* is generated depending on three basic factors as expressed in the following formula:

$$Q = I^2 R t$$

where *I* is the current passing through the metal combination, *R* is the resistance of the base metals and the contact interfaces, and *t* is the duration/time of the current flow. In an actual welding process, there are numerous parameters; some researchers had identified more than 100, to influence the results of a resistance welding. In order to have a systematic understanding of the resistance welding technology, the most influential parameters are summarized into the following eight types:

1) Welding current

The welding current is the most important parameter in resistance welding which determines the heat generation by a power of square as shown in the formula. The size of the weld nugget increases rapidly with increasing welding current, but too high current will result in expulsions and electrode deteriorations. The figure below shows the typical types of the welding current applied in resistance welding including the single phase alternating current (AC) that is still the most used in production, the three phase direct current (DC), the condensator discharge (CD), and the newly developed middle frequency inverter DC. Usually the root mean square (RMS) values of the welding current are used in the machine parameter settings and the process controls.

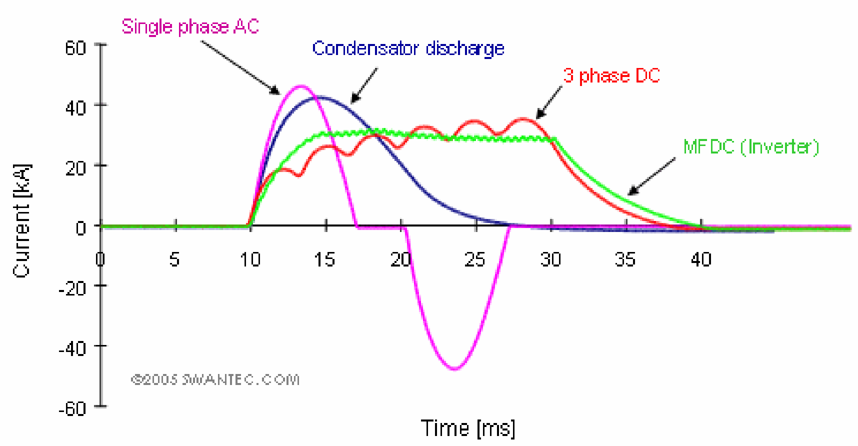


Figure 2.2: Welding Current

2) Welding Time

The heat generation is directly proportional to the welding time. Due to the heat transfer from the weld zone to the base metals and to the electrodes, as well as the heat loss from the free surfaces to the surroundings, a minimum welding current as well as a minimum welding time will be needed to make a weld. If the welding current is too low, simply increasing the welding time alone will not produce a weld. When the welding current is high enough, the size of the weld nugget increases with increasing welding time until it reaches a size similar to the electrode tip contact area. If the welding time is prolonged, expulsion will occur or in the worst cases the electrode may stick to the work piece.

3) Welding force

The welding force influences the resistance welding process by its effect on the contact resistance at the interfaces and on the contact area due to deformation of materials. The workpieces must be compressed with a certain force at the weld zone to enable the passage of the current. If the welding force is too low, expulsion may occur immediately after starting the welding current due to fact that the contact resistance is too high, resulting in rapid heat generation. If the welding force is high, the contact area will be large resulting in low current density and low contact resistance that will reduce heat generation and the size of weld nugget

4) Contact resistance

The contact resistance at the weld interface is the most influential parameter related to materials. It however has highly dynamic interaction with the process parameters. The figure below shows the measured contact resistance of mild steel at different temperatures and different pressures.

The contact resistance generally decreases with increasing temperature but has a local ridge around 300°C, and it decreases almost proportionally with increasing pressure. All metals have rough surfaces in micro scale. When the welding force increases, the contact pressure increases thereby the real contact area at the interface increases due to deformation of the rough surface asperities. Therefore the contact resistance at the interface decreases which reduces the heat generation and the size of weld nugget. On the metal surfaces, there are also oxides, water vapour, oil, dirt and other contaminants. When the temperature increases, some of the surface contaminants (mainly water and oil based ones) will be burned off in the first couple of cycles, and the metals will also be softened at high temperatures. Thus the
contact resistance generally decreases with increasing temperature.

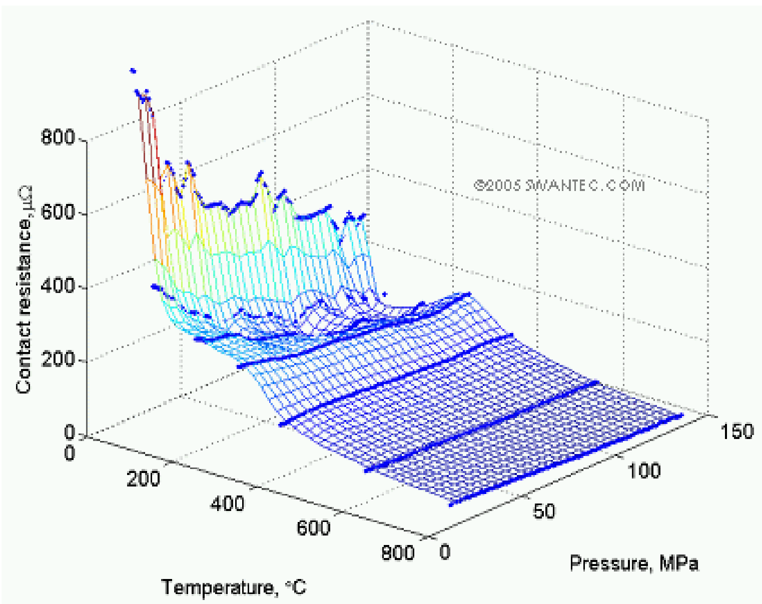


Figure 2.3: Contact Resistance

5) Materials properties

Nearly all material properties change with temperature which adds to the dynamics of the resistance welding process. The resistivity of material influences the heat generation. The thermal conductivity and the heat capacity influence the heat transfer. In metals such as silver and copper with low resistivity and high thermal conductivity, little heat is generated even with high welding current and also quickly transferred away. They are rather difficult to weld with resistance welding. On the other hand, they can be good materials for electrodes. When dissimilar metals are welded, more heat will be generated in the metal with higher resistivity. Hardness of material also influences the contact resistance. Harder metals (with higher yield stress) will result in higher contact resistance at the same welding force due to the rough surface asperities being more difficult to deform, resulting in a smaller real contact area. Electrode materials have also been used to influence the heat balance in resistance welding, especially for joining light and non-ferrous metals.

6) Surface coatings

Most surface coatings are applied for protection of corrosion or as a substrate for further surface treatment. These surface coatings often complicate the welding process. Special process parameter adjustments have to be made according to individual types of the surface coatings. Some surface coatings are introduced for facilitating the welding of difficult material combinations. These surface coatings are strategically selected to bring the heat balance to the weld interface. Most of the surface coatings will be squeezed out during welding, some will remain at the weld interface as a braze metal.

7) Geometry and dimensions

The geometry and dimensions of the electrodes and work pieces are very important, since they influence the current density distribution and thus the results of resistance welding. The geometry of electrodes in spot welding controls the current density and the resulting size of the weld nugget. Different thicknesses of metal sheets need different welding currents and other process parameter settings.

8) Welding machine characteristics

The electrical and mechanical characteristics of the welding machine have a significant influence on resistance welding processes. The electrical characteristics include the dynamic reaction time of welding current and the magnetic / inductive losses due to the size of the welding window and the amount of magnetic materials in the throat. The up-slope time of a welding machine can be very critical in micro resistance welding as the total welding time is often extremely short. The magnetic loss in spot welding is one of the important factors to consider in process controls. The mechanical characteristics include the speed and acceleration of the electrode follow-up as well as the stiffness of the loading frame/arms. If the follow-up of the electrode is too slow, expulsion may easily occur in projection welding.

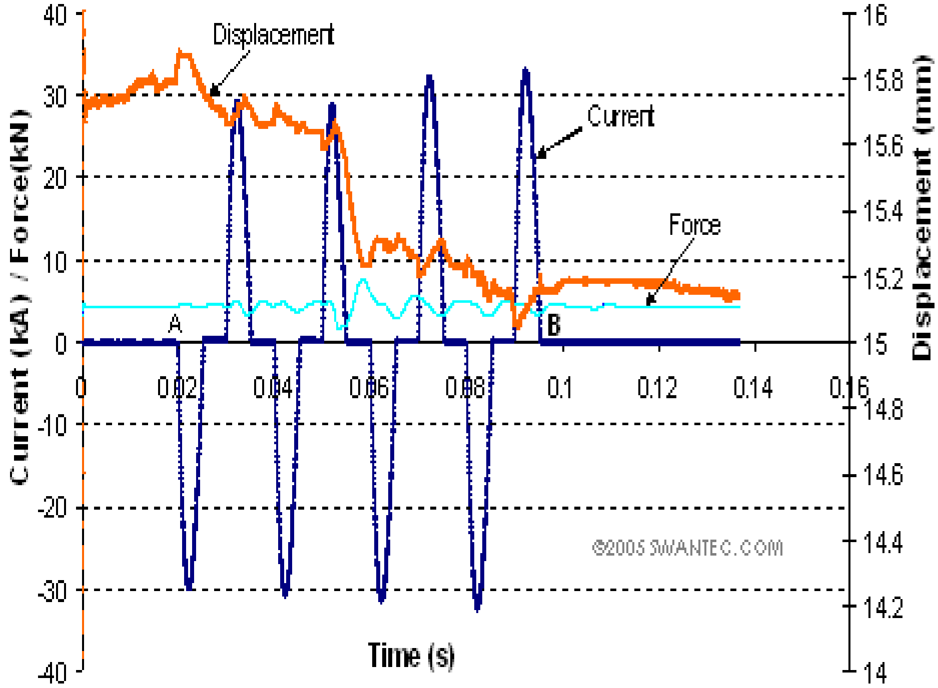


Figure 2.4: Measured Process Parameters

The spot weld cycle is clearly defined in figure 2.5.

Squeeze time, the welding current is applied at the end of this time. ***Weld time***, the welding current flows through the circuit. ***Hold time***, the electrode pressure is maintained until the metal has somewhat cooled. ***Off time***, the interval of the hold time to the beginning of the squeeze time

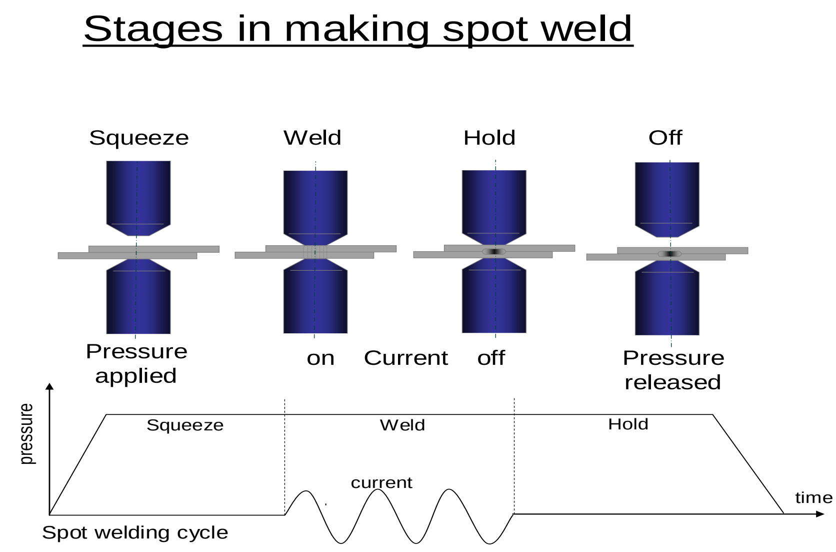


Figure 2.5: Spot Weld Cycle

__Squeeze time__, the welding current is applied at the end of this time. *__Weld time__*, the welding current flows through the circuit. *__Hold time__*, the electrode pressure is maintained until the metal has somewhat cooled. *__Off time__*, the interval of the hold time to the beginning of the squeeze time. Slope Control refers to rise and fall of the welding current as shown in figure 2.6.b. The current may be made to build up gradually (upslope) or to decrease gradually (down slope or current decay). Upslope gives the electrode a few impulses of time to seat before they have to carry the full welding current. The down slope or decay helps to reduce internal cracking of the weld nugget. Retarding the cooling action ensures a proper temperature during the forging action. An increase in electrode pressure as the weld solidifies produces the forging effect (figure 2.6.c). Multiple impulse welding cycles (figure 2.6.d) provide short heating periods alternating with short cooling periods for better control of the weld nugget, which reduces spitting. Spitting refers to the molten metal being propelled out from the weld nugget.

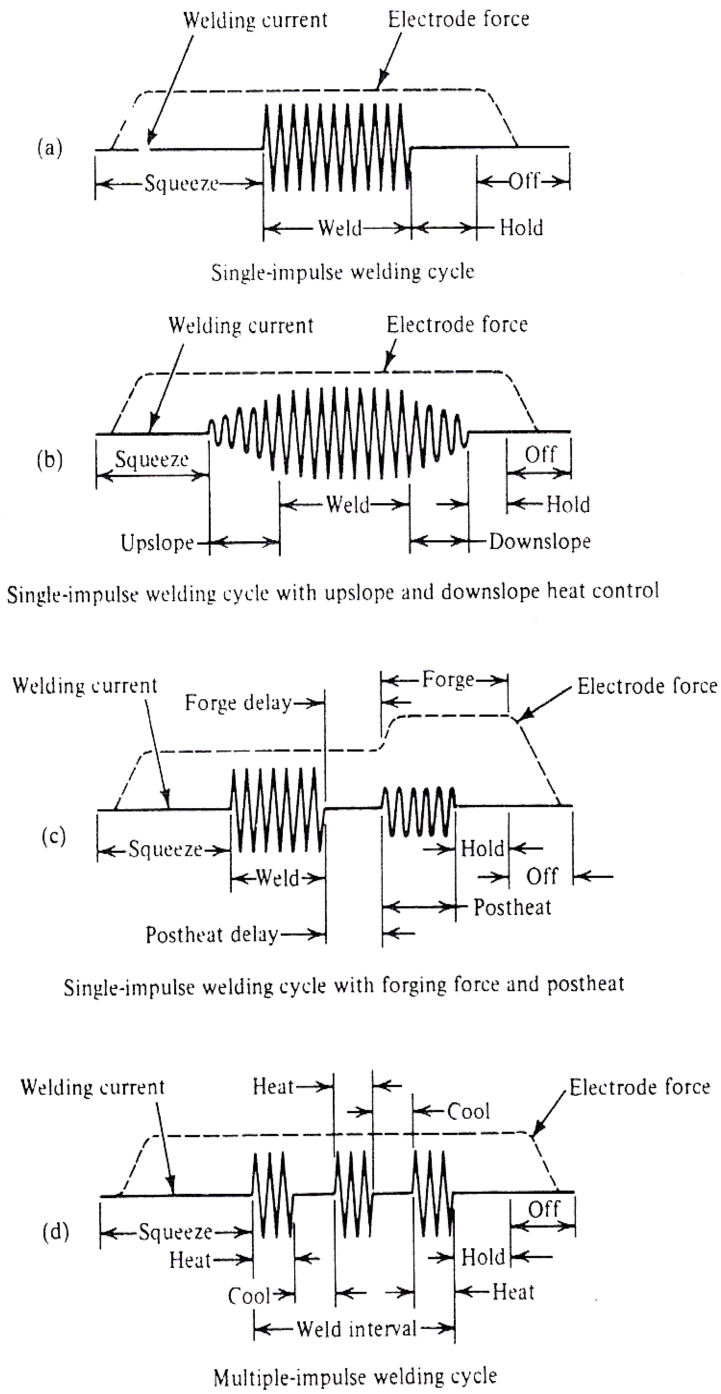
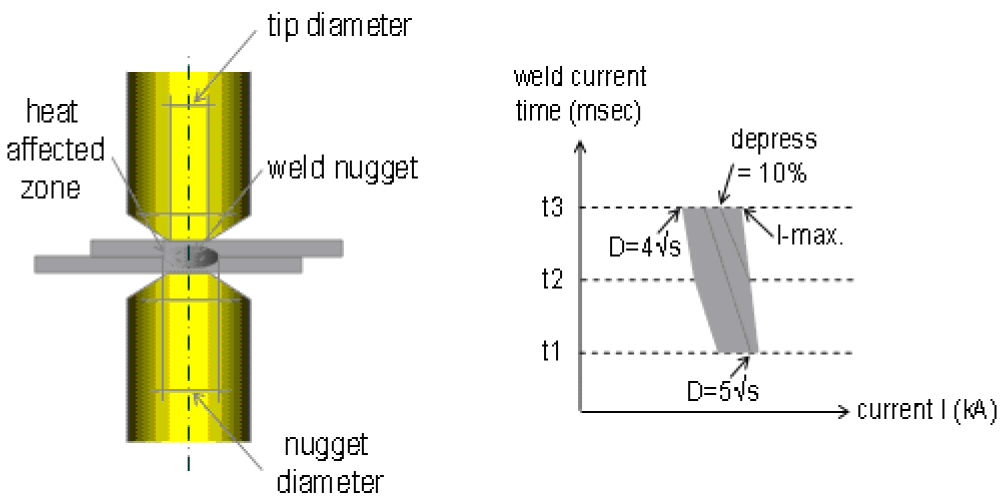


Figure 2.6: Basic resistance Spot Welding Cycles show the relationship of time, current, and electrode force for each segment

Depression is observed in spot welds when high pressure is applied by the electrode to the plates as shown in figure. 2.7. The maximum value of depression is 0.10 times thickness of sheet. The variation w.r.t current is also shown. The graph reveals that with increasing value of current and time , depression is also increasing.



Depression of the electrode by spot welding

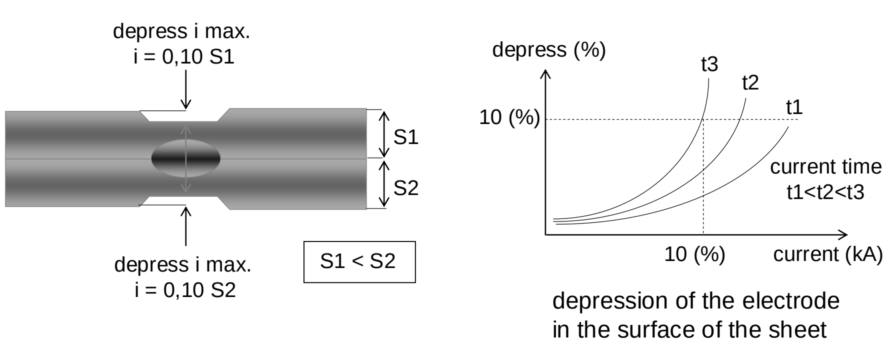


Figure 2.7: Depression in the sheet

The weld nugget diagram is shown in figure 2.8. Nugget formation is the most important aspect of resistance spot welding. This is the fusion area between two plates to be joined.

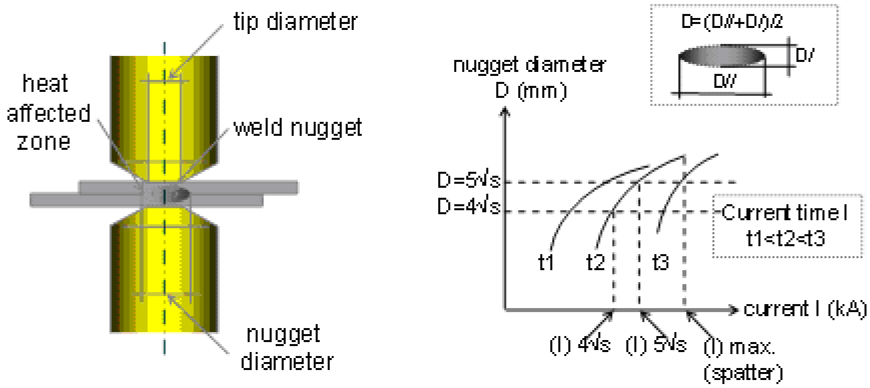


Figure 2.8.a: Influence of Weld Current on Nugget Diameter

During the process of spot welding very high current flows for extremely short duration (0.02sec – 0.05 sec, ammeter cannot respond so quickly. In spot welding current is measured with help of totoidal coil. When high current flows it generates magnetic field and magnetic flux interlink with the coil generate Electromotive force in proportion to rate of change of current to time V = K di/dt K is constant. Coil output V is in proportion to the coil area and nos. of turns This type of sensor can measure any large current in differential value. To get absolute value it is interlink with electronic circuit.

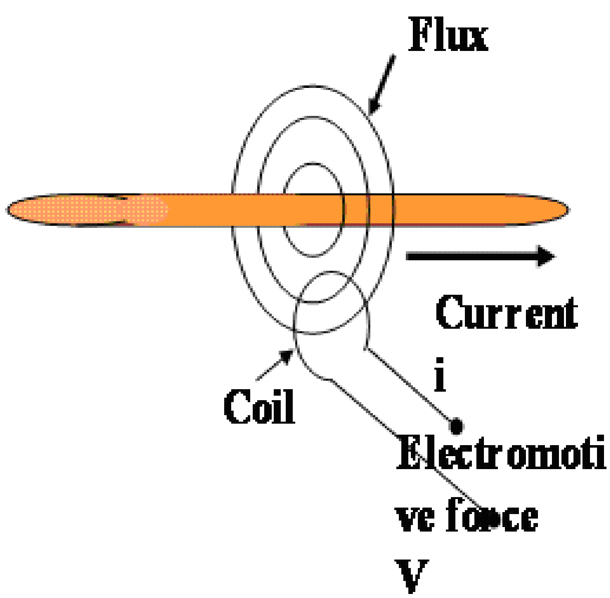


Figure 2.8.b: Current Measurement

2.3 RECENT WORK

Resistance spot welding is an important method in automobile manufacturing till today and a typical vehicle could need 3000– 7000 spot welds [7,8]. Quality and performance of the resistance spot welds are very important to the durability and safety design of vehicles [9]. The quality of the spot-weld was examined by destructive tests to determine whether a satisfactory weld had been produced, such as quasi-static tensile test and dynamic cycle test. Pal and Bhowmick [10] studied the high cycle fatigue behavior of DP780 steel sheet and found that DP780 spot-weld joints had almost similar fatigue behavior at low load high cycle and high load low cycle. Khan et al. [11] studied the hardness profile of dissimilar HSLA350/DP600 resistance spot welds and found that the hardness in the fusion zone (FZ) was higher than that in the base metal (BM) due to the formation of lath martensite.

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According to published literature, research on the spot welding started in early 1950's. Temperature distribution during the process of spot welding is one of the crucial aspects for the study. Temperature distribution at various zones during the process is clear from the following figure 2.9

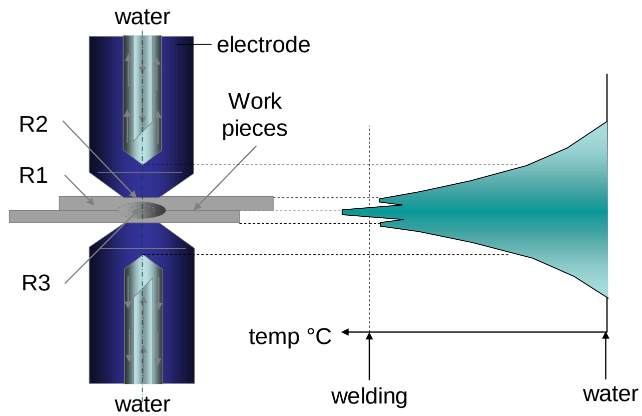


Figure 2.9: Temperature Distribution

The attributes for spot weld quality were studied by many researchers. Spindella [3] suggested that good welds are welds with large buttons and high tensile strength without expulsion or partial button. In Newton et al [4], a weld with full size nugget and at least minimum strength, and without cracks, flash or porosity was regarded as good weld. Their study also tried to define nonconformable weld as those of too small weld size, or with cracks, excessive porosity, excessive expulsion, and damaged adhesive layers for weld bonding. These classifications are generally qualitative and depend on multiple parameters, in addition to the materials welded (Steel or Aluminum). In many cases, the nugget width or button diameter is used as sole parameter to describe the quality of a spot weld.

Current, time and pressure are the three variables which influences weld quality. The variation of current and pressure; and relation of current and time is shown in figure 2.10

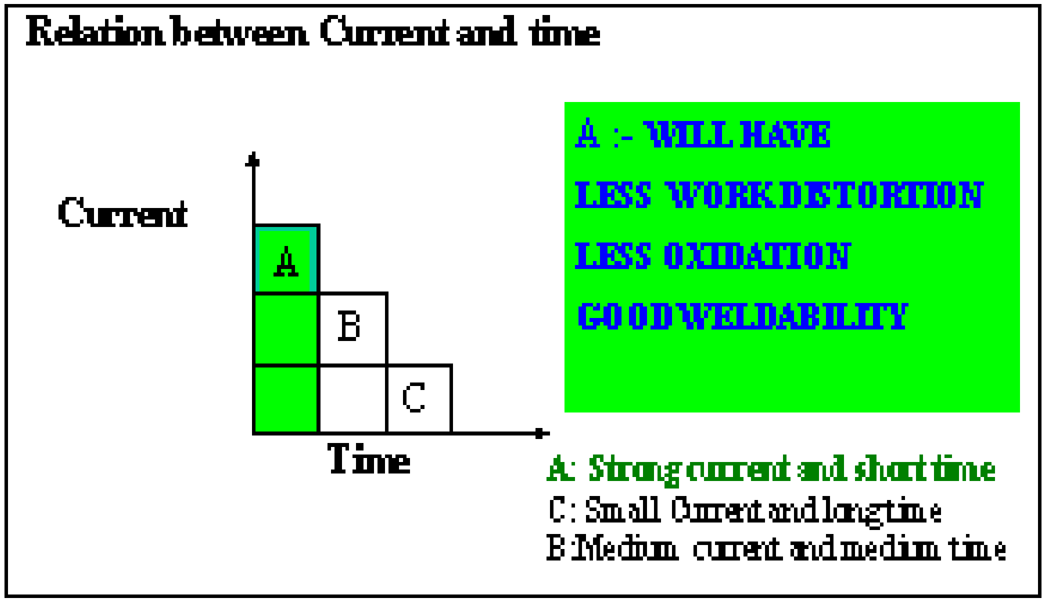


Figure 2.10.a: Relation ship of current and time on weld quality

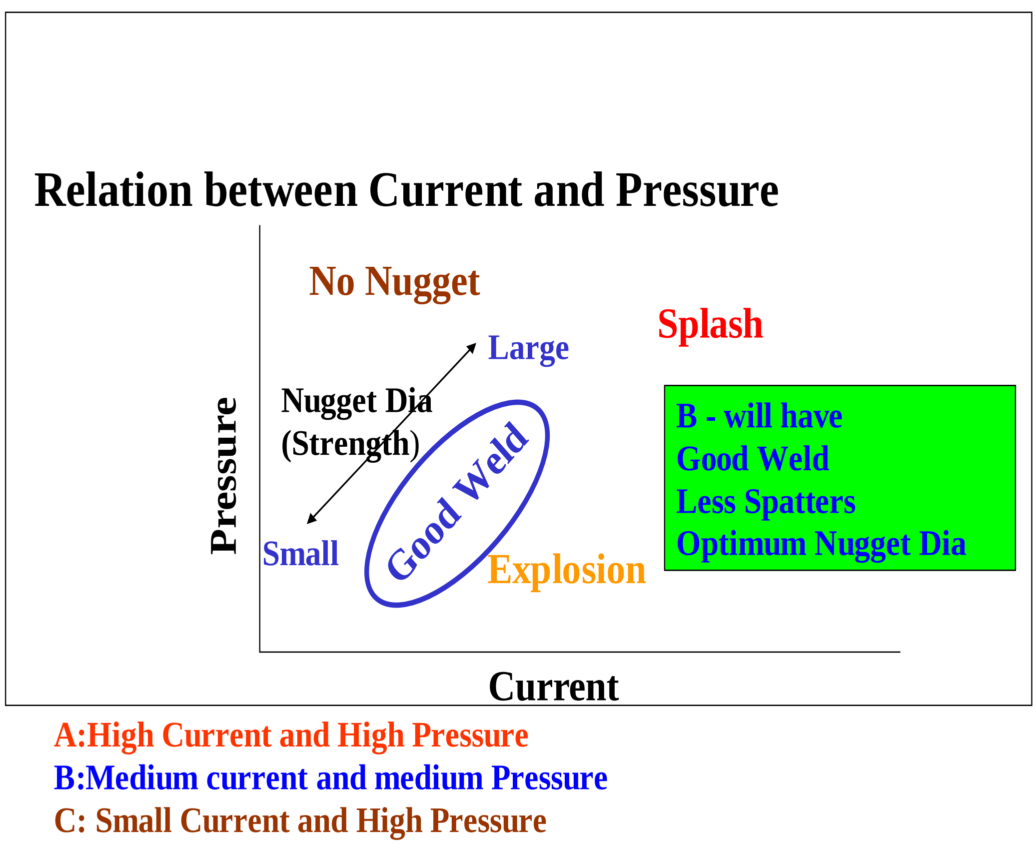


Figure 2.10.b: Relation between current and pressure for weld quality

Zhou [6] attempted to link a weld's quality to its attributes under tensile shear testing. The use of combined statistical design and analyses, and computer simulation provided a systematic and effective means to study multivariate nature of spot welds. Through his integrated numerical analysis he found out effect of weld parameters such as weld diameter, penetration, indentation, size of HAZ and sheet thickness of base metal on spot weld quality. He also provided J-integral, which was further used to describe fracture behavior of welded joint by treating edge of weld as crack.

2.4 SUMMARY

Spot welding is metal joining process and widely used in sheet metal industry. The basic resistance welding process has not appreciably since long time. At its most, it consists of passing electrical current through two or more layers of the metal that are being held together by force, when current passes through this "sandwich", the metal is heated and coalesces. The process is controlled combination of forging and melting. Temperature along the interfaces in the welding processes is the important aspects of welding. Various studies are conducted to study thermal effects during the processes. The main consideration during the spot welding is formation of correct nugget. The works have been done to study the effects of weld parameters on nugget growth experimentally and also using finite element method.

CHAPTER 3

EXPERIMENTAL SETUP & PROCEDURE

This chapter deals with the details of experimental procedure and apparatus used in the work. The sections discusses about the characteristics/specification of the machines and material utilized in the project. The information about the spot weld joint is also discussed herewith.

DETAILS OF THE APPARATUS

The Spot welding Machine and the Testing machine for measuring hardness and nugget size are given below

3.1 Spot Weld Machine

The IT (Integrated Transformer) Spot Welding Gun-X Type is used for welding of the plates. The conventional rating of the transformer for conventional spot welding machine is 150KVA and for IT gun it reduces to 38KVA, thus reducing the losses.

Figure 3.1 : IT Spot Weld Gun

The specifications of the machine are listed in Table 3.1

Specification of the IT Spot Weld Gun	
Make	Techno, Italy
Rating	38KVA
No load Secondary Voltage	5.14V
Supply Voltage	415V,50Hz
Throat Depth	470mm
Throat gap	230mm
Air Pressure	6bar
Force	180Kgf – 220Kgf

Table 3.1: Specification of the IT Spot Weld Gun

Tip material used is *CRM 16-CuCrZr* with composition Cr 0.4 - 1 % , Zr 0.02 -0.1 % & Cu-bal. The Conductivity and hardness ranges from75 ~ 80 and 130~170 BHN respectively. *IS819 1957 (Part II & II-A)* is used for selecting the proper electrode tip specification. The tip diameter is 13mm and is required to be dressed after 2000 spots(approximately four times in a shift).

Property	*Value*
Thermal Conductivity	3.014 X 10^3 W/m.º C
Electrical Resistivity	3.83 X 10^{-2} μΩm
Specific Heat	4.102 X 10^2 kg/m^3
Convection Heat Coefficient	4.187 X 10^4 W/ m^2 º C

Table 3.2: Physical properties of electrode

TE450 is a microprocessor welding control unit for IT spot weld guns. The welding control unit is used to control the welder parts, and in particular the thyristors adjusting the welding current. The control unit includes specific functions to be used when working with welding guns, such as: double stroke control. TE450 can work in constant current mode; it displays the welding current and check the current according to the set limits. It is possible to select 63 different welding programs; it is possible to directly recall 2 programs by means of an external selector commonly installed on the handle. Besides simple 4 times cycle, the control unit enables to carry out welding processes with per-weld current, post weld current , slope and pulses.

Main Technical Data

- Simplified programming by means of 5 push buttons and LCD display.
- 63 welding programs to be stored up; 2 programs can be recalled from the handle.
- 18 programmable parameters for each program.
- Slope and pulse functions; pre-weld and post-weld functions.
- Double working modes: standard and constant current.
- Automatic double stroke function
- Welds counter.
- Compensation of secondary current to weld oxidized sheets and rods
- Single and automatic cycle. WELD/NOWELD function.
- Control of solenoid valve 24V dc,72W max with protected output against short circuit
- Self adjustment of mains frequency 50/60 Hz

As soon as the welding control unit is turned on, the displays shows the supply frequency as shown below in figure 3.2.

SUPPLY FREQUENCY 50 HZ	TE 450 REL 1.50 WELD CONTROL

Figure 3.2 : Display of TE450

To start the programming push simultaneously the push buttons for at least a second. After 8seconds of inactivity, the control unit will automatically end the programming operation and enable the working process. The first selection concerns the number of programs to be used for the adjustment in process. After having selected the number of the program, it is possible to select the parameters forming the program by means of push buttons. The display shows the following data:

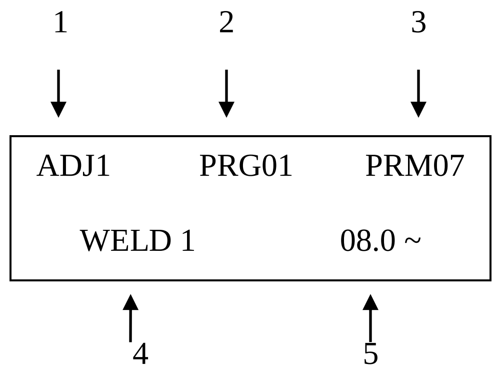


Figure 3.3: Parameters of IT gun

1) Selected adjustment(ADJ1=ADJUSTMENT 1, ADJ2=ADJUSTMENT 2)
2) Number of selected program(PRG01= program number 1)
3) Identification mark of selected parameter
4) Name of the parameter
5) Value of parameter

The value of the welding parameter can be adjusted by means of the push button + or – either increasing or decreasing the value shown by the display. The parameters can be adjusted to different values according to the type of parameter, the limit range for each parameter given in following table.

Table 3.3: Types of parameter and their ranges

Parameter Number	*Parameter*	*Range Value*
A	Working Mode	1K – PW%
B	Control Mode	No Current Degree
C	Stroke	Short – Long – Automatic
1	Squeeze 1	01-99 cycles
2	Squeeze	01-99 cycles
3	Pre-Weld	0-99.5 cycles
4	Pre-Power	01 – 99%
5	Cold 1	0 – 50 cycles

6	Slope Up	0 – 25 cycles
7	Weld 1	0.5 – 99.5 cycles
8	Power 1 Current 1	10 – 99% 2 – 36 Kamp
9	N.Impluse	0 – 99
10	Cold 2	1 – 50 cycles
11	Slope Down	0 – 25 cycles
12	Cold 3	0 – 55 cycles
13	Post Weld	0 – 99.5 cycles
14	Post Power	1 – 99%
15	Hold Time	1 – 99 cycles
16	Off Time	0 – 99 cycles
17	Current Min Angle Mini	2.0 – 36.0 Kamp 001 - 180°
18	Current Max Angle Max	2.0 – 36 kAmp 001 - 180°

3.2 Micro Hardness Tester

The term Micro Hardness test usually refers to static indentations made with loads not exceeding 1 kgf. The indenter is either the Vickers diamond pyramid or the Knoop elongated diamond pyramid. The Micro hardness test method according to ASTM E-384 specifies a range of loads using a diamond indenter to make an indentation which is measured and converted to a hardness value. It is very useful for testing on a wide type of materials as long as test samples are carefully prepared. There are two types of indenters, a square base pyramid shaped diamond for testing in a Vickers tester and a narrow rhombus shaped indenter for a Knoop tester. Typically loads are very light, ranging from a few grams to one or several kilograms, although "Macro" Vickers loads can range up to 30 kg or more. The Micro-hardness methods are used to test on metals, ceramics, composites - almost any type of material. There are a number of considerations in Microhardness testing. Sample preparation is usually necessary in order to provide a specimen that can fit into the tester, make a sufficiently smooth surface to permit a regular indentation shape and good measurement, and be held perpendicular to the indenter. Usually the prepared samples are mounted in a plastic medium to facilitate the preparation and testing. The indentations should be as large as possible to maximize the measurement resolution.

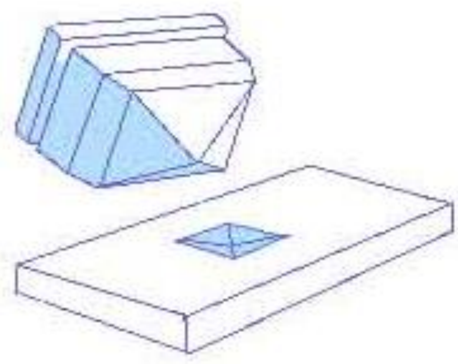


Figure 3.4: Pyramid shaped diamond for Vickers Hardness Test

The hardness testing equipments with specification given below is used for the experiments.

Machine	Micro Vickers Hardness Testing Equipments
Make	M/s Future Tech, Japan
Load Used	1Kgf
Least Count	0.1 HV
Indentor	Pyramid shaped Diamond Indentor

Figure 3.5: Future Tech Micro Hardness tester

3.3 Universal Testing Machine

The UTM for measuring the shear strength is shown figure

Figure 3.6: Universal Testing Machine

The features of UTM and specifications are listed below:

- Controller with high level of operability and safety
- Software linked with test machine on many dimensions.
- High quality test data
- Diverse System Lineup
- Various accessories accommodating all users lineup

Table 3.4: Specifications of Tensile Testing Machine

Machine	Universal Testing Machine
Make	M/s Shimadzu, Japan
Capacity	25 tons
Least Count	0.1 N
Cross Head Speed during Testing	20 mm/min

3.4 FEA tool – ANSYS software

Finite Element Analysis is technique to simulate loading conditions on a design and determine the design's response to those conditions. The Finite Element method of structural analysis was created by academic and industrial researchers during 1950s and 1960s. The underlying theory is over 100 years old, and was the basis pen-and-paper calculations in the evaluation of suspension bridges and steam boilers.

ANSYS is a complete FEA software simulation package developed by ANSYS Inc – USA. It is used by engineers worldwide in virtually all fields of engineering:

- Structural
- Thermal
- Fluid (CFD, Acoustics, and other fluid analyses)
- Low and High Frequency Electromagnetics

System Requirements to run ANSYS 9.0
Pentium IV, 1.4 GHz
2 GB RAM
SVGA Monitor
650 MB Hard disk Space
Windows 2000, Windows XP
Microsoft TCP/IP
Ethernet Network Adapter

Table 3.5: System Requirements for ANSYS 9.0

3.5 TEST MATERIAL

The experiment was conducted on Advanced High Strength Steels DP780 and DP600. Mechanical properties of these steels are as follows.

Mechanical Properties	DP780	DP600
Tensile strength (MPa)	842	610
Yield strength (MPa)	530	395
Yield tensile rate	0.63	0.65
Elongation (%)	18.5	26

Table 3.6: Material mechanical properties.

ELECTRODE SHAPE AND SIZE

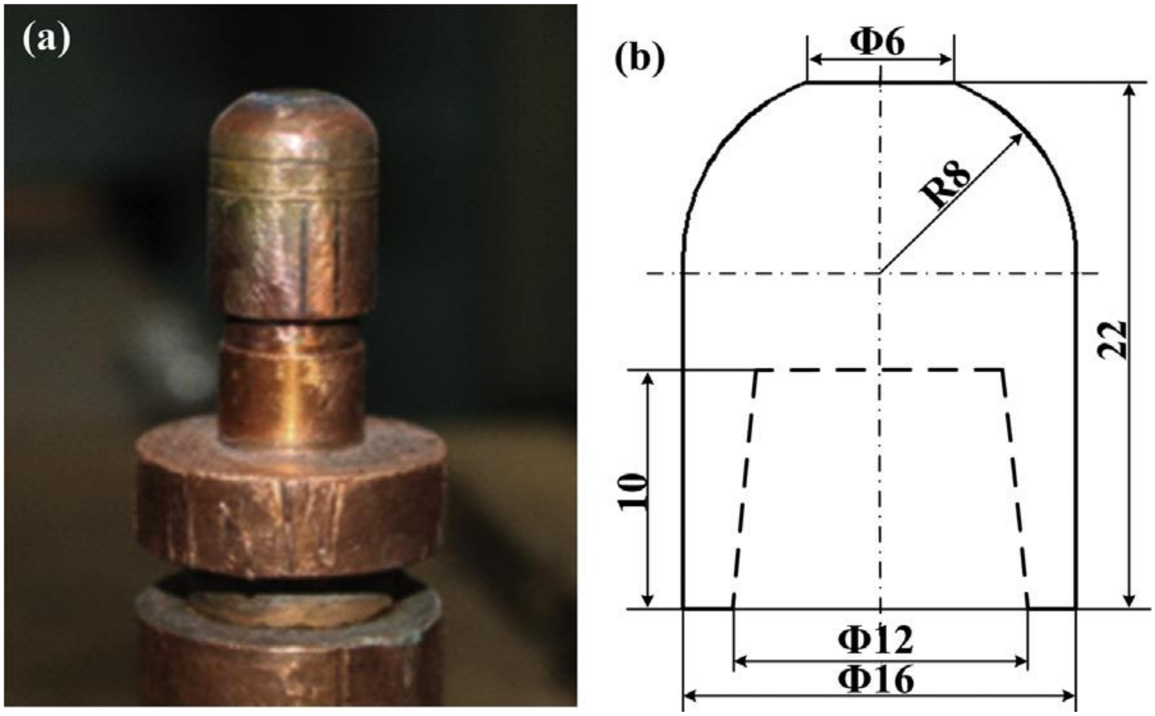


Figure 3.7 Electrode shape (a) and geometry dimensions (b).

3.7 EXPEIMENTAL PROCEDURE

The objective of the thesis is to study the behavior of spot welds analytically. The procedure for conducting the experiments and performing the analysis is herewith discussed.

3.3.1 Material Specification Details

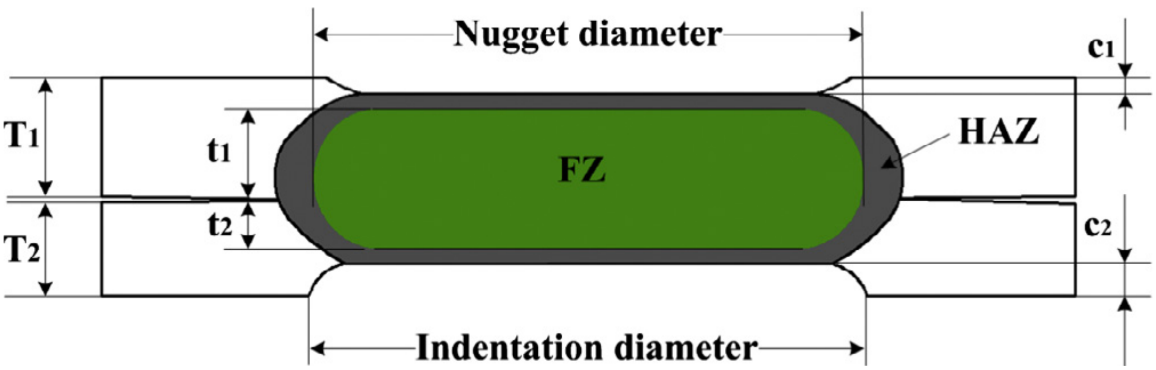
1.2 mm thick dual phase steel DP780 and 1.5 mm thick dual phase steel DP600 were used as the base metals.

Table 3.8 : Dimensions of Test Piece

Nominal thickness of plate (mm)	*W(mm)*	*L(mm)*	*P(mm)*
1.2 mm to 1.5 mm	30	100	30

The mechanical properties of the base metals are presented in Table 3.8

	Tensile strength (MPa)	Yield strength (MPa)	Yield tensile rate (%)	Elongation (%)
DP780	842	530	0.63	18.5
DP600	610	395	0.63	26



As discussed in later sections, the main parameters of spot welding includes current, cycle time, pressure and accordingly certain variables are effected during the process. For this study, current and cycle time were selected as parameters to be varied and this effects are to be seen on Nugget diameter, Hardness of weld zone as well as hardness of HAZ, Penetration and shear strength.

The first set of experiments was conducted by varying cycle time and keeping other parameters constant. The conditions for the experiments is listed below in table

Parameter	*Value*
Material	AHSS DP 780, DP600
Thickness of work material	1.2 mm, 1.5 mm
Force	220Kgf
Current	6-12 kA
Cycle time varied: 12, 14,16,18, 20 cycles	

Table3.9: Conditions for experiments

With these conditions, the series of spot welds made is described in table given below. *The weld is made by varying cycle time and keeping other parameters constant.*

Value of Cycle time	*Spot number*
12 cycles	a , b
14 cycles	c , d
16 cycles	e , f
18 cycles	g , h
20 cycles	i , j

Table 3.10: Spots Welds for first experiment

The joint made for first experiment is shown below

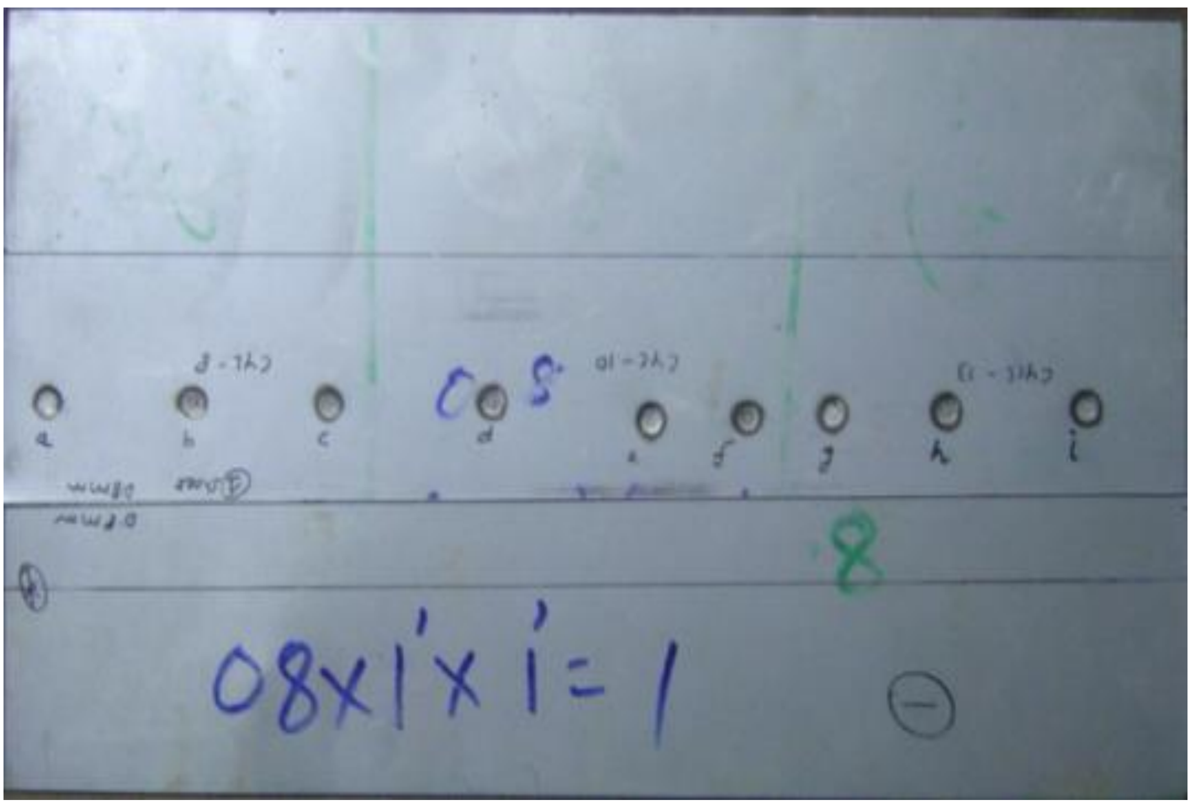


Figure 3.8: Lap Joint with cycle time varying

The second set of experiments was conducted by varying the value of current and keeping other parameters constant. The conditions for the same are given in table 3.11

Parameter	*Value*
Material	AHSS
Thickness of work material	1.3 mm
Force	220Kgf
Cycle Time	10 cycles
Current varied	9000Amp;9500Amp;10,000Am;10,500Amp;11,000Amp

Table 3.11: Conditions for second experiments

With these conditions, the series of spot welds made is described in table given below. *The weld is made by varying value of current and keeping other parameters constant.*

Value of Current (Amperes)	*Spot number*
9000	a , b
9500	c , d
10,000	e , f
10,500	g , h
11,000	i , j

Table 3.12: Spots Welds for second experiment

The picture of the joint made by second experiment is shown in figure 3.9

Figure 3.9: Lap Joint with Current Varying

After making the joint with above stated conditions, the welds are examined and tested with equipments listed in last section. Nugget diameter is measured at after taking cross section.

3.3.2 Analytical Procedure

The ANSYS is taken as FEA tool. Thermal analyses and stress analyses is done of the plate material of thickness 1.3 mm. The advanced high Strength Steel material DP780 and DP600 is taken as the base metal.

The procedure for analytical study of FEA method is now discussed. Following four steps used for FEA analysis are listed below:

- Preliminary Decisions
- Preprocessing
- Processing
- Solution

1) **Preliminary Decisions:** This involves selection of type of analysis which is to be done, depending upon the nature of the problem. The analysis type usually belongs to one of the following disciplines:

   - *Structural:* Motion of solid bodies, pressure on solid bodies, or contact of solid bodies.
   - *Thermal:* Applied heat, high temperatures, or changes in temperature
   - *Electromagnetic:* Devices subjected to electric currents (AC or DC), electromagnetic waves, and voltage or charge excitation.
   - *Fluid:* Motion of gases/fluids, or contained gases/fluids.

The *structural and thermal analysis* is done for the performing the analysis on spot welded joints. Firstly thermal analysis is done and then structural analysis is done on the plate.

2) **Preprocessing:** The process of pre processing includes creating the solid model, performing meshing and defining the material.

- *Creating the Solid Model:* A typical solid model is a geometry defined by volumes, areas, lines and key points. Also, a model with just areas and bellows such as a shell or 2D plane model is still considered a solid model in ANSYS terminology. As an alternative to create a model directly in ANSYS, it can be created in some other CAD software like PRO-E, AutoCAD, UNIGRAPHICS, CATIA etc. the model is then imported into ANSYS. The plate to be welded is created in AutoCAD software and then imported as *.sat* file. The pate with dimension 100X50X0.8 is taken for the purpose of analysis.
- *Defining Material Properties:* ANSYS allows choosing predefined set of properties for a given material. For this work own material library is made. The common inputs required for defining material includes Young's modulus, Poisson ratio, modulus of elasticity, density as mechanical properties and thermal conductivity, thermal expansion. The material is defined on the basis of thermal and mechanical properties defined in section 3.2
- *Creating FEA model(Meshing):* ANSYS do not use the solid model in the solution of the model. It needs to use finite elements. To create FEA model, meshing is done on the solid model. Meshing is the process used to "fill" the solid model with nodes and elements. The three steps in meshing were followed:
    - *Defining the element attributes* which includes element types(determines element characteristics – Degree of freedom, element shape, dimensionality); element category(line elements, shell elements, 2D solids and 3D solids).
    - *Specifying mesh controls* to control mesh density both on global and local level
    - *Generating mesh*

3) **Processing:** In this step the boundary conditions, thermal conditions and load conditions are applied. The conditions for each as per the work are defined below:

Boundary conditions for thermal analysis:

- In boundaries room temperature of 30°C is applied
- Upper surface in contact with electrode area, temperature is 500°C is applied
- Lower surface in contact with other plate, temperature of 1500°C is applied

Boundary and Load Conditions for structural analysis:

- Output of thermal analysis is taken as input for the stress analysis.
- Boundaries of panel are fixed.
- Upper surface in contact with the electrode area , load of 1800N is applied
- Lower surface in contact with other plate, Z translation is fixed.

4) Solution: The output of the analysis is seen in this step. Thermal analysis is first solved and after that structural analysis is chosen with conditions specified in previous step.

3.4 REPEATABILITY

The spots welds are made on sheet with specifications of joint and material discussed above. The conditions for making the joint and variations in the parameters are also referred in section 3.3.To get better degree of accuracy at similar conditions two spots are made. This is done to avoid any mistake which can occur during measurement process.

3.5 LIMITATION OF APPARATUS

The force range of the particular IT spot weld gun is 180Kgf – 220Kgf but for thicker plates this force may be insufficient. In these cases, thus, IT spot gun can give some non-confirming results.

Also the current range for IT gun is 8,000 – 13,000Amperes and with this range expulsions were not possible to be studied.

CHAPTER 4

RESULTS AND DISCUSSIONS

The objective of this chapter is to give the experimental and analytical results which are conducted for the project. Also, the inferences from the experiments are given this chapter.

4.1 EXPERIMENTAL RESULTS

The first set of experiments is conducted under following conditions:

Material: Dual Phase Advanced High Strength Steel DP780, DP600
Thickness of sheet: 1.3mm
Electrode Force: 6.0 kN
Current: 6 kA to 12 kA

Melting rate

Fig. 4.1a shows the influence of welding current on the melting rate of the DP600/DP780 welded joints. When the welding current was lower than 10.0 kA, the melting rate of the DP600 side was higher than that of the DP780 side. While the welding current was between 10.0 and 12.0 kA, the melting rates of both sides tended to be equal. For the DP780/DP600 welded joints, the melting rate of the DP600 side was higher than that of the DP780 side with the increasing of the welding current, as shown in Fig. 4.1b. Pouranvari and Marashi [15] researched the spot-welded joint dilution of low carbon and austenitic stainless steels with the increasing of welding current, and found that the dilution increased by increasing welding current up to 8.5 kA and then kept remain beyond 8.5 kA.

The effect of welding time on the melting rate of the welded joints was illustrated in Fig. 4.2, and the melting rate of DP600 side was higher than that of the DP780 side. For the DP600/DP780 welded joints, when the welding time was between 18 and 22 cycles, the melting rates of both sides were equal. With the extension of welding time, the melting rate of the DP780 side decreased at 26 cycles while the melting rate of the DP600 side increased (Fig. 4.2a). For the DP780/DP600 welded joints, the melting rates of both sides were similar with the extension of welding time (Fig. 4.2b).

Fig. 4.3a shows the influence of electrode force on the melting rate of the DP600/DP780 welded joints. The melting rate of the DP600 side was higher than that of the DP780 side. With the increasing of electrode force, the melting rate of the DP780 side decreased from 71.85% to 62.31% while the melting rate of the DP600 side kept increasing. For the DP780/DP600 welded joints, with the increasing of electrode force, the melting rate of the DP600 side increased first and then decreased slowly while the melting rate of the DP780 side decreased first and then increased slowly. When the electrode force was 4.0 kN, the melting rates of DP600 and DP780 sides reached the maximum values (76.83% and 68.57%), as shown in Fig. 4.3b.

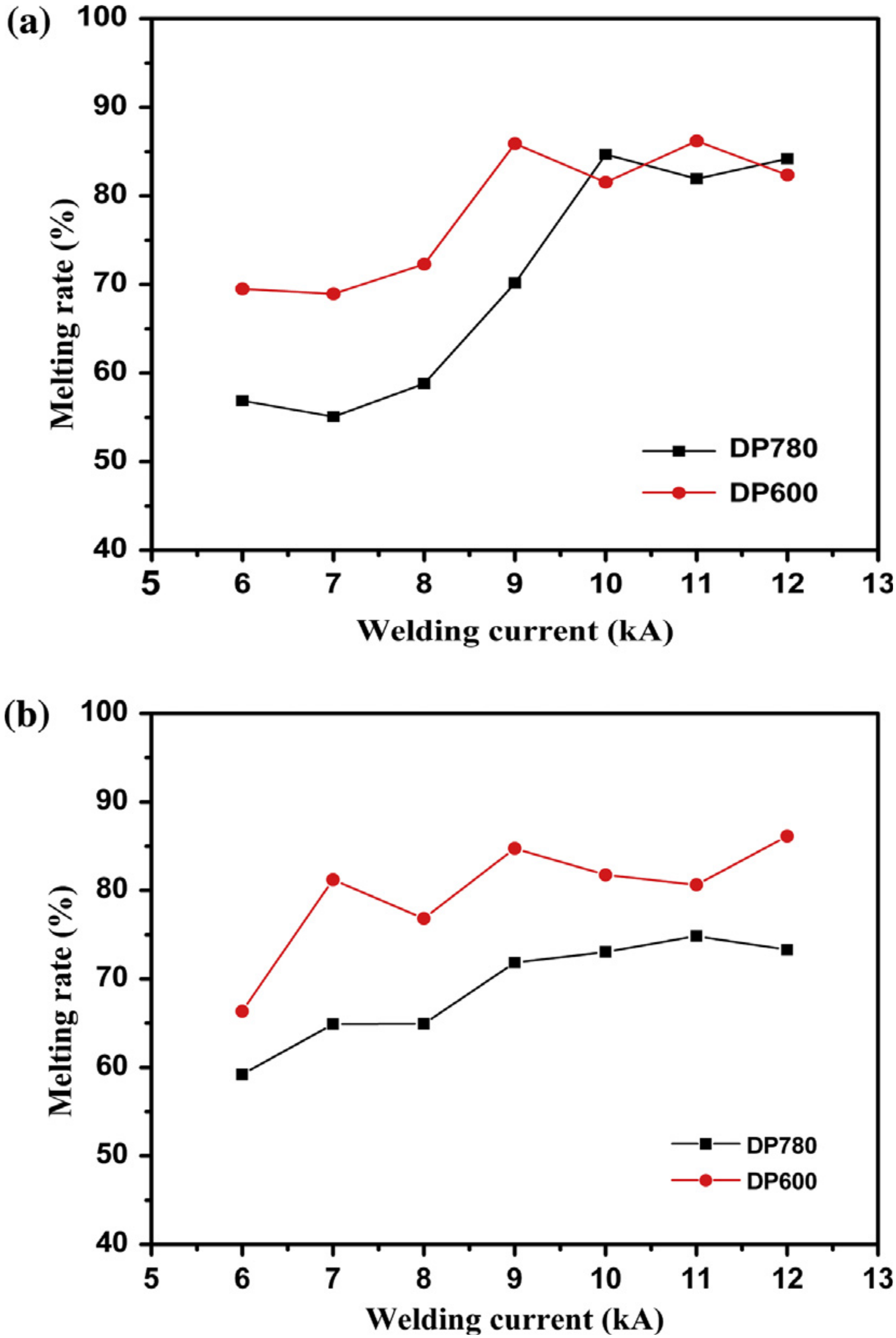


Figure 4.1. The effect of welding current on the melting rate of the welded joints (T = 18 cycles, F = 4.0 kN), (a) DP780/DP600 and (b) DP600/DP780.

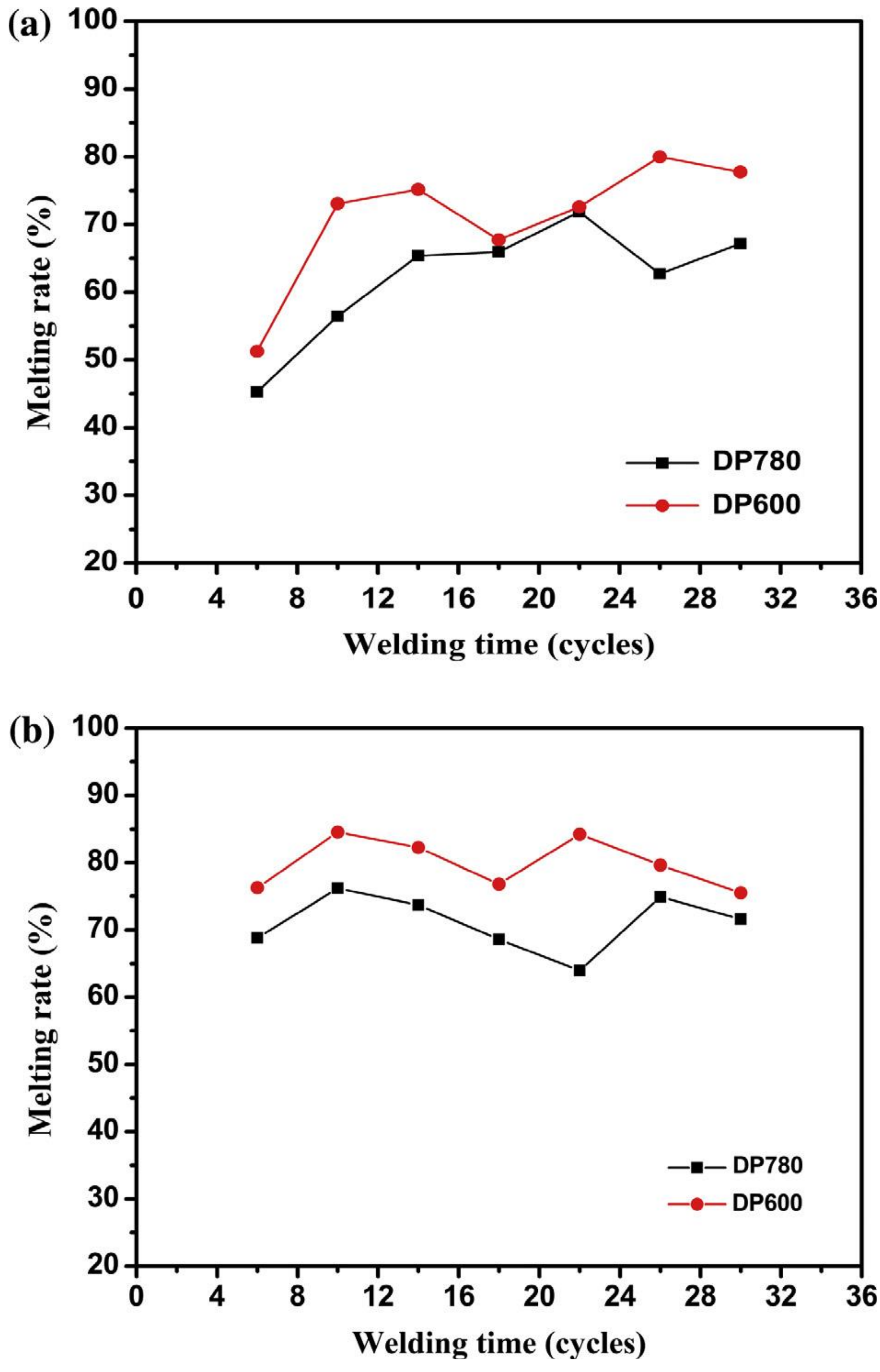


Figure 4.2. The effect of welding time on the melting rate of the welded joints (I = 8.0 kA, F = 4.0 kN), (a) DP600/DP780 and (b) DP780/DP600.

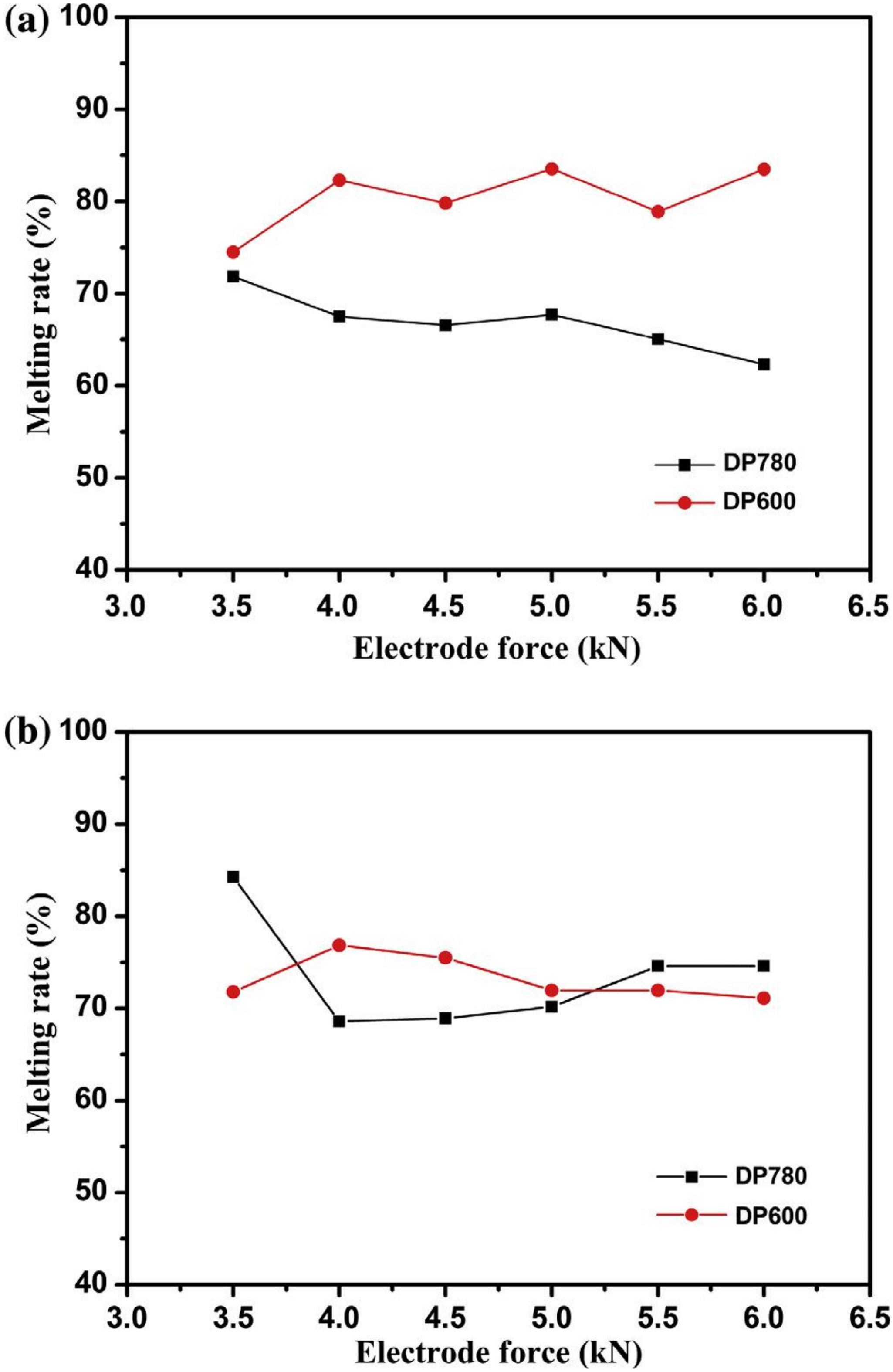


Figure 4.3. The effect of electrode force on the melting rate of the welded joints (I = 8.0 kA, T = 18 cycles), (a) DP600/DP780 and (b) DP780/DP600.

Indentation rate

Electrode indentation depth should be kept at a minimum value. Decreasing indentation depth can enhance the spot weld load carrying capacity and energy absorption capability [16]. In order to attain a good weld surface, indentation should be below the limits of 20% of steel thickness.

Fig. 4.4 shows the influence of welding current on the indentation rate of the DP600/DP780 and DP780/DP600 welded joints. With the increasing of welding current, the indentation rate of the DP780 side was always higher than that of the DP600 side. When the welding current was 10.0 kA, the indentation rate had more than the limits of 20%. The reason should be the spot welded joints had been experienced expulsion. Expulsion leads to the formation of excessive indentation, and indentation causes significant material flow and gross deformation within the sheet metal [17, 18].

The effect of welding time on the indentation rate of the welded joints was illustrated in Fig. 4.5. For the DP600/DP780 welded joints, the indentation rate of DP780 side increased gradually and reached the maximum value (25.04%) at the welding time 26 cycles. The growth rate of the indentation rate of the DP600 side decreased when the welding time was beyond 10 cycles (Fig. 4.5a). For the DP780/DP600 welded joints, both indentation rates increased first and then decreased before 22 cycles. When the welding time was beyond 22 cycles, the indentation rate of the DP600 side kept increasing and the indentation rate of the DP780 side reached the maximum value (21.45%) at 26 cycles (Fig. 4.5b).

Fig. 4.6 shows the effect of the electrode force on the indentation rate of the welded joints. With the increasing of the electrode force, the indentation rates of DP600 and DP780 sides increased first and then decreased, and the indentation rate of DP780 side was always higher than that of the DP600 side. For the DP600/DP780 welded joints, the maximum indentation rates of the DP600 and DP780 sides were reached at electrode force 5.5 kN, 15.91% and 22.83%, respectively (Fig. 4.6a). For the DP780/DP600 welded joints, the maximum indentation rates of the DP600 and DP780 sides at electrode force 5.0 kN were 14.12% and 16.73%, respectively (Fig. 4.6b).

The maximum tensile strength value of galvanized chromate steel sheets' RSW was obtained in welding current 11.0 kA and at electrode force 6.0 kN for welding time 10 cycles, and the indentation rate was 8%. However, the maximum tensile strength value of DP780 and DP600 sheets' RSW was obtained in welding current

8.0 kA and at electrode force 4.0 kN for welding time 18 cycles without expulsion, and the indentation rates of DP600/DP780 and DP780/DP600 were 16.73% and 17.27%, respectively.

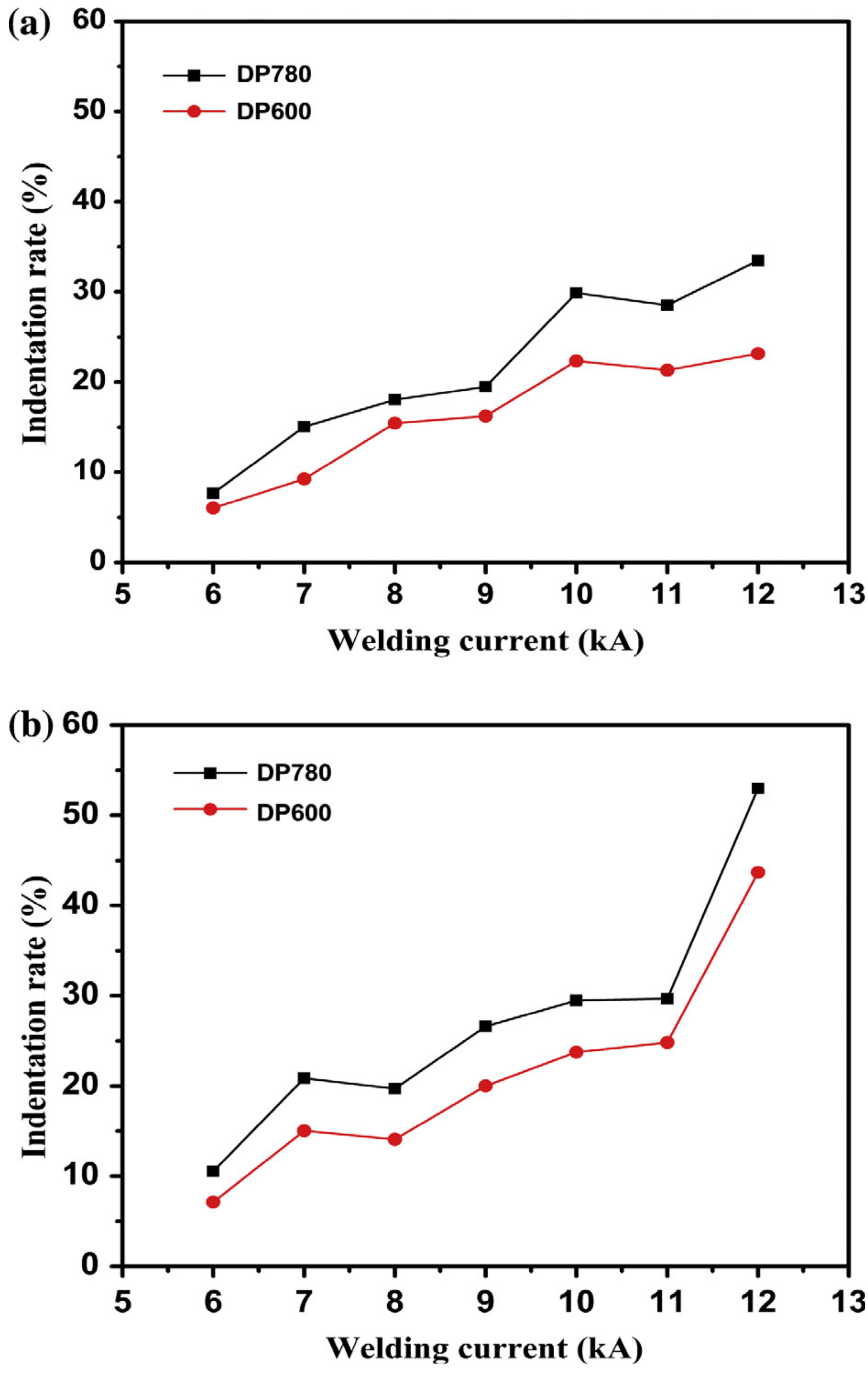


Figure 4.4. The effect of welding current on the indentation rate of the welded joints (T = 18 cycles, F = 4.0 kN), (a) DP600/DP780 and (b) DP780/DP600.

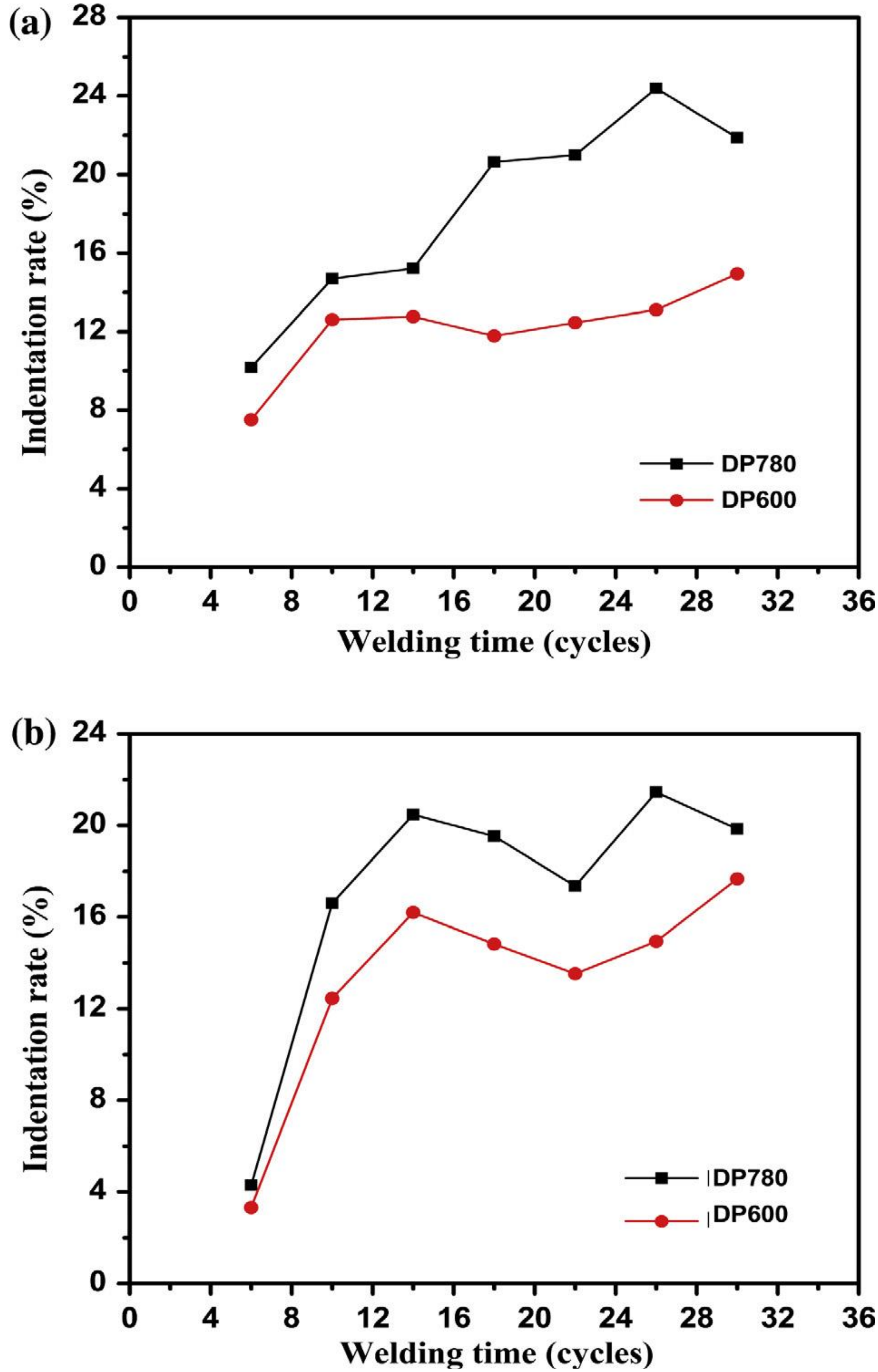


Figure 4.5. The effect of welding time on the indentation rate of the welded joints (I = 8.0 kA, F = 4.0 kN), (a) DP600/DP780 and (b) DP780/DP600.

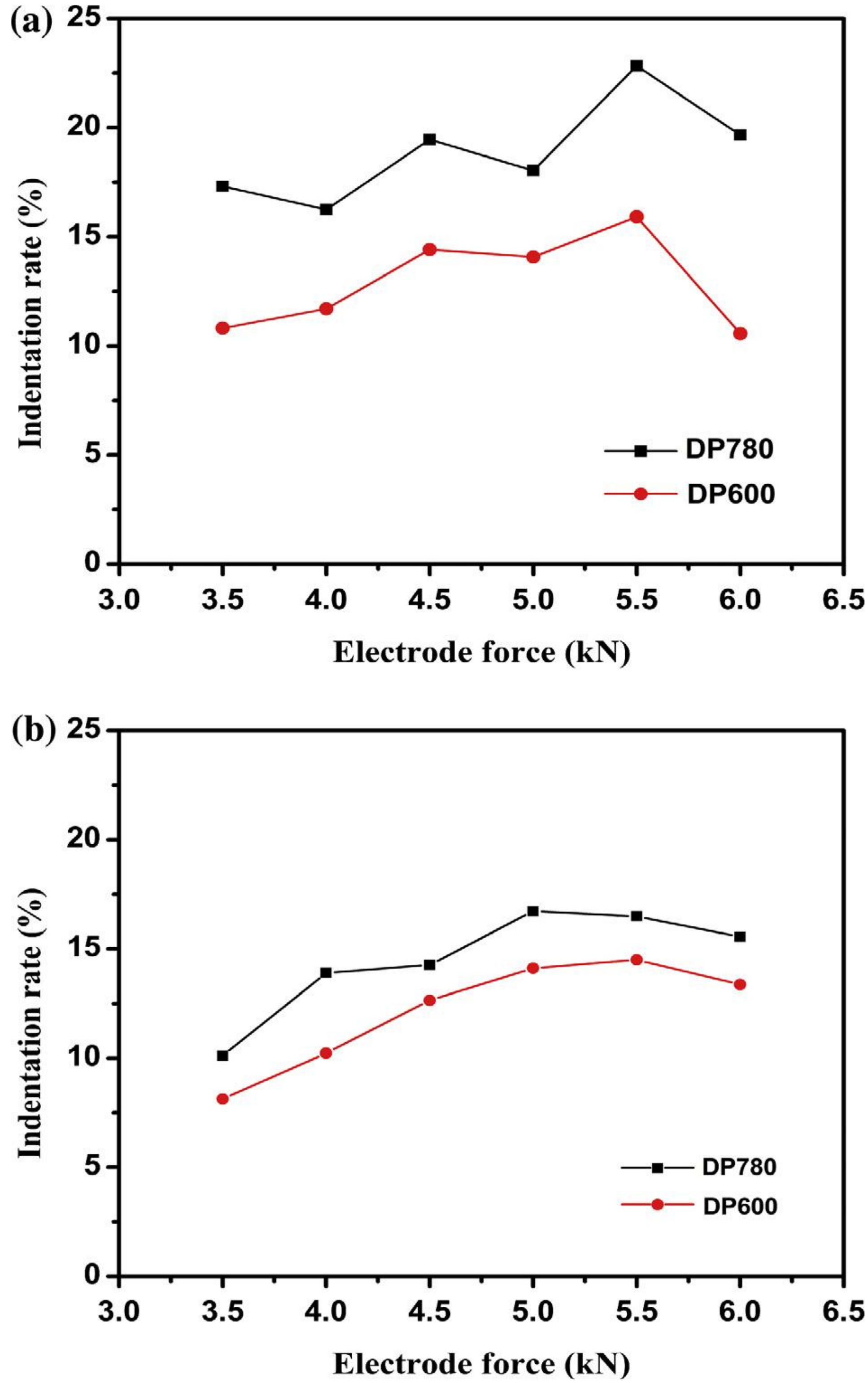


Figure 4.6. The effect of electrode force on the indentation rate of the welded joints (I = 8.0 kA, T = 18 cycles), (a) DP600/DP780 and (b) DP780/DP600.

Nugget diameter

Fig. 4.7a shows the effect of welding current on the nugget diameter.

With the increasing of welding current, the nugget diameters of two BM lap orders gradually increased and then decreased. The nugget diameters of DP780/DP600 welded joints were larger than those of DP600/DP780 welded joints. Marya and Gayden [19] researched the RSW of two galvanized DP600 steels with 1.8 and 2.0 mm sheet thickness, and found that the nugget diameters in both steels stabilized slightly above 6.0 mm with the increasing of welding current. In this research, the nugget diameters in both

BM lap orders stabilized above 7.0 mm, and the similar phenomenon was reported in the literature [12].

As welding times were increased, the nugget diameters of DP780/DP600 welded joints were larger than those of the DP600/ DP780 welded joints, as shown in Fig. 4.7b. Fig. 4.7c shows the effect of electrode force on the nugget diameter. As can be seen, the nugget diameters gradually increased with the increasing of electrode force, and BM lap order has no effect on the nugget diameter. Ma et al. [20] researched the nugget diameters for high and low electrode force (3.34 kN and 2.00 kN) welds for different welding times diameter. In this study, the nugget diameter at electrode force 4.0 kN was bigger than electrode force 6.5 kN, and the similar phenomenon was reported in the literature [21].

Based on the above results, the lap order of DP780/DP600 tended to get a larger nugget diameter than that of DP600/DP780 for the different welding currents and times.

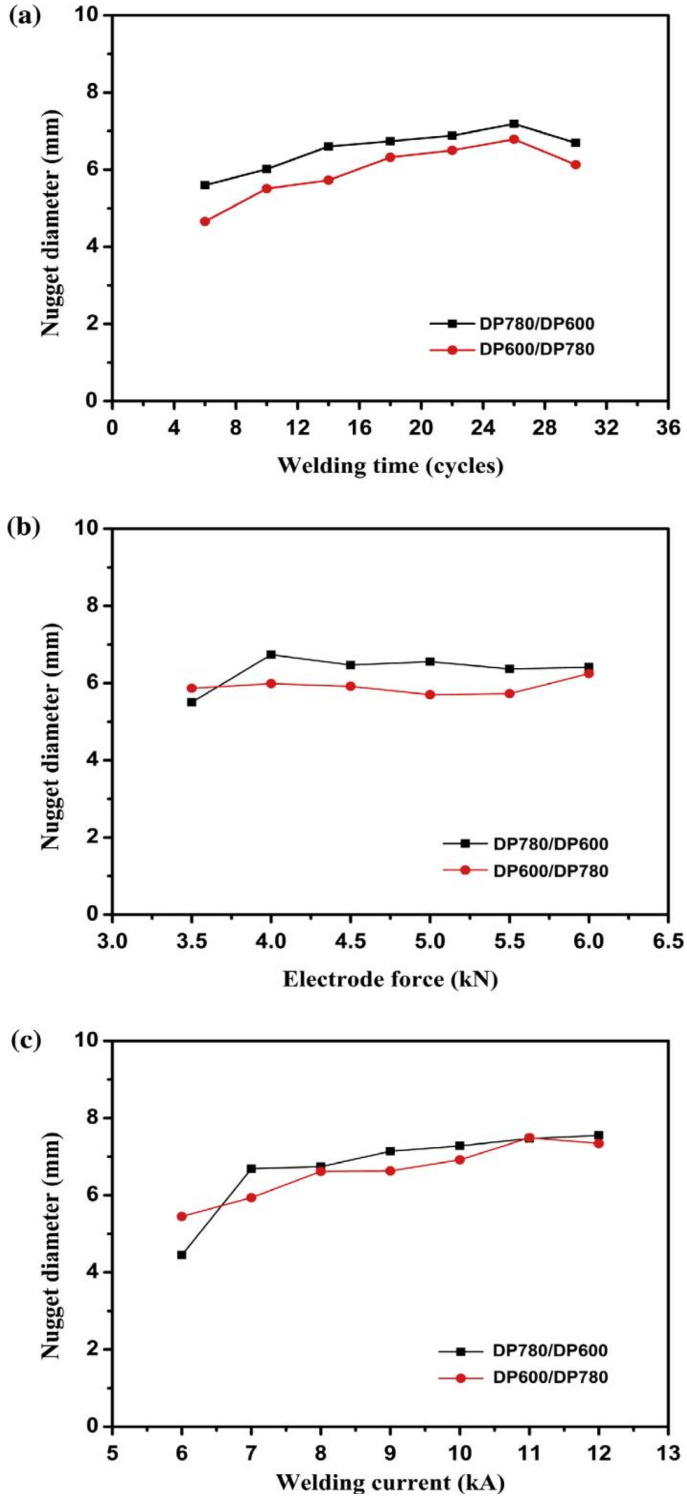
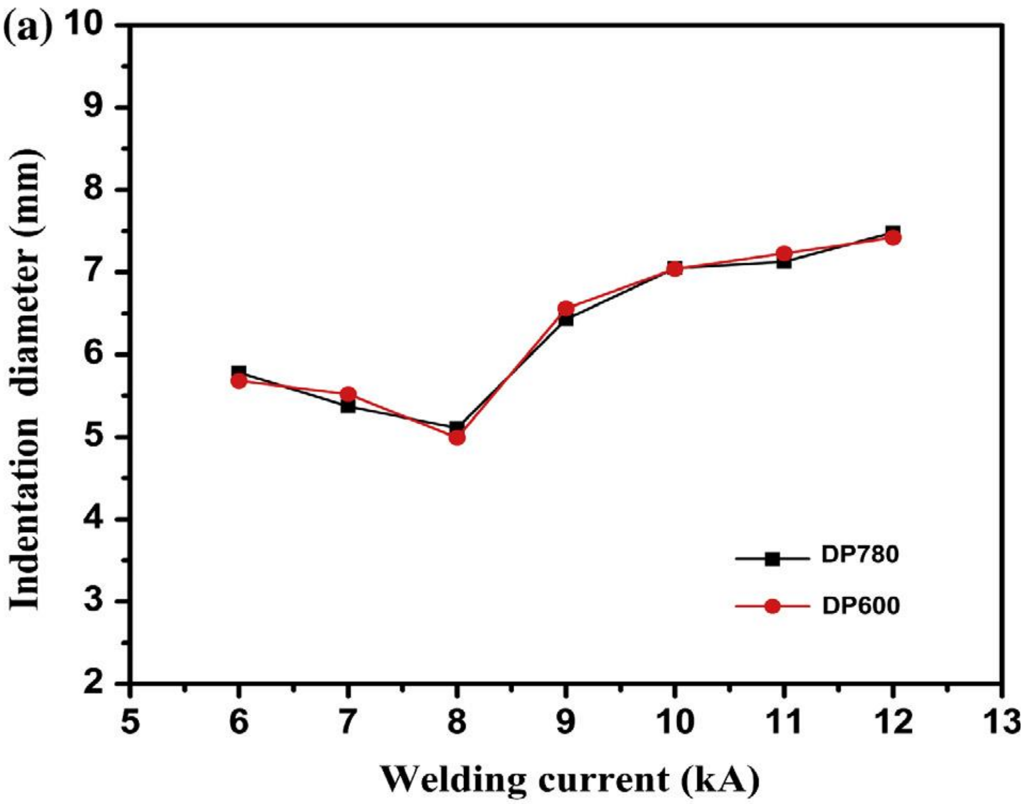


Figure 4.7. The effect of process parameters on the nugget diameter, (a) welding current (I = 8.0 kA, F= 4.0 kN), (b) welding time (T = 18 cycles, F = 4.0 kN) and (c) electrode force (I = 8.0 kA, T = 18 cycles).

(a)


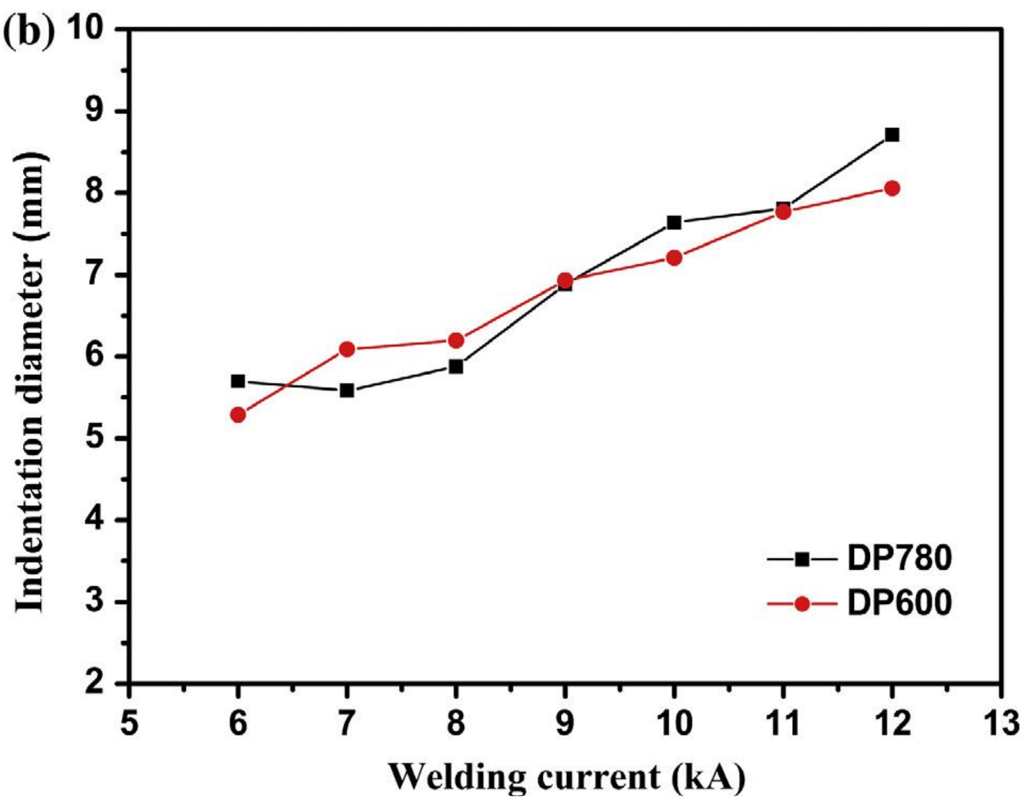
(b)


Figure 4.8. The effect of welding current on the indentation diameter, (a) DP780/DP600 and (b) DP600/DP780.

Indentation diameter

Fig. 4.8 shows the effect of welding current on the indentation diameters of welded joints. As can be seen, with the increasing welding current, both side indentation diameters increased gradually.

However, the indentation diameters of the DP600/DP780 welded joints got the minimum value (4.99 mm) with the welding current 8.0 kA. With the increasing of welding time, the indentation diameters of the DP780/DP600 welded joints increased gradually, and both side indentation diameters were approximately equal (Fig. 4.9a). The indentation diameters of the DP600/DP780 welded joints increased first and then decreased gradually. The indentation diameter of DP780 side was always larger than that of the DP600 side (Fig. 4.9b).

As electrode forces were increased, the indentation diameters of the DP600/DP780 and DP780/DP600 welded joints remained constant, as shown in Fig. 4.10. The BM lap orders have little effect on the indentation diameters for the different welding currents and electrode forces. The indentation diameter depended to a great extent on the electrode geometry and electrode pressure [13].

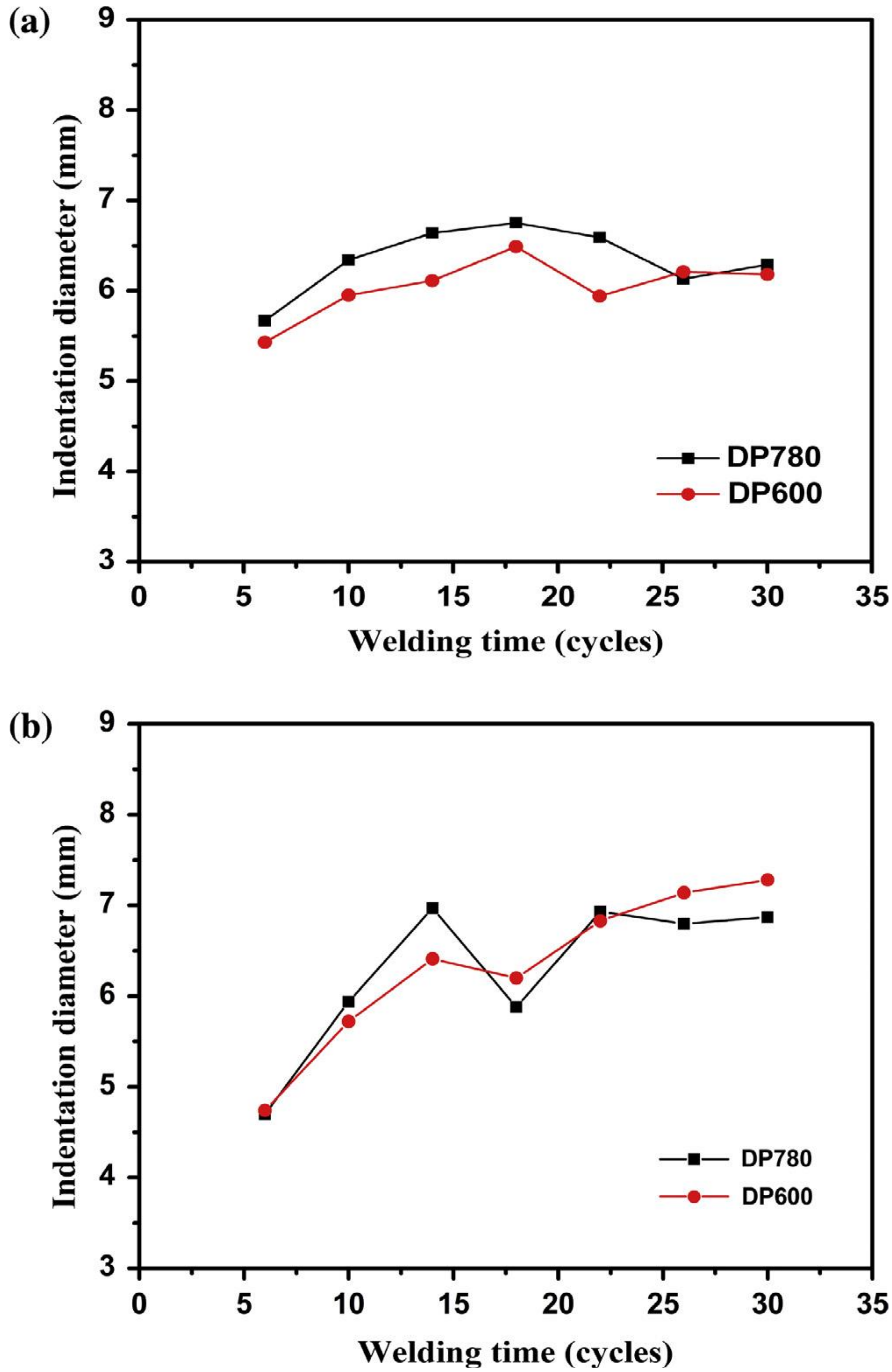


Figure 4.9. The effect of welding time on the indentation diameter, (a) DP780/DP600and (b) DP600/DP780.

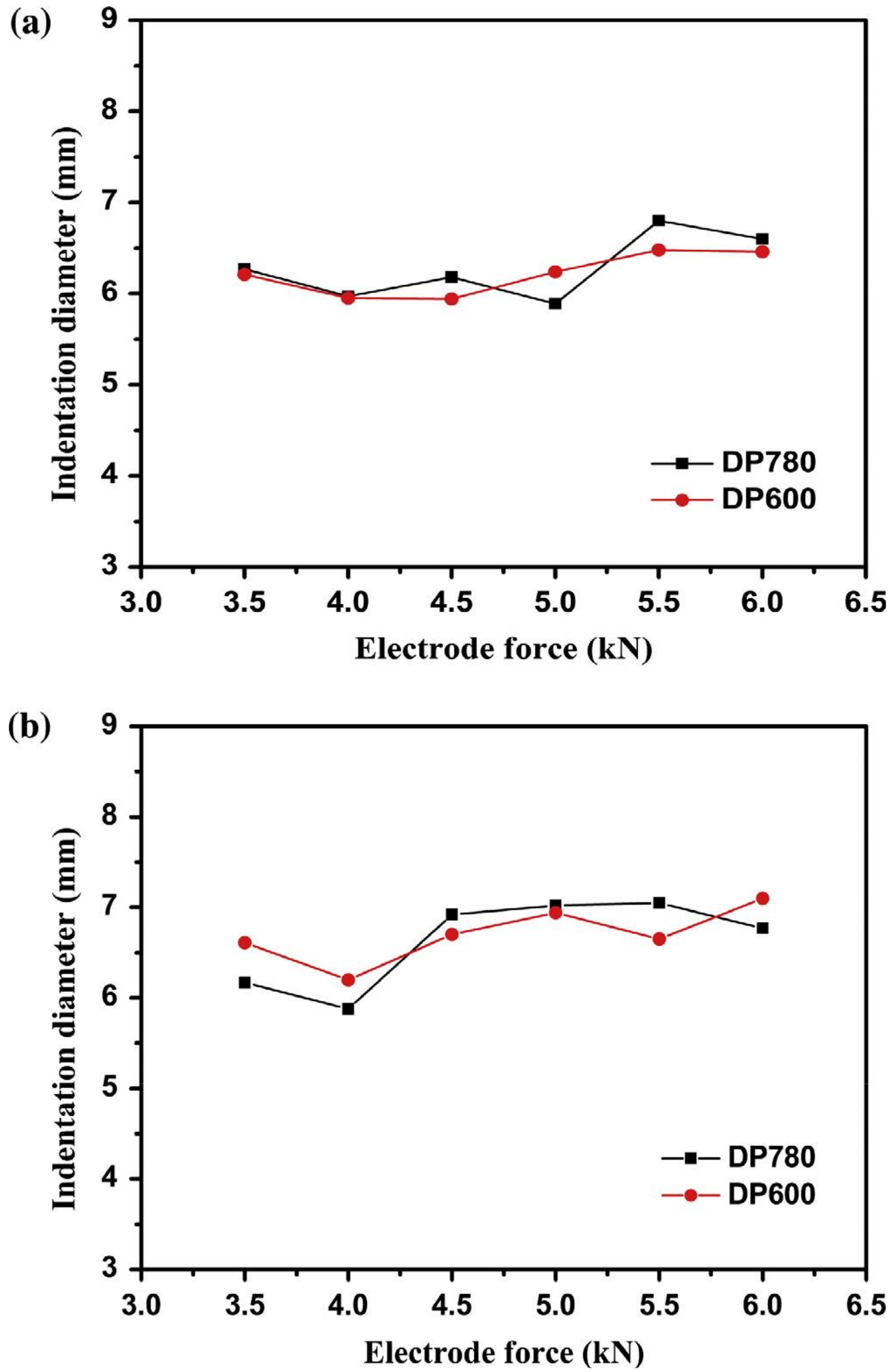


Figure 4.10. The effect of electrode force on the indentation diameter, (a) DP780/DP600 and (b) DP600/DP780.

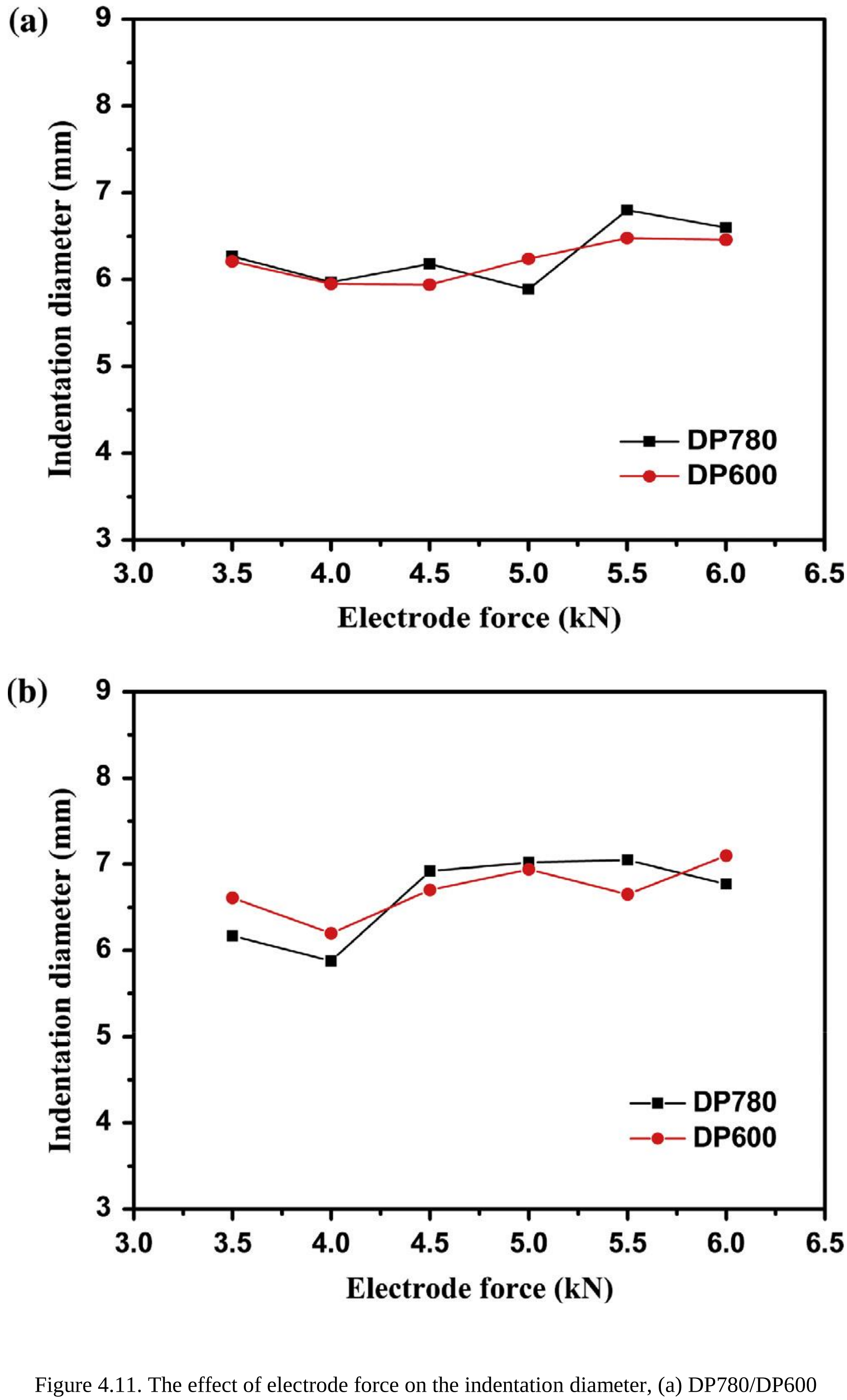


Figure 4.11. The effect of electrode force on the indentation diameter, (a) DP780/DP600 and (b) DP600/DP780.

4.2 ANALYTICAL RESULTS

The analysis done on ANSYS is summarized here. The analysis is done on basis of boundary conditions stated in section 3.3. Based on those, the results in graphical form are given in figure 4.12. Thermal analysis gives the temperature distribution on the plate with specified conditions. Temperature distribution along the thickness is also shown graphically.

The second stage of analysis is covered in figure 4.12.e-h. The structural analysis is done at this stage. The stress distribution of heated plate and also along the thickness is shown graphically. The range of temperature is shown on axis.

Spot Weld Analysis

Thermal Analysis

Meshed Model

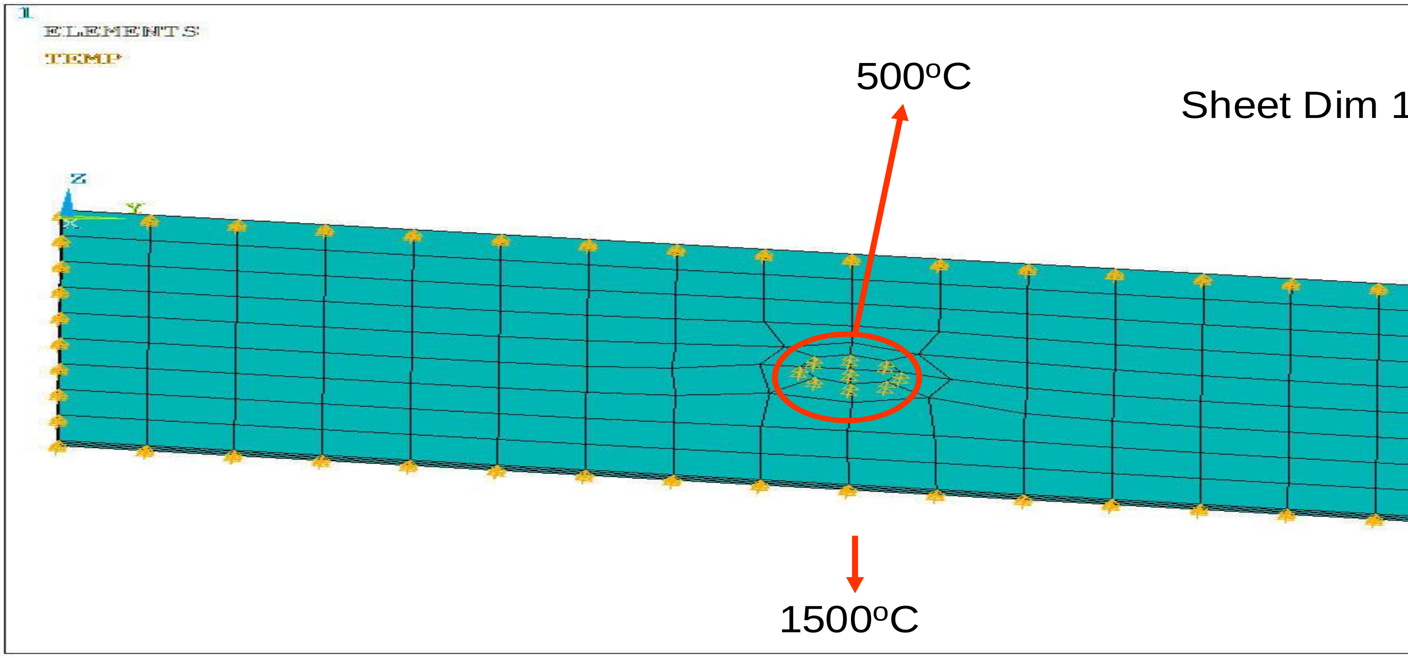


Figure 4.12: Thermal Analysis

Temperature Distribution in Faying surf

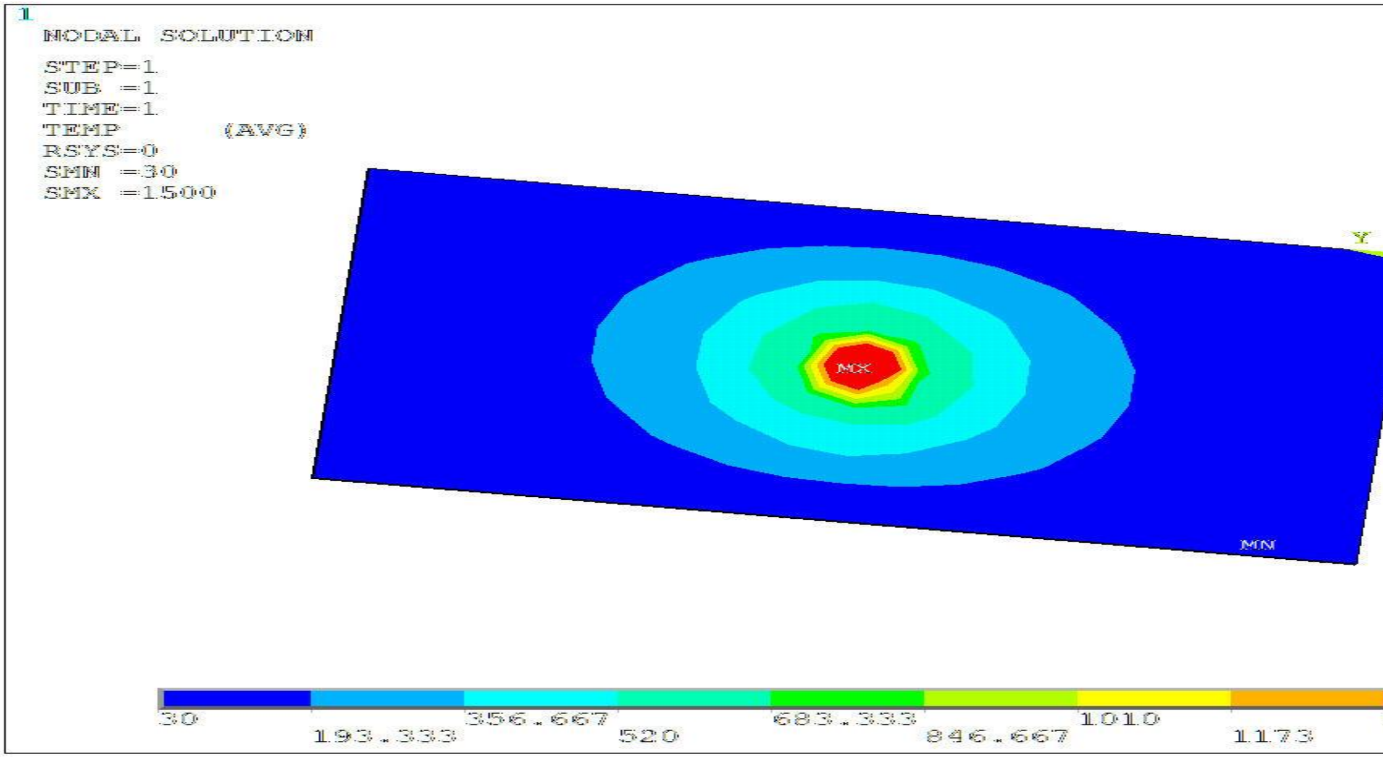


Figure 4.13: Temperature distribution at faying surface

Temperature Distribution at Electrode – Workp Interface

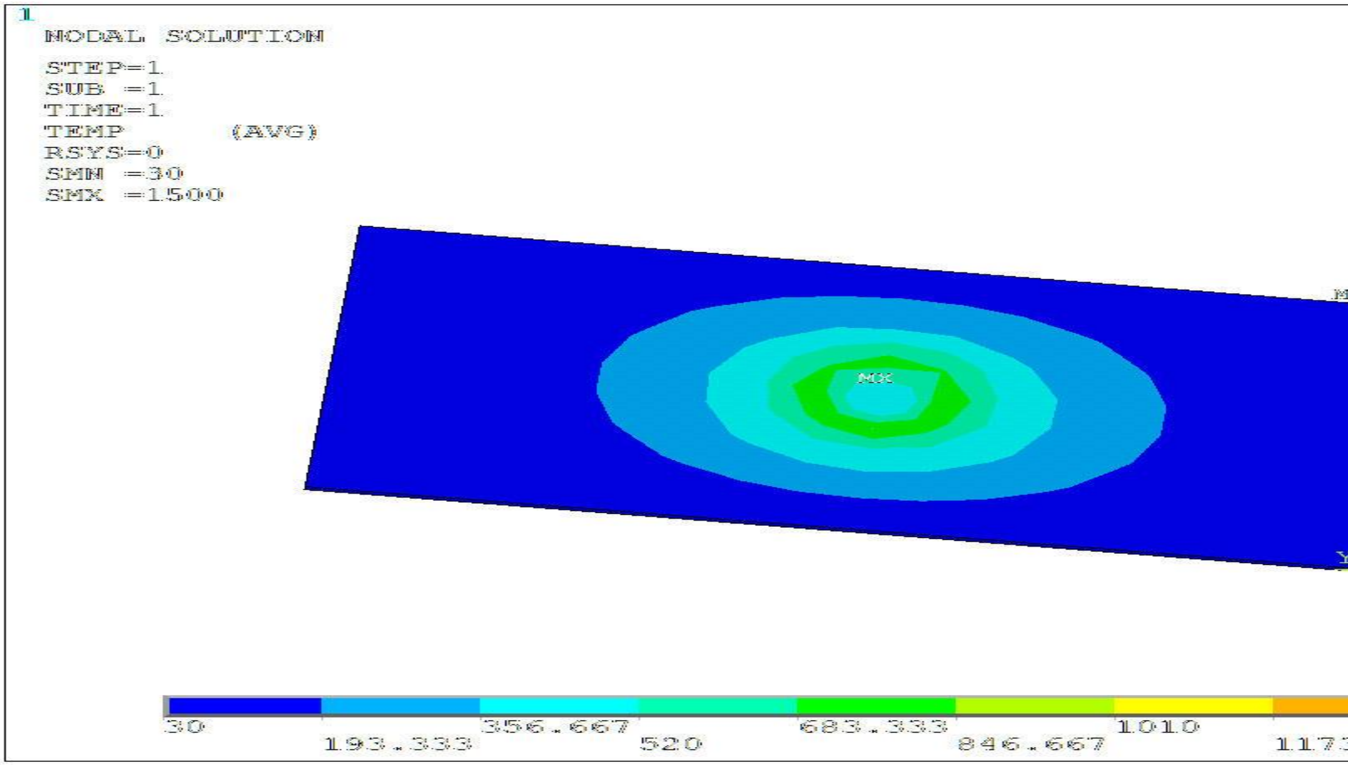


Figure 4.14: Temperature distribution at electrode workpiece interface

Temperature Distribution along the thickness

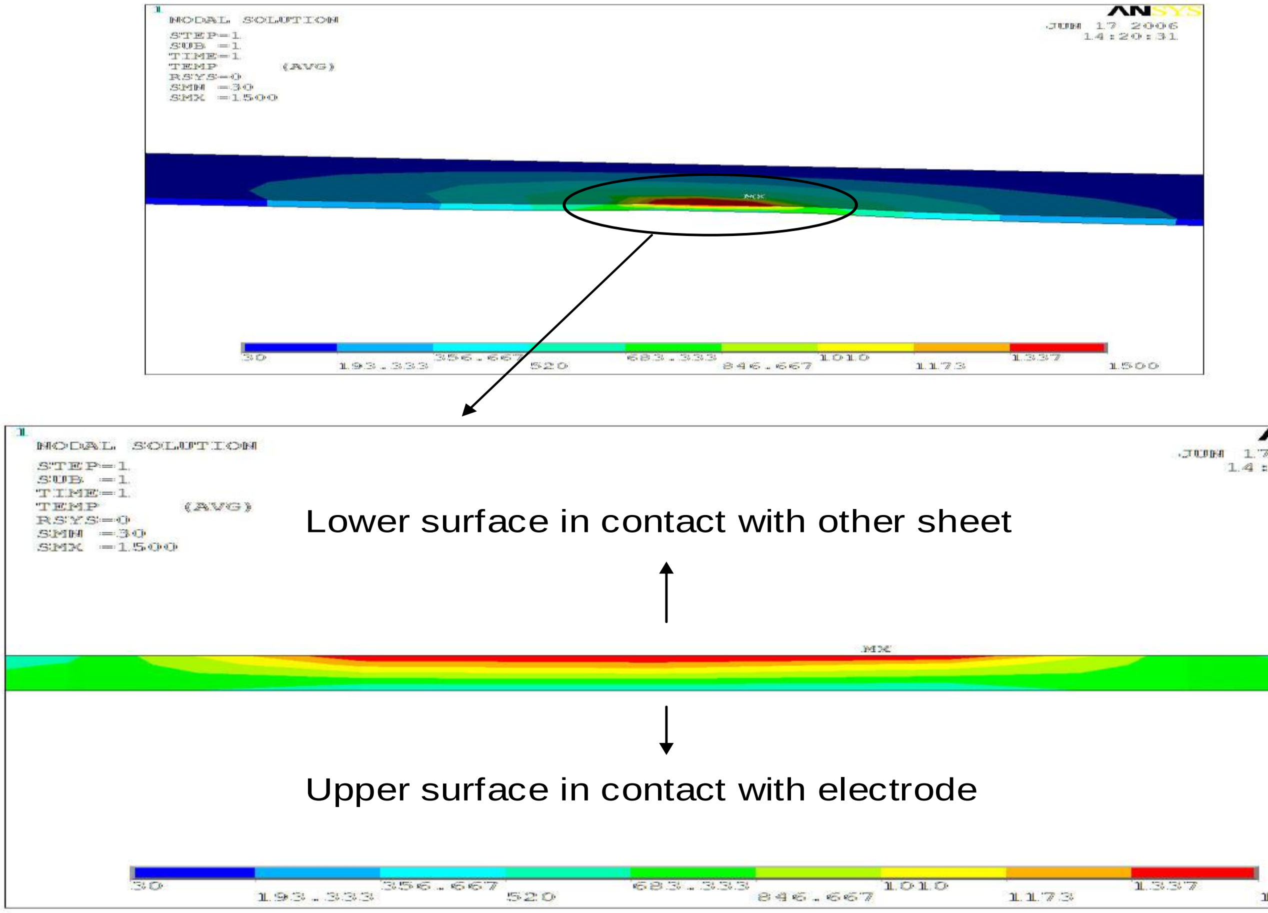


Figure 4.15: Temperature distribution along the thickness

Structural Analysis

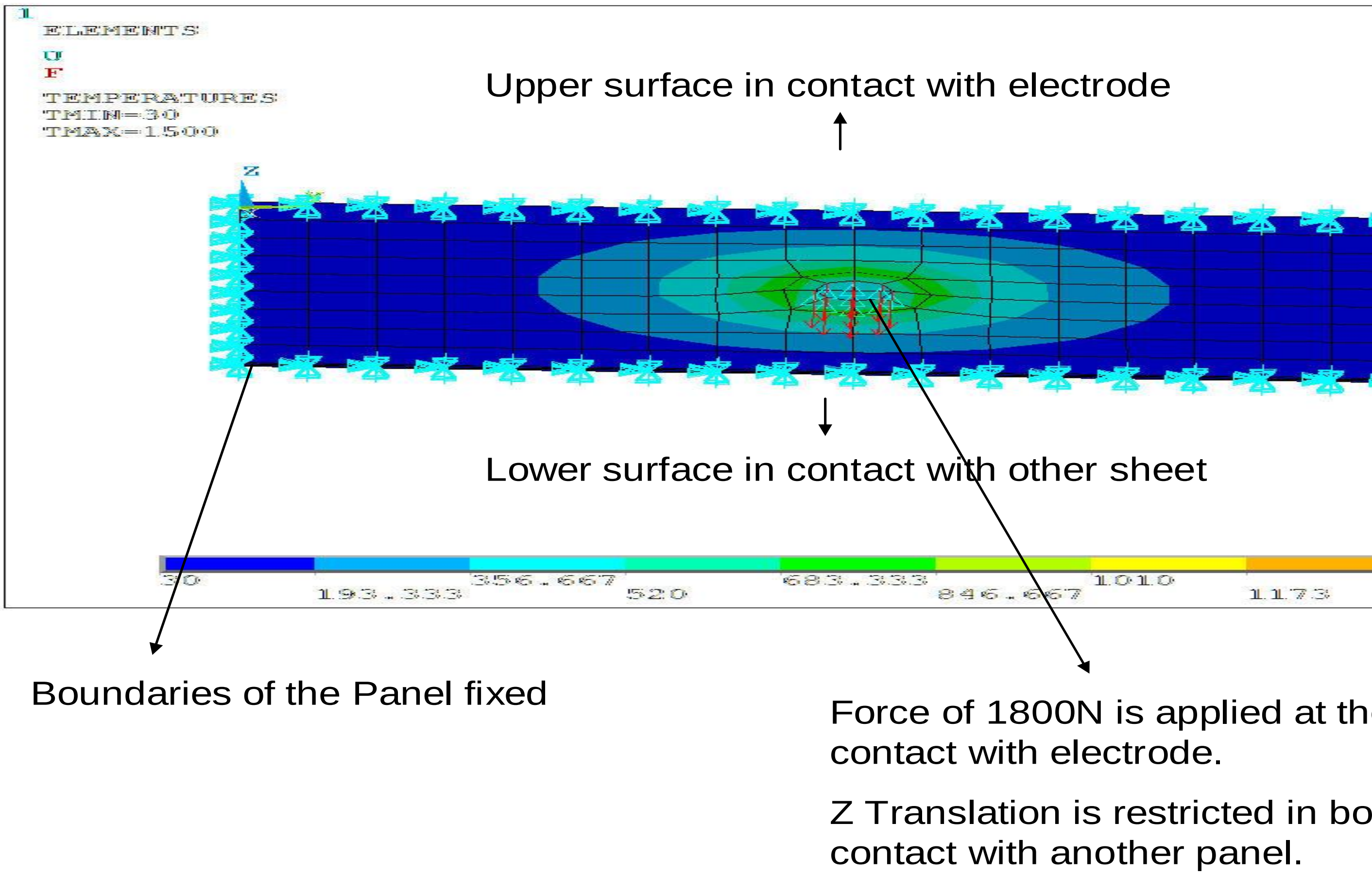


Figure 4.16: Structural Analysis

Stress Plot for the faying surface of heated sheet

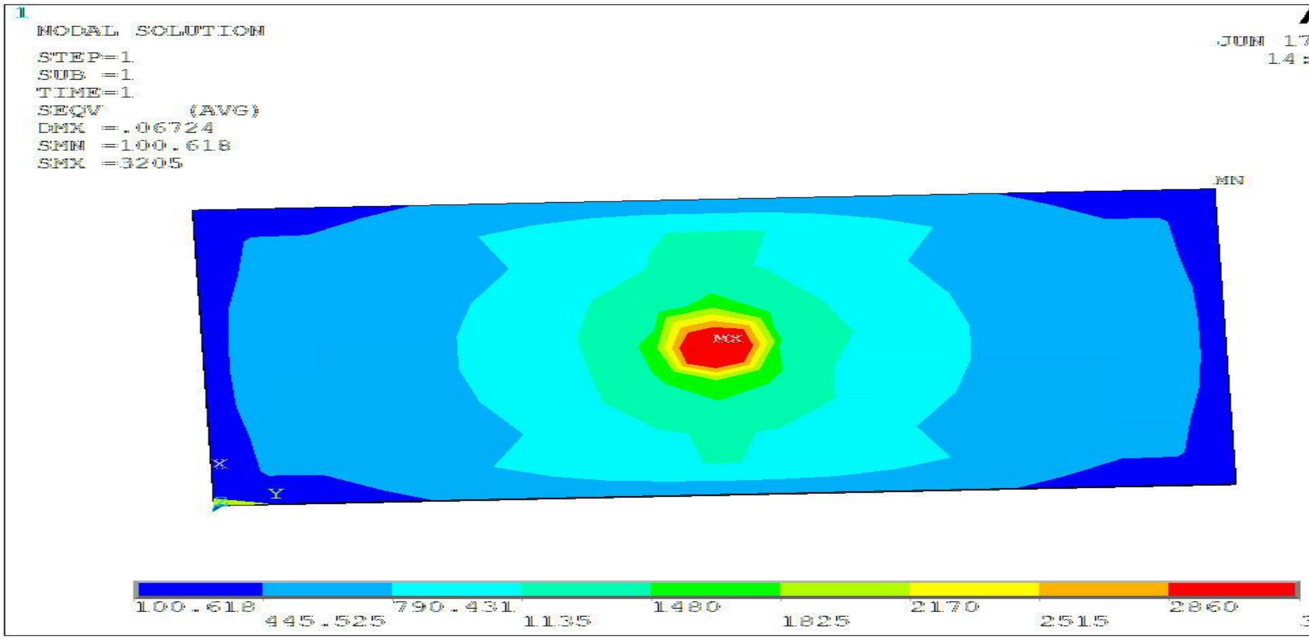


Figure 4.17: Stress Plot at faying surface

Stress Distribution along the thickness

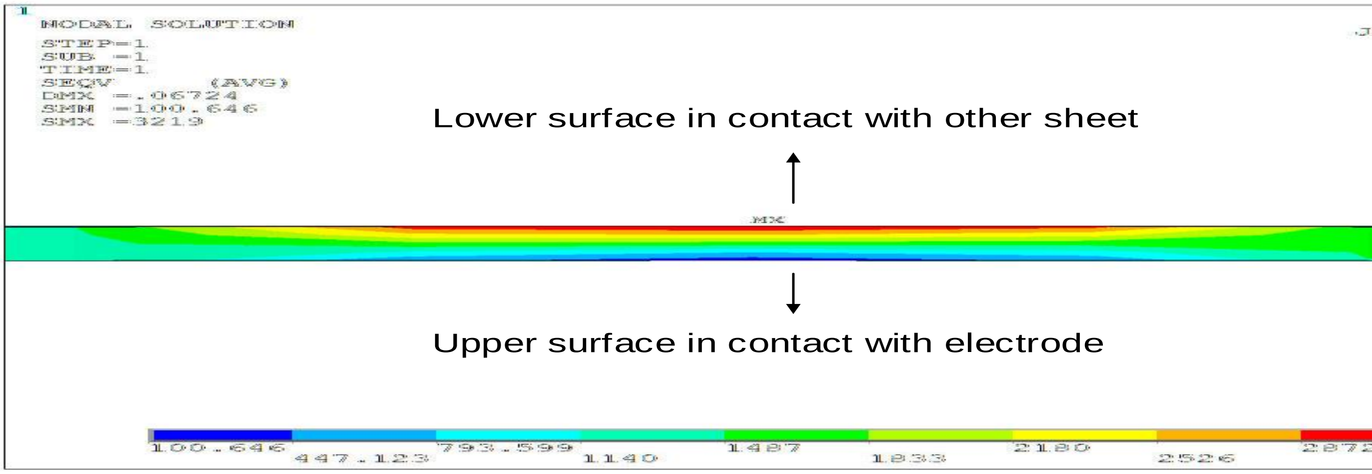


Figure 4.18: Stress Distribution along the thickness

Deformation Plot

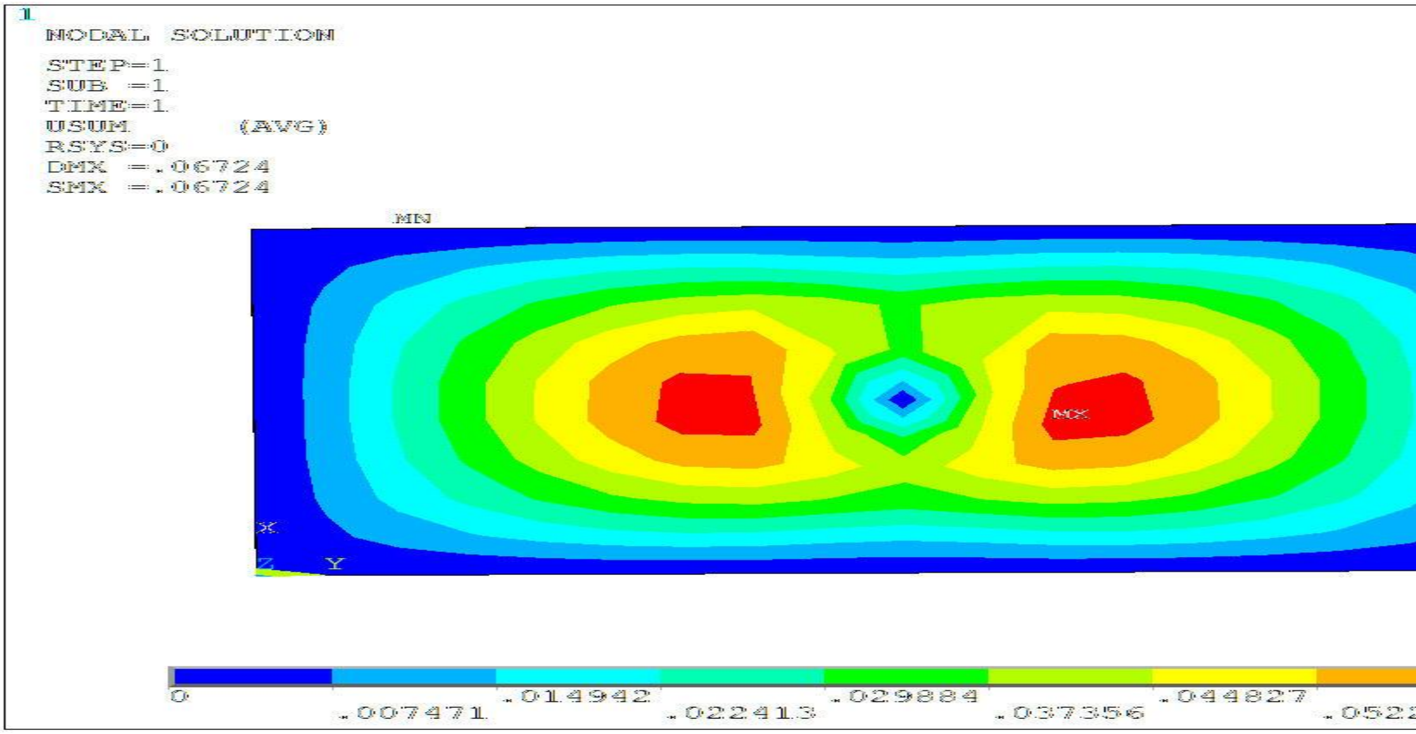


Figure 4.19: Deformation Plot

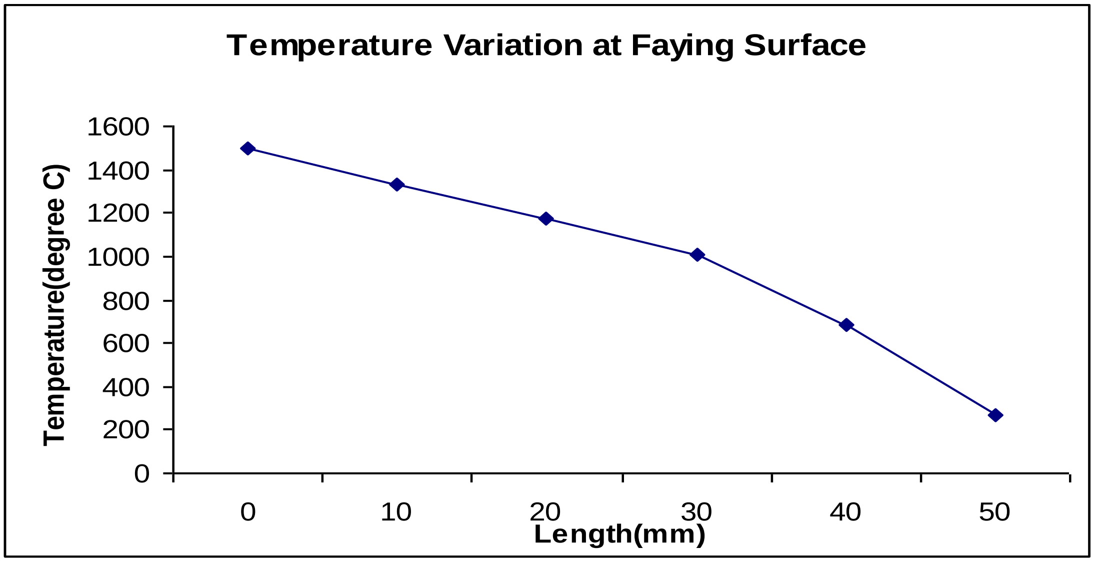


Figure 4.20: Temperature at faying surface

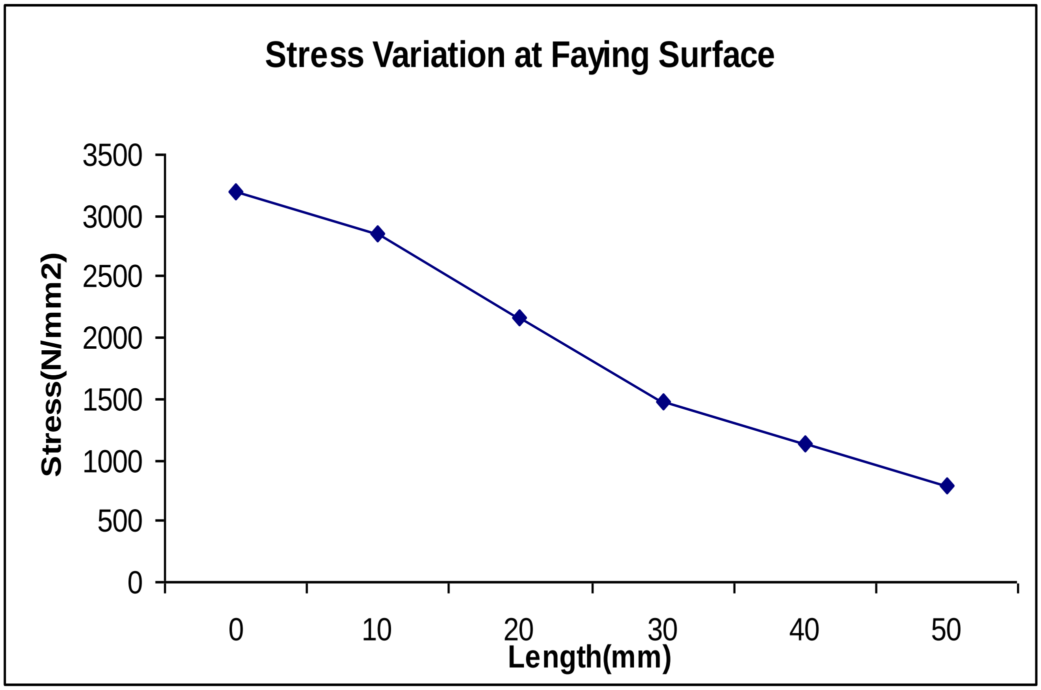


Figure 4.21: Stresses at Faying surface

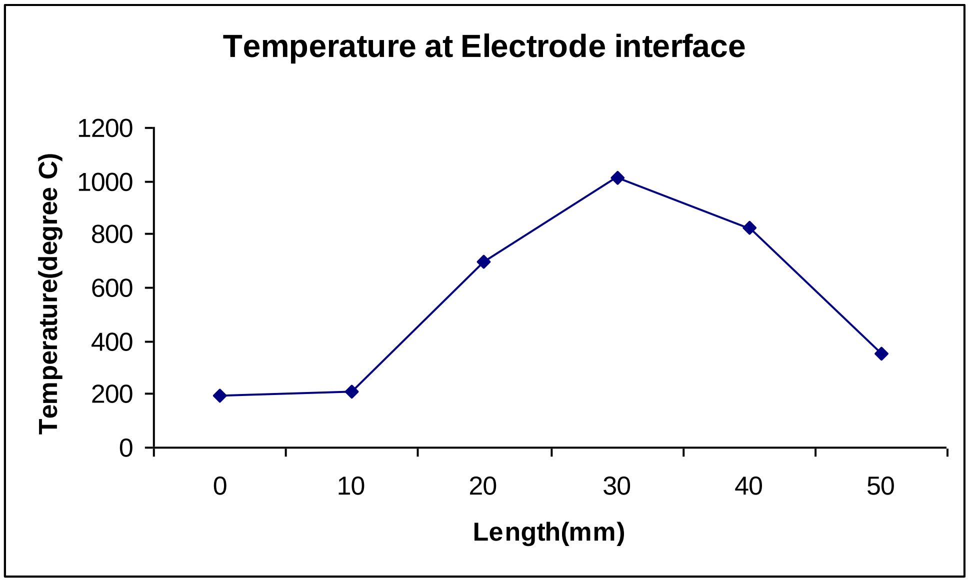


Figure 4.22: Temperature variation at electrode surface

Based on the outputs referred in figure 4.12, graphical representation of temperature distribution is shown in figure 4.13 and figure 4.14. The graphs are drawn for one quadrant moving along the length (axis symmetric). The graph reveals that temperature is decreasing while moving away from the nugget and the minimum value of temperature is at the end. The stress nature can be similarly studied. The stresses are maximum near the center and decreases as shown in figure 4.14. The stresses are minimum at the ends of the plate. The comparison of temperature distribution at faying surface and work piece electrode interface shows that the temperature at fusion zone decreases continuously after moving away from the centre of nugget but at electrode work piece interface, temperature increases and then decreases. The maximum temperature is always less at electrode surface than the faying surface.

CHAPTER 5

CONCLUSIONS

Resistance Spot Welding is one of the simplest methods of joining two or more dissimilar metals. Recognized fundamental variations in spot welding are force, cycle time and current. The effect of the variations on weld properties is done successfully.

Macro characteristics of the dissimilar thickness dual phase AHSS joints were described in terms of melting rate, indentation rate, nugget diameter and indentation diameter. Some results can be concluded as follows:

(1) The melting rate of the DP600 side is always higher than that of the DP780 side of the welded joints, and the reason is that weld nugget moves towards the DP600 side.

(2) The indentation rate of the D600 side is always lower than that of the DP780 side of the welded joints. This can be attributed to the greater resistivity and more heat input of DP780 side.

(3) The DP780/DP600 welded joints tend to get a larger nugget diameter than DP600/DP780 welded joints with the same process parameters. The indentation diameters of both sides depend on the electrode geometry and force.

Finite element modeling and analysis provide insightful information regarding the stress and the temperature distribution. It has been shown that the finite element modeling of the resistance spot welding process can provide good simulation. It is common practice in industry to use welding conditions tabulated in handbooks as the starting point to develop a welding schedule. The results presented herein indicate that there is another alternative: the use of analytical model. Finite element modeling and analysis is well developed technique. Using this method, one can investigate weld nugget formation for a variety of materials to be joined and different electrode configurations. The use of an analytic tool by process engineer provided him with another procedure to develop weld schedules before going onto the shop floor to conduct tests.

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ANNEXURE 1

Table I: SPOT WELDING DATA

Sheet thickness, t [mm]	**Electrode force, F [kN]**	**Weld current, I [A]**	**Weld time [cycles]**	**Hold time [cycles]**	**Electrode diameter, d [mm]**
0.63 + 0.63	2.00	8 500	6	1	6
0.71 + 0.71	2.12	8 750	7	1	6
0.80 + 0.80	2.24	9 000	8	2	6
0.90 + 0.90	2.36	9 250	9	2	6
1.00 + 1.00	2.50	9 500	10	2	6
1.12 + 1.12	2.80	9 750	11	2	6
1.25 + 1.25	3.15	10 000	13	3	6 7
1.40 + 1.40	3.55	10 300	14	3	6 7
1.50 + 1.50	3.65	10 450	15	3	6 7
1.60 + 1.60	4.00	10 600	16	3	6 7
1.80 + 1.80	4.50	10 900	18	3	6 7
2.00 + 2.00	5.00	11 200	3x7+2	4	7 8
2.24 + 2.24	5.30	11 500	3x8+2	4	7 8
2.50 + 2.50	5.60	11 800	3x9+3	5	8

ANNEXURE 2

JIS Z 3139 STANDARD

Scope:

This Japanese Industrial Standard specifies the method of macro test and details for section of spot welded joint of metallic materials not more than 5.0 mm in plate thickness.

Two - Plate Lap Joint

This is regarding the shape of test piece. The shape of test piece shall confirm to Figure I and Table II, and shall be cut from test material joined by not less that 10 continuous spot weldings The pitch of the spots (P) shall confirm to the value shown in Table II as the standard.

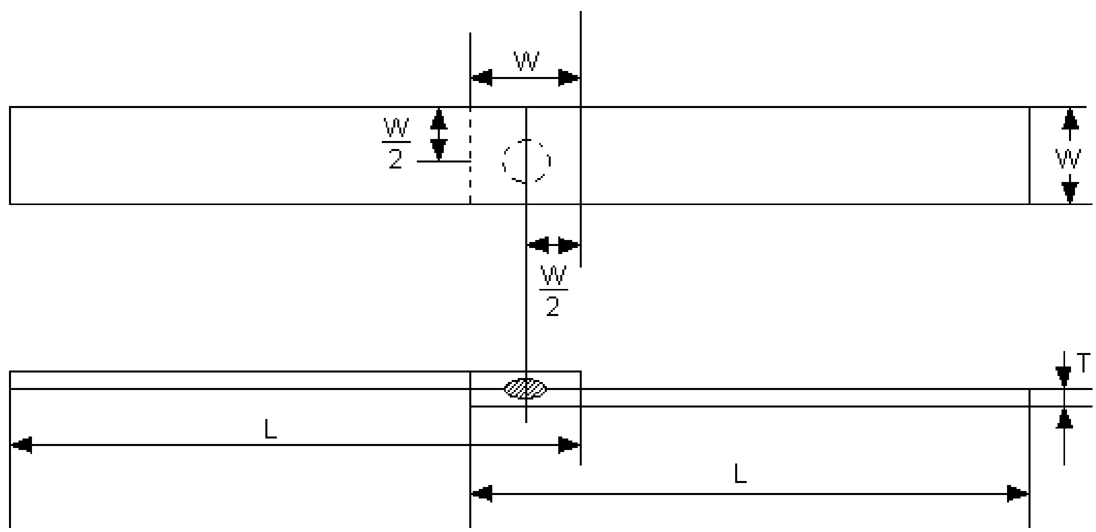

Figure I: Shape of the Test Material

Table II: Dimension of Test Piece and Test Material

Nominal Thickness of plate t (mm)	**W(mm)**	**L(mm)**	**P(mm)**
Under 0.8	20	75	20
0.8 to 1.3 excl	30	100	20
1.3 to 2.5 excl	40	125	40
2.5 to 3.5 excl	50	150	55
3.5 to 4.4 excl	50	150	70
4.4 to 5.0 excl	50	150	80

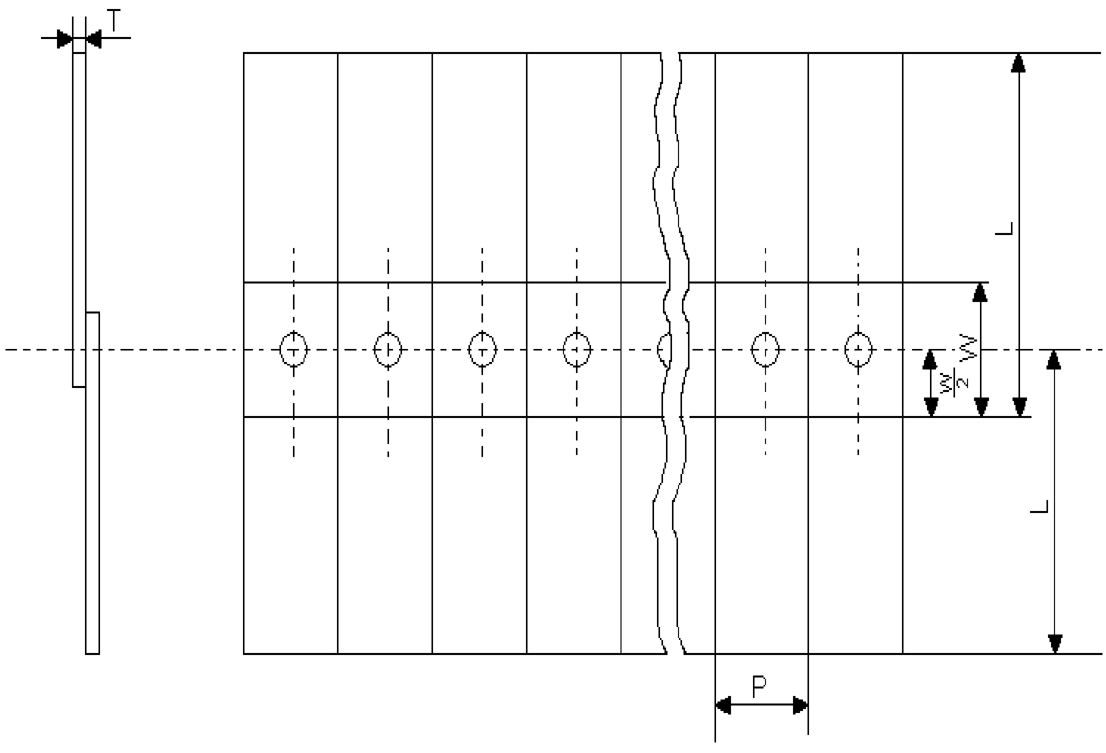

Figure II: Continuous Spot Welding Test Material

In figure II, the value of pitch should confirm to value shown in table II as standard, but it may be adjusted as the purpose of the may require. The test piece for the joint of plates different in thickness and quality shall have a thickness of the base metal, whichever is less in the product tensile strength and the thickness.