EFFECT OF CLAMPING DISTANCE AND VOLTAGE ON WELDABILITY OF DISSIMILAR WELDING

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Specially dedicated to

My beloved parents, siblings and those who have guided and inspired me

Throughout my journey of learning

Jaffrey Kumil

Rositah Tiun

Vebster

Veynessa

Veyonna

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ABSTRACT

In welding technology, there are a lot of parameters that would give different effects on the weldability, specifically in welding of dissimilar metal. In this study, carbon steel and stainless steel are welded by using metal inert gas welding or MIG by using ER308 filler wire and the parameters involve in this study are clamping distance and voltage. The objectives of this study are to study the effect of clamping distance and voltage on dissimilar welding and to determine which clamp is the most suitable in improving weld quality. The output for this study is focusing on the defects caused by different parameters and the hardness on the fusion zone. In this study, the current and speed is kept constant throughout the experiment. This study involves the microstructural preparation which involves the mounting, grinding, polishing, and finally the etching process in order to perform hardness test. Visual inspection is done by using naked eyes to determine the defects caused by different parameters. Comparison on the weld quality of sample welded by using same parameters including voltage is done to find out how different clamping distance would affect the weld quality. Parameter optimization is done by using Taguchi Method and Analysis of Variance is used to determine the most significant parameter that affects hardness at the fusion zone. From the analysis, the highest hardness value and minimum defects can be seen visually is on sample welded by using 21 V and 3.75 cm distance of clamping, which is by using clamp 2. The most significant parameter that affects the hardness is the distance of clamping. Confirmation test is done at the end to validate the result of experiment.

ABSTRAK

Dalam teknologi kimpalan, terdapat banyak parameter yang akan memberi kesan yang berbeza pada kebolehkimpalan, khususnya dalam mengimpal logam yang berbeza. Dalam kajian ini, keluli karbon dan keluli tahan karat dikimpal dengan menggunakan kimpalan gas lengai logam atau MIG dengan menggunakan dawai pengisi ER308. Parameter yang terlibat dalam kajian ini adalah jarak pengapitan dan voltan. Objektif kajian ini adalah untuk megkaji kesan jarak pengapitan dan voltan atas kebolehkimpalan dua logam yang berbeza. Kajian ini juga adalah untuk menentukan apit yang sesuai dalam menaiktaraf kualiti kimpalan. Output kajian ini bertumpu kepada kecacatan dan kekerasan pada titik tertentu yang disebabkan oleh parameter yang berbeza. Kajian ini melibatkan penyediaan untuk menganalisa mikrostruktur dan ujian kekerasan. Pemeriksaan visual dilakukan dengan menggunakan mata kasar untuk mengenalpasti kecacatan yang disebabkan oleh parameter yang berbeza. Perbandingan dari segi kualiti kimpalan pada spesimen yang dikimpal dengan menggunakan parameter yang sama termasuk voltan yang sama dilakukan untuk mengetahui bagaimana jarak pengapitan menjejaskan kualiti kimpalan. Kaedah Taguchi digunakan dalam menentukan parameter optimum dan ANOVA digunakan untuk mengenalpasti parameter yang memainkan peranan penting dalam menentukan nilai kekerasan. Berdasarkan daripada analisis data, nilai kekerasan yang tertinggi dan kecatatan minimum adalah pada sampel yang dikimpal pada 21 V dan pada jarak 3.75 cm, di mana apit yang digunakan adalah apit ke-2. Parameter yang memberi lebih banyak kesan kepada nilai kekerasan adalah jarak pengapitan. Akhir sekali, ujian pengesahan dilakukan dengan menggunakan parameter optimum untuk mengesahkan nilai kekerasan dan kecacatan yang dapat dilihat secara visual

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CHAPTER 1

INTRODUCTION

1.1 RESEARCH BACKGROUND

Welding is a process of joining metal which is widely used in the sector of manufacturing of most engineering and structural machineries. Welding is a joining process with a simple set up, high joint efficiency and low cost of fabrication. (Chin-Hyung Lee, 2012). In order to obtain good weld joint strength of sheet metal, it is essential to have a good clamping device.

Welding jigs are device that enables material to be easily and rapidly setup and held. Welding jig is designed and fabricated for the purpose of holding parts in alignment and to ensure accurate fit-up with no need for tack welding (Alber A.SADEK, 2000).Welding jigs or fixtures are used in holding parts to be assembled in a correct position for welding. There are differences between welding jigs and tacking tools, where tacking tools are used only when the part is to be tack-welded. Welding jigs are designated to be much heavier compared to tacking tools in order to resist added forces caused by the heat within the part. (G.hoffman).

1.2 PROBLEM STATEMENT

In dissimilar welding, there are numbers of technological difficulties arising and one of the methods to overcome the problems is by improving the clamping system. Welding dissimilar metals is normally complex compared to the welding of similar metals (Alber A.SADEK, 2000). Distortion and warping is the main problem during welding and this is caused by the design of the jig itself. Problems in dissimilar welding make the joint to be easily cracked and caused failure. (Yaowu Hu, 2012). This is mainly caused by partial penetration due to inadequate heat dissipation and brittle intermetallic compound.

In designing welding jigs, there are some basic considerations that should be taken such as heat dissipations. It is important to ensure proper heat to be maintained in the weld area and the priority goes to the amount of heat required. Thus, in this research, the effect of clamping, specifically, the distance of clamping is studied to reduce defects in welding.

1.3 OBJECTIVES

The objectives of this project are to:

a) To study the effect of clamping distance and voltage on dissimilar welding.
b) To determine the most suitable clamp to be used to improve weld quality.

1.4 SCOPES

The scopes of this project are to:

a) Perform experiment on dissimilar welding of stainless steel and carbon steel to study the effect of clamping distance and voltage changes.
b) Perform experiment by using MIG welding machine.

1.5 SUMMARY

The study on the effects of clamping distance and voltage on weldabilty of dissimilar welding is presented in this thesis and is organized into five chapters. The first chapter had discussed on the project background, problem statements, objectives and the scopes related to the study. The next chapter, Chapter 2 will discuss on the literature review of the project and it will be focusing on the recent study that approximately related to the title. It is an important in order to obtain predicted outcome in this study and it is in form of book, articles and journals. Chapter 3 will gives the research methodology, the design of experiments, tools and equipment involve in the study. Chapter 4 will be presenting the data obtain and the analysis of data obtain from the study. Then, lastly the result is summarized in the final chapter, Chapter 5.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter is the literature review on dissimilar welding and the effects of clamping on the weldability on dissimilar welding. This chapter is also about the review on the material involve in the study and process related to study.

2.2 PROBLEMS IN DISSIMILAR WELDING

Melting and solidification of weld metals and base metal are the processes that are involved in localized fusion zone which is caused by a transient thermal heat source. Temperature which does not spread uniformly happens on the welded joints and base metal due to confine heating and subsequent cooling (B. Taljat, 1998). Uniform temperature distribution is one of the important aspects to be taken in order to avoid defect in welding.

Dissimilar metal joining is widely used in many products in chemical, petrochemical and nuclear engineering. The application of the dissimilar metal joints does not only limited to the different requirements of various service conditions, such as heat resistance, corrosion resistance and magnetic properties, but it also resulting in large savings of expensive materials, which reduced cost of product. In order to meet design requirements, dissimilar welding is applied (Alber A.SADEK, 2000).

In the process of joining dissimilar material, it is more challenging to study the mathematical reproduction of residual stress if compared to the residual stress in joining similar material. This is caused by the differences in metallurgical properties of the materials to be joined, the physical properties and also the mechanical properties. (E.K. Dimitrios, 2005; S. Nadimi, 2008; D. Akbari, 2009; D. Deng K. O., 2009; D. Deng S. K., 2011).

Partial penetration is one of the problems in dissimilar welding which is caused by different properties, physically and chemically. Those are different in terms of heat capacity, thermal conductivity, thermal expansion coefficient, and temperature where the metal melts. Inappropriate heat treatment in welding of dissimilar welding caused the occurrence of brittle intermetallic compound which caused low strength of joint (H.C. Chen, 2011; Z. Sun, 1995; C.W. Yao, 2009; A. Mathieu, 2007; S. Chakraborty, 2010).

Dissimilar metals are hard to be welded on account of the establishment of brittle intermetallic phases and varied difference in physical and mechanical properties. To obtain good weld join strength, the formation of the solid solution in the weld pool is needed whereas the formation of intermetallic is not needed. It is critical to minimize the thickness of intermetallic phases in the fusion zone (Jokiel, 2006;Van Tienhoven, 2006) (Katayama, 1998). The greatest main issue in dissimilar welding is due to the differences in physical properties of base metals, as well as on certain level of metallurgical incompatibility.

Residual stress from welding is the primary source of deformation in welded panels especially in thin sections. This occurs when the residual stress level exceeds the buckling limit of the weld joint out of plane distortion occurs (Michaleris, 1997). The total stress on a part is the stress from the combination of in-service loads and the residual stress (Price, 2007). Residual stress contributes to diminished fracture resistance (Gachi, 2009). The welding parameters need to be controlled in order to control both geometric tolerances and material properties that are desirable to mitigate residual stress.

2.3 GAS METAL ARC WELDING (GMAW)

Metal Inert Gas (MIG) welding is commonly used and accepted slang term that was appropriate when the process was first invented. In the beginning, the gasses used for shielding the weld area were known as “Inert” or “Nobel” gasses. Today, the proper terminology is “Gas Metal Arc Welding” or GMAW. This is the best description since most gasses or gas mixtures used are neither Inert nor Nobel gasses, and in many cases they are actually reactive gasses.

This type of welding is also sometimes refers as “Wire Wheel Welding” because of the usage of wire wheel to feed the filler metal to the weld joint. MIG can weld almost any types of metal and one of the biggest attractions about MIG process is how fast it is able to weld more than just steel. Metals that are commonly welded using MIG welding are mild steel, stainless steel and aluminum. This welding process can weld many more alloys and combination of metals. One common dissimilar welding that is usually done is welding stainless steel to steel. Other metal that can be welded range from copper to titanium. The list of metals that can be welded is extensive and range from very common metals to extremely exotic.

Gas Metal Arc Welding (GMAW) is a once welding process that uses an arc between a continuous filler metal electrode and a weld metal. The process is used with shielding from an externally supplied gas and without the application of pressure; it was developed in the late 1940’s for welding aluminum and has become popular. There are numbers of variations depending on the type of shielding gas, type of the metal transfer, type of the metal welded and so on. It has been named MIG welding, CO_2 welding, Fin wire welding, Spray arc welding, Pals arc welding, Dip transfer welding, Short circuit arc welding and various trade names. (Phule, 2004). Figure 2.1 shows the MIG welding machine that are commonly used,

Figure 2.1: MIG Welding Machine

2.3.1 Power Supply and Equipment

MIG welding power supplies are referred as CV or “Constant Voltage” power supplies. The power supply produces electrical current to create arc to weld the metal with. The term CV means that the heat settings are controlled with voltage. When MIG welding, the machine is always set by voltage and this type of power supply keeps the voltage t consistent level.

MIG welding require a wire feed system and this system is what feeds the electrode or filler wire to the weld joint. This is where the “Wire Wheel Welding” comes from. The wire feeds come in many different forms. Some are part of the power supply, and the higher-end models come in stand-alone form or are contained inside a briefcase. He wire feed is regulated in IPM or “Inches per Minute”. This is how the speed of the filler wire is regulated and set. The wire feed system also controls shielding gas and all welding operations that are signaled from the MIG gun. The MIG gun has a handle with a trigger that is attached to the wire feed through a cable. The MIG gun feeds the filler wire, the shielding gas, and electricity to the joint. Once the trigger is hit, the MIG gun shields the weld area from the air, produces the arc and welding process is started by feeding wire to the joint.

2.3.2 Shielding Gases

There are many shielding gases used for MIG welding and since the electrodes are solid metal wire, some form of shielding gases from the air is needed. The gases range from inert gases to reactive ones. In many cases, the gasses used are a combination of two or more gasses. Some of the commonly used gasses are argon, carbon dioxide, helium (in rare cases) and oxygen (in small percentages).

For most welding applications, combination of Argon and Carbon Dioxide are used. When it comes to welding gases, Argon produces a lot of smoke while welding. Some of the most commonly used gases for welding carbon steel are 100% Carbon Dioxide, 25% Carbon Dioxide and 75% Argon, and 2% Carbon Dioxide and 8% Argon.

2.3.3 Electrodes or Filler wire

MIG/Mag is a flexible and fast method for semi or fully automatic welding. Welding can be performed in all positions and a normal plate thickness would be between 2 and 10 mm. Pulsed arc welding offers the best flexibility and is particularly suitable when high alloyed stainless steel and nickel based filler is used.

2.4 CLAMPING SYSTEM

Clamping is the most important system in counteracting welding to induced distortion. Distortion effect increases as the clamp is moved closer to the weld centerline (Shenk, 2009). Distortion is reduced by increasing the clamping force, but above a certain threshold, it has diminishing returns (Schenk, 2009). Jigging of material during welding is necessary to make sure the flatness where the main function is to hold and retain the component in the rigid alignment. It is important for the designed jig to have the ability to provide good access of welding, to be rigid and robust (G.hoffman).

The main consideration during designing welding jig is the clamping system, whether it is user friendly or not. User friendly clamping systems are those which can be clamped and released easily without consuming too much time in order to prevent material deformation. The distortion of material due to clamping and weld squeezing is calculated in the displacement-based finite formulation:

$$\{F\} = [K]\{\delta\} \tag{2.1}$$

Clamping system is one of the parameter that affect distortion and it is an important aspects since clamping system is always needed in welding operation in order to fix the workpiece. Mitigation methods had been developed for the purpose of reducing distortion by using different approaches such as LSND welding (Q. Guan Dang, 1994; Aa, 2007) (Aa, 2007), thermal tensioning (P. Michaleris, 1999; M. Deo, 2003), pre-deformation (Masubuchi, 1980) or by using optimized welding sequence (C. L. Tsai, 1999) (M. Mochizuki M. Hayashi, 2000; M.H Kadivar, 2000). The used of clamp as an in-line distortion mitigation technique will caused probable advantage where there will be no energy consuming technique will be introduced further in the process.

Influence of clamps mechanically had been studied mathematically on overlap joint and the result showed that distance of clamping have crucial influence on deformation. Other than that, by referring to the research, the closer the clamps, the less distortion will occur (S. Roeren, 2006). Josseran et. al. (E. Josserand, 2007) obtains result that showing the rate of cooling at the weld seam can affects the clamps and thermal contact condition.

2.5 MILD STEEL

Steel is any alloy of iron which consist 0.2% to 2.1% of carbon which act as hardening agent. Other metals that are used as hardening agent are chromium, manganese, tungsten and vanadium. Instead of the maximum limit of 2% of carbon in the manufacture of carbon steel, the proportions of manganese is 1.65%, both carbon and silicon 0.6% each are fixed. Meanwhile, the proportions of cobalt, chromium, niobium, molybdenum, titanium, nickel, tungsten, vanadium and zirconium are not fixed. Mild steel or also known as mildest grade of carbon is a typically carbon steel which contain a low amount of carbon which is 0.05% to 0.26%. Mild steel has high machinability which is rated at 55% to 60% and can be easily shapes due to its inherent flexibility. This type of steel can be hardened by carburizing to make it as an ideal material to produce range of consumer products. Mild steel possesses good formability, good weld ability and the cost of mild steel is comparatively low compare to the other steel.

2.6 STAINLESS STEEL

Stainless steel is not a new discovery but in facet are old materials that have been found in many products to ease human lives (Ali Bin Hamzah,1997). The demand of material is increasing by time and the criteria that are looked inside the material are such as lightweight, high strength, low cost and varied uses. These are the reason why scientist and material engineers put double efforts in producing materials with criteria of good or better than the previous one.

Stainless steel is alloy with a high percentage of chromium that is not less than 10.5%. Rust resistant is there because there is an oxide of chromium on the surface of the steel. Other elements are also mixed in order to improve abrasive resistant, fabrication and machinability and strength for examples nickel, molybdenum, cuprum titanium, silicon, manganese, columbium, aluminum, nitrogen and sulphur (Zainal Abidin Ahmad et al., 1999).

Stainless steel is being chosen based on rust and heat resistant, mechanical properties, fabrication abilities, availability and cost. Mostly, rust resistant and mechanical properties are the main factor for choosing stainless steel (Cam and Kocak, G. et al.,1998).

2.7. TAGUCHI METHOD

In the experiment planning, Taguchi technique is applied as it has become a powerful tool in improving productivity during research and development. This is to obtain a high quality product which can be product quickly by using low cost. This method is developed by Dr. Taguchi of Nippon Telephones and Telegraph Company, Japan. This method is developed based on 'ORTHOGONAL ARRAY' experiment which give reduced 'variance' for the experiment with optimum settings of control parameters.

The marriage of Design of Experiments with optimization of control parameters to obtain best result is achieved in the Taguchi Method 'Orthogonal Arrays' (OA) is provide a set of well balance (minimum) experiments and Dr. Taguchi's Signal-to-Nose ratios (S/N), which are log functions of desired output, serve as objective functions for optimization, help in data analysis and prediction of optimum results. There are 3 Signal-to-Noise ratios of common interest for optimization:

(i) Smaller-The-Better

$$n=-10\log_{10}[\text{mean of sum squares of measured data}] \quad (2.2)$$

(ii) Larger-The Better

$$n=-10\log_{10}[\text{mean of sum squares of reciprocal of measured data}] \quad (2.3)$$

(iii) Nominal-The-Best

$$n=-10\log_{10}\frac{\text{square of mean}}{\text{variance}} \quad (2.4)$$

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This project is done by performing experiment by using MIG welding machine. This experiment is about to join dissimilar welding and do testing on the weldability through visual appearance and by using Vickers hardness test. Before testing is conducted numbers of steps started with welding and followed by the sample preparation is done and is explained in detail in this chapter. Figure 3.1 shows the flow chart on the research methodology. The flowchart of this study is as presented in Appendix H.

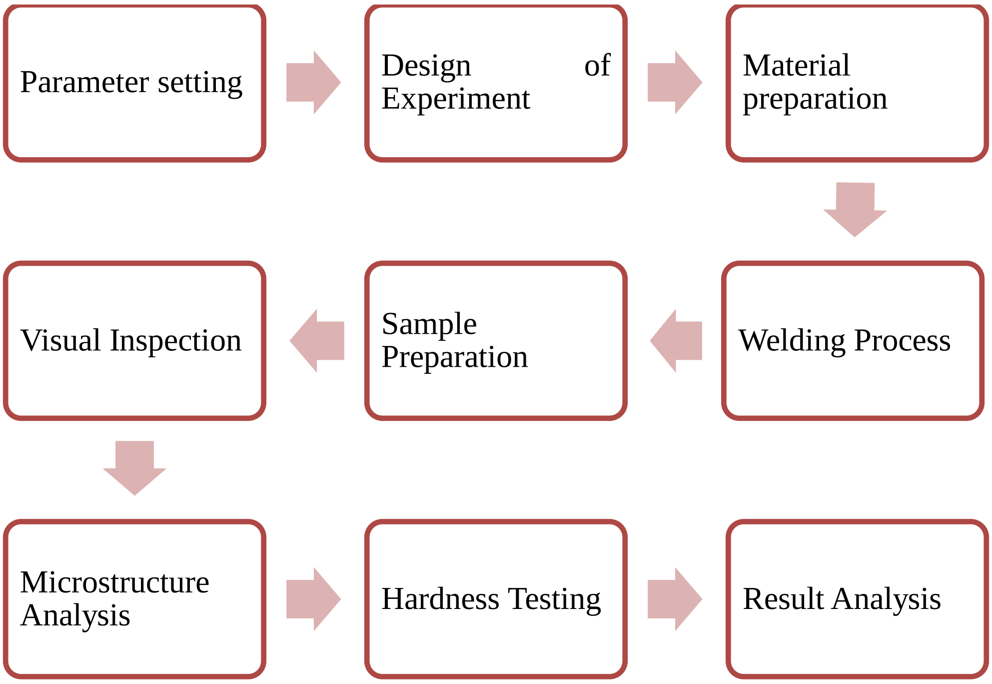


Figure 3.1 Flow chart

3.2 PARAMETER SETTING

In order to find out the effect of clamping distance and voltage changes on the weldabilty on dissimilar welding, the current and speed is remain constant. This is due to the significant effect causes by current and the speed. The table below shows the welding parameters used in the experiment.

Table 3.1: Welding Parameters

Welding Parameter	
Welding Current (A)	95 A
Welding Speed (mm/s)	4mm/s
Gas	99.999% Argon
Filler wire	ER308 wire

3.2.1 Material dimension and welding joint configuration

(A) Material dimension

The materials involved in this study are stainless steel and mild steel. These materials are widely used in automotive industry. The materials are 3mm in thickness and are cut in the dimension of 50mm×50mm. The material is cut by using shearing machine (NS Guillotine Searing) as shown in Figure 3.2.The machine setting is depending on the type of material to be cut.

Figure 3.2: Shearing Machine (Model type MVS-C 6/31)

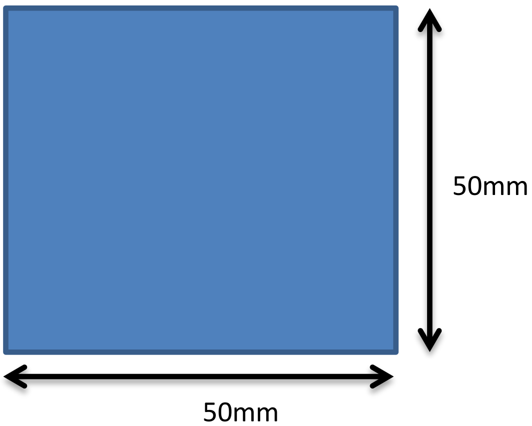


Figure 3.3: Material Dimension

(B) Welding Joint Configuration

The welding configuration used in the experiment is the single vee butt weld joint.

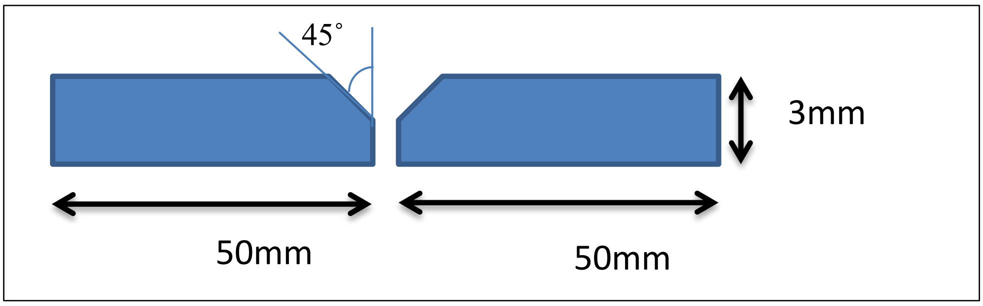


Figure 3.4: Welding Joint Configuration

3.2.2 Design of Experiment

Taguchi's orthogonal design uses a special set of predefined arrays called orthogonal arrays (OAs) to design the plan of experiment. These standard arrays stipulate the way of full information of all the factors that affects the process performance (process response). The corresponding OA is selected from the setoff predefined OAs according to the number of factors and their levels that will be used in the experiment. Table 3.2 below shows the welding parameters and their level, whereas Table 3.3 shows L16 Orthogonal array. The outputs of the experiment are the defects and the hardness.

Table 3.2: Welding Parameters and Their Level

Welding Parameters	Level 1	Level 2	Level 3	Level 4
Clamping distance	1.5	2.2	1.9	3.75
Voltage	19	21	23	25

Table 3.3: L16 Orthogonal Array

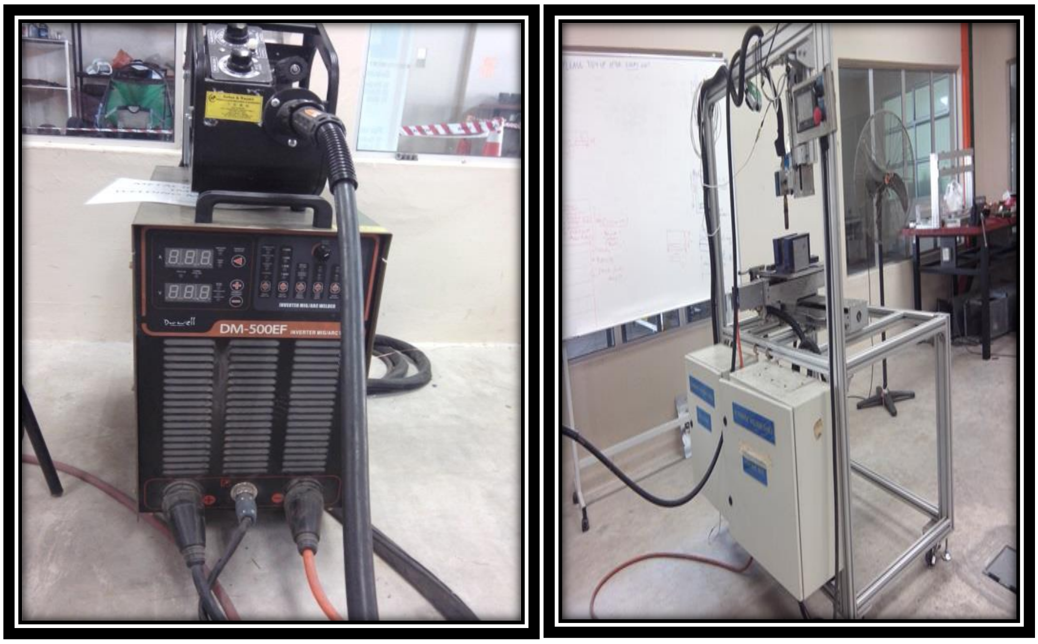
Experiment	Voltage (V)	Clamping Distance(cm)	Type of Clamp
1	19	1.5	Clamp 1
2	19	2.2	Clamp 1
3	19	1.9	Clamp 2
4	19	3.75	Clamp 2
5	21	1.5	Clamp 1
6	21	2.2	Clamp 1
7	21	1.9	Clamp 2
8	21	3.75	Clamp 2
9	23	1.5	Clamp 1
10	23	2.2	Clamp 1
11	23	1.9	Clamp 2
12	23	3.75	Clamp 2
13	25	1.5	Clamp 1
14	25	2.2	Clamp 1
15	25	1.9	Clamp 2
16	25	3.75	Clamp 2

3.3 WELDING PROCESS

3.3.1 Equipment for MIG Welding

(A) MIG Welding Machine

MIG welding process has been selected to join carbon steel of thickness 3mm and stainless steel of thickness 3mm. Figures below shows the MIG welding machine and the automatic table that are used to weld the materials. The filler wire used in the joining process is ER308.

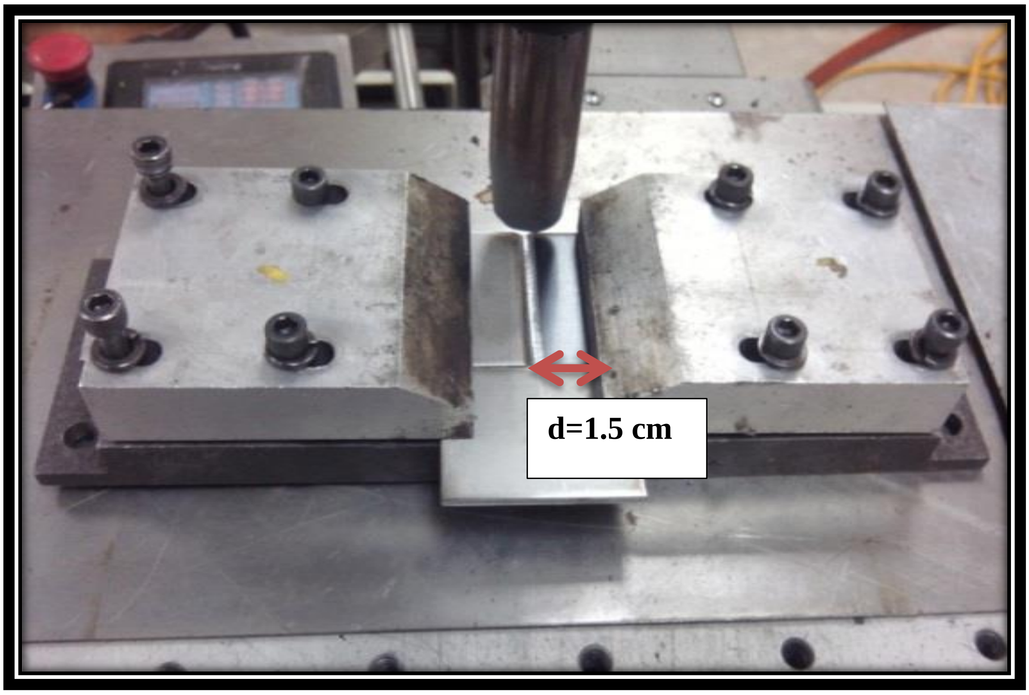


(a) (b)

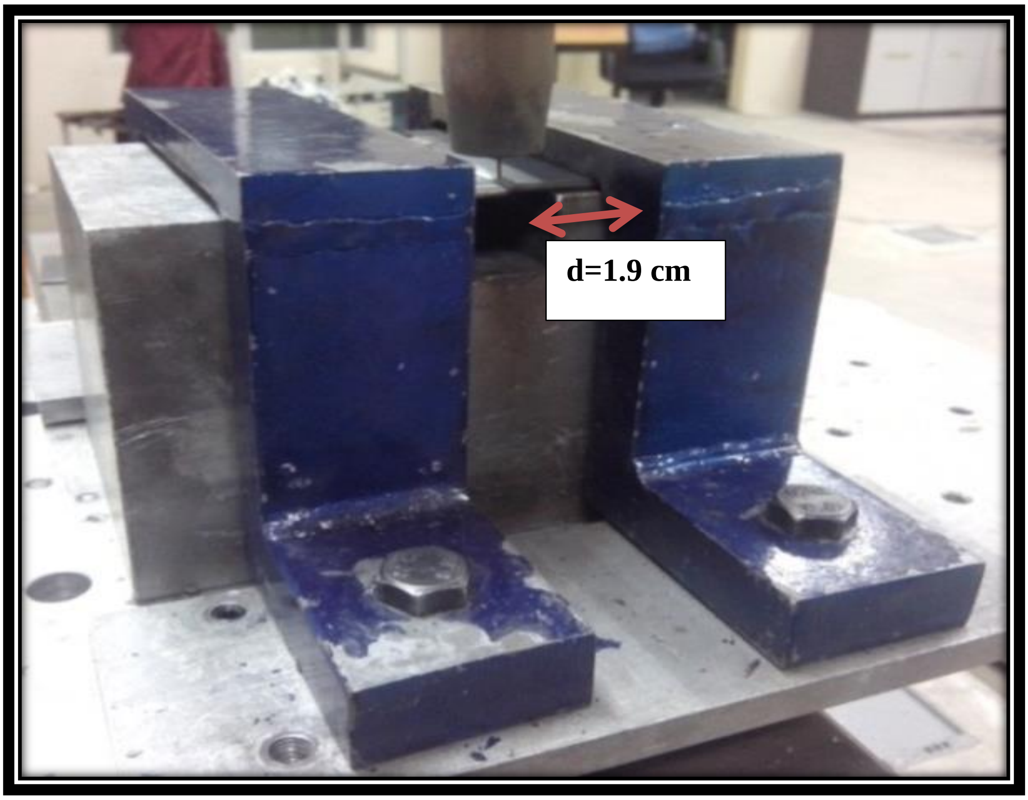
Figure 3.5: (a) MIG Welding Machine (b) Automatic Table

(B) Welding Clamp

Two types of clamp with different availability in terms of distance is used in this experiment. Figure below shows the clamp that are used and the distance are measured from the welded joint. Clamp 1 is as shown in figure 3.6 (a) below, and the distance is measure from the weld joint to the clamp, and it is in the minimum distance which is 1.5 cm. Figure 3.6 (b) shows Clamp 2 , and the figure shows the material which is clamped at its minimum distance of 1.9 cm, measured from the weld joint.



(a)



(b)

Figure 3.6: (a) Clamp 1 (b) Clamp 2

3.3.2 Material Composition

The table below shows the mechanical composition of carbon steel, stainless steel and material composition of filler wire.

(A) Material composition of carbon steel

Table 3.4 Material Composition of Carbon Steel

Material	Fe(%)	C(%)	Si(%)	Mn(%)	Cr(%)	Mo(%)	Ni(%)	Co(%)	Cu(%)
Carbon steel	99.5	0.0910	0.005	0.196	0.0493	0.0158	0.0371	0.001	0.001

(B) Material Composition of Stainless Steel

Table 3.5: Material Composition of Stainless Steel 304

Material	Fe(%)	C(%)	Si(%)	Mn(%)	Cr(%)	Mo(%)	Ni(%)	Co(%)	Cu(%)
Stainless steel 304	71.5	0.0617	0.473	1.36	17.1	0.0888	8.39	0.149	0.601

(C) Material Composition of ER308 wire

Table 3.6 : Material Composition of ER308 Wire

Material	Fe(%)	C(%)	Si(%)	Mn(%)	Cr(%)	Mo(%)	Ni(%)	Co(%)	Cu(%)
Stainless steel 304	71.5	0.0617	0.473	1.36	17.1	0.0888	8.39	0.149	0.601

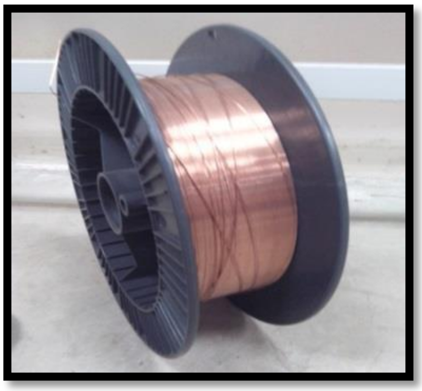


Figure 3.7: ER308 Wire

3.3.3 Specimen Cut Off

The welded specimen, which is shown in Figure 3.8 (a) is then cut by using Electrical discharge Machine (EDM) wire cut machining (Figure 3.8(b)). This machine is preferred since it is suitable for high precision machining for all types of conductive and for metallic to cut workpiece by using electrical discharges (sparks).

(a) (b)

Figure 3.8 (a) Welded Specimen (b) EDM Wire Cut Machine

3.4 SAMPLE PREPARATION

3.4.1 Sectioning

After the material is cut by using the EDM wire cut machine, it is then cut by using Sectioning Machining to obtain a small sample which is prepared to a detail and rather lengthy procedure. It is important to choose the correct cut-off wheel to make sure distortion or burn can be prevented. It also the best way for time saving Figure 3.9 below shows the sectioning machine used.

Figure 3.9: Sectioning Machining

3.4.2 Mounting

After the sectioning process is completely done for the 16 specimens, it is mounted by using cold mounting. Figure 3.10 below shows the process flow of cold mounting. The purpose of mounting is to ease the process of hardness test and microstructure analysis.

Powder transparent and liquid of cold-curing resin are mixed together with 2:1 proportion

↓

The small pieces of sample is placed inside the mould and the mixed solution is poured inside.

↓

The mould is placed inside the cold mounting machine for 10 minutes

Figure 3.10 Process Flow of Cold Mounting

Figure 3.11 shows the powder and the liquid that are mixed to form a solution for cold mounting of the specimen that had been sectioned. Figure 3.12 shows the mold at which the solution is poured into.

Figure 3.11: Powder Transparent and Liquid of Cold-Curing Resin

Figure 3.12: Mold for Cold Mounting

As had been explained on the process flow of cold mounting, after the specimen is placed inside the mold and the solution is poured into it, it is placed inside the cold mounting machine for 10 minutes as shown in Figure 3.13.

Figure 3.13: Cold Mounting Machine

3.4.3 Grinding

After the mounting process is done, the specimen is grinded by using Buehler HandiMet 2, roll grinder as shown in Figure 3.14 Grinding is a finishing process that is done to improve surface finish, abrade hard materials, and tighten the tolerance on flat and cylindrical surfaces by removing a small amount of material. This roll grinder provides a self-contained four-stage grinding station with controlled water flow for lubricant and flushing. Those four stages of grinding stages used four different rolls of CarbiMet Paper Rolls: Grit 240, 320, 400 and 600. The purpose to let the water flow during grinding process is to make sure grinding residue can be removed.

Figure 3.14: Buehler HandiMet 2, roll grinder

3.4.4 Polishing

After grinding process, polishing is continued and the equipment used to polish the surface of the specimen is Metkom FORCIPOL 2V Grinder-polishing, Figure 3.15. This process is done in order to remove scratches, and this process is continued until smooth, mirror-like surface is produced. Forcipol 2V consist of two discs and have a variable range of speed between 50 and 600 rpm.

Figure 3.15: Metkom FORCIPOL 2V Grinder-Polisher

3.4.5 Etching

This experiment involves two different metals, and each of them requires different solution for etching. As for stainless steel, it is etched through electrolysis with 10% oxalic acid by using 12V whereas carbon steel is etched by applying 4% Nital on the surface.

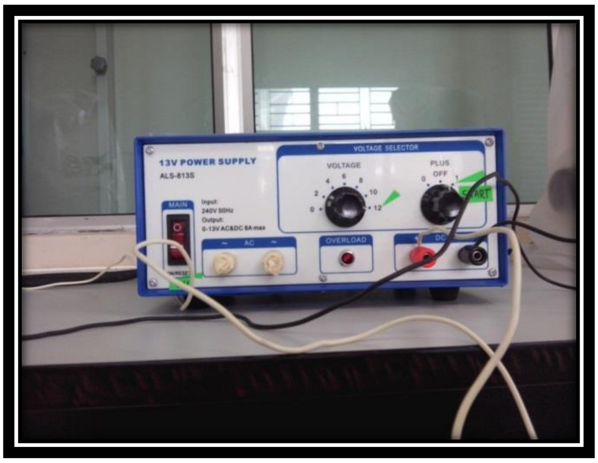


Figure 3.16: Electrolyte Etching for Stainless Steel

Figure3.17: Mounted Specimen with wire attached on the surface of Stainless Steel

3.5. CHARACTERIZATION TECHNIQUE

(A) Visual Inspection

As the output of this experiments are the defects and the hardness, the visual inspection is done first before proceeding to microstructure preparation. Visual inspection is done with naked eye. It is very useful as an inspection method with regard to acceptability of welds in respect of regularity, surface roughness, and weld spattered. This is also done to observe the presence of external defects such as unfilled craters, undercuts, overlaps and cracks.

(B) Hardness test

Measurement to the ductility is by using Vickers hardness test, as hardness of metal is usually an indication of its ductility. The Vickers hardness profiles across the base metal of carbon steel, base metal of carbon steel, heat affected zone (HAZ) and the fusion zone are measured 500gf or 5kN for 10 sec dwell time. It is done by using MMT-X7 hardness tester as shown in Figure 3.18.

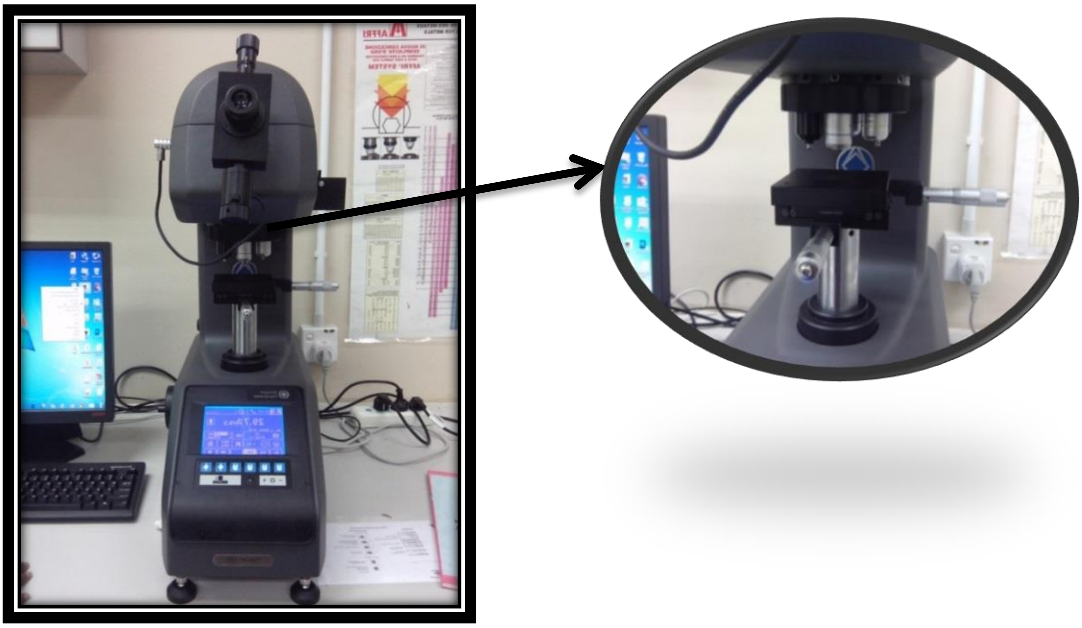


Figure 3.18: Vickers Hardness Test

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

This chapter present the data obtained from the experiment. The data is discussed according to the desired outputs which are hardness and defects. The result of hardness is analyzed by using Taguchi Method to determine the factor level of prediction to determine the optimized parameter in order to obtain the highest hardness value. Then, based on the hardness value, the defects that can be seen visually on both specimens are compared. The microstructure analysis is presented and the grain formations are analyzed based on the hardness at certain point, including the heat affected zone (HAZ). Finally, in the end of this chapter, a validation test is done and discussed to validate the result obtain from the analysis using Taguchi Method.

4.2 HARDNESS MEASUREMENT

Vickers hardness across base materials and the welded seam is measured by using macro hardness tester. A total of 21 points were indented across the specimen to measure the hardness value. The points are located at the base metal and HAZ of carbon steel, base metal and HAZ of stainless steel and another 9 points at the fusion zone.

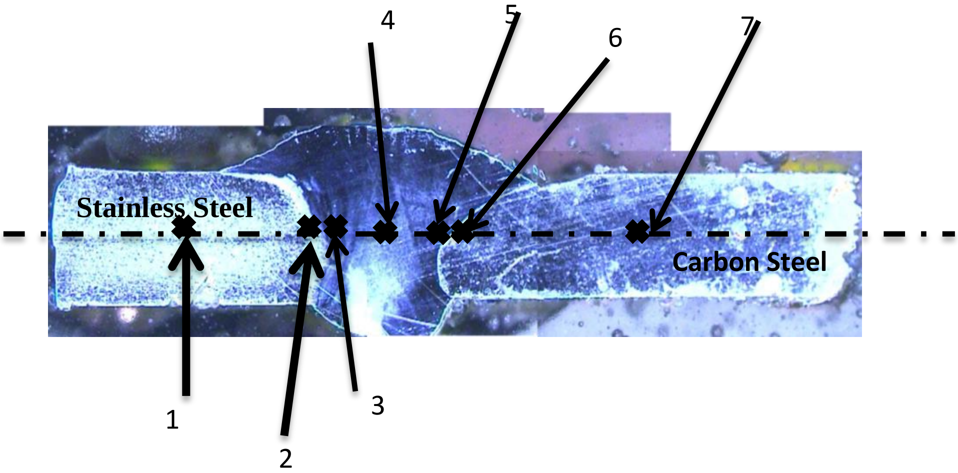


Figure 4.1 Point of Indenting for Hardness Test

Based on the overall result of hardness test on those points, it shows that the value of hardness is at the highest at the fusion zone, which is at point 4. Table 4.1 shows the tabulated data of hardness on the fusion zone and from the data, it can be seen that the value of hardness is highest sample 8.

Table 4.1: Result of Hardness Test

No	Voltage (V)	Clamping Distance(cm)	Type of Clamp	Hardness(HV)
1	19	1.5	Clamp 1	390.73
2	19	2.2	Clamp 1	393.03
3	19	1.9	Clamp 2	386.0
4	19	3.75	Clamp 2	447.43
5	21	1.5	Clamp 1	385.90
6	21	2.2	Clamp 1	403.73.
7	21	1.9	Clamp 2	390.73
8	21	3.75	Clamp 2	454.90
9	23	1.5	Clamp 1	389.03
10	23	2.2	Clamp 1	407.7
11	23	1.9	Clamp 2	393.04
12	23	3.75	Clamp 2	437.53
13	25	1.5	Clamp 1	339.07
14	25	2.2	Clamp 1	396.13
15	25	1.9	Clamp 2	359.47
16	25	3.75	Clamp 2	409.97

Based on the result obtained below, a graph is of Hardness versus number of experiment is constructed. From the graph shown in Appendix A, it shows that the highest value of hardness is on experiment 8, with hardness value of 454.90 HV.

4.3 ANALYSIS USING MINITAB

Based on the result of hardness at the fusion zone, analysis by using Minitab 15 is done and the graphs shown below are obtained. From the graph for which the response of signal-to-noise for which larger is better, the graph shows that the value of hardness is the highest at 21 V and distance of 3.75 cm. From the graph, it also shows that the hardness is the lowest at 25 V and at the distance of 1.5cm. The factor level of prediction is obtain for the highest value of hardness and is presented in the Table 4.2.

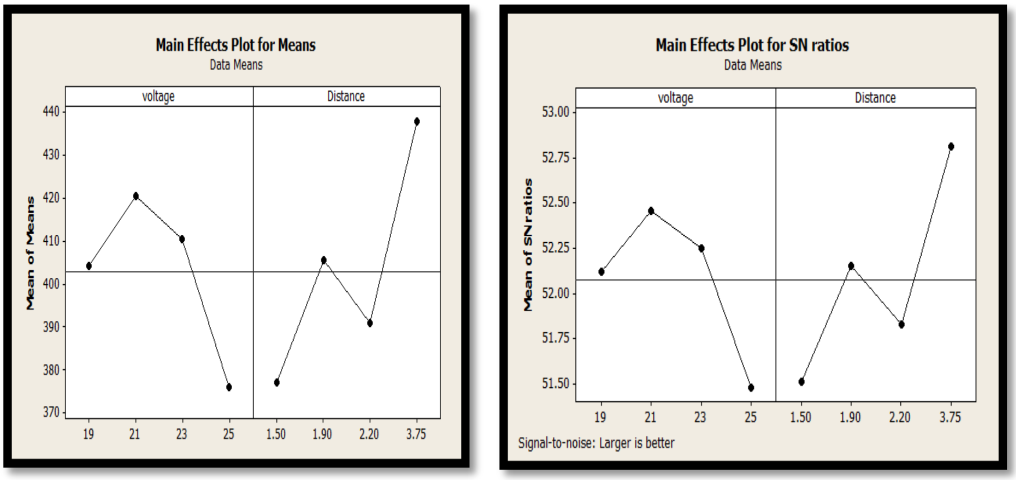


Figure 4.2: (a) Main Effects Plot for Means (b) Main effects Plot for SN ratios

The table below shows the level of prediction based from the analysis using Taguchi Method.

Table 4.2: Factor Level for Prediction

Factor Levels For Prediction		
Voltage (V)	Clamping Distance (cm)	Hardness, HV
21	3.75	454.9

4.4 ANALYSIS OF VARIANCE (ANOVA)

By using Minitab 15, an analysis is done to determine which parameter gives more significant effects on the value of hardness. From the date obtained, a pie chart is generated using to show the contribution of the parameters on the value of hardness.

Table 4.3 ANOVA

Source	F	P-value
Voltage	4.21	0.040
Distance	7.85	0.007

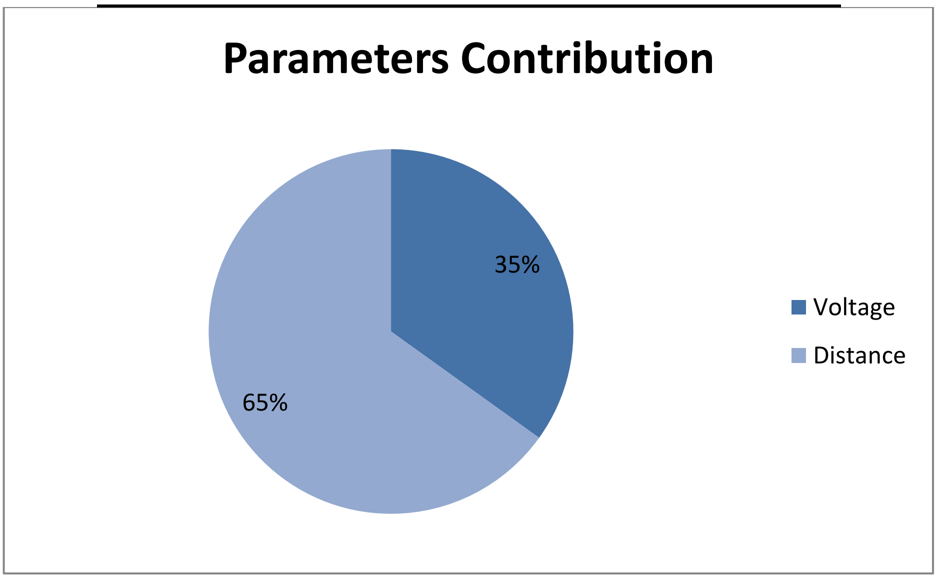


Figure 4.3: Parameters Contribution

From the pie chart above, from the two parameters that are being studied, it shows that the distance of clamping contribute more than the voltage with the percentage of 65%. The remaining 35% is the contribution of the voltage on affecting the value hardness at the fusion zone.

4.5 HARDNESS ANALYSIS BASED ON THE HIGHEST AND THE LOWEST VALUE OF HARDNESS

By taking sample 9, which has the highest value of hardness, a graph of the 7 point, at which at the average value of every point had been calculated is plotted. From the plotted graph below, it shows that the hardness value of the base metal of stainless steel is 282.7 HV but it increase as it hit the affected zone (HAZ), with the value of 282.7 HV. This is due to the finer grain structure at the HAZ which caused the hardness of HAZ is higher from the base metal (P. Sathiya, 2010). For carbon steel, the graph shows that at the base metal, the hardness at the base metal of carbon steel is 140.50 HV but then the hardness increase to 171.10 HV. At the fusion zone, the hardness value increase rapidly. The graph show the diminution of the hardness from the base metal to the fusion zone which is produced as a consequence of microstructural change. The increase in hardness of HAZ is attributed to the formation of finer grain size.

(A) Plotted Graph Based on The Highest Hardness Value

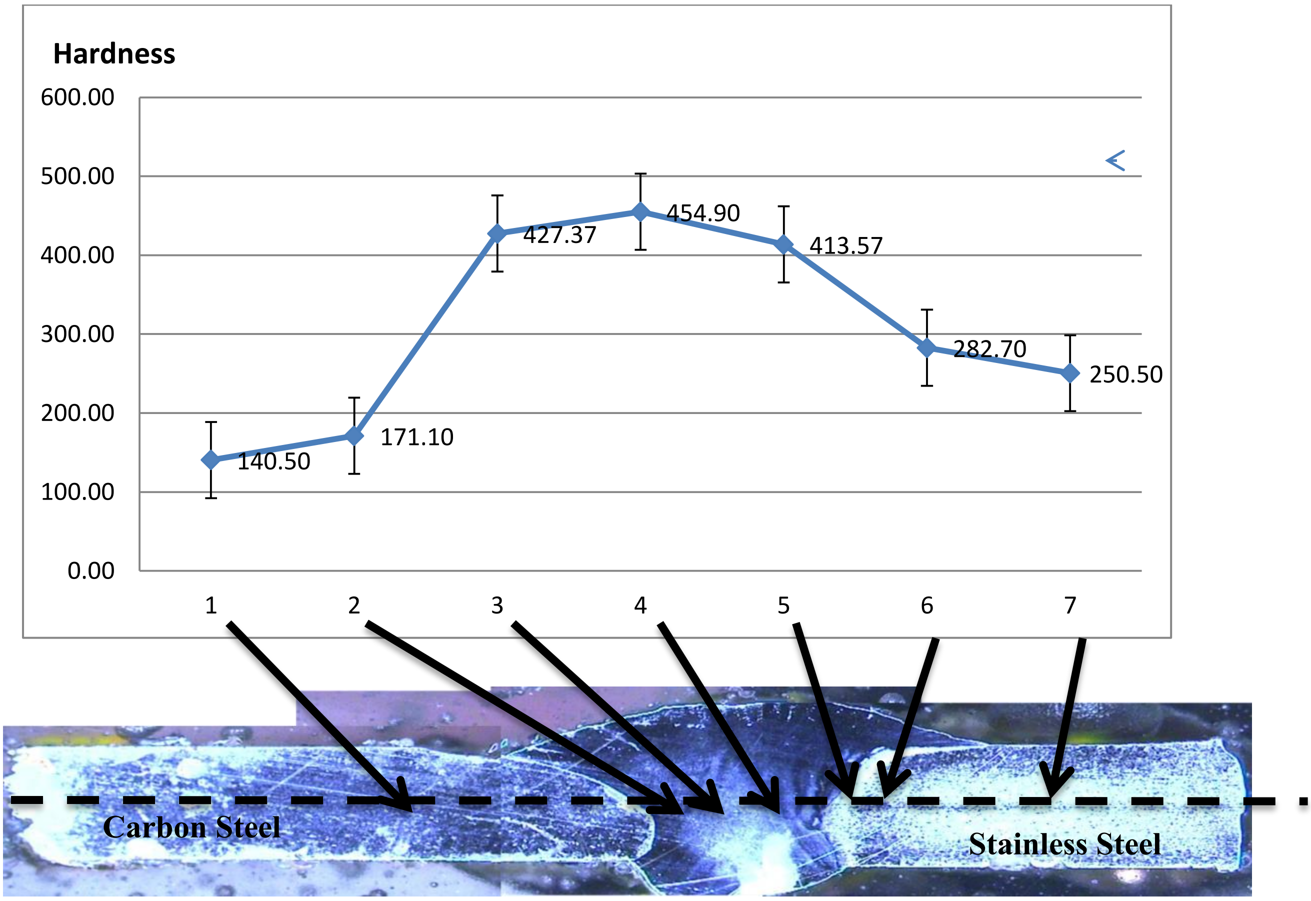


Figure 4.4: Labeled point of Hardness Test Sample 8

(B) Plotted Graph Based On The Lowest Hardness Value

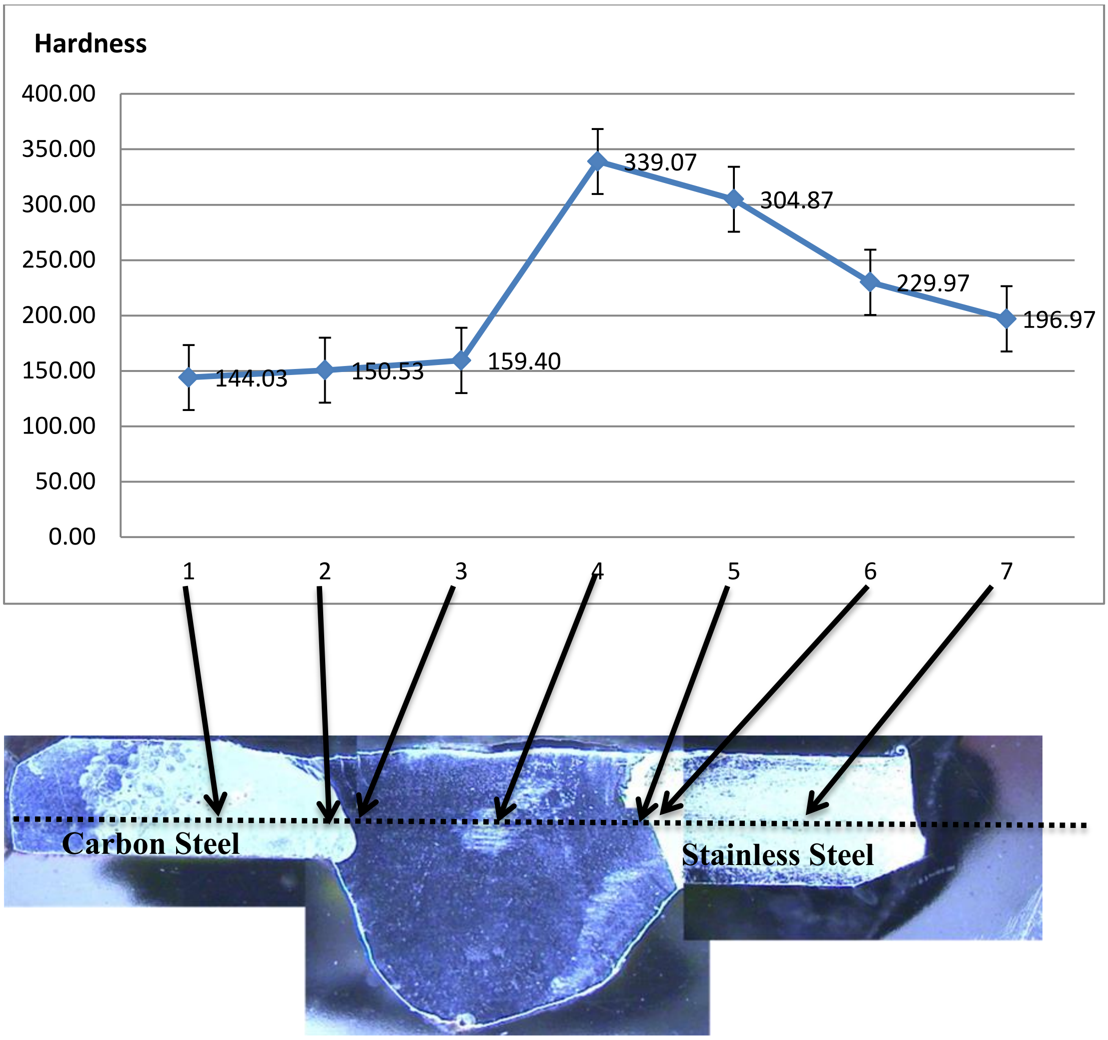


Figure 4.5: Labeled point of Hardness Test on Sample 13

4.4. Weld Quality Based on the Lowest and Highest Hardness (Visual Appearance)

A. Comparison on the welding in term of clamping distance by using Clamp 1 (Lowest Hardness Value)

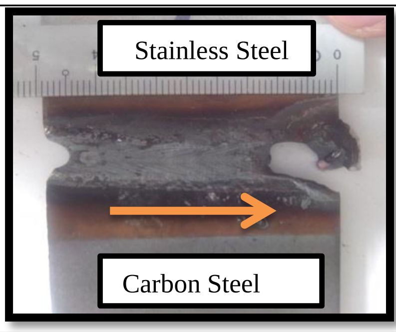
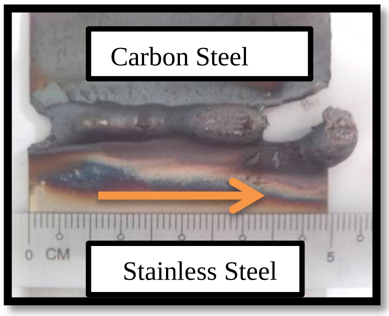
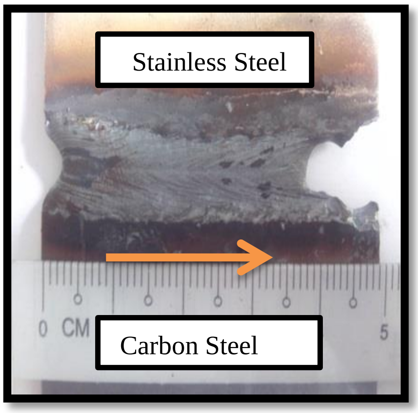
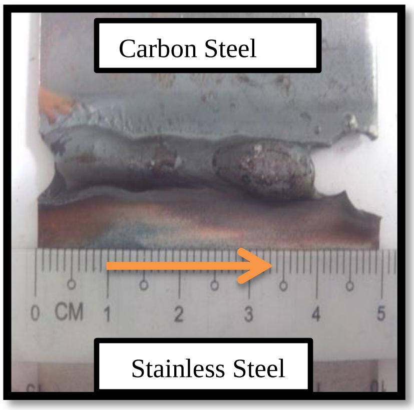
DISTANCE OF CLAMPING	TOP VIEW	BOTTOM VIEW	DESCRIPTION
1.5 cm	 	 	Type of Welding: MIG welding Current: 95A Speed: 4mm/s Voltage: 25V Gas: 99.99% Argon Filler: ER308 wire Clamp 1
2.2 cm	 	 	

Figure 4.6: Comparison on the welding in term of clamping distance by using Clamp 1

The sample shown in the Figure 4.6 are welded by using the same parameter, which is the same type of welding, same amount of current and voltage which are 95A and 25V respectively, speed of 4 mm/s, 99.99% Argon gas is used. Both samples are welded by using the same filler material, ER308 wire. From the comparison of the welded sample above, by using clamp 1 with the distance of 1.5 cm and 2.2 cm, the quality of both specimen are poor. This is caused by too high of voltage and there are no visible difference since the distance are too close each other. The value of hardness welded at distance of 1.5 cm is lower compare to the hardness of the sample welded at the distance of 2.2 cm.

B. Comparison on the welding in term of clamping distance by using Clamp 2 (Highest Hardness Value)

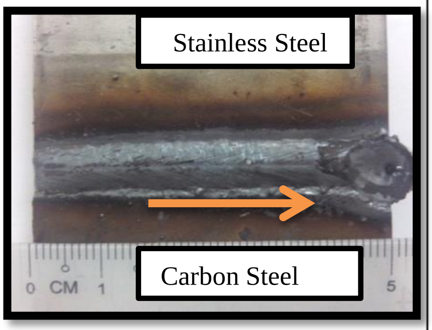
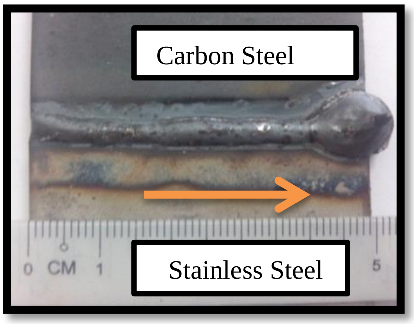
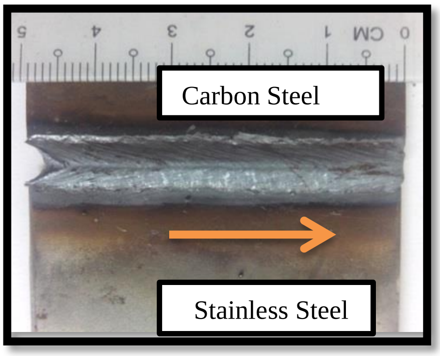
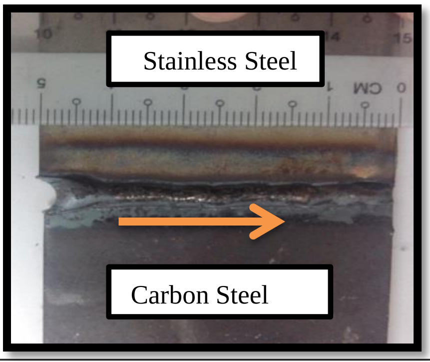
DISTANCE OF CLAMPING	TOP VIEW	BOTTOM VIEW	DESCRIPTION
1.9cm			Type of Welding: MIG welding Current: 95A Speed: 4mm/s Voltage: 21V Gas: 99.99% Argon Filler: ER308 wire Clamp 2
3.75cm			

Figure 4.7: Comparison on the quality of welding in term of clamping distance by using Clamp 2

The sample shown in the Figure 4.7 are welded by using the same parameter, which is the same type of welding, same amount of current and voltage which are 95A and 21V respectively, speed of 4 mm/s, 99.99% Argon gas is used. Both samples are welded by using the same filler material, which is ER308 wire. From the comparison of the welded sample above, by using clamp 2 with the distance of 1.9 cm and 3.75 cm, the quality of sample welded at the distance of 3.75 cm is better. This can be seen visually on the defects found on the surface of the welded sample of the specimen welded with the distance of 1.9 cm, where defects such as spatter and un-uniform bead is seen visibly The value of hardness welded at distance of 1.9 cm is lower compare to the hardness of the sample welded at the distance of 3.75 cm and this support the statement that the sample welded at distance of 3.75 cm is better compare to sample welded at the distance of 1.9 cm. The comparison of the remaining of 12 specimens is tabulated and presented in Appendix A to Appendix F.

4.5 DEFECTS BASED ON THE HIGHEST AND LOWEST HARDNESS (VISUAL INSPECTION)

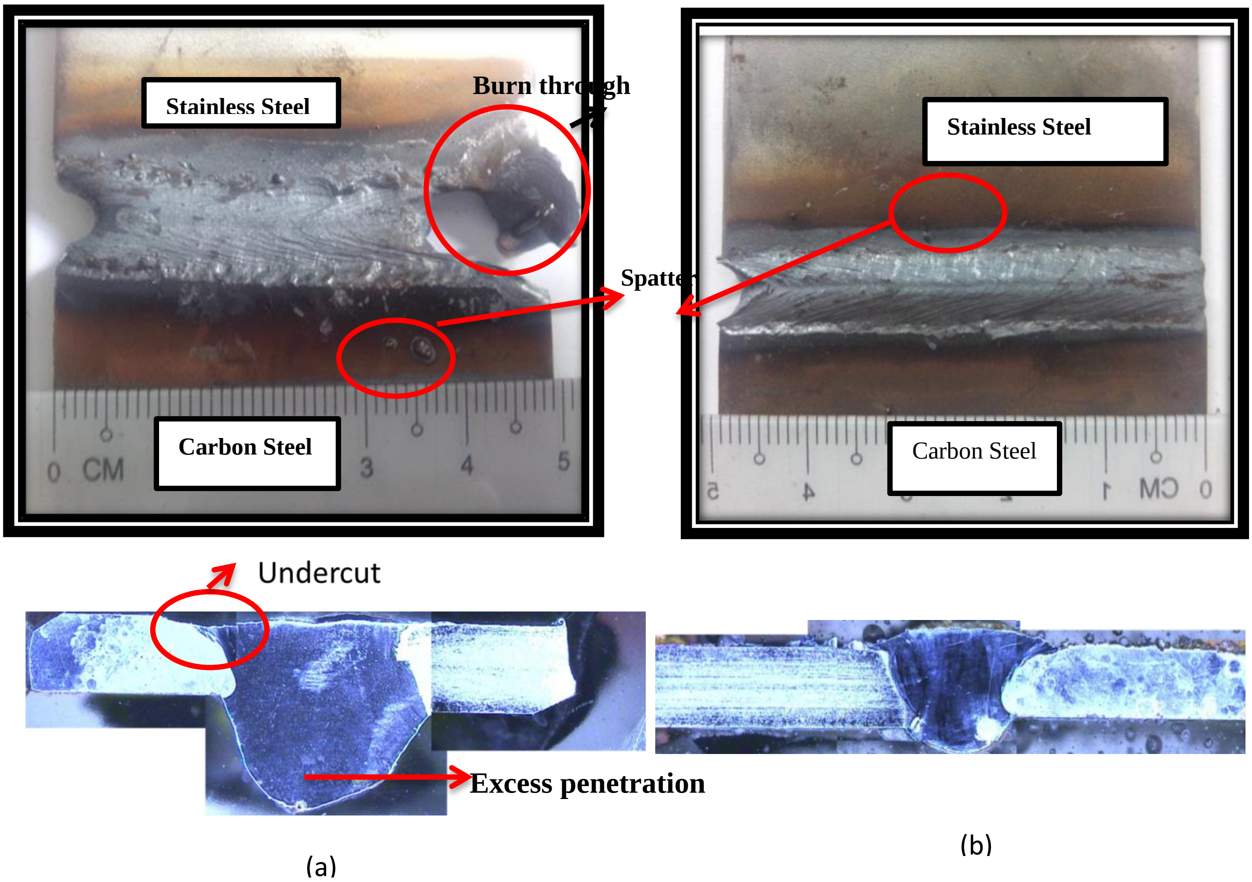


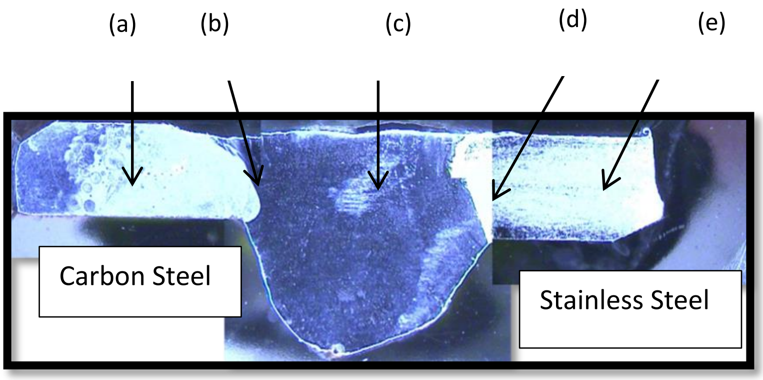
Figure 4.8: (a) Voltage: 25V, Clamping Distance: 1.5cm (b) Voltage: 21V, Clamping Distance: 3.75cm

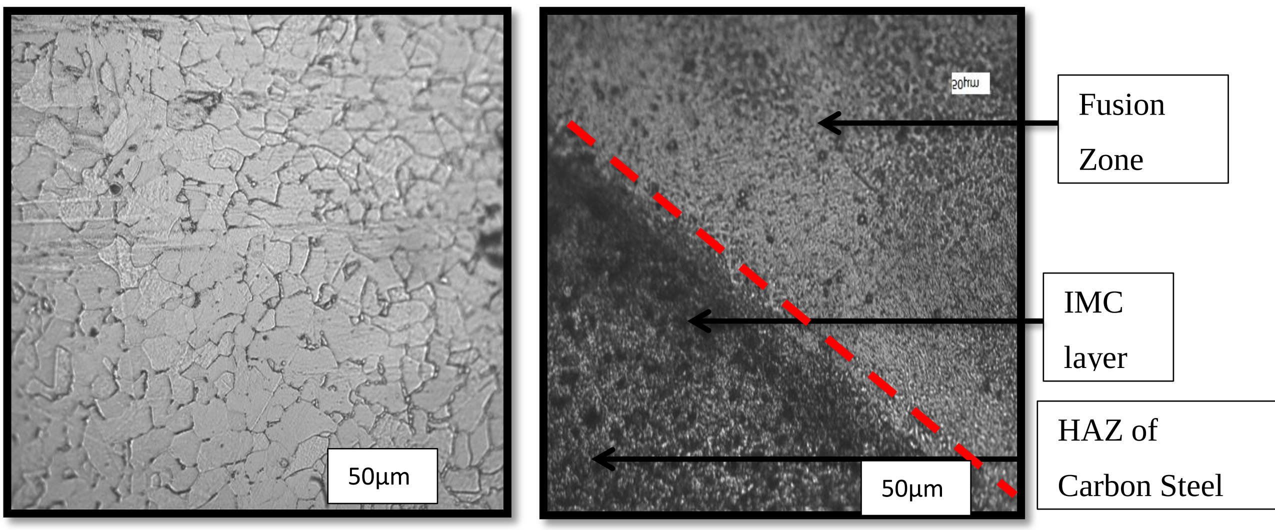
Based on the labeled defect on both specimens with the highest and lowest hardness value, it shows that there are many defects can be seen visually on the sample with the lowest hardness. The defects that can be seen clearly are undercut, spatter, burn through and excess penetration. The visible defects that can be seen that affect the value of hardness is the excess penetration on the sample welded using 25V and 1.5 cm of clamping distance. This defect is most probably caused by too high of voltage and the distance of clamping which is too close that cause the heat input to be concentrated on the weld area.

4.6 MICROSTRUCTURAL ANALYSIS

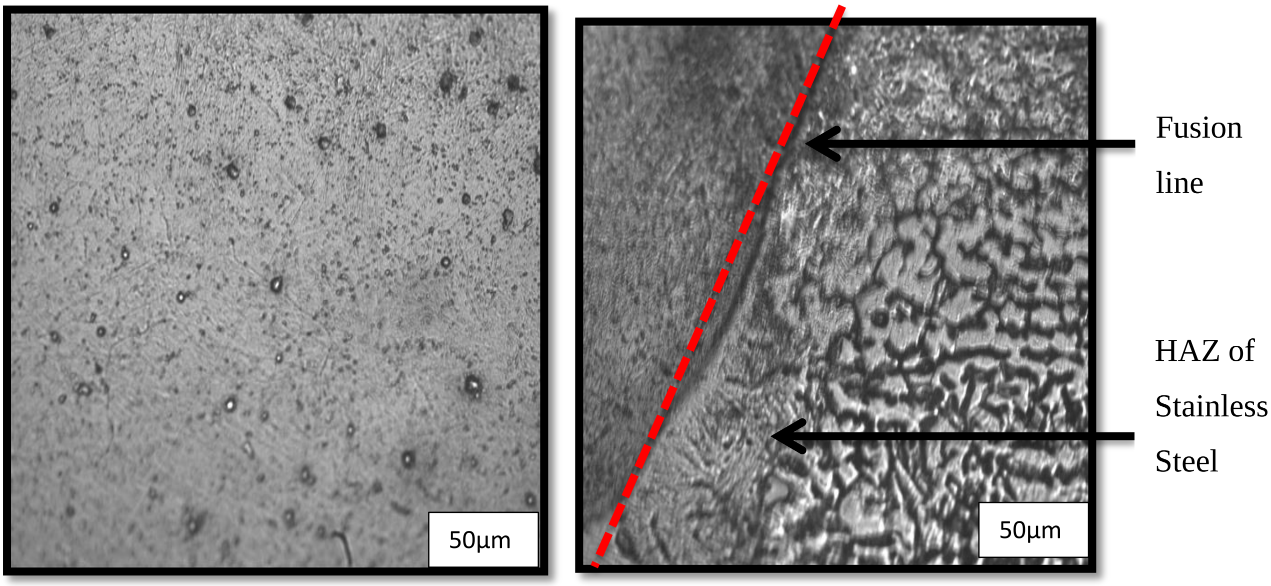
(A) Microstructure Analysis of Sample 13 (Lowest Value of Hardness)

As the mounted specimen had been etched, the microstructure of the metal can be seen and in this experiment, magnification of 50× had been used to observe the grain formation. Based on the hardness value, the specimens with the highest and lowest value of hardness are observed under microscope. Based on the analysis, it can be found that all HAZ and weld area microstructure exhibit almost the same behavior. As had been discussed earlier, at HAZ area, the microstructure are finer compare to the base metal, and thus causes the value of hardness at HAZ is higher compare to hardness at the base metal.





(a) (b)



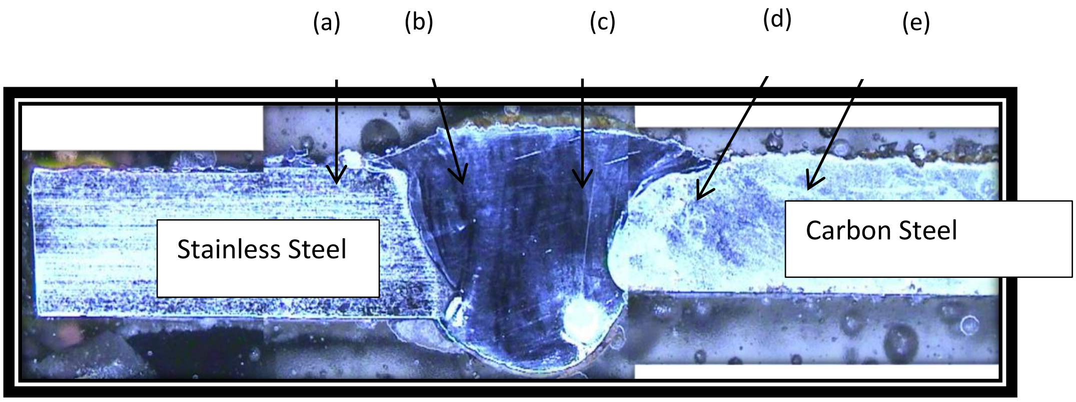
(c) (d)

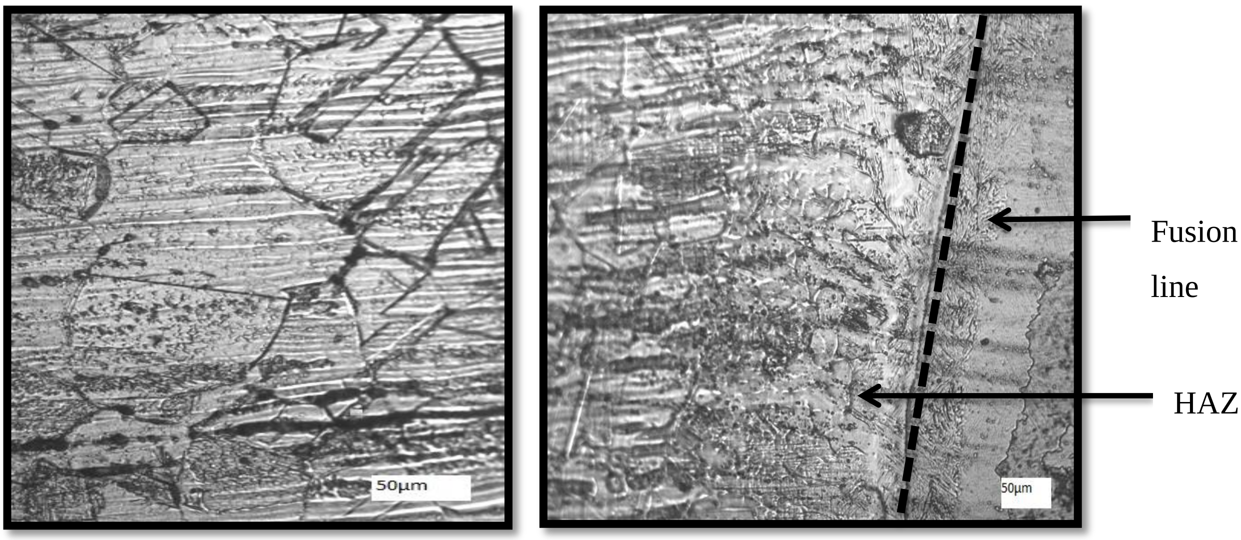
(e)

Figure 4.9: (a) Parent Metal of Carbon Steel (b) HAZ of Carbon Steel and Fusion Zone (c) Weld Zone (d) Fusion Zone and HAZ of Stainless Steel (d) HAZ of Stainless Steel

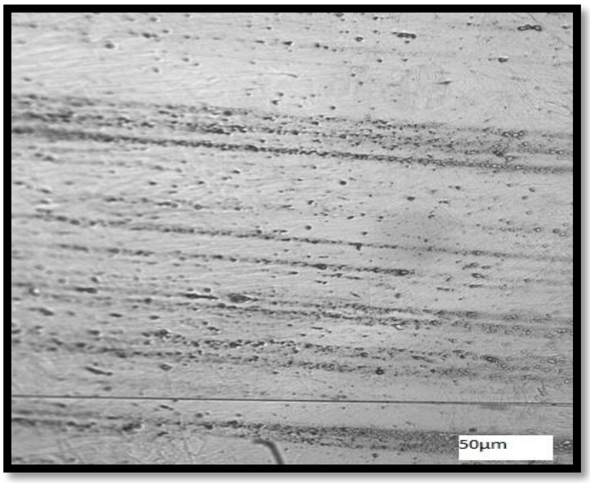
Figure 4.9 (a) shows the microstructure at the parent metal of carbon steel and if compare with the grain size at the HAZ of stainless steel, the grain shown at the HAZ is finer. This is the reason of the hardness at the HAZ is higher than at the parent metal (P. Sathiya, 2010). In Figure 4.9 (b)), the formation of intermetallic compound layer (IMC) can be clearly seen as the material of the filler sire used is stainless steel. The finer grain structure at the weld zone causes the hardness to be high. Figure 4.9 (d) shows the boundary between the weld zone and HAZ of stainless steel and finer grain structure at the HAZ causes the hardness to be higher. Figure 4.9 (d) shows the microstructure at stainless steel and as can be seen, the grain are coarser and this cause the hardness to be slightly low compare to the hardness at the HAZ.

(B). Microstructure Analysis for Sample 8 (Highest Value of Hardness)

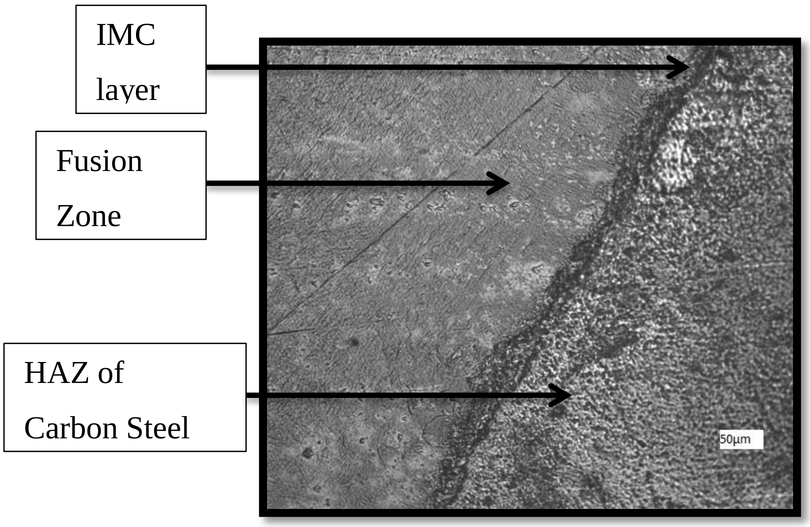


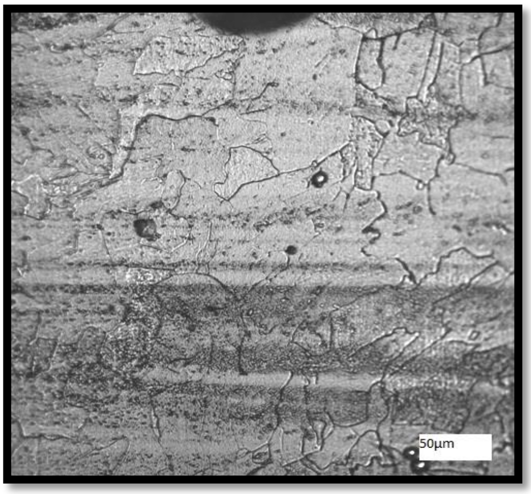


(a) (b)



(c)





(d) (e)

Figure 4.10: (a) Parent Metal of Stainless Steel (b) HAZ of Stainless Steel and Fusion Zone (c) Weld Zone (d) Fusion Zone and HAZ of Carbon Steel (d) HAZ of Carbon Steel

From Figure 4.10, the microstructures exhibit the same as the structure at selected points which are at the parent metal of materials, HAZ and fusion zone. As had been discussed previously, the size of grain size gives different value of hardness. From Figure 4.10, the grain structures at base metal are coarser which cause the value of hardness to be low. Formation of IMC layer can be seen at the boundary of fusion zone and HAZ of carbon steel.

4.7 VALIDATION TEST

Based on the analysis using Taguchi Method, an optimized parameter is obtained in order to get the highest value of hardness. From the analysis, the highest value of hardness is by using clamp 2 with the distance of 3.75 cm and 21 V. A validation test to validate the result obtained is done by using those parameters. Welded specimen is inspected visually, and hardness test is done. The table below shows the parameter used for the validation test.

Table 4.4: Parameter for Validation Test

Parameter set-up	
Voltage	21 V
Clamping Distance	3.75 cm
Type of Clamp	Clamp 2
Speed	4 mm/s
Current	95 A

4.7.1 Hardness Test

Hardness test is done by using the parameters in Table 4.3, whereas Figure 4.11 shows the result obtained from hardness test. From the figure, the result shows that the maximum hardness is at point 4, which is located at the fusion zone. The results obtained are in the range of the data of experiment done previously. From the data obtained, the highest value obtained from the validation test is 455.22 HV, compared to 454.90 HV obtained from the previous experiment. The value obtained validates the experiment at which highest value of hardness is obtained when the specimen is welded at 21 V by using clamp 2 with the distance of 3.75 cm.

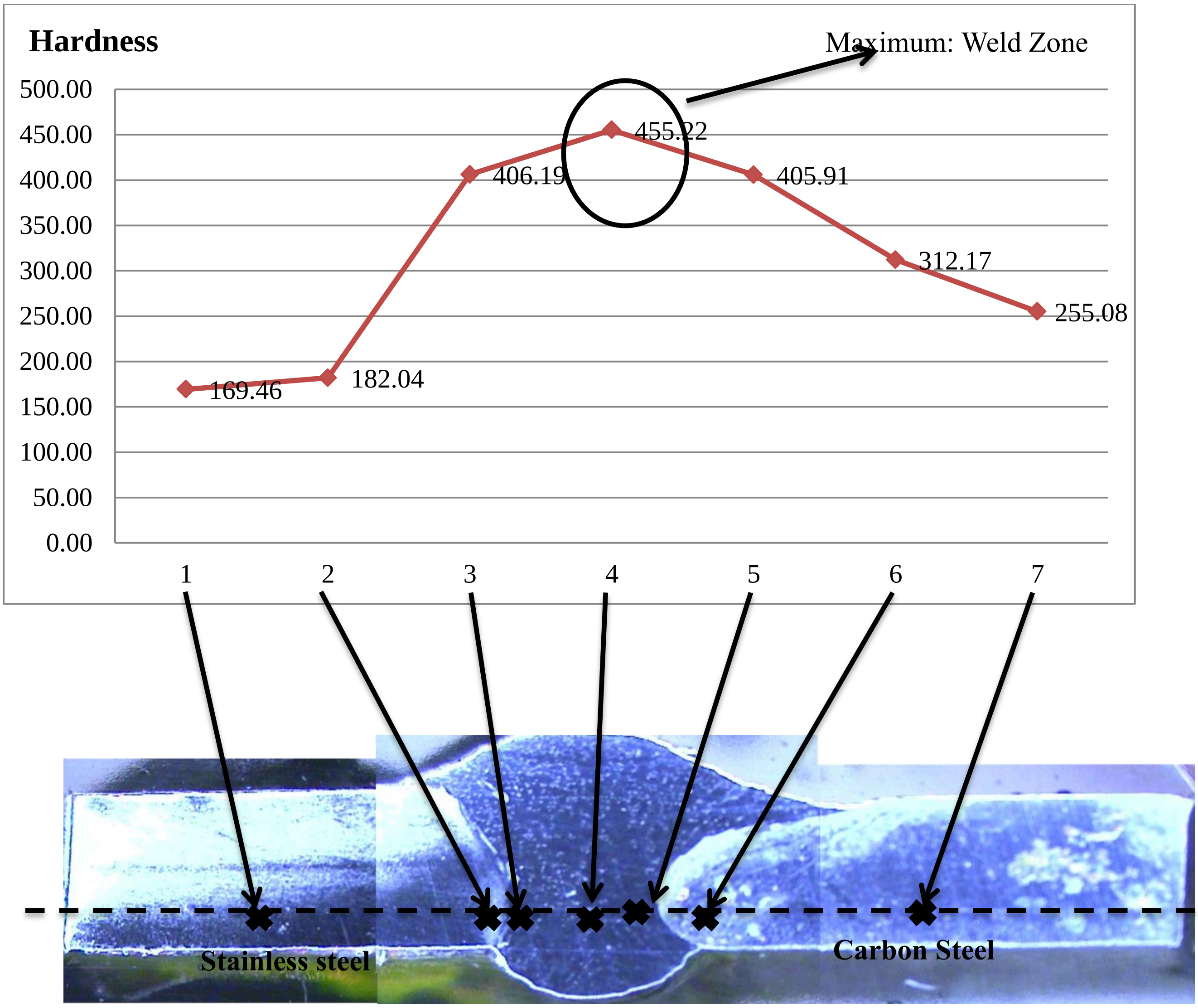
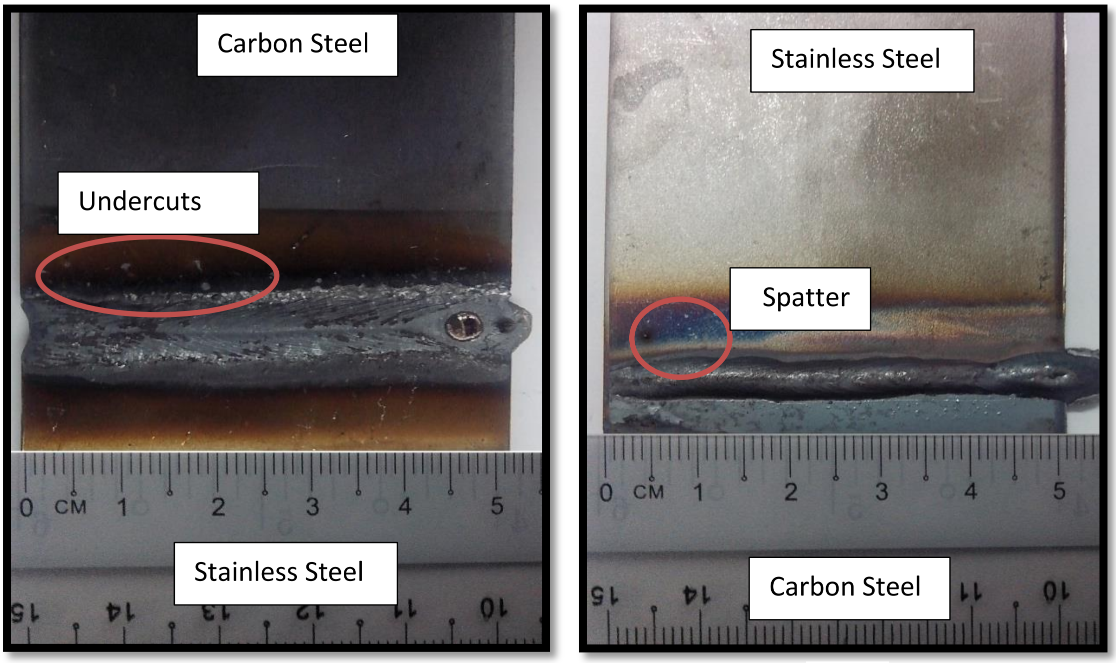


Figure 4.11: Sample Welded Using Optimized Parameter

4.7.2 Visual Inspection

Defect is one of the output in this study, and thus, visual inspection is done on the specimen welded by using the optimized parameters. The figure below shows the top and the bottom view of the welded sample.



(a) (b)

Figure 4.12: (a) Top View (b) Bottom View

Figure 4.12 shows the welded sample for validation test and based on the inspection done visually on the sample, it can be seen that there are not much defects can be found on it. The defects that can be seen obviously are spatter and undercuts. By comparing to the defects found on the specimen welded using the same parameter previously, the defects that occur on the sample weld for validation test are slightly the same. This shows that, specimen welded using the optimized parameter will gives good weld quality as well.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSIONS

1. As a conclusion, the most significant parameter these studies that affect the hardness of welding at the fusion zone is the clamping distance. From the study done, it shows that the voltage is not the priority to be considered compare to the distance of clamping when current and speed are kept constant.

2. At 21V, the hardness is at the highest and the weld quality is better at distance of 3.75 cm compare to 1.90 cm which is by using clamp 2. The lowest hardness is obtained when clamp 1 is used and 25V is set for the experiment.

3. From visual inspection, the quality is very poor for sample welded using the shortest distance which is 1.5 cm if compared to the quality of sample welded using a farther distance which is 3.75 cm. It can also be conclude that based on the visual appearance, the quality of weld is better when welded at the farther distance as the defects are minimized.

4. From the analysis using Minitab 15, the graph generated shows that the hardness is at the highest when using Clamp 2 with the distance of 3.75 cm.

5. From the prediction, a validation test is done and the results are match. For the overall conclusion, objectives are achieved and the result of validation test supports the result of the study.

5.2 RECOMMENDATION

As for recommendation, for future works of welding using MIG, welding using a correct parameter are important to obtain good quality of weld and based on this study, choosing a correct welding clamp is important as different clamp will gives effect based on the voltage setting. For a higher voltage of welding, farther distance is recommended in order to reduce heat input to be concentrated at the fusion zone.

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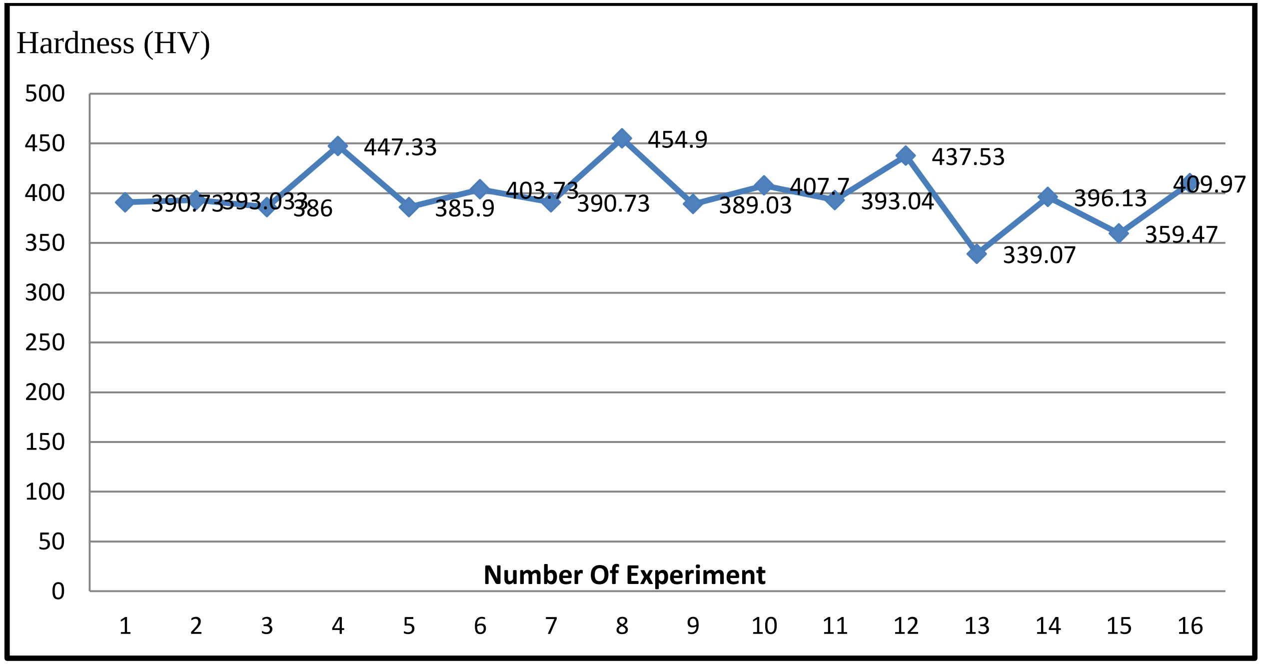
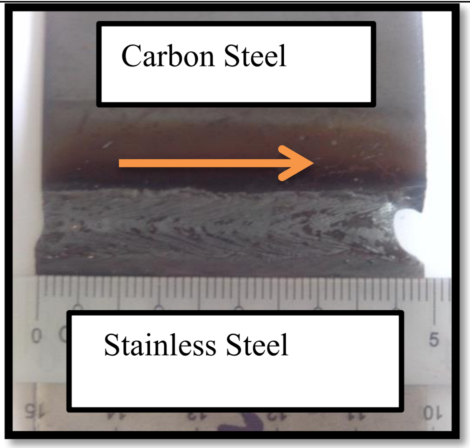
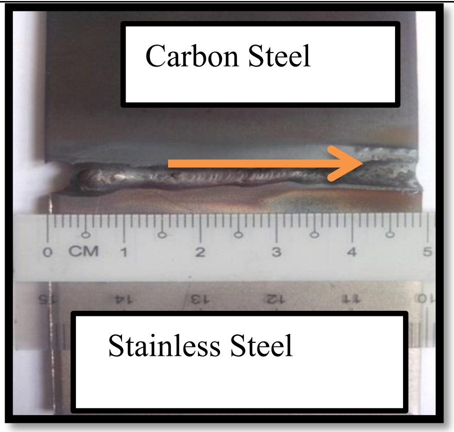
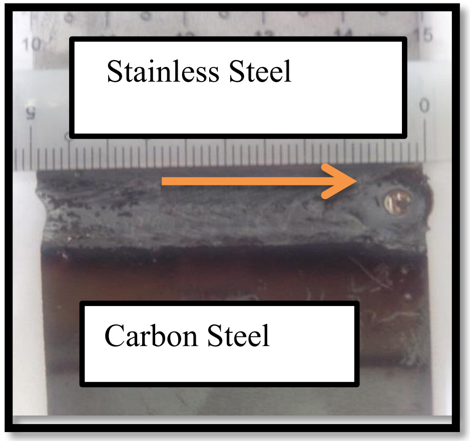
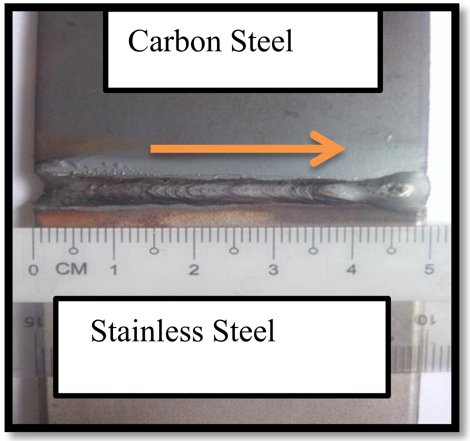
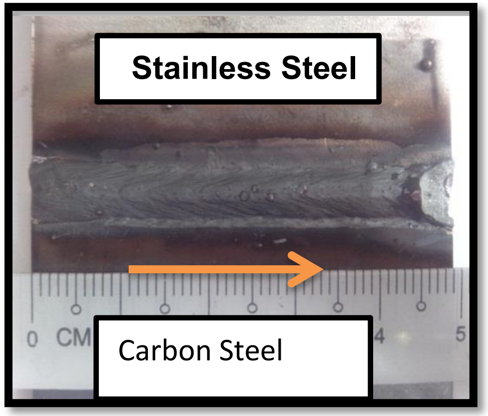
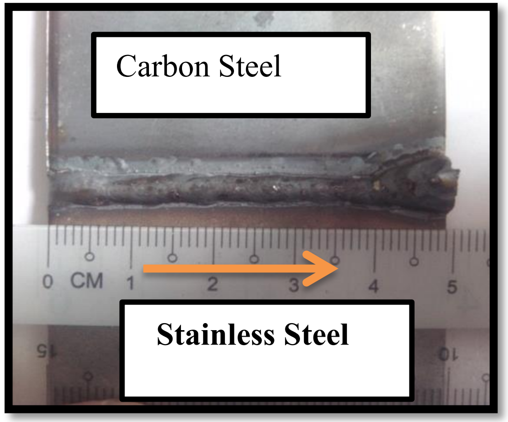
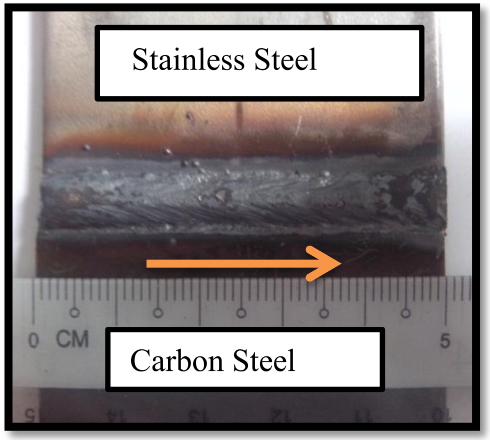
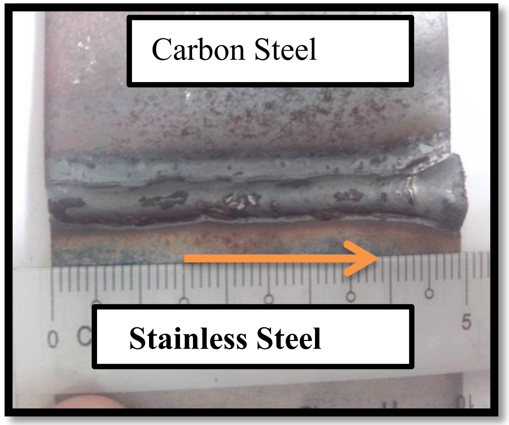
APPENDIX A

Graph Of Hardness Vs Number Of Experiment



APPENDIX B

Distance (cm)	Top View	Bottom View	Description
1.5			Type of Welding: MIG welding Current: 95A Speed: 4mm/s Voltage: 19V Gas: 99.99% Argon Filler: ER308 wire Clamp 1
2.2			

Distance (cm)	Top View	Bottom View	Description
1.9			Type of Welding: MIG welding Current: 95A Speed: 4mm/s Voltage: 19V Gas: 99.99% Argon Filler: ER308 wire Clamp 2
3.75			

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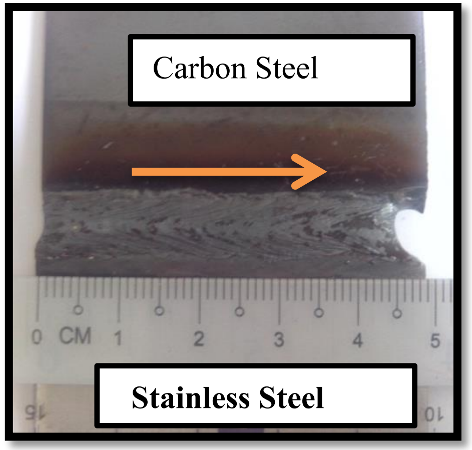
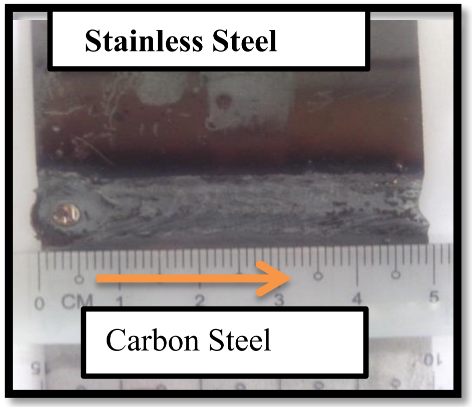
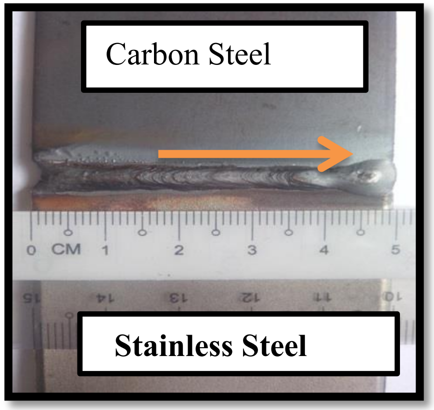
<tr><th>Distance (cm)</th><th>Top View</th><th>Bottom View</th><th>Description</th></tr>
<tr><td>1.5</td><td></td><td></td><td rowspan="2">Type of Welding:
MIG welding
Current: 95A
Speed: 4mm/s
Voltage: 21V
Gas:
99.99% Argon
Filler:
ER308 wire
Clamp 1</td></tr>
<tr><td>2.2</td><td></td><td></td></tr>
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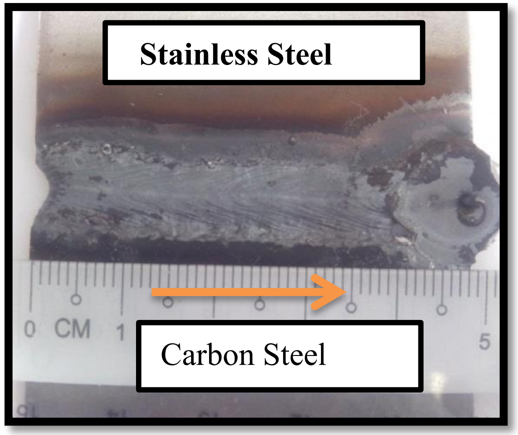
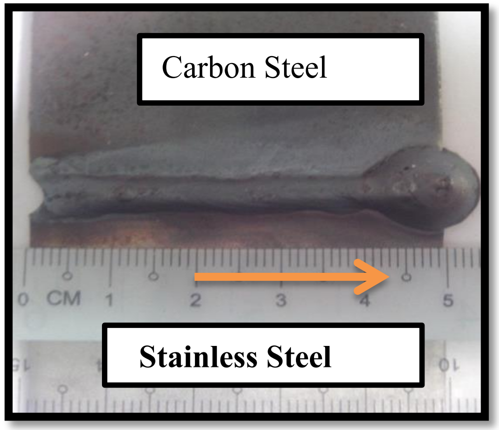
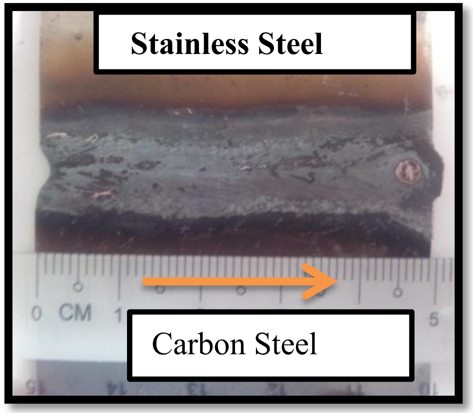
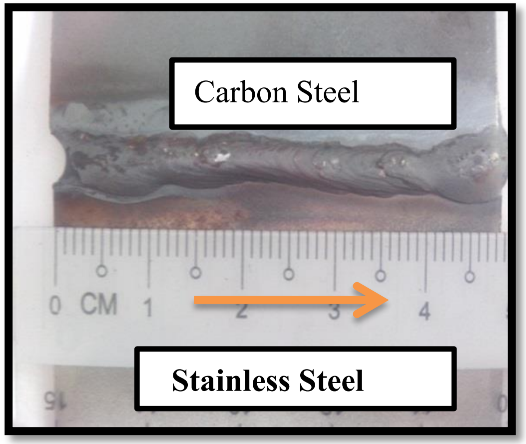
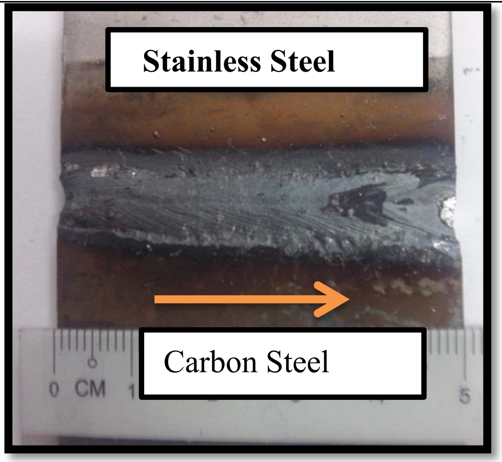
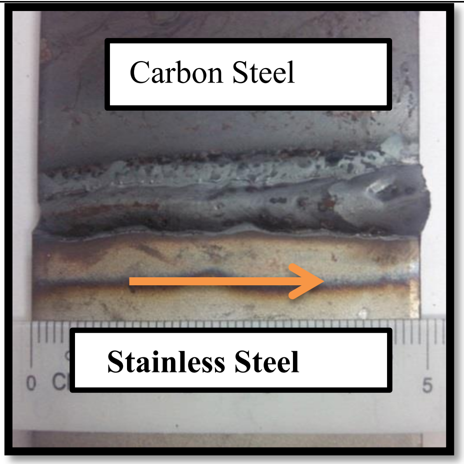
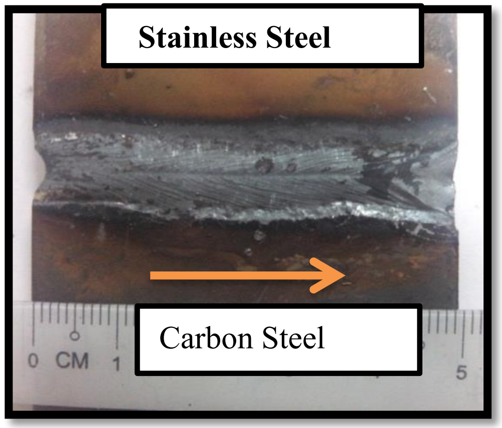
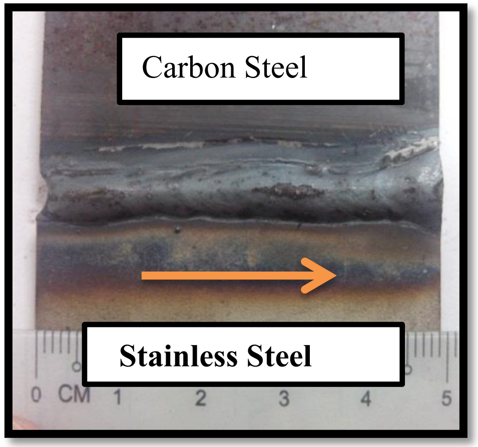
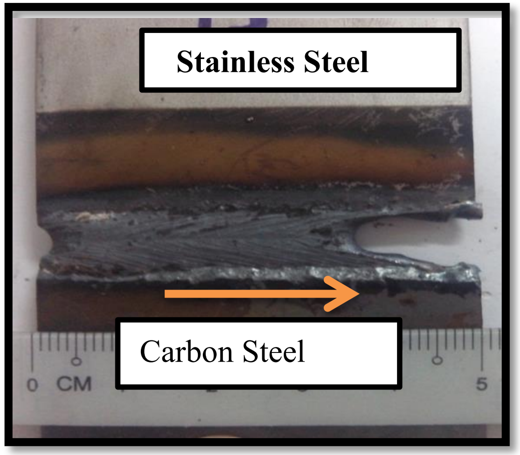
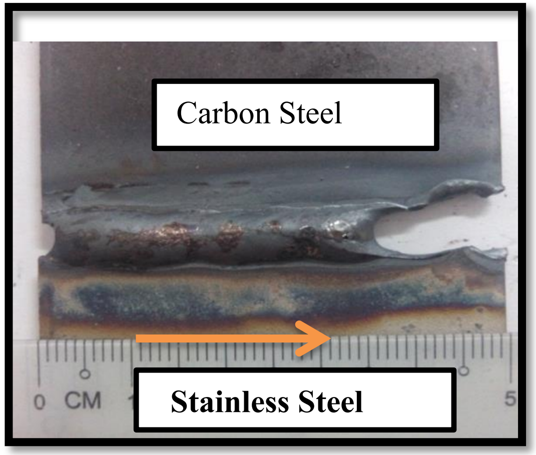
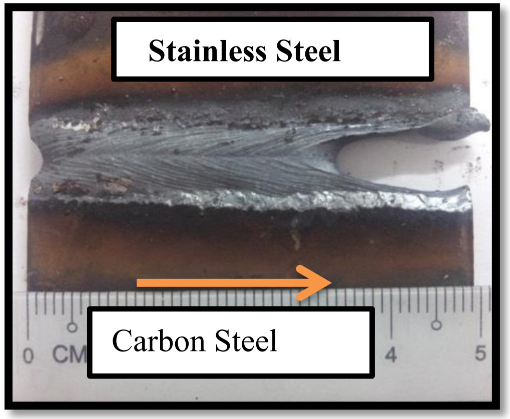
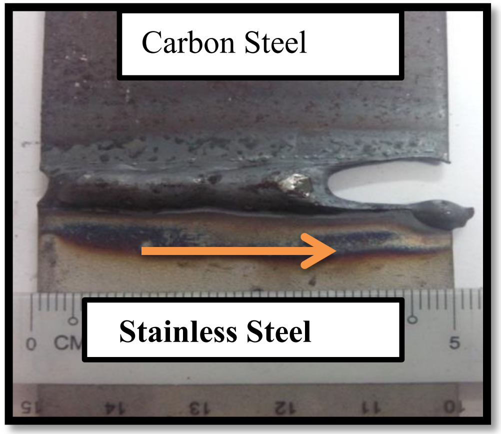
Distance (cm)	Top View	Bottom View	Description
1.5			Type of Welding: MIG welding Current: 95A Speed: 4mm/s Voltage: 23V Gas: 99.99% Argon Filler: ER308 wire Clamp 1
2.2			

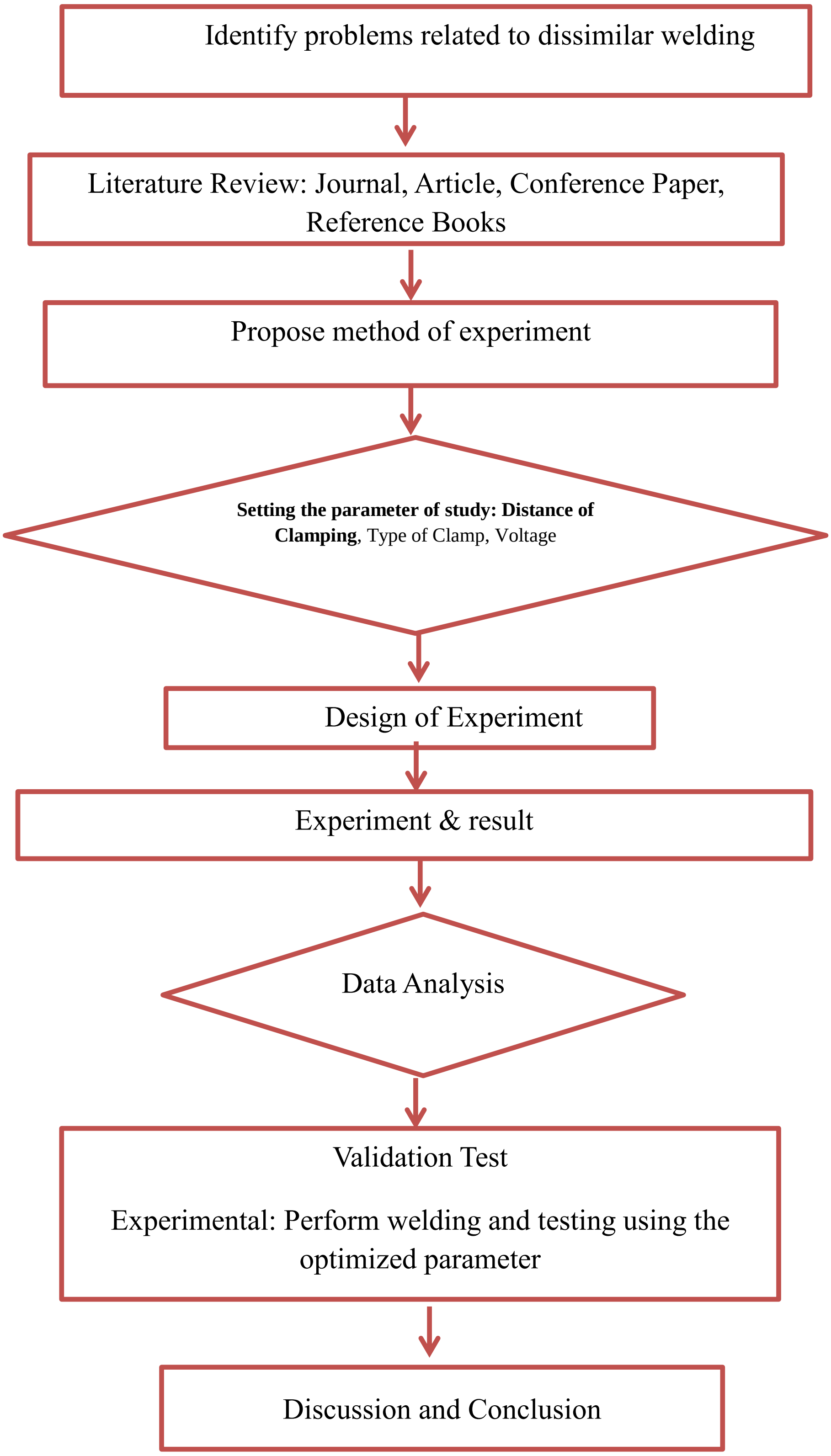
APPENDIX F

Distance (cm)	Top View	Bottom View	Description
1.9			Type of Welding: MIG welding Current: 95A Speed: 4mm/s Voltage: 23V Gas: 99.99% Argon Filler: ER308 wire Clamp 2
3.75			

Distance (cm)	Top View	Bottom View	Description
1.9			Type of Welding: MIG welding Current: 95A Speed: 4mm/s Voltage: 25V Gas: 99.99% Argon Filler: ER308 wire Clamp 2
3.75			

APPENDIX H

PROJECT FLOW CHART



APPENDIX I

GANTT CHART FINAL YEAR PROJECT 1

		W1	**W2**	**W3**	**W4**	**W5**	**W6**	**W7**	**W8**	**W9**	**W10**	**W11**	**W12**	**W13**	**W14**
Understanding title and identifying Problems	Plan														
	Actual														
Review Journal	Plan														
	Actual														
Identify Scopes and Objectives	Plan														
	Actual														
Methodology	Plan														
	Actual														
Report Writing	Plan														
	Actual														
Presentation	Plan														
	Actual														

APPENDIX J

GANTT CHART FINAL YEAR PROJECT 2

		Week1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13	Week 14
Material Preparation	**Plan**														
	Actual														
Parameter setup	**Plan**														
	Actual														
Pre test	**Plan**														
	Actual														
Experiment (welding)	**Plan**														
	Actual														
Microstructure	**Plan**														
	Actual														
Defect Inspection	**Plan**														
	Actual														
Analysis	**Plan**														
	Actual														
Report Writing	**Plan**														
	Actual														