INVESTIGATION OF MIG WELDING ON DISSIMILAR THICKNESS OF METAL SHEETS (STEEL AND STAINLESS STEEL)

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ABSTRACT

Based on different welding parameters, a welding process between mild steel and stainless steel were performed in this experiment using metal inert gas (MIG) machine. The objective of this experiment was to investigate the effect of welding voltages (15V, 20V and 25V) wire feed rates (80 ipm and 100ipm) and filler metals (ER70S-6 and ER308L) to the microstructure and mechanical properties of the welded mild steel to stainless steel specimens. The microstructure changes and the mechanical properties result from tensile and hardness test were analyzed and compared between the welded zones, heat affected zone (HAZ) and base metal. From the results obtained the grain size of weld zone and HAZ increases when the welding voltage and wire feed rate increases. The strength of the welded joint was directly proportional to the increasing in voltage and wire feed rate but their hardness value was irreversibly proportional towards the increasing parameter value. Filler metal of ER70S-6 shows better result in hardness test while filler metal of ER308L shows better strength in the joint. In conclusion, increasing voltage and wire feed rate will increases the strength but lowered the hardness of the joint. Filler ER308L was suitable to be used to increase strength of the joint while filler ER70S-6 was more suitable in increasing the hardness of the joint.

ABSTRAK

Berdasarkan parameter kimpalan yang berbeza, satu proses kimpalan antara keluli ringan dan keluli tahan karat telah dijalankan dalam eksperimen ini menggunakan logam gas lengai (MIG) mesin. Objektif eksperimen ini adalah untuk mengkaji kesan daripada voltan kimpalan (15V, 20V dan 25V) kadar kelajuan wayar (80 ipm dan 100 ipm) dan logam pengisi (ER70S-6 dan ER308L) untuk mikrostruktur dan sifat mekanikal keluli dikimpal bersama. Perubahan mikrostruktur dan hasil sifat-sifat mekanik daripada tegangan dan ujian kekerasan dianalisis dan dibandingkan antara zon yang dikimpal, zon terjejas haba (HAZ) dan logam asas. Daripada keputusan yang didapati saiz struktur butiran daripada kimpal zon dan HAZ meningkat apabila voltan kimpalan dan kenaikan kadar kelajuan wayar. Kekuatan sendi dikimpal adalah berkadar terus dengan peningkatan dalam kadar kelajuan voltan dan wayar tetapi nilai kekerasan mereka berkadar songsang apabila nilai parameter kian meningkat. Logam pengisi ER70S-6 menunjukkan hasil yang lebih baik dalam ujian kekerasan manakala logam pengisi ER308L menunjukkan kekuatan yang lebih baik dalam kimpalan ini. Kesimpulannya, meningkatkan voltan dan kadar kelajuan wayar akan meningkatkan kekuatan tetapi mengurangkan kekerasan sendi. Pengisi ER308L sesuai untuk digunakan untuk meningkatkan kekuatan sendi manakala pengisi ER70S-6 adalah lebih sesuai dalam meningkatkan kekerasan sendi.

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CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

This chapter explains about background of study, problem statement, objectives and scopes of this study. By referring to the problem statement the purpose of this study can be clearly identified. Based on the objectives and scope of this study, the output and the detail from this study can be acquired.

1.2 BACKGROUND OF STUDY

The Tailor welded blank (TWB) designation is used in the broad sense to include conventional TWBs, two or more sheets of steel welded along adjacent edges as flat blanks prior to forming, tailor welded tubes (TWT) of multi-gage or grade side-walls, and patch-type TWBs, or a steel "patch" overlapping another steel blank. The industry is growing rapidly as the quality of the welding and throughput of the process continue to increase The tailor welded blank (TWB) industry continues to experience steady growth (Weimer, 2000). Each auto company now has TWB applications and the growth rate is approximately 25% to 30% per year in North America, Europe and Japan. The leading objectives continue to be cost reduction, structural improvement and mass reduction. Certain companies continue to recognize quality improvements as a major objective, especially with door inners and one-piece body side TWBs. While there continue to be numerous small (under 0.75 meters), simple, one-weld applications, the growth is spreading into larger, more complex products (Auto/Steel Partnership, 2001)

Nowadays, welded material finishing is one of the most important things in determining the strength of the welded joint metal in the structure. These processes are an important and necessary aspect of manufacturing operations. This experiment deals with the Gas Metal Arc Welding (GMAW) also known as Metal Inert Gas (MIG) welding. During the welding process, due to the different quantity of heat input and quality of weldments, microstructure and mechanical properties of the steel joint may not resulted as needed. The cycle of heating and cooling occurs during the welding affects the microstructure and surface composition of welds and adjacent base metal (Davis, 2006). Changing in microstructure of the welded zone and HAZ would affect the strength and hardness of the specimen joint. Thus, the weakest part of the joint was depending on the selection of the parameters in the MIG welding.

1.3 PROBLEM STATEMENT

Manufacturing cost and working operation reduction ability became an important factor in today's metal technology application. Using dissimilar type of steel with dissimilar thickness could save the manufacturing cost and reduce the working operation ability. By applying the tailor welded blank (TWB), different thickness of steel was joined together in order to place the optimum steel thickness and strength to the structure. Increasing the strength of the joint using TWB would increase the safety aspect of the structure, reduce the manufacturing cost and working operation ability which is an important application needed in the industries. Therefore applying the TWB in the welding joint was an essential method and should be applied in most of the steel welded structures.

1.4 PROJECT OBJECTIVE

The main objective of this study is to investigate the effect of welding parameters (voltage, wire feed rate and filler material) to the microstructure and mechanical properties of the steel-stainless steel joint.

1.5 PROJECT SCOPES

(i) Mild steel (AISI 1010) and stainless steel (AISI 304) sheets are used as study material.

(ii) The welding method employed is MIG welding by using two types of filler metal (ER308L and ER70S-6).

(iii) Different welding voltages (15V, 20V and 25V) and wire feed rates (80 ipm and 100 ipm) are used to join the sample using butt joint.

(iv) The microstructures of the welded specimens were analyzed using optical microscope.

(v) Mechanical testing of tensile and hardness test were done and the relation of the result to the welding parameter was investigated.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

The purpose of this chapter is to provide a review of past research efforts related to MIG welding parameter, mechanical properties of welded join metal and their microstructure analysis. The review is organized chronologically to understand on how the past research efforts would help on this subsequent groundwork of studies.

2.2 METAL INERT GAS (MIG) WELDING PRINCIPLE

Welding component of MIG welding also known as Gas Metal Arc Welding (GMAW) is very important in order to get the best mechanical properties of the welded metal in this project. It is a process of which an electric arc is formed and maintained between a continuously fed filler metal electrode wire and weld pool. In the arc heat, the electrode wire is melted and the molten metal (droplets) is transferred across the arc into the weld pool.

The arc and the weld pool are shielded from the atmosphere contamination by an externally supplied gas. The shield gas can be argon, CO_2 or Ar + CO_2 gas mixture depending on the type of base of metal being welded. Generally for welding of nonferrous metals argon is used as the shield gas and for welding of ferrous metal, CO_2 or Ar + CO_2 gas mixture is used.

The process is found to provide a stable arc and good process control when a direct current (DC) power sources are employed with the electrode positive (DCEP)

polarity. The DCEP provides stable arc, greater heat input to the cathodic base metal for good penetration and a fluid weld pool. (Baldev et al. 2006)

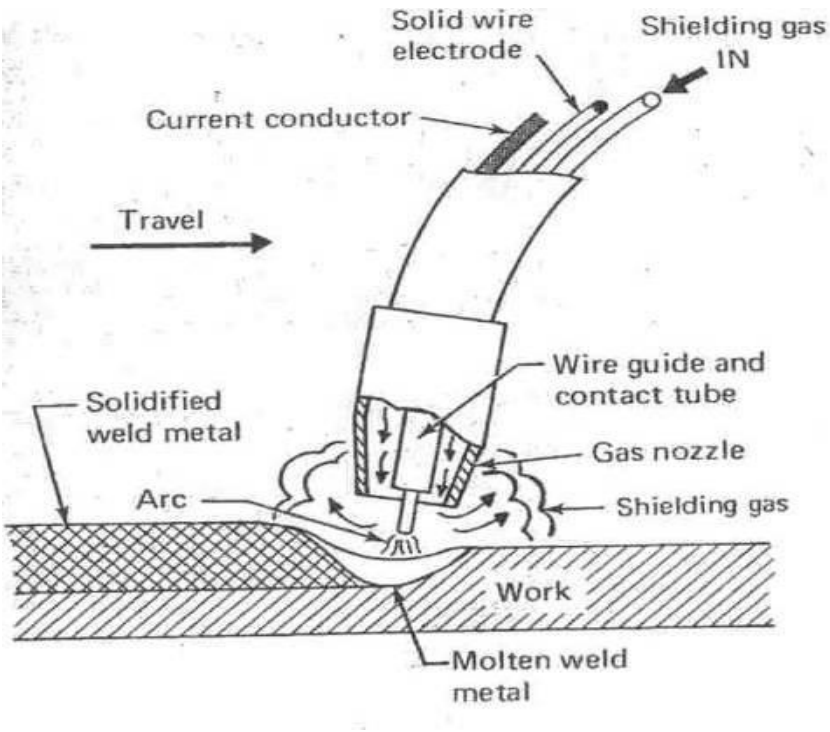

Figure 2.1: Gas shielded metal arc welding process

Source: Baldev et al, (2006)

2.3 WELDING PARAMETERS AND THEIR EFFECTS

Weld quality and weld deposition rate are both related by the various welding parameters and joint geometry. A welded joint can be produced by various combinations of welding parameters as well as joint geometries. Parameters like welding current, arc voltage, welding speed, electrode feed speed, electrode extension, electrode diameter and joint geometry are the process variables which control the weld deposition rate and weld quality. These parameters have influence to a varying degree on the deposition rate, weld bead shape, depth of penetration, cooling rate and weld induced distortion in each of them (Baldev et. al, 2006).

2.3.1 Wire Feed Rate of Welding

The wire feed unit supplies the electrode to the work, driving it through the conduit and onto the contact tip. Most models provide the wire at a constant feed rate, but more advanced machines can vary the feed rate in response to the arc length and voltage. Some wire feeders can reach feed rates as high as 30.5 m/min (1200 in/min), but feed rates for semiautomatic GMAW typically range from 2 to 10 m/min (75–400 in/min) (Mandal, 2006).

Figure 2.2: Result of fast wire feed rate

Source: Mandal, (2004)

Figure 2.3: Result of slow wire feed rate

Source: Mandal, (2004)

Welding voltage and wire feed rate related to each other as they need to be in a balanced relationship with one another. The welding wire feeding rate needs to be adjusted to suit the voltage so that everything runs smoothly and the only way to know this is by start welding and see what the arc does. How the arc sounds and how it is welded along when welding the specimens together were noted. If the wire is fed too fast it will keep punching into the metal. The wire feeding rate needs to slow down in order to avoid it from continuing to do so. Same goes when the opposite thing happened to the welding metal. It shows that the wire is going too slow and the speed need to be increased (Mandal, 2004).

2.3.2 Welding Arc Voltage

Arc voltage is the voltage between the electrode and the job during welding. It is determined by arc length for any given electrode. Open circuit voltage, on the other hand, is the voltage generated by the power source when no welding is done. Open circuit voltage generally varies between 50V to 100V while the arc voltages are between 17 to 40V. This arc voltage depends on the arc length and the type of electrode used. When arc length increased, the arc resistance will also increase which resulting in higher drop in voltage. That means when arc voltage increase, the current will also increase.

How much the voltage a weld requires depends on numerous variables including metal thickness, type of metal, joint configuration, welding position, shielding gas and also wire diameter speed. As the arc voltage determines height and width of beads, it is important to select the best voltage when welding the specimens together. In order to select the best voltage, weld on a scrap metal and and turns down the voltage until the arc starts stubbing into the work piece. Then, start welding again and increase the voltage until the arc becomes unstable and sloppy. A voltage midway between these two points provides a good starting point (Mandal, 2004).

2.3.3 Welding Speed

The linear rate at which the arc moves along the welds joint is called welding speed. Welding speed is important because it controls the actual welding time and hence affect the cost of production. Therefore the speed generally is fixed in mechanized welding while the other parameters like current and/or arc voltage varied to control the weld deposit and quality. When welding speed is increased, heat input per unit length of welded joint decrease, less filler metal is deposited resulting in less weld reinforcement and defects and uneven bead shape may result. Same goes when decreasing the welding speed, the filler metal deposition rate will increase, heat input rate also increase, weld bead gets wider and more convex, penetration decrease with further decrease in speed and a large molten pool would occur with resulting a rough bead and possible slug inclusion defect.

With excessive welding speed, there is a substantial drop in thermal energy per unit length of welded joint resulting in undercutting along the edge of the weld bead because of insufficient deposition of filler metal to fill the path melted by the arc. Within limits the welding speed can be adjusted to control weld size and depth of penetration (Baldev et al. 2006).

2.4 TYPE OF ELECTRODES

Choosing the suitable electrode for MIG in really important as it would influence the mechanical properties of the weld and is a key factor of weld quality. In general the finished weld metal should have mechanical properties similar to those of the base material with no defects within the weld. A wide variety of electrodes exist in order to achieve such goals. Commercially electrodes available in the market contain deoxidizing metals such as silicon, manganese, titanium and aluminium in small percentage to help prevent oxygen porosity. The suitable electrodes chosen would definitely influence the mechanical properties and reduce the defects of the weld area.

2.4.1 Filler Metals

A variety of stainless steel electrodes are manufactured to produce weld metal similar in composition to most base metals. However, the composition of the core wire may differ from that of the base metal in order to improve corrosion resistance of the weld deposit, eliminate underbead cracking and minimize carbide precipitation (Tewari et al, 2002). In the transfer of metal through the arc very little nickel is lost from nickel bearing stainless steel electrodes. There is a slight loss in chromium and a greater loss of some of the other elements but this loss may be compensated by alloy additions to the coating.

Manganese and silicon are included in the stainless steel electrode coverings to reduce oxidation. Titanium is added to promote weldability, to produce an easily removable slag and to prevent carbide precipitation. In most designs, niobium is used to prevent carbide precipitation. Lime is an extremely important ingredient in the

covering since it tends to eliminate hydrogen. Any material that is high in carbon is excluded because of the affinity of chromium for carbon especially at welding temperature. The covering used on stainless steel electrodes is similar to that employed on the low –hydrogen type carbon steel electrodes.

For Mild steel welding, it is eminently weldable using 6013 electrodes or G3Si1 (SG2) MIG wire up to 18mm thick. Above that it is probably wise to change to 7018 electrodes but the wire can remain as G3Si1 or SG2. These MIG wires are usually low hydrogen, often lower than low hydrogen electrodes, but beware of some of the lesser known brands. Some of the higher grades of mild steel need low hydrogen rods to match the strength, and some need low alloy (such as 1% Nickel steel) for strength and low temperature toughness (British Stainless Steel Association, 2010).

The usual choice for the filler when welding stainless to mild steel is 309L filler. 309L is over alloyed stainless steel (19/10) so when diluted by the mild steel gives a deposit approximately like 308L / 304L. Although a standard 308 type filler can be used for joining a 304 type stainless steel to carbon steel, more highly alloyed fillers such as the 309 types (23 12L to BS EN 12072) are preferable. This would avoid cracking in the weld dilution zone that can be a problem if a 308 type (19 9L to BS EN 12072) filler is used, where there can be too low a ferrite level and martensite may also be formed on cooling (Cunat, 2007). In this experiment 309L and 308 type filler were used as one of the parameters of the welding.

2.5 WELDING DEFECTS

Most welds contain defects (porosity, cracks, slag inclusions, etc.). The question is to determine if they are significant considering the application. Typically, the applicable codes or standards specify the maximum allowable limits of these types of defects in a weld based on the application. Sometimes discontinuities that may not affect mechanical properties may reduce corrosion performance. The properties of the heat-affected zone (HAZ) are one of the significant factors to consider when evaluating the soundness of the weld joint. The HAZ may be

considered as a discontinuity because of the metallurgical alterations as a result of the welding heat, which cause very rapid heating and cooling rates. Grain growth, phase transformations (i.e brittle untempered martensite which can form depending on the cooling rate and the chemical composition of the base material), formation of precipitates or overaging (loss of strength in precipitation-hardened alloys) all has a drastic effect on the properties of the HAZ. It is possible to improve the weld zone properties by controlling the cooling rate. This may be accomplished by slowing the cooling rate down either by increasing the heat input or reheating the metal up before welding.

2.5.1 Porosity

Gas pocket is formed in the weld metal when they are entrapped during solidification. Molten steel readily absorbs hydrogen, carbon monoxide and other gases to which it is exposed. Since these are not suitable in solid metal, they are expelled as the metal solidifies. Standard shielded arc electrodes with organic coating such as E6010 produce an atmosphere around the arc that contains hydrogen, a notable contributor to porosity. When using such electrons, welding should be done slowly to allow the gases time to escape since too high of travel speed causes rapid solidification of the weld metal leading to porosity (Genculu, 2007).

2.5.2 Incomplete fusion/ penetration

Although these terms are sometimes used interchangeably, lack of fusion occurs when the weld and base metal fail to adequately fuse together. It can also be encountered between weld passes. It may be caused by not raising the temperature of the base metal or previously applied weld metal to melting point or failure to remove the slag or mill scale. Lack of penetration is typically due to inadequate heat input for the particular joint that is being welded and is usually seen at the sidewalls of a welded joint, between weld passes or at the root of the weld joint. The shielding gas can also influence the penetration; typically helium is added for nonferrous metals and carbon dioxide is added ferrous metals (to argon) to increase penetration (Genculu, 2007).

Figure 2.4: Incomplete fusion/penetration

Source: Genculu, (2007)

2.6.3 Undercut

This defect occurs when a groove that is formed adjacent to the weld as a result of the melting of the base metal remains unfilled. An example is shown in the macrograph below (at the toe of the fillet weld) along with the appearance of this type of defect on a radiograph of a groove weld.

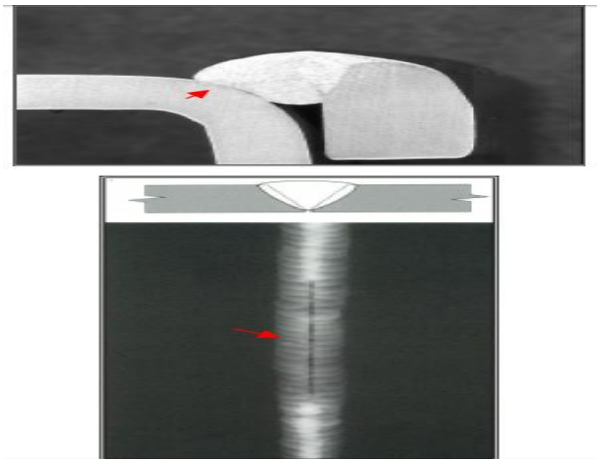

Figure 2.5: Undercut defect

Source: Genculu, (2007)

2.6.4 Cracks

Cracks are the most serious type of weld defects that can lead to catastrophic failure in service. One way to categorize them is as surface or subsurface cracks. Another way would be as hot (which occur during or immediately after the weld is made or cold (cracks that occur after the weld has cooled to room temperature-sometimes within hours or days). In general, weld or heat-affected zone cracks indicate that the weld or the base metal has low ductility and there is high joint restraint. Many factors can contribute to this condition such as rapid cooling, high alloy composition, insufficient heat input, poor joint preparation, incorrect electrode type, insufficient weld size or lack of preheat. Some common causes and remedies are given in the table below (Genculu, 2007).

Table 2.1: Cracks defect

Causes	Remedies
Highly rigid joint	Preheat Relieve residual stresses mechanically Minimize shrinkage stresses using the backstep sequence (a longitudinal sequence in which welds passes are made in the direction opposite to the progress of welding)
Excessive dilution (change in chemical composition of a weld deposit caused by the admixture of the base metal)	Change welding current and travel speed Weld with covered electrode negative; butter the joint faces prior to welding (buttering is deposit surfacing metal to provide metallurgical compatible weld metal to the subsequent weld passes)
High sulfur base metal	Use filler metal low in sulfur
High residual stresses	Redesign weldment, change welding sequence, applies intermediate stress relief
High hardening	Preheat, increase heat input, heat treat without cooling to room temperature

Source: Genculu, (2007)

2.6 STAINLESS STEELS (AUSTENITIC STEEL)

Stainless steel is a low alloy steel with high percentage of chromium that is not less than 10.51%. Rust resistant is there because there is an oxide of chromium on the surface of the steel. Other elements also mixed to improve abrasive resistance, fabrication and machinability and strength. Examples are nickel, nitrogen and sulfur.

The choosing of stainless steel in usually based on rust and heat resistance, mechanical properties, fabrication abilities, availability and cost. Mostly, rust resistance and mechanical properties are the main factor for choosing stainless steel.

Stainless steel is comprised of new kinds. There are ways to categorize it that have been made by many organizations. AISI has catalogued steel with chemical composition and gave 3 digit numbers which tells us the basic group or alloys in the group. Another way is to gather the alloys according to the microstructure because that basic structure that control the mechanical properties of metal. The table shows classed of AISI for stainless steel and connection to microstructure.

Table 2.2: AISI classing for stainless steel

SERIES	ALLOY TYPES	STRUCTURE
200	chromium, nickel, manganese or nitrogen	Austenitic
200	chromium and nickel	Austenitic
400	chromium only	Ferritic or martenistic
500	Low chromium (<12%)	martenistic

Source: Cunat, (2007)

Austenitic steels are dominant in the market and therefore were used in this project. The group includes the very common AISI 304 and AISI 316 steels but also the higher-alloy AISI 310S ASTM N08904. This steel is characterized by its high content of austenitic-formers, especially nickel. They are also alloyed with chromium, molybdenum and sometimes with copper, titanium, niobium and nitrogen. Alloying with nitrogen raises the yield strength of the steels. Austenitic steels cannot be hardened by heat treatment because they are soft and highly formable. Their hardness and strength are increased by cold working (Cunat, 2007).

The steel type of 304, 316, 304L and 316L has very good weldability. The problem of this type of steel is that the corrosion after welding and their unsusceptible to hot cracking mainly because they solidify with a high ferrite content. They should therefore be welded using a controlled heat input. Steel and weld metal with high chromium and molybdenum contents may undergo precipitation of brittle sigma phase in their microstructure if they are exposed to high temperatures for a certain length of time. The transformation from ferrite to sigma or directly from austenite to sigma proceeds most rapidly within the temperature range of 750-850˚C. Welding with a high input leads to slow cooling, especially in light-gauge weldments. The weld's holding time between 750- 850˚C then increases, and along with the risk of sigma phase transformation. (Baldev et al, 2006)

2.7 MEDIUM CARBON STEEL (MILD STEEL)

Carbon Steel is principally a mixture (or Alloy) of Iron and Carbon with small amounts of silicon, sulphur, phosphorous, and manganese. Other elements may be added to the steel to impart a specific quality to enhance its usefulness. An Alloy may be thought of as a recipe, but still Iron has other elements or ingredients to enhance the properties of the Iron. In plain carbon steels it is the Carbon additive that has the greatest effect on the strength and weldability of the steel. The carbon is added to the Iron in varying amounts to harden or strengthen the steel.

As the carbon content increases the hardness and tensile strength increases and the ductility, plasticity, and malleability will decrease. The reason the carbon content or carbon recipe varies is to produce a family of steels that exhibit the desired characteristics for a given application. In general as the carbon content increases the weldability (how easily welded) decreases. In other words the higher the carbon content the more likely special procedures such as preheating, interpass temperature control and postheating are necessary. The following chart groups carbon content, typical uses and weldability.

Table 2.3: Characteristics of carbon steel

Group	Content %	Typical usage	Weldability
Low carbon steel	0.15 Maximum	Welding electrodes, rivets and nails softer easily formed shapes.	Excellent weldability with all processes usually no preheat interpass or postheat necessary
Mild steel Plain carbon	0.15 to 0.30	Plate, angle, and bar stock for general fabrication. Mild steel accounts for a large segment of welded parts of Industry where good plasticity and ductility is required.	Readily weldable with all processes without preheat, interpass, or postheat except for very thick sections.
Medium carbon steel	0.30 to 0.50	Used for Machine parts, gears, and where parts may be hardened by heat treating.	Parts may be readily welded with all process if preheat, interpass temperature controls, and post heat recommendations are followed. Use Low hydrogen Electrodes and appropriate filler wire. Heat treating after welding may be applied
High carbon steels	0.50 to 1.0	Springs, Dies, Railroad Track, Many tools, Band saws, and Knives. Also used where a sharp edge is required.	Usually require preheat interpass temperature control and postheat. Special heating and cooling procedures in a furnace such as normalizing may be required to restore the properties of the metal after welding. High carbon Electrodes designed for welding tool steels or the specific alloy are readily available from welding supply companies.

Source: Genculu, (2007)