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# A Review on Prediction of Heat Affected Zone of Al-6061 alloy For GMAW weld joint

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**ABSTRACT**

**Aluminium and its alloys are having variety of applications in today's industrial scenario. The use of Al and its alloy is increasing day by day due to its specific properties like light weight, high strength, and excellent corrosion resistance. The Al alloys are categorized on the basis of alloying elements like copper, manganese, silicon, magnesium, zinc, etc. in which aluminum is a predominant metal. Selection of alloying element in any solute depends on use of material requirement for specific application. The various Al alloys like 6061, 6063, 6051, 7075 etc, are presently fulfilling today's industrial requirement. In alloy 6061 first digit indicates that it is (Mg+Si) alloy series where magnesium and silicon are major alloying elements, second digit indicates no modification to the original alloy, and last two digits identifies it in the 6xxx series. Al alloy 6061 used where good corrosion resistance and strength are needed like marine fittings, pipelines, aircraft and aerospace components, heat exchangers, bicycle frames etc. Gas metal arc welding (GMAW) has been used widely to join Al alloy in automotive and shipbuilding industry because of its advantages over other welding techniques, like high welding speed, less distortion, no slag removal, high weld metal deposition rate, high weld quality and precise operation etc. During welding process melting of the base material must occur and heat transfer through conduction in to the base material, heating during the welding process can cause grain growth in the volume of material adjacent to the weld metal which reduces the strength of the metal near the weld. This portion is called Heat Affected Zone (HAZ). The maximum failures of large structures were observed from the Heat affected zone of welding. The HAZ can be minimizing by selecting the appropriate welding parameters like current, voltage and speed etc. By considering above the present study was undertaken to review of welding parameters from the available literature on the bead geometry, microstructure and mechanical properties of MIG welding process.**

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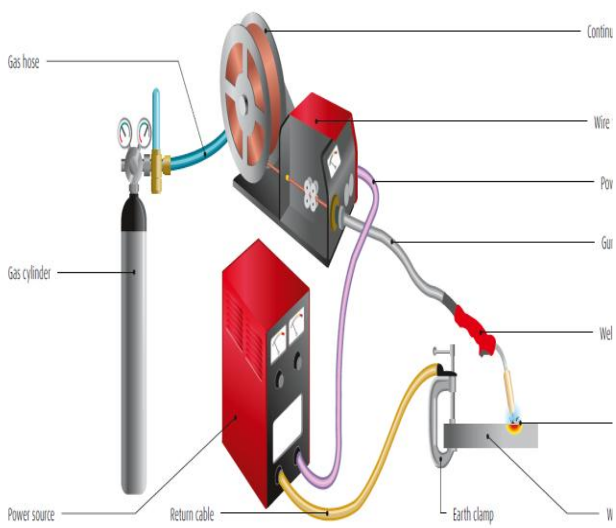
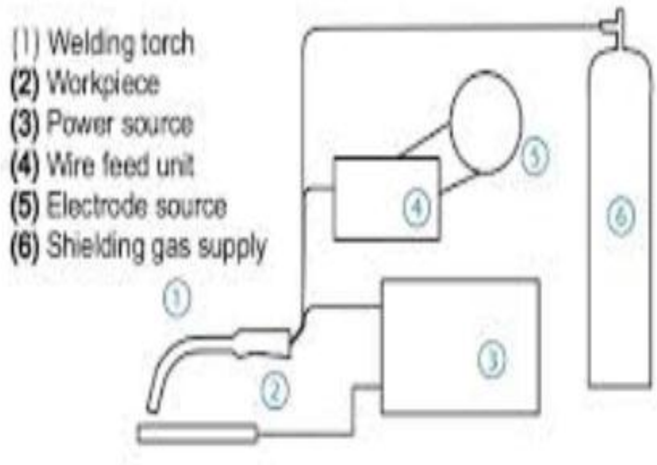
## I. INTRODUCTION

Aluminum alloys are alloys in which aluminum is the predominant metal. The typical alloying elements copper, magnesium, magnese, silicon, tin and zinc. An Al and aluminum alloy plays an important role in engineering and metallurgy field because of fabrication and formability. Higher strength 6061 alloy finds broad use in welded structural members such as Truck and marine frames, front and rear suspension frames, and pipelines. The most common temper 6061 aluminiumis T6-solution heat treated and artificially aged.MIG welding has been used widely to join pieces of aluminum alloys in construction of automotive frame, marine frame, and pressure vessels. In the MIG contamination, an electric potential is established between the electrode and the work piece that needs to be welded, such electric potential will cause the current to flow and consequently a thermal energy will be generated in the partially ionized inert gas. The circuit diagram of GMAW is illustrated in fig.1 (a). It consist of various parts as 1) welding power source and cables 2) Inert Gas cylinder 3)filler wire and wire feed unit 4) welding gun and cooling water supply. Various Inert gases are used in MIG welding like Argon, carbon dioxide, Argon and $CO_2$ mixtures, argon mixtures with oxygen or helium mixtures. The working principle of GMAW illustrated in fig. (b). in which a continuous electrode (the wire) is fed by powered feed rolls (wire feeder) in to the weld pool. An electric arc is created between the tip of the wire and the weld pool. The wire is progressively melted at the same speed at which it is being fed and forms part of the weld pool. Both the arc and the weld pool are protected from atmospheric contamination by shield of inert (non-reactive) gas, which is delivered through a nozzle that is concentric with the welding wire guide tube.

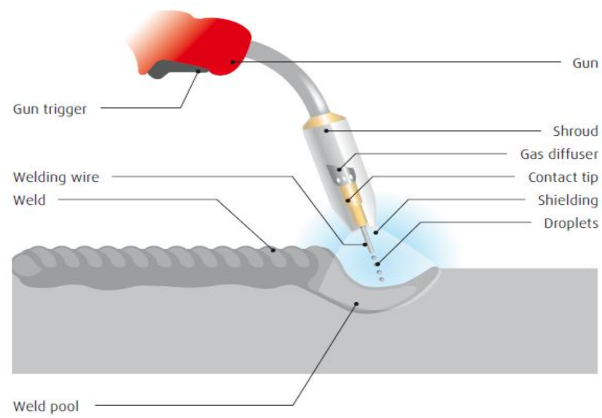



(a)

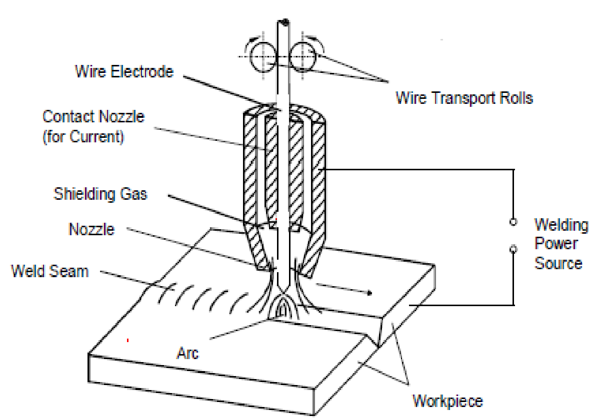



(b)

Fig: 1 (a) and (b) Circuit diagram of GMAW




(c)



(d)

Fig: 1 (c) & (d) working principle of GMAW

In order to make a welded joint in an aluminum structure using the arc welding process melting of the base material must occur. During the melting operation, heat transfers through conduction into the base material adjacent to the weld. Typically, the completed weldment is divided into three distinct areas: the weld metal, the heat-affected zone adjacent to the weld, and the base material beyond the HAZ that has been unaffected by the welding operation. The HAZ portion consist of different zones adjacent to the weld metal like grain growth zone, recrystallised zone, partially transformed zone and tempered zone as illustrated in fig.2 Because the HAZ will experience cycles of heating and cooling during the welding operation, arc welding on materials which have been strengthened by work hardening or precipitation hardening, will change its properties and may be extremely different than that of the original base alloy and the unaffected area of the base material. The chemical composition, physical properties, Mechanical properties and processing properties of AA 6061 illustrated in table-1 to 2.

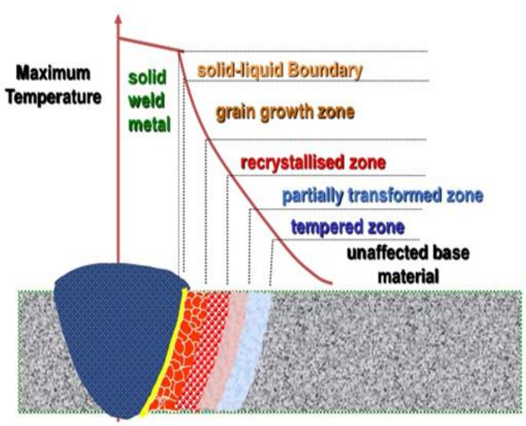



Fig-2 Geometry of Heat Affected Zone

TABLE 1

Chemical properties of 6061 AA

| **Alloy** | | Minimum | Maximum |
|---|---|---|---|
| **Si** | | 0.40 | 0.8 |
| **Fe** | | 0.0 | 0.7 |
| **Cu** | | 0.15 | 0.40 |
| **Mn** | | 0.0 | 0.15 |
| **Mg** | | 0.8 | 1.2 |
| **Cr** | | 0.04 | 0.35 |
| **Zn** | | 0.0 | 0.25 |
| **Ti** | | 0.0 | 0.15 |
| **Other** | Each | 0.0 | 0.05 |
| | Total | 0.0 | 0.15 |
| **Aluminium** | | 98.61 | 95.8 |

TABLE 2

Physical properties and Mechanical properties of 6061 AA

| **Physical Properties** | | **Mechanical Properties** | |
|---|---|---|---|
| Density | 2.70 g/cm$^3$ | Tensile Ultimate strength | 240 Min MPa |
| Melting Point | 582 - 652 $^{o}$C | Tensile Yield strength | 260 – 310 MPa |
| Coefficient of Thermal Expansion | 23.5 x 10$^{-6}$ m/m-$^{o}$C | Hardness Brinell | 276 MPa |

| | | | |
|---|---|---|---|
| Modulus or Elasticity | 70 GPa | Elongation at Break (50mm dia rod) | 95 HB |
| Thermal Conductivity | 166 W/m.k | Poisson's Ratio | 9 – 13% |
| Specific heat capacity | 0.896 J/g-$^{o}$C | Fatigue strength | 0.33 |
| Electrical Resistivity | 0.040 x 10 $^{-6}$ Ω.m | Machinability | 96.5MPa |

## II. HEAT AFFECTED ZONE IN WELDING

The studies of HAZ in welding investigated by different researchers are as follows.

K.P.Kolhe and C.K.Datta [1] were studied microstructure, phase analysis; mechanical properties and HAZ width of submerge arc welded specimens for different passes with different heat inputs. They investigated the microstructure of 16mm thick mild steel plate was carried out using metallurgical microscopy with image analysis software. The hardness, impact energy and micro hardness of multipass welded joint were tested by using Rockwell hardness testing machine and charpy V- notch testing machine. The various subzones in the microstructures were observed in the HAZ of SA weld are spheroidized, partially transformed, grain refined and grain coarsened. The proportionate value of micro hardness was observed for low heat input where as for increased heat input variations in hardness value was observed. They concluded welding parameters of SAW used to control the microstructure, phases and mechanical properties of welded joint and help to get the robust welded structure of mild steel. P.A.Stathers,*etal*. [2] were found relationship between hardness and tensile properties for HAZ in Al alloy 6061-T651. They used Vickers micro hardness testing machine for measuring hardness and tensile testing by using IN-STRON 8501 Servo-hydraulic testing machine for MIG welded specimens. They were found that hardness is a sole variable for estimating the yield and tensile strength of the heat affected zone (HAZ) in welding. The relations have been expressed mathematically as follows 0.2% Yield stress = 2.9263 HV – 44.289… ( i ) Tensile strength = 2.4079 HV + 46.39 …(ii) X.Yue, *etal.* [3] were investigated the effect of heat input and preheats on the HAZ and hydrogen induced cracking tendency of BA-160 (Blast resistance steel). Welding of specimens were carried by using GMAW with (Ar+15% $H_2$) gas shield. Lower critical stress was checked by implant test and hardness test carried using Vickers hardness testing machine. Microstructures of welded specimens were studied using optical microscopy and transmission electron microscopy (TEM). Fracture behaviour after implant test observed by Scanning electron microscopy (SEM). They observed lowest hardness in the course grained HAZ of weld specimen. However the hardness of the fusion zone is lower compared to HAZ and Base metal for low heat input. Whereas fusion zone hardness decreases as compared to using low heat input without preheating. When welded with high heat input with preheating, are beneficial to reduce the cracking tendency for BA-160. Because the lower critical stress (LCS) with preheat is higher than that without preheat. K.S.Bang,*etal.* [4] were studied HAZ hardness and tensile strength in welds made with different heat inputs in fine-grained ferritic-pearlitic TMCP steel. First they estimated softening zone by micro hardness distribution using Vickers hardness Test, after that the degree of softening was also predicted using an established microstructural evolutional model and al rule of mixtures. Microsturural study along softening zone was carried out with optical microscope, tensile strength of MIG Welded specimens tested with universal testing machine. They observed that softening zone width increased continuously to 10 KJ/mm, the minimum hardness in the softened zone decreased slightly after a rapid decrease up to 6KJ/mm due to the softening effect, welded join tensile specimens were broken at the HAZ instead of Base metal. The reduction of tensile strength was similar to that of hardness and showed a maximum of 20% at 6 KJ/mm. M.Miyazaki,*etal*.[5] were investigated the influence of the grain size on the weld heat affected zone cracking of Gas metal arc(GMA) welds on A 6061 was studied using a varestraint test. The maximum crack length increased when the grain size was increased from 0.005 to 2mm. the crack lengths were measured using a magnifying glass eyepiece, crack photographs taken by Scanning electron microscopy (SEM). They observed the solidus temperature was increased by Si and decreased by Mg, the maximum crack length was longer in the case of 4043(silicon based filler metal) than 5356(Magnesium based filler metal). Filler metals may affect the weld chemistry and respective mechanical and thermodynamic properties. S.Y.Marchant [6] was investigated the effect of welding current on welding speed and hardness of heat affected zone and weld metal of mild steel material, mild steel weldment was welded under varying welding current by using MMAW process in 1G position. The test specimen was then grinded and hardness of each specimen was measured at three points i.e. Parent metal, HAZ and weld metal by using Brinell hardness tester. It was observed that with increase in welding current melting rate of electrode was increased hence welding time was reduced. So welding speed was increased. With increase in welding current hardness of HAZ and weld metal was also decreased due to increase in heat input. A.N.Boob and G.K.Gattani [7] were studied effect of manual arc welding process parameters like heat input and welding speed on width of Heat affected zone for Ms 1005 Steel. All the samples were dipped in 2% nital agent and finally dried by using air blower. The microstructure of base metal, weld zone as well as heat affected zone of all the samples have been carried out by optical microscope having 400X zoom. It was observed that welding speed increase the width of HAZ decreases and by increasing heat input decreases the toughness. C.Rodriguez,*etal*.[8] were used the small punch test (SPT) for the mechanical characterization of small areas such as the different zones of HAZ in any material, as it uses very small test specimens (10x10x0.5mm$^3$). SPT can be used to obtain mechanical properties like yield strength, ultimate strength and elongation of small regions. This test was used to evaluate how these properties change inside the HAZ of a welded joint made on quenched and tempered steel. During test the applied load and deflection of the specimen central point (DCP) measured with the help of a crack opening displacement (COD) type extensometer. . Micro hardness of specimen was measured by using Vickers micro hardness testing machine. Load deflection curve is the only information collected in the small punch test. Mechanical properties were found by using some mathematical relations. R.R.Ambriz,*etal*.[9] were investigated Local mechanical properties of a weld zone, in a 6061-T6 aluminum alloy subjected to modified indirect electric arc technique. The mechanical properties of the base metal, the weld metal and the heat affected zone (HAZ) were determined by means of usual and instrumented indentation testing, as well as micro-traction testing. It showed the intress of the hardness mapping for identifying the different zones resulting from the welding process J.A.Vargas,*etal*.[10] were studied yield strength and microstructure during welding (GMAW) for different heat inputs. A transient thermal analysis was developed to model the problem in a numerical form using finite element method (FEM) and these results were compared with experimental data showing good agreement. All the mechanical tests carried out by using universal testing machine, Hardness testing on Vickers microdurometer and temperature measurements by Thermocouples. The methodology and results of this work could be used as a tool to optimized welding processes based on the prediction of mechanical properties such as yield strength and micro hardness.A. Hooda,*etal*.[11] were identified the empirical relationship of process parameters to predict the yield strength of inert gas metal arc welded AISI 1040 medium carbon steel. The Process parameters such as welding voltage, current, wire speed and gas flow rate were studied. The experiments were conducted based on a four-factor, three-level, and face centered composite design matrix. Response Surface Methodology (RSM) was applied to optimizing the MIG welding process parameters to attain the maximum yield strength of the joint. S.D.Ambekar and S.R.Wadhokar [12] were studied Parametric Optimization of Metal inert gas welding process by using Taguchi method on stainless steel AISI 410.Sixteen experimental runs (L16) based on an orthogonal array Taguchi method were performed. The ANOVA and signal to noise ratio is applied to identify the most significant factor and predicted optimal parameter setting. This paper presents the effect of welding parameters like welding speed, welding current and wire diameter on penetration.

## III. DISCUSSION

From the available literature studied by various researchers the following discussion is made.

### 1] Effect of heat input on HAZ width and Mechanical properties of material

In arc welding, energy is transferred from the welding electrode to the base metal by an electric arc. When the welder starts the arc, both the base metal and the filler metal are melted to create the weld. This melting is possible because a sufficient amount of power is supplied to the electrode. Heat input is a relative measure of the energy transferred per unit length of weld. It influences the cooling rate, which may affect the mechanical properties and metallurgical structure of the weld and the HAZ.

Heat input cannot be measured directly. It can be calculated from the measured values of arc voltage, current and travel speed. Heat input is calculated as the ratio of the power (V x I) to the velocity of the heat source (S).

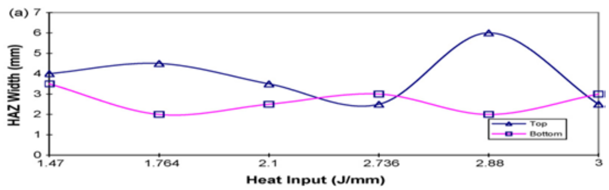



Fig-3 (a) Influence of heat input on heat-affected zone (HAZ) width. [Ref.1]

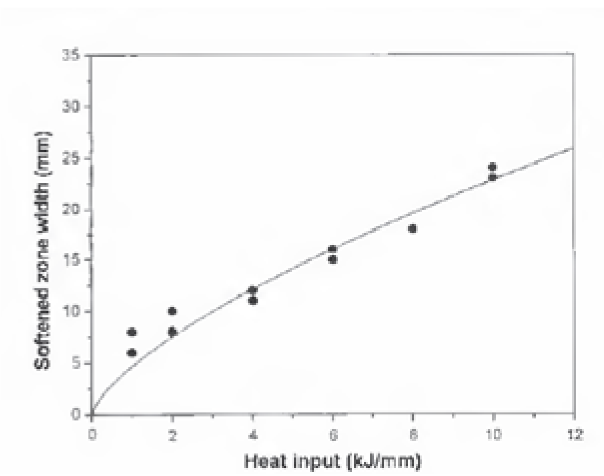



Fig-3 (b) Variation in softened zone width as a function of heat input. [Ref.4]

Variation of heat affected zone width is a function of heat input as heat input increases gradually increases the HAZ width shown in Fig (a) and (b). Varying the heat input will affect the material properties in the weld. As heat input increases Yield strength and tensile strength decreases and percent elongation increases. Variation of hardness of material is a function of heat input as heat input increases hardness of the material decreases at a specific level after that it reaches at a constant value shown in Fig (c) and (d).

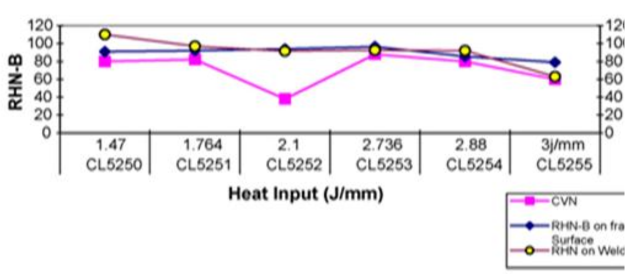



Fig-4 (a) Variation of hardness as a function of Heat input. [Ref.1

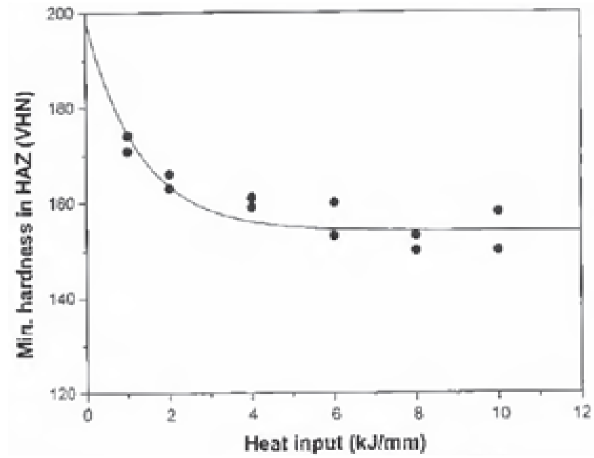



Fig-4 (b) Relation between hardness and heat input. [Ref.4]

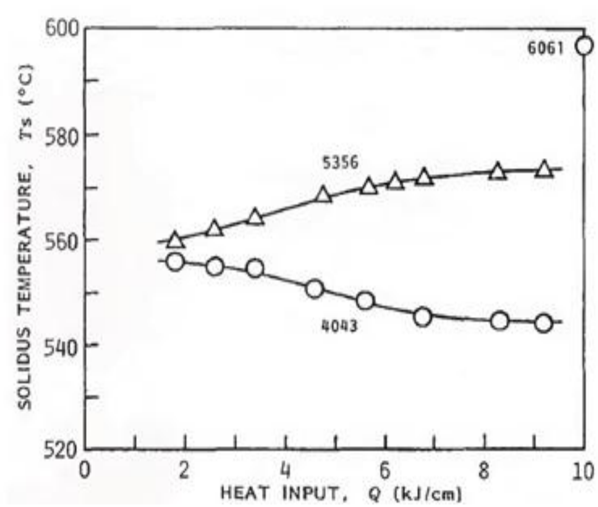


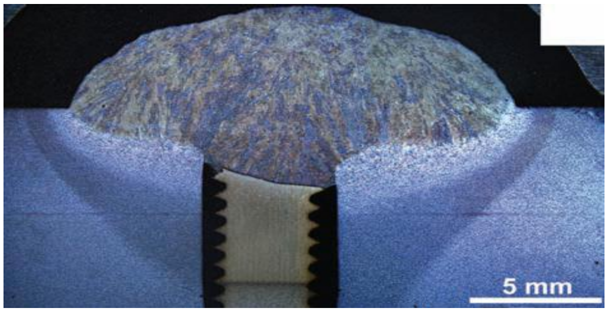

Fig-4(c) Relation between solidus temperature and heat input.

[Ref.5]

Variation of heat input also affects on solidus temperature of material, as heat input increases solidus temperature increases for magnesium based filler material used ie.5356 and solidus decreases for silicon based filler material used ie.4043. Shown in Fig (e). On the basis of this information we can select filler material for welding.

**2] Effect of heat input and preheating on microstrucre of material**

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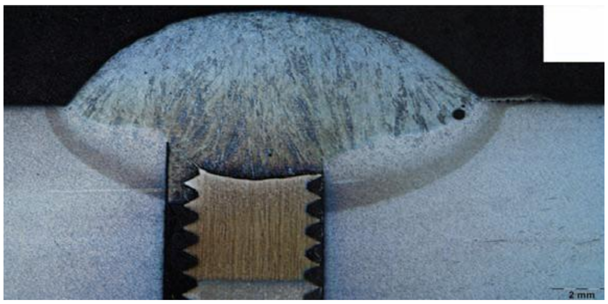

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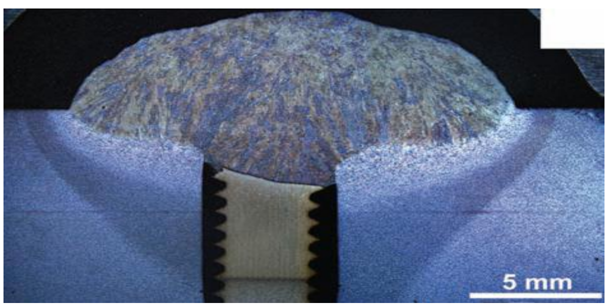


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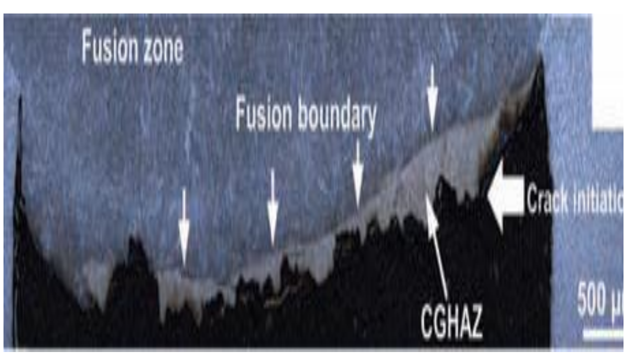
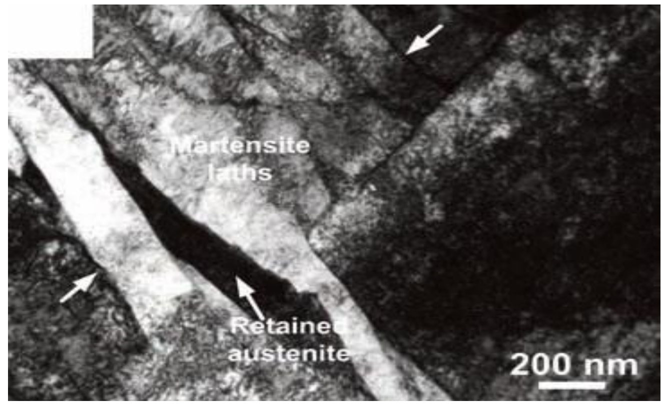



[D]

Fig-5 (a) Macrostructure of implant test specimens welded under different Conditions. A- — Weld with low heat input; B — weld with high heat input; C — weld with low heat input, preheat at 150°C beforeWelding; D — macrostructure of a fractured implant specimen after loading showing the fracture path. [Ref.3]

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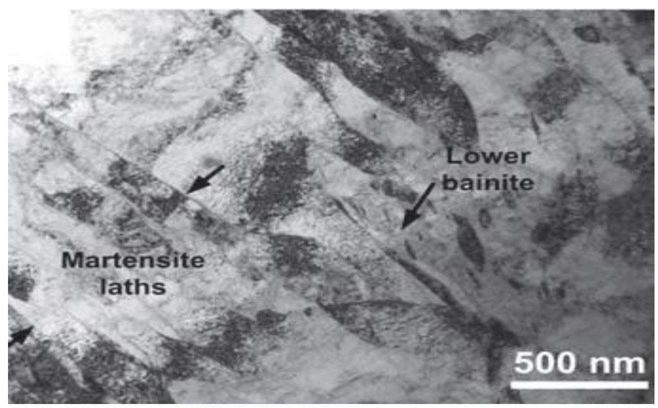


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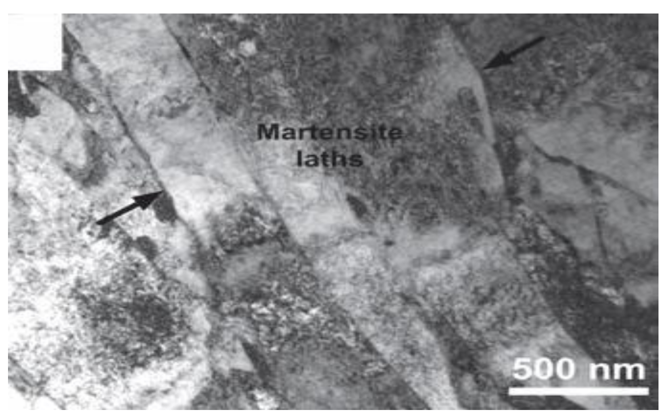


 

[C]

Fig-5 (b) Bright-field TEM micrographs for the CGHAZ of BA-160. A — Weld with low heat input; B — weld with high heat input; C — weld with low heat input, preheat at 150°C before welding. [Ref.3]

In microstructure study diffusion-controlled transformation products such as ferrite or pearlite cannot be observed and martensite is the predominant feature in the coarse grained HAZ due to the high alloy addition in BA-160 steel. This results in high hardenability shown in Fig-a (A to C). Further investigated under higher magnification as shown in Fig-b (A to C) a packet of martensite laths can be observed at lower heat input. The dark region between martensite laths is retained austenite due to high nickel addition in BA-160 steel. At higher heat input lower bainite is formed in the CGHAZ under slower cooling rates. Martensite laths were observed in high heat input with preheating. The mixture of martensite and lower bainite has a lower hardness as compared to the martensite microstructure formed with low heat input. When preheat is applied with low heat input welding conditions, the hardness is decreased and the microstructure is a mixture of martensite and a small fraction of bainite.

3] **Effect of Distance from weld centerline on the mechanical properties of material**

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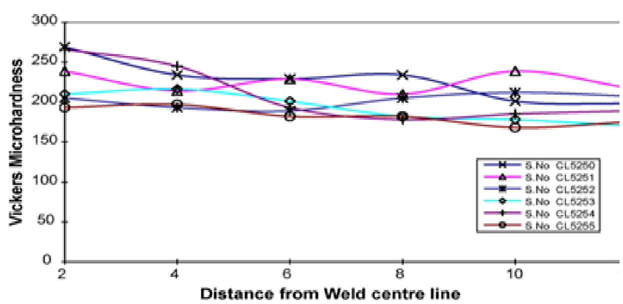


Fig-6 (a) Relation between hardness and Distance from weld centre line. [Ref.1]

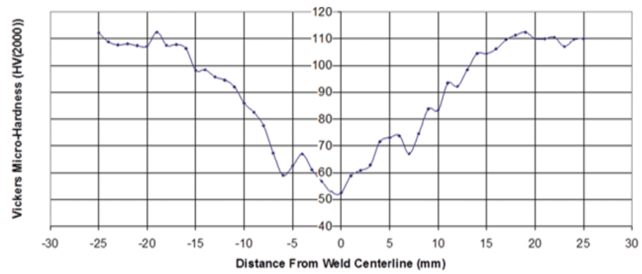


Fig-6 (b) Relation between hardness and Distance from weld centreline. [Ref.2]

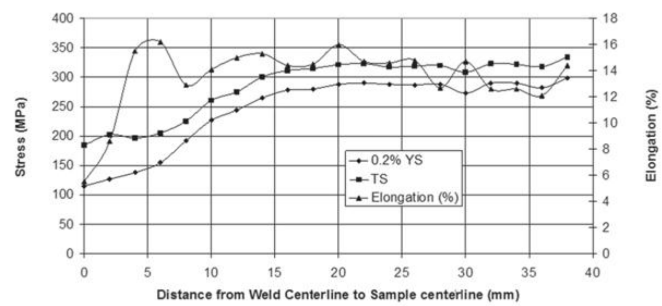


Fig-6 (c) Relation between stress and Distance from weld centreline. [Ref.2]

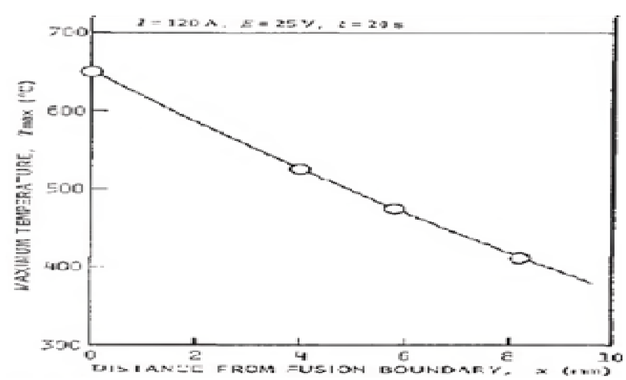


Fig-6 (d) Relation between Maximum Temperature and Distance from fusion boundary. [Ref.5]

As we observe from weld centreline to base metal, Temperature of material decreases, hardness of the material increases also tensile strength, yield strength and elongation of the material increases. This shows that the values of hardness and mechanical properties are lower in the HAZ portion shown by Fig-6 (a) to (c). During welding the heat transfers through conduction into the base material adjacent to the weld. The weldment is divided into three distinct areas: the weld metal, the heat-affected zone adjacent to the weld, and the base material beyond the HAZ that has been unaffected by the welding operation. The HAZ portion consist of different zones adjacent to the weld metal like grain growth zone, recrystallised zone, partially transformed zone and tempered zone.

## IV. CONCLUSION

From available literature it is observed that for estimation of Heat affected zone, micro hardness measurement from weld metal to base metal is necessary, by which HAZ and its sub-zones can be thoroughly studied. However temperature distribution by using thermocouple wires helps to study the cooling rate and its effect on mechanical properties of propagate the specimen. During tensile testing with universal testing machine, it is observed that fracture may possible at HAZ or the area of HAZ where maximum hardness found. Because it is observed increment in HAZ hardness introduce more brittleness, Hence, it is necessary to predict the HAZ by controlling welding parameters such as current, voltage and speed or heat input. Also prediction may possible by applying different cooling conditions with its different mediums, like conditioned air, oil, water etc. The preheating of weld specimens may gave better improvement for prediction of HAZ. Microstrural study from weld metal to base metal with the help of optical microscope is necessary to study the grain size, percentage of phases and its effect on mechanical properties of metal like Hardness, toughness, tensile strength, yield strength etc. Most of the researchers used Gas metal arc welding process for the above study because of its advantages over other welding techniques, like high welding speed, less distortion, no slag removal, high weld metal deposition rate, high weld quality, precise operation etc. Al alloy 6061 used where good corrosion resistance and strength required like marine fittings, pipelines, aircraft and aerospace components, heat exchangers, bicycle frames etc.

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