A Review on TIG/MIG Welded Joints

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Abstract

In the present review article, the research and progress in tungsten inert gas (TIG) and metal insert gas (MIG) welding of different materials are critically reviewed from different perspectives. Gas tungsten arc welding have been used to investigate the weld-ability of high strength alloys. Some important process parameters of TIG and MIG welding and their effects on weld quality are discussed. The mechanical properties of welded joints such as tensile strength, hardness, and other important structural properties are also reviewed. The aim of this research paper is to review the recent progress in TIG and MIG weldments of different materials and to provide a basis for follow-on research.

Keywords: MIG, Process Parameters, TIG, Welded Joints

I. Introduction

Welding is a material joining process in which two or more parts are coalesced at their contacting surfaces by a suitable application of heat and/or pressure. Many welding processes are accomplished by heat alone, with no pressure applied; others by a combination of heat and pressure; and still others by pressure alone, with no external heat supplied. In some welding processes, a filler material is also added to facilitate coalescence. Among all welding process gas tungsten arc welding (GTAW) process is a very versatile, all-position welding process that is widely used to join Ni-/Co-base alloys. TIG welding developed during 1940 at the start of the Second World War. In GTAW, the heat for welding is generated from an electric arc established between a non-consumable tungsten electrode and the work-piece. GTAW can be performed manually or adapted to automatic equipment, and can be used in production as well as repair welding situations. GTAW is most commonly used to weld thin sections of stainless steel and non-ferrous metals such as aluminum, magnesium and copper alloys. The process grants the operator greater control over the weld than competing processes such as shielded metal arc welding and gas metal arc welding, allowing for stronger, higher quality welds. However, GTAW is comparatively more complex and difficult to master, and furthermore, it is significantly slower than most other welding techniques. In spite this, it has further more advantages over other types of welding processes and welds almost all metals including dissimilar ones with a wide range of power supplies.

II. Literature Review

In recent years, considerable research work has been carried out throughout the world for predicting the strength and other mechanical properties of different kinds of materials welded by gas tungsten arc welding (GTAW) or tungsten inert gas welding (TIG) process. A brief and selective review of the relevant available information is presented under the following headings. The available literature is categorized in the following broad areas:

- On the basis of effect of process parameters.
- On the basis of optimization technique.
- On the basis of residual stress formation during welding process.
- On the basis of microstructure effect.

A. *On the Basis of Effect of Process Parameters*

Gadewar SP et al. [1] investigated the effect of process parameters on bead geometry of welded joints. TIG welding was performed on 3 mm thick 304 stainless steel. The test result shows that, as the welding current and gas flow rate increases with the thickness of the work piece the front width and back width value across the weld was also increases from 3 to 5 mm for 1 mm thick work piece and from 4 to 6 mm for 2mm thick work piece which affect the mechanical property of welds with great extent.

Wang Q et al. [2] studied the influences of process parameters of TIG arc welding on the microstructure, tensile property and fracture of welded joints of Ni-base super-alloy. For welding, plate width of 1.2-1.5 mm, welding current in the range of 55-90 A, with variable welding speed in the range 2100-2900 mm/min was used. From experimental result it was observed that, the heat input increases with increase of welding current and decrease of welding speed.

Raveendra A. et al. [3] performed experiment to check the effect of pulsed current on the characteristics of weldments by GTAW. The 3 mm thick sheet of steel were tested using different frequencies. More hardness found in the HAZ zone of all weldments may be due to grain refinement. Higher tensile strength found in the non-pulsed current weldments. The researcher observed that UTS and YS value of non-pulsed current were more than the parent metal and pulsed current weldments. The geometry of the weld specimen prepared by the author is shown below in Fig. 1.

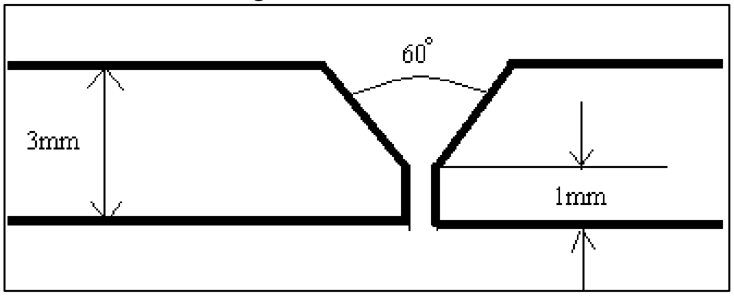

Fig. 1: Edge Preparation of Weld Specimens [3].

The importance of parametric variation effect of GMAW process as reported by Saha S et al. [4] shows that higher welding speed along with higher welding current (at same heat input level) enhance the weld metal mechanical properties of AISI 304 SS welds of 4mm thickness. Failure of welded joint during tensile deformation is shown in the figure in which weld metal W1 shows comparatively higher strength than weld metal W2. The tensile stress-strain curve of weld metal is shown below in Fig. 2.

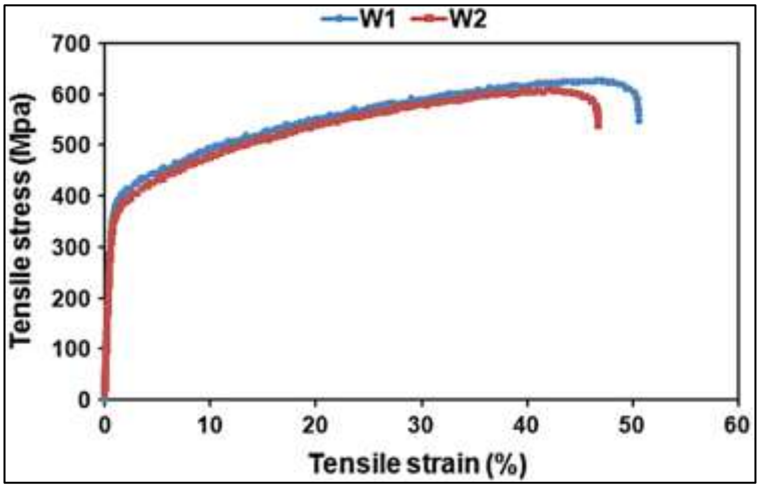

Fig. 2: Tensile Stress-Strain Curve of Weld Metal [4].

Mathur A et al. [5] studied the properties of gas tungsten arc weld of AISI 304 stainless steel of 6 mm thickness. Welding was performed with current in the range 48-112 A and gas flow rate 7 -15 l/min. From the analysis it was concluded that, due to the presence of various alloying elements and post weld heat treatments the tensile strength and ductility of the base metal is significantly higher than the weld bead.

Khoushid AM et al. [6] studied the mechanical properties of welded aluminum 6061pipe using three different types of welds. Weldments with rotation speed (1800 RPM) and travel speed 4mm/min of MIG, TIG and Friction welding were compared. The microstructure of the welds, including the nugget zone and heat affected zone, has been compared and concluded that the micro hardness values are higher in the weld region of FSW joints compared to MIG and TIG. Furthermore, FSW welds exhibit higher strength values compared to others.

Kumar CR A et al. [7] studied the influence of process parameters i.e. current, welding speed and gas flow rate of 316LN stainless steel using TIG welding. The response surface methodology is employed to develop the empirical relationship. Using the Finite Element analysis numerical data generated on the influence of process variables on weld-bead geometry, regression models correlating the weld-bead shape parameters with the process parameters and the experimental result shows that the welded steel joint is at 95 % confidence level.

Singh N et al. [8] performed TIG welding of grade 202 AISI stainless steel and compare the single V butt and double V butt joint at different current rates by keeping other parameters constant. On the basis of tensile strength, micro hardness and microstructure of weldments it was obtained that the double v joint obtained at high current has more tensile strength, hardness and toughness than the single V joint.

B. On the Basis of Residual Stress Formation During Welding Process

The effect of microstructure, hardness distribution and tensile properties of welded butt joints of 6063 T6 aluminum alloy have been studied by Singh P et al. [9] using conventional TIG and Friction stir process. From result the heat affected zone of friction stir welding is narrower having higher strength and ductility at same temperature. Furthermore, friction stir welds required less pre-operations and prevents joints from fusion related defects compared to TIG welding joints.

Sivakumar J et al. [10] proposed simulations of the welding process of thermal welding for butt joint using finite element analyses. The base metal is aluminum alloy AA6061 – T6. The simulations are performed with the commercial software ANSYS. The temperature distribution pattern and magnitude obtained from this simulation is used for computation of the residual stresses and distortion due to welding which are the major sources for weld crack. The residual stresses obversed by the author at around 10 mm away from weld is shown below in Fig. 3.

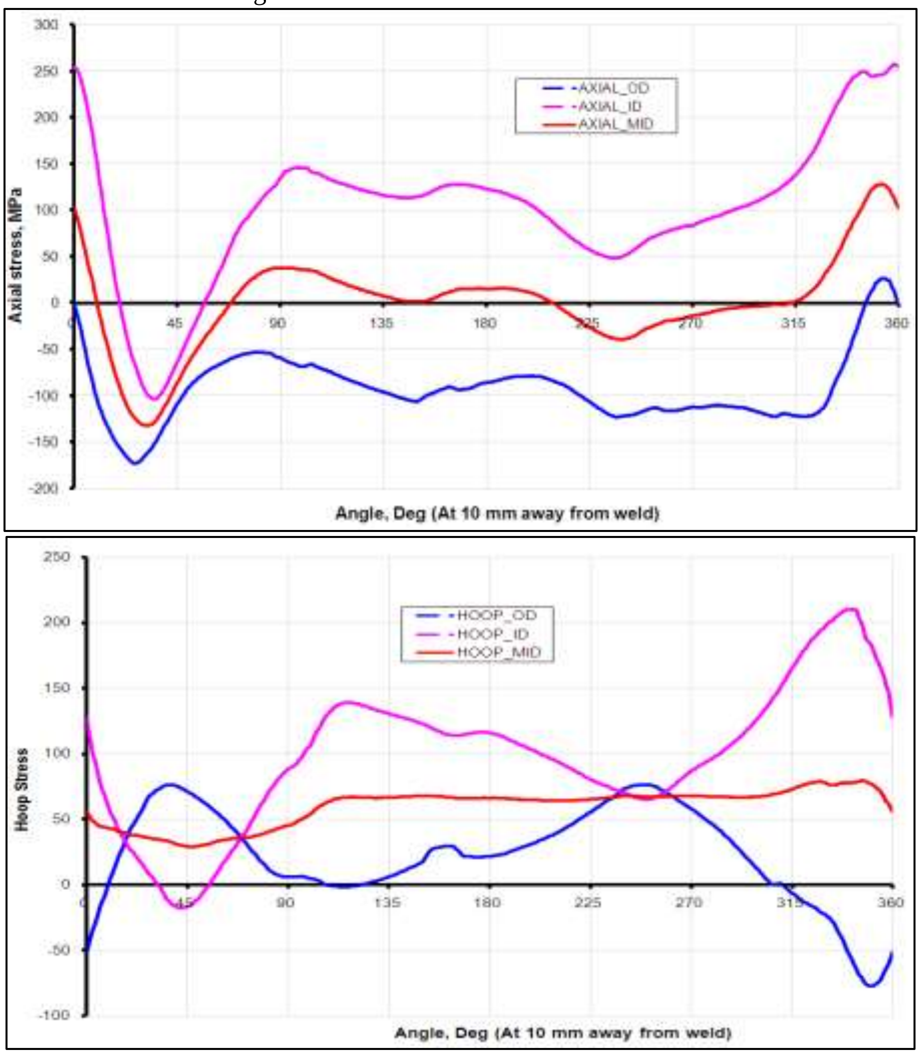

Fig. 3: Residual Stress at 10 mm Away From Weld around the Circumference [10].

Prasad VV et al. [11] studied the residual stress developed during circumferential TIG welding by 3D simulation ANSYS code. For this the temperature histories for outer and inner surfaces are plotted. The high temperature gradients in the surfaces lead to a plastic deformation in and around the weld zone. During the cooling phase due to the shrinkage and deformation in the weld zones. High compressive stress is developed on the outer surface and a tensile residual stress is developed on the inner surface. That is, from outer surface to inner surface the nature of residual stress changes from compressive to tensile.

Limwongsakorn S et al. [12] proposed finite element model for determining the effect of corrosion fatigue from TIG welding process on AISI 304 stainless steel. The residual stress result obtained from the FEA model with testing condition of frequency (f) = 0.1 Hz and the equivalent load of 67.5 kN (equal to 150 MPa) with R = 0.25 showed that corrosion fatigue life of 1,794 cycles.

Aggarwal HK et al. [13] investigated the effect of thermal fatigue on mechanical behavior of the heat affected zone on ferritic side of bimetallic welds. The bimetallic weld of 6mm thickness of ferritic steel SA516 Grade 70 and stainless steel 304L were fabricated using TIG welding process. The result show that the ultimate tensile and yield strength increases with increasing number of cycles. Further, due to increase in number of cycles in thermal shock assessment of bimetallic weld zone the material hardens with decrease in ductility.

Skriko T et al. [14] investigated the effect of stress ratio on the fatigue strength of TIG-dressed fillet weld joints of S960 grade steel. Statistical analyses using finite element (FE) modeling were performed to define geometric parameters and their effect on the stress concentration of the TIG-dressed fillet weld joints. From the experimental result it was concluded that, the fatigue strength of TIG-dressed ultra-high strength steel fillet weld joints decreased when the applied stress ratio R, was increased. Moreover, TIG-dressing produced high compressive residual stresses towards the base material in the vicinity of the TIG-dressed region. FAT values from experimental fatigue tests with different stress ratios is presented below in Table 1.

Table – 1
FAT Values from Experimental Fatigue Tests with Different Stress Ratios [14].

	m	$FAT_{50\%}$	$FAT_{95\%}$ (k_1)	$FAT_{95\%}$ (k_2)	m	$FAT_{50\%}$	$FAT_{95\%}$ (k_1)	$FAT_{95\%}$ (k_2)
All R	4	254	190	200	2.47	178	128	135
R = 0.1	4	280	219	238	3.64	261	200	218
R = 0.25	4	268	244	252	4.01	269	244	252
R = 0.38	4	255	186	209	1.90	142	89	106
R = 0.5 - 0.6	4	213	144	166	4.43	222	156	178

Ferro P et al. [15] proposed a numerical model for the TIG-dressing process in which all metallurgical and mechanical phenomena were taken into account in the residual stress computational process. From the experiment, it was observed that the stress distribution at the weld toe of the as-welded joint was found to be positive (tensile stress) and highly concentrated at the notch tip. While, the residual stress redistribution induced through TIG-dressing is not singular and is changed from tensile in nature to compressive.

C. *On the Basis of Microstructure Effect*

Hussain AK et al. [16] investigated the effect of welding speed on tensile strength of the welded joint by TIG welding process of AA6351 Aluminium alloy of 4 mm thickness. The strength of the welded joint was tested by a universal tensile testing machine. Welding was done on specimens of single v butt joint with welding speed of 1800 -7200 mm/min. From the experimental results, it was revealed that strength of the weld zone is less than base metal and tensile strength increases with reduction of welding speed.

Amudarasan NV et al. [17] studied the tensile and impact properties of AISI 304L stainless steel using Gas tungsten arc welding with austenitic and duplex stainless-steel filler metal. Welding was done on specimen of single V butt joint of 3mm thickness. From the experimental results, it was found that the austenitic stainless-steel joints fabricated using duplex stainless-steel filler metal are superior compared to the joints fabricated using austenitic stainless steel.

Mortezaie A et al. [18] have welded AISI 310S austenitic stainless steel with Inconel 718 using gas tungsten arc welding (GTAW) process using different filler combinations to determine the relationship between the microstructure of the welds and the resultant mechanical and corrosion properties comprising of austenitic as well as nickel based grades, where Inconel 82 filler metal has been reported to offer optimum properties at room temperature also it has exhibited higher corrosion resistance among all tested filler metals.

The effect of single pass and multipass (double and triple pass) on mechanical and corrosion behavior of GTA welded AISI 304L joints have been studied by Mirshekari GR et al. [19] and it is reported that due to the increase in the d- ferrite content and grain refinement the hardness values from the weld zone towards the base metal was increased in all weldments and also as the number of weld passes increase, the hardness and corrosion resistance of these joints also increases. The hardness at different zones of the weldments is shown in Fig. 4.

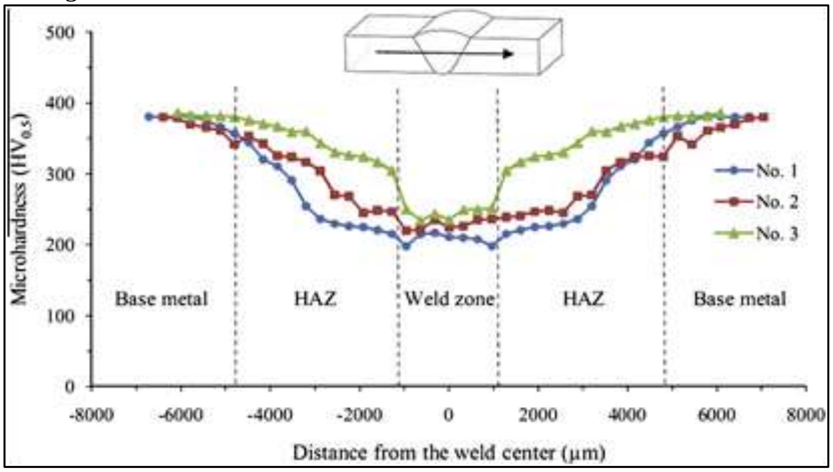

Fig. 4: Microhardness Profile Showing Hardness of Different Zones of The Weldments [19].

Anawa EM et al. [20] have studied the weldability of 316 austenitic stainless steel using automatic tungsten gas shielded arc welding process and the result show that welding current is inversely proportional with tensile strength and directly proportional with impact strength, which directly affects the weld quality of steel joint. While increasing gas flow rate increases the impact and tensile strength which improves the toughness and ductile properties of the weld.

Alexopoulos ND et al. [21] examined the mechanical behavior of Inconel 718 TIG welds. For this Tensile, constant amplitude fatigue and fracture toughness tests were performed in welded specimen. From experimental results it was observed that, tensile strength properties were remains same while the tensile ductility decreased by more than 40 %. Cyclic stress-strain curves showed that Inconel 718 experiences a short period of hardening followed by softening for all fatigue lives. However, a marginal decrease was noticed in the toughness of the welded specimen.

Ito K et al. [22] investigated the effect of friction stir processing on TIG weld beads to improve the fatigue resistance of TIG welded SS400 steel plates. By using friction stir process, the tensile properties were merely same. But the bending strength and bending fatigue resistance of TIG-welded steel plates were increased nearly about 40%. The FSP produces ultrafine grains beneath the surface which improves surface hardness.

Li S et al. [23] studied and compared the microstructure, hardness profile, tensile properties and fatigue crack growth behavior of tungsten inert gas (TIG) welded DP780 steels with different notches. The experimental result shows that the hardness of the sub-critical HAZ (soft zone) reduced significantly to an average of 220 HV compared to the BM hardness (~270 HV). Further, the joint showed a superior tensile strength with a joint efficiency of 94.6%.

BA Rajshekhar et al. [24] proposed a finite element analysis of welded joint to find the strength of joint under cracking. A triangular weld of 10mm thickness is considered to join the members. From destructive technique analysis, the result shows that the life of a joint decreases with increases of fatigue stress. Moreover, it is always desirable to have lesser alternating stress for better life of the joint. The Minimum and alternating stress in the structure examined by the author is presented below in Table 3.

Table – 2
Minimum and Alternating Stress in The Structure [24].

Weld condition	*Minimum Stress Across the Section (Mpa)*	*Fatigue Stress for Alternating Stress (Mpa)*
Full	*24.049*	*147.4745*
80%	*26.67*	*144.08*
60%	*29.707*	*144.811*
40%	*51.092*	*156.215*
20%	*58.238*	*164.519*

Livieri P et al. [25] analyzed the thickness effect in thin steel welded structures under uniaxial fatigue loading. Using non-load carrying and load-carrying cruciform joints made of steel of two millimetres thickness. From the result, the numerical analysis showed that the fatigue failure moves from weld toe to weld root as a function of the main plate thickness and the transition plate thickness depends on the weld joint shape.

D. On the Basis of Optimization Technique

A study on parametric optimization of pulsed GTA welded 304L SS of 3mm thickness in the autogenuous mode of square butt joint by Giridharan PK et al. [26] concludes that welding speed affects the bead geometry of these welds most influentially followed by the pulse current while other parameter like pulse current duration have least affect among the considered parameters.

Chuaiphan W et al. [27] have investigated the effect of welding speed on microstructures and mechanical properties of GTA-welded austenitic stainless steel (AISI 201 SS) joints and the results show that with increase in welding speed, a reduction in the dendrite length and inter-dendritic spacing in the weld zone occurs, which consequently affects the mechanical properties of these joints.

Lee JH et al. [28] investigated the effect of three different welding methods on the microstructural and mechanical characteristics of dual phase steel (DP780). By experiment it was found that the fatigue life of laser-and TIG-welded steel was similar, with both being greater than that of MAG-welded steel. The fatigue resistance of laser and TIG-welded materials is comparable, but the resistance of a MAG-welded material is poor at all strain amplitude. The Fig.5 below shows the tensile stress-strain curves of the base metal and welded materials.

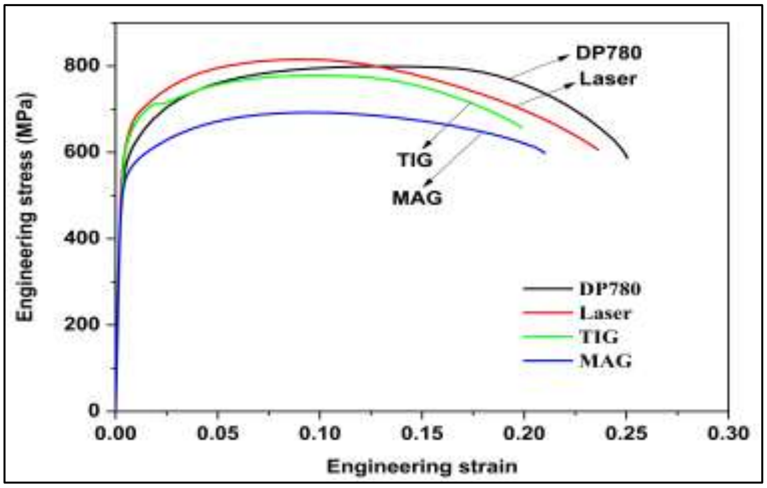

Fig. 5: Tensile Stress-Strain Curves of the Base Metal and Welded Materials [28].

Pujari KS. et al. [29] performed TIG welding of AA 7075-T6 Aluminium alloy and compares the weld pool geometry. On the basis of Taguchi approach and Utility concept, a model was developed to optimize various process parameters. The experimental result analysis showed that the combination of higher levels of Peak current, Base current, Gas flow rate and lower level of welding speed and intermediate level of Pulse on time and Frequency is essential to achieve simultaneous maximization of Penetration and minimization of Face width and Back width.

Dewan MW et al. [30] studied the effect of rotating-bending and pulsating torsional load on welded and non-welded AISI 1018 low carbon steel rods. For this, a multi-axail rotating-bending-torsion fatigue testing unit was designed to evaluated the effect of biaxial load on welded structure. It is observed that the rotating bending fatigue life of welded specimen reduced compared to base metal as a result of complex thermal cycle during welding process. And under combined loading conditions base metal specimens did not exhibit any significant difference on the fatigue behavior. However, for the welded specimens, the fatigue strength was reduced by about 12.8%.

Arunkumar A et al. [31] investigated the breaking stress under tensile load in the weldment of T-joint using TIG welding process. Using low carbon steel as a base material and copper filler material. Also, Taguchi optimization method was used to optimize the fillet weld section in experimental analysis. The investigation shows that 0.3mm gap between parent material with 60º angle gives a maximum breaking stress. The analytic results for stresses with different angle are shown below here. Also by increasing the gap the breaking stress gradually decreases. The von-misses stress with different angle and gape observed by the researcher are presented in Table 2.

Table – 3
Analysis Results for Von-Misses Stress with Different Angle and Gape [31].

Gap Between Parent Plates (mm)	*Breaking Stress for 25 KN (Mpa)*		
	30°	*45°*	*60°*
0.3	*140.07*	*197.17*	*242.04*
0.6	*142.89*	*197.91*	*247.02*
0.9	*149.12*	*205.09*	*252.73*

Vinoth A et al. [32] studied the effect and compares the different techniques of shielding gas supply for pure titanium of grade-2 using gas tungsten arc welding. Using four types of shielding gases i.e. pure argon, pure helium, premixed gases of (Ar+He) 75:25% respectively and alternative gas supply of Argon and Helium. From the experimental result, it was evaluated that the alternate shielding gas improves the tensile strength, welding speed, ductility, reduces crack porosity and produces good quality welds.

Table – 4
Various Workpiece Geometry Taken By Researchers.

S.No	*Welding Process*	*Current (A)*	*Speed (mm/min)*	*Voltage (V)*	*Gas flow rate (l/min)*	*Types of Welding Joints*	*Plate Thickness (mm)*	*Reference*
1	*GTAW*	*226*	*75*	*29.5*	*16*	*Square butt joint*	*4*	*Saha S et al. [4]*
2	*MIG*	*180*	*194*	*20*	*-*	*Butt Weld*	*-*	*Khoushid AM et al. [6]*
3	*TIG*	*170*	*100*	*20*	*-*		*-*	
4	*TIG*	*150*	*130*	*-*	*17*	*Butt joint*	*-*	*Kumar CR A et al. [7]*
5	*TIG*	*135*	*180 (Avg)*	*-*	*15*	*V Butt joint*	*6*	*Singh N et al. [8]*
6	*TIG*	*90*	*120*	*-*	*20*	*Butt joint*	*150×75*	*Singh P et al. [9]*
7	*GMAW*	*249 (Avg)*	*354*	*31.3-31.7*	*-*	*Butt Joint*	*5*	*Skriko T et al. [14]*
8	*TIG*	*180*	*234*	*13.2*	*-*			
9	*GTAW*	*90*	*84*	*14*	*10*	*V Butt joint*	*3*	*Amudarasan NV et al. [17]*
10	*GTAW*	*59*	*150*	*12*	*-*	*Butt joint*	*6*	*Mirshekari GR et al. [19]*
11	*GTAW*	*211.4*	*16*	*14*	*10*	*Square Butt joint*	*3*	*Giridharan PK et al. [26]*
12	*GTAW*	*85*	*90*	*15*	*-*	*Square Butt joint*	*150×100×2*	*Chuaiphan W et al. [27]*
13	*GTAW*	*95*	*150*	*13*	*-*			
14	*GTAW*	*110*	*210*	*11*	*-*			
15	*GTAW*	*152*	*-*	*11*	*40*	*V Butt joint*	*6*	*Vinoth A et al. [32]*

III. CONCLUSION

The above sections, evaluates the area where several research work carried out on TIG/MIG welding in the past. By considering several aspects of corrosion resistance properties, microstructure, dissimilar metal welding and Optimization of different welding process using experimental and numerical approaches. Some of the results are mentioned below:

1) Using higher welding speed with higher current enhance the mechanical properties of the weld metal.
2) Welding speed adversely affects the bead geometry of welded joints.

3) Alternating shielding gas using in the TIG weldments increases tensile strength, reduces crack porosity and ductility of the weld.
4) Under uniaxial fatigue loading the fatigue failure moves from weld toe to weld root.
5) During commercial TIG welding the residual stresses changes from outer to inner surface from compressive to tensile.
6) The size of heat effected zone is less when low heat input is used while welding stainless steel using GTAW process.

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