# Experimental investigation on TIG welded of austenitic stainless steel L304

K.Perumal [1], N.Vivek [2], M.S.Venkataaramanan[3], R.Gurubalaji[4]

[1,2,] Assistant Professor, Department of mechanical engineering, K.S.R.College of Engineering, Tiruchengode,India.

[3,4,]BE Scholars, Department of mechanical engineering, K. S. R, College of Engineering, Tiruchengode,India.

[1]emailperumal@ksrce.ac.in, [3]emailm.s.ve1996@gmail.com, [4]email2013gurubalaji@gmail.com

**Abstract - The purpose of the present study is to investigates the effects of the different kinds of oxides fluxes($TiO_2$,$SiO_2$,$MnO_2$,$CaF_2$,) used in tungsten inert gas (activated TIG) process on weld bead penetration, mechanical properties(hardness) of type 304 stainless steel. The TIG welding was applied to 6mm thick stainless steel plates through a thin layer of flux to produce a bead-on –plate welded joint. The fluxes used were packed in powdered form, the bead-on –plate test was performed ,then the depth and width of the weld were measured using an optical projection machine, hardness were measured using Vickers hardness machine, Activating flux materials consisted of a different type of combination mixture. Experimental result indicate that using $CaF_2$ fluxes leads to a increase the depth of penetration compared with conventional TIG weldig process, but $TiO_2$ fluxes leads to decrease the bead width of penetration compared with conventional TIG weldig process. Experimental result indicate that using different type of mixing fluxes leads to a increase the depth of penetration compared with conventional TIG weldig process. Experimental result indicate that micro-hardness analysis across the weld profile yielded almost similar trend in both TIG and A-TIG welded sample with base metal having the highest hardness value and HAZ the lowest.**

**Keywords:** TIG welding, weld bead Penetration, flux, mechanicalproperties (hardness),stainless steel.

## 1.INTRODUCTION

Austenitic stainless steel SUS 304L has been widely used in aircraft industry, chemical processing (heat exchanger), food processing, Dairy industry (milk cans) and etc due to it's excellent strength and scale resistance at high temperature and highest corrosion resistance. The TIG welding process or (GTAW) is used when a good weld appearance and a high quality of the a weld are required. In this process, an electric arc is formed between a tungsten electrode and the base metal the arc region is protected by an inert gas or mixture of gases [1].

In TIG welding shielding gas plays an important role. Composition of a shielding mixture in [1.5% H2-Ar, 5%H2-Ar] arc welding depends mostly on the kind of material to be welded. The selection of the shielding gas should be considered the chemical-Metallurgical processes between the gases and the molten pool that occur during welding [2].

Two factors determine weld geometry,the first critical factor is weld metal chemical composition and the second factor is the adding of small quantities of surface-active elements to the weld pool thus the application of a layer of flux on the surface of the base metal before welding can effectively overcome the problem of variations in weld penetration [3].

TIG welding has mainly used for welding specimen with thickness of less than 6mm .In order to overcome this disadvantages of convectional TIG welding, activated TIG welding was invented. It is proved that activated TIG welding could

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increase the weld penetration at same time the weld width does not increase [4].

During welding, the arc heats a joint plate is locally, and thetemperature distributions in the weldment are not uniform. Heatingand cooling cycles induce non-uniform thermal strains in both

the weld metal and the adjacent base metal. The thermal strainsproduced during heating then produce plastic upsetting. Thesenon-uniform thermal stresses combine and react to produce internalforces that cause shrinkage and distortion.Experimental result show that a presence of the shrinkage and distortion in turnaffects the fabrication,precision(shapeand dimensional tolerance),and function (reliability and stability) of finished products [5].

Gas tungsten arc welding, also known as tungsten inert gas(TIG) welding, produces an arc between a tungsten electrode andthe workpiece. An inert gas shields the arc, electrode, and moltenpool from atmospheric contamination.When welding thinnermaterials, edge joints, and flanges, welders generally do not use filler metals However, for thicker materials, welders primarilyuse externally fed filler metal. TIG welding is a popular techniquefor joining thin materials in the manufacturing industries. Thistype of welding achieves a high quality weld for stainless steelsand non-ferrous alloys. Compared with gas metal arc welding,the major limitations of TIG welding include its inferior jointpenetration, its inability to weld thick materials in a single pass,and its poor tolerance to many material compositions, includingcast-to-cast variations in the composition of certain impurities, asdescribed [6].

The experimental result indicate that the $Cu_2O$, NiO, $SiO_2$, and CaO fluxes, there is aspecific range of flux quantities to enhance the weldpenetration in ATIG welding. The effective range of flux quantities for $SiO_2$ and CaO is relatively wider than thatfor the $Cu_2O$ flux. The $Al_2O_3$ flux has no effect on increasingthe weld penetration. The oxygen content in the weld pool plays animportant role in increasing the weld penetrationthrough the reversal of the surface-tension gradient onthe weld pool from negative to positive over a certainrange (70 to 300 ppm for SUS304 stainless steel).A too-low or too-high oxygen content in the weld doesnot enhance penetration [7].

The increases in weld depth and thedecrease in bead width are significant with use of the$Cr_2O_3$, $TiO_2$, and $SiO_2$. The greatest improvement functionin the penetration is with the use of $SiO_2$, but the$Al_2O_3$ led to the deterioration in the penetration andexcessive slag compared with the conventional TIG processfor stainless steel 304 welds. The CaO has no effecton A-TIG penetration.When using A-TIG welding, physically constricting theplasma column and reducing the anode spot, tends to increasethe energy density of the heat source and electromagneticforce of the weld pool, resulting in a relativelynarrow and deep weld morphology compared with the conventional TIG welding [8].

The results of this work have shown that the use of a flux, even of extremely simple formulation, can greatly increase(up to around 300%) the weld penetration in TIG welding. Itwas possible to obtain full penetration welds in 5 mm thickplates of austenitic stainless steel with no preparation andcurrents of about 230 A. The operational characteristics ofthe ATIG process were not very different from those ofconventional TIG welding, Therefore, simple fluxes of only one component presentan adequate performance for ATIG welding, resulting in agreat increase of penetration in comparison to TIG welding,without any important deterioration of the welding conditionsor of the microstructure of the welds [9].

The experimental results indicate that using Using $SiO_2$, $MoO_3$, and $Cr_2O_3$ fluxes not only significantlyincreased penetration capability, but also improved mechanicalstrength of the grade 2205 stainless steel welds compared withconventional TIG weldsUsing activated TIG welding increased both the joint penetrationand the weld depth-to-width ratio. This in turn reducedthe angular distortion of the grade 2205 stainless steel activatedTIG weldment. In this study, grade 2205 stainless steel TIGwelding with $SiO_2$ flux produced a full joint penetration andthe greatest weld depth-to-width ratio. As a result, the angulardistortion value was almost zero [10]

Table 1
Chemical composition of base metal (wt.%)

| C | Si | Mn | Cr | Ni | Mo | Fe |
|---|---|---|---|---|---|---|

| | | | | | | |
|---|---|---|---|---|---|---|
| 0.012 | 0.294 | 1.16 | 18.26 | 8.48 | 0.066 | 71.4 |

In this study, six different kind of oxide fluxes were used to systematically study the effect of the single component flux on the appearance and specfic activating multi component flux composition to systematically investigate weld beadpenetration, mechanical properties in stainless steel (SUS304).

## 2. EXPERIMENTAL PROCEDURE

In this study, SUS304 austenitic stainless steel plate was selected as the test specimen Table1 list the chemical composition of this steel.Plates 6mm in thickness were cut into150×100mmstrips, roughly polished with 400 grit silicon carbidepaper to remove surface contamination, and then cleaned withacetone. Activated flux was prepared using sixkindsof singlecomponent oxides packed in powdered form($TiO_2$,$SiO_2$,$MnO_2$,$CaF_2$,ZnO,$Fe_3O$). These powderswere mixed with acetone to produce a paint-like consistency.Before welding, a thin layer of the flux was brushed on to thesurface of the joint to be welded. The coating density of flux wasabout 5–6mg/$cm^2$. Fig. 1 shows a schematic diagram of activatedTIG welding.

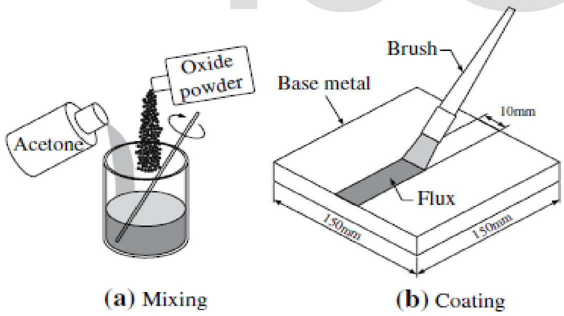


Fig 1. Schematic diagram of activated TIG welding

The care had been taken to apply flux in a uniform layer and the width of the coating was made slightly more than the width of the weld bead.Afterpainting the flux, the ethanol was allowed to evaporateleaving flux on the surface before welding. The melt runs were made manually at a constant speed of 150 mm/minute. The surface was cleaned with a wire brush to remove spatter. The welding parameters employed in this investigation are given in Table 2

The specimens of adequate size were cut from the weld bead in the transverse direction for macroscopic and microscopic analysis. The samples were ground and polished according to the standard metallographic practice with emery papers, alumina polisher and diamond paste polisher in the order. Polished specimens were etched with reagent of following composition

Etchant- 30 g$FeCl_3$ +10 ml HCl + 3 ml HnO3 + 20ml $H_2O$for macro and micro analysis. Etchant time was taken as 15 to 20 seconds.The macrostructure of the weld beads were observed in a stereo zoom microscope and images were recorded using a digital image capturing facility. The profile of the beads was measured with the help of Image j software.

Table 2Welding parameters

| | |
|---|---|
| Welding speed | 150 mm/min |
| Polarity | DCEN |
| Welding current | 140 A |
| Shielding gas | 99.9% Pure argon |
| Shielding gas flow rate | 12 L/min |
| Electrode used | 2.4mm diameter,2% thoriated tungsten |
| Arc length | 2 mm |
| Electrode tip angle | 55 degrees |
| Electrode tip | Taper |

The Vickers hardness testing method consists of indenting the test material with a diamond indenter, in the form of a right pyramid with a square base and an angle of 136° between opposite faces subjected to a load of 1kg to 100kg. The full load is normally applied for 10 to15 seconds. The two diagonals of the indentation left in the surface of the material after removal of the load are measured using a microscope and their

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average calculated as shown in fig 2. The area of the sloping surface of the indentation is calculated. The Vickers hardness is the quotient by dividing the kilogram of load by the square mm area of indentation

HV=1.854 F/D2

F= Load in Kg

D= Arithmetic mean of the two diagonals in mm

HV= Vickers hardness number

Here Micro Hardness survey with diamond pyramid indenter having 136$^o$ apex angle is carried out to study the hardness across the weldment covering weld interface, HAZ and base metal at 0.5kg load. The full load is almost applied for 20 seconds. Indentations are at a minimum span of 0.2 mm

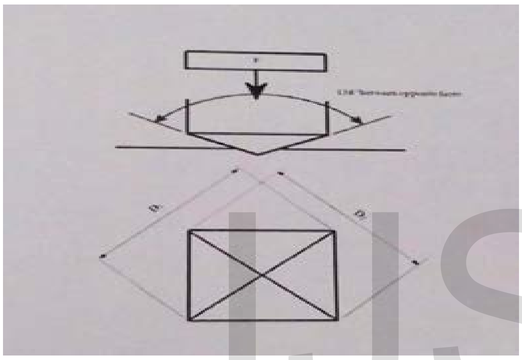


Fig 2. Vickers hardness indenter

## 3. RESULTS AND DISCUSSION

### 3.1. Evaluation of the electrode tip

The evaluation experimentwasperformed using a direct currentelectrode negative TIG power supply. Bead-on-plate TIG weldingwas carried out with and without SiO2 flux at electrode diameters of2.4 mm.The experimental results in Fig.3aclearly indicatedno damage to the tip of the 2.4mm electrode during TIG weldingwithout flux. However, the 2.4mm electrode tip melted seriouslyduring TIG welding with SiO2 flux (Fig. 3b) as a result of a higherheat input during activated TIG welding.The effectof activated flux and electrode diameter on arc voltage. The weldcurrent, travel speed, and electrode diameter were maintained at aconstant value, and it was found that the arc voltage increaseswhenactivated TIG welding techniquewasused.

### 3.2. Effect of oxide flux on weld bead penetration

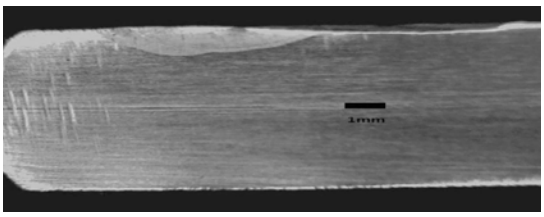
Figure 4 shows the cross-sections of TIG welds without and with flux in 6 mm thick stainless steel 304 plates. There is significant variation in weld depth and bead width of A-TIG weld morphology.

a The conventional TIG electrode with diameter 2.4mm

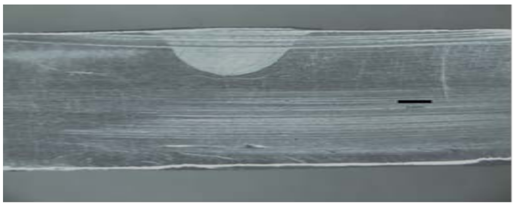
b The activated TIG electrode with diameter 2.4mm

Fig. 3. Effect of activated flux on TIG electrode tip

The increases in weld depth and the decreasein bead width are significant with use of the$CaF_2$, $SiO_2$compare to conventional TIG welding.The increase in weld depth and bead width significant with use of the $MnO_2$compare to conventional TIG welding. In the present work, the greatest improvement function penetration capability occurred with the use of $SiO_2$ 100% compared with the conventional TIG welding, However the $TiO_2$ has no effect on A-TIG pnetration.

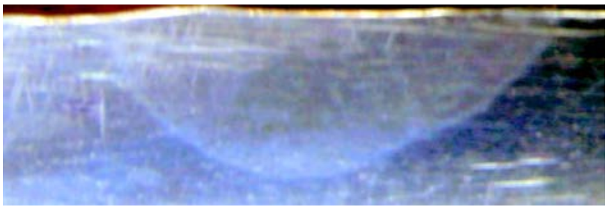


a Conventional TIG welding



b.With $SiO_2$ flux

c With $TiO_2$ flux

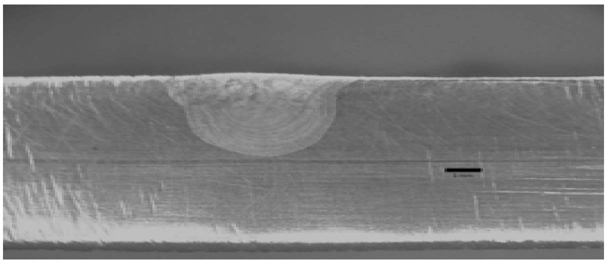


d With $CaF_2$ flux

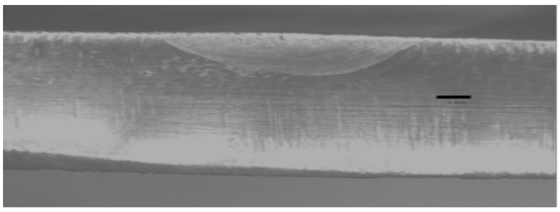
e With $MnO_2$ flux

Fig. 4. Effect of activatedflux on weld bead penetration.

It can also be seen in Fig.4 that TIG welding with $SiO_2$,$TiO_2$,$CaF_2$ can significantly increase the weld depth to bead width ratio compared with the conventional TIG welding.



a Multi flux composition 75% $SiO_2$ + 25% $TiO_2$



b Multi flux composition 50% $SiO_2$ + 50% $TiO_2$

Fig. 5 Effect of activated multi flux on weld bead penetration

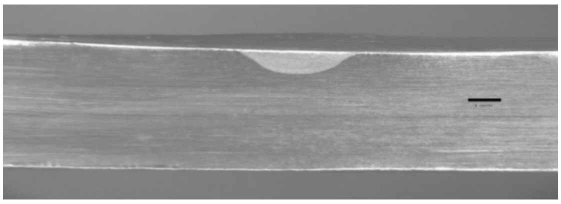


Fig 5 shows the cross- sections of TIG welds multi flux composition is significant variation in weld depth and bead width of A-TIG weld morphology. The increases in weld depth and the decrease in bead width are significant with use of the mixture of composition 75% $SiO_2$+ 25% $TiO_2$compare to conventional TIG welding. the greatest improvement function penetration capability occurred with the use of mixture composition 75% $SiO_2$ +25% $TiO_2$ flux 187% compared with the conventional TIG welding. It can also be seen in Fig.5 that TIG welding with mixtur of composition 75% $SiO_{2+}$25% $TiO_2$ can significantly increase the weld depth to bead width ratio compared 208% with the conventional TIG welding.

**3.3 Effect of Oxide Fluxes on Mechanical Properties**

Micro hardness analysis was conducted with diamond pyramid indenter at 500 g load across the weldment covering weld metal, HAZ(Heat Affected Zone) and base metal as shown fig.5. The experimental results of the hardness profile of the welds made with conventional TIG welding and A-TIGwelding are shown in the fig.6 and fig.7.

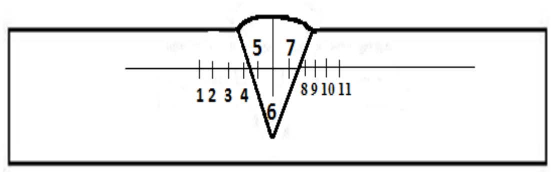



Fig.5 Location points for Vickers hardness analysis

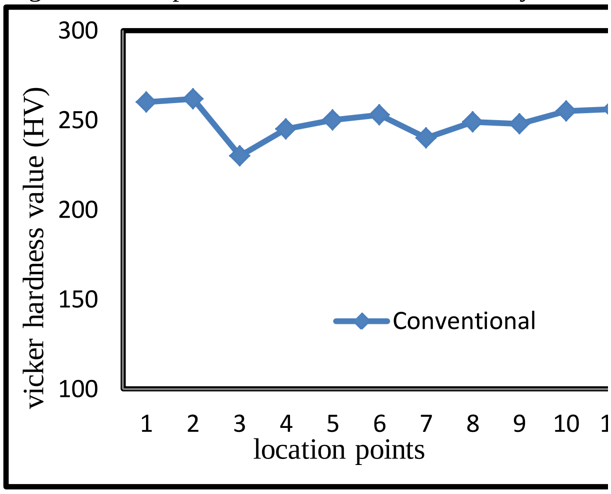



Fig.6 Micro hardness profile across the weldment for Conventionl TIG



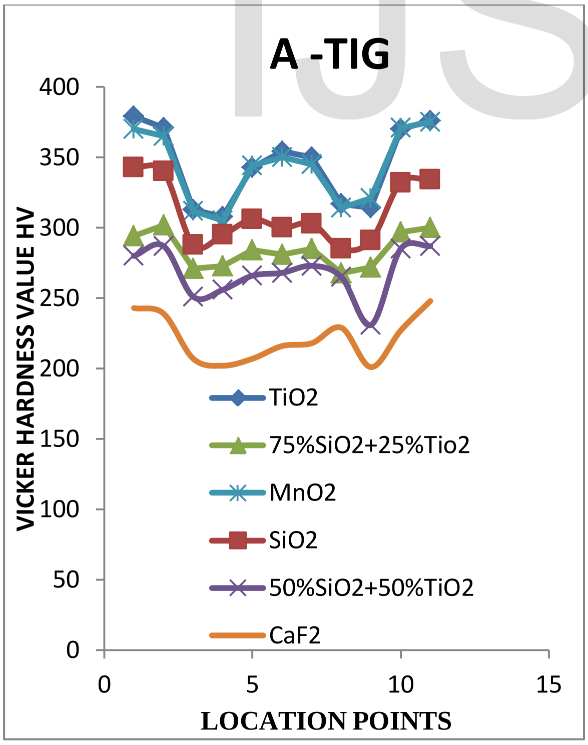



Fig.7 Micro hardness profile across the weldment for A-TIG welded specimens

The average value of hardness for normal TIG in weld region was 251 Hvwhile that in the HAZ was 231Hv value. Average base metal hardness was found to be 263 Hv, Hardness variation curves of all A-TIG welded samples showed similar pattern with weld metal having hardness value more than the HAZ. This may be due to increase in mean grain size after welding process and grain coarsening of austenitic phase in the HAZ . In all the results, base metal showed higher hardness value than weld and HAZ. Maximum% increase in Hv across weld region with respect to conventional TIG was observed for single flux $TiO_2$(39.23%), Maximum % increase in Hv across HAZ region with respect to conventional TIG was observed for single flux TiO2 (34.91%).

## 4. Conclusions

Activated TIG welding is an innovative improvisation of conventional TIG welding and it is now capable of improving the quality and productivity in a simple and economic manner which can be utilized effectively in the industrial field

- The results have shown that the use single fluxes have improved the depth of penetration of maximum of 100 % increase compared to conventional TIG welding. A maximum increase of 134% in aspect ratio was also observed compared to conventional TIG welding.

- The results have shown that the use multi fluxes have improved the depth of penetration of maximum of 186 % increase compared toconventional TIG welding. A maximum increase of 208% in aspect ratio was also observed compared to conventional TIG welding.

- The results have shown that the use single fluxes $TiO_2$have no improved the depth of penetration,However the increase in weld depth and bead width significant with use of the $MnO_2$compare to conventional TIG welding.

- Micro-hardness analysis across the weld profile yielded almost similar trend in both TIG and A-TIG welded sample with base metal having the highest hardness value and HAZ the lowest.

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