Keyhole Tungsten Inert Gas welding - A Review

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Abstract: Quality and productivity play important role in manufacturing market. The main objective of industries is to produce better quality product at minimum cost and increase productivity. Welding is the most vital and common operation use for joining of two similar and dissimilar parts. In this paper an overview of current research in Keyhole Tungsten Inert Gas (K-TIG) welding of different material has been presented. K-TIG is a high speed, single pass, full penetration welding technology that eliminates the need for wire, edge bevelling or skilled operators and produces flawless welds faster than TIG welding in materials up to 13mm in thickness. Fundamental concepts and definitions commonly used in keyhole Tig welding are introduced. The purpose of this review is to introduce the possibilities for further research in this field.

***Index Terms*: K-TIG, Keyhole gas tungsten arc welding, Microstructures, Mechanical properties, TIG**

I. INTRODUCTION

TIG welding is an arc welding process that uses non-consumable tungsten electrode to produce the weld. The weld area is protected from atmosphere by an inert shielding gas (argon or helium), and a filler metal is normally used. The power is supplied from the power source (rectifier), through a hand-piece or welding torch and is delivered to a tungsten electrode which is fitted into the hand piece. An electric arc is then created between the tungsten electrode and the work piece using a constant-current welding power supply that produces energy and conducted across the arc through a column of highly ionized gas and metal vapour. The tungsten electrode and the welding zone are protected from the surrounding air by inert gases. The electric arc can produce temperatures of up to 20000 ℃ and this heat can be focused to melt and join two different part of material. The weld pool can be used to join the base metal with or without filler metal. Schematic diagram of TIG welding and mechanism of TIG welding are shown in fig. 1 & fig. 2 respectively.[1]

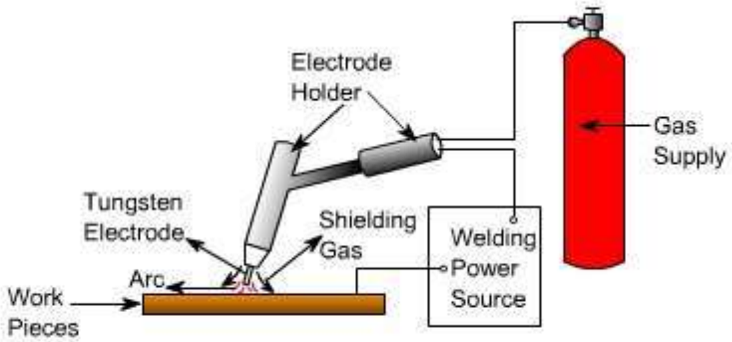

fig 1: schematic diagram of tig welding system.[1]

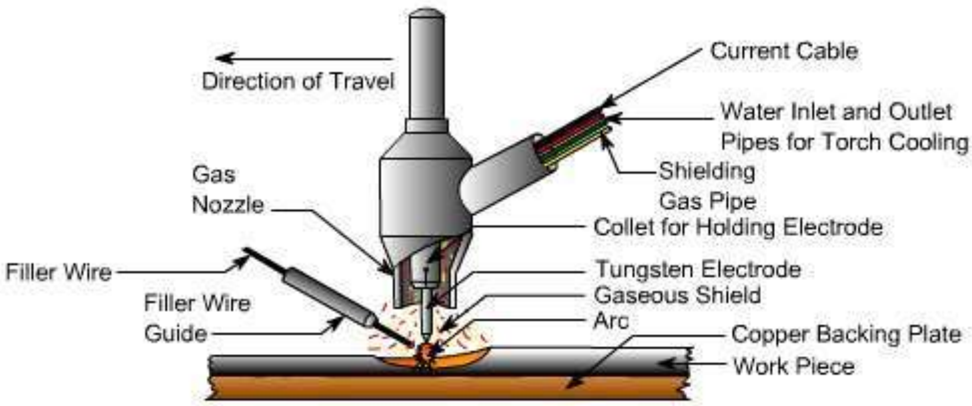

fig. 2: principle of tig welding.[1]

Tungsten electrodes are commonly available from 0.5 mm to 6.4 mm diameter and 150 - 200 mm length. The current carrying capacity of electrode depends on whether it is connected to negative or positive terminal of DC power source.

The power source required to maintain the TIG arc has a drooping or constant current characteristic which provides an essentially constant current output when the arc length is varied over several millimetres. The capacity to limit the current to the set value is equally crucial when the electrode is short circuited to the work piece, otherwise excessively high current will flow and it damaging the electrode. Open circuit voltage of power source ranges from 60-80 V.

A high-quality weld can be achieved by employing TIG welding. However, the melting depth of a single-pass TIG process is no larger than 3 mm because of the limited penetration ability. A thick work piece requires suitable joint preparation and multi-pass welding is required to deposit additional filling metal into the seam groove. The welding efficiency is thus low and the processing cost is high. Laser beam welding (LBW), electron beam welding (EBW), and plasma arc welding (PAW) are effective methods of joining mid thickness (6–13 mm) work pieces. However, the capital equipment costs of LBW and EBW are high, while the keyholling process in PAW is not that stable. Submerged arc welding is another welding process widely used to join mid-thickness work pieces. The welding efficiency is relatively high compared with that of multipass welding using TIG; however, suitable joint preparation, additional filling metal and additional flux are needed in this process.[2]

To enhance the efficiency of TIG process, the energy density and arc pressure of welding arc are improved by modifying the welding torch to achieve keyhole mode welding.[3]

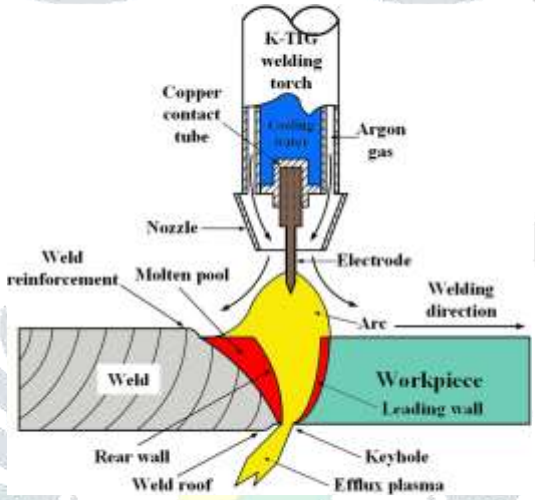

fig. 3: schematic of k-tig process, the specially made torch, and the morphology of the molten pool[4]

Keyhole gas tungsten arc welding (K-TIG) was developed by the Commonwealth Scientific and Industrial Research Organization (CSIRO) to address these problems with traditional keyhole welding methods. K-TIG was developed based on conventional GTAW. Cooling water circulation was introduced in the constricting nozzle of the welding torch, and a higher welding current was adopted to increase the current density. The electromagnetically induced arc force is much higher in K-TIG than in GTAW. This force pushes the liquid metal in the molten pool outward, forming a keyhole. The molten pool anchors itself to the root face of the weldment. The arc force, liquid metal density, and surface tension reach equilibrium, and this keeps the keyhole stable. K-TIG is capable of single-pass, full-penetration welding of thick plates. The welding equipment is based on a conventional GTAW power source and a specially designed welding torch as shown in fig. 3. The equipment and production costs are low and the welding efficiency is very high. Additionally, K-TIG welding is suitable for on-site production.[4]

II. LITERATURE REVIEW

S. Lathabai et al. studied keyhole gas tungsten arc welding of 6.35 mm thick commercially pure zirconium. The procedure involved the use of a simple machined square butt edge preparation and required no filler metal additions. Welding parameters used were current of 350 A, voltage of 12 V with 500 mm/min Travel speed. Argon was used as primary and back shielding gas. Mechanical testing revealed 100% joint efficiency for the zirconium K-GTA welded test plates. Microstructural examination showed that the KGTA welds were free from gross porosity and other defects, in agreement with the results of the radiographic testing.[5]

Yan Xie et al. studied characterization of keyhole gas tungsten arc welded AISI 430 steel and joint performance optimization. Using K-TIG, 8-mm-thick AISI 430 ferritic stainless steel was successfully welded by his team. Welding parameters used were current of 550, 580 and 630 A, voltage of 17, 17.4 and 17.2 V respectively with 400, 500 and 600 mm/min Travel speed. The mechanical properties and corrosion resistance of the joint were tested. Three methods to enhance joint performance were trialled; high-frequency pulse arc welding (HFP-AW), austenite interlayer addition, and post-welding heat treatment (PWHT). Heat input was decreased by 42.24% when using HFP-AW. They concluded that the mechanical properties and corrosion resistance of the enhanced joints improved. In particular, the tensile properties of the PWHT joint and the corrosion resistance of the joint with the austenite interlayer were better than those of the base metal. The optimal tensile strength of CAW joint reached 59.2% of that of the base metal, and achieved the same strength as shielded metal arc welding, gas metal arc welding, and GTAW. The tensile strength and elongation rate of the interlayer added joint were 27.8 and 245.5% higher, respectively, than those of the CAW joint. [4]

Yueqiao Feng et al. studied keyhole gas tungsten arc welding of AISI 316L stainless steel of mid thickness ranging from 6 to 13 mm. Plates were joined using an I groove in a single pass without filler metal. The effects of welding parameters on the fusion zone profile were investigated. The weld properties, including mechanical properties, microstructure, and corrosion resistance, were analysed by them. They found the primary weld Microstructures were austenite and δ-ferrite and the tensile strength and impact property of the weld were almost the same as those of the base metal, while the corrosion resistance of the weld was even better than that of the base metal. The practical application of K-TIG welding to join mid-thickness workpieces in industry Was demonstrated and an ideal process for welding AISI 316L of mid-thickness with high efficiency and low cost was presented.[2]

S. Lathabai et al. compared keyhole and conventional gas tungsten arc welds in commercially pure (CP) titanium of 12.7 mm thickness without expensive filler metal addition or joint preparation. The microstructure and mechanical properties of the resultant weld joint had been compared with those of a multipass conventional GTAW joint in CP titanium prepared from plates of the same thickness with a double-V edge preparation and the addition of a matching filler metal. Welding parameters used were current of 600 A, voltage of 16 V with 250 mm/min Travel speed. They showed the differences in the net heat input and weld thermal cycles associated with the two processes led to similar microstructures, albeit of different degrees of refinement. As a result, the tensile and hardness properties of the two welded joints were similar to each other and comparable to those of the base material. It is concluded that the keyhole GTAW, with its significantly higher productivity combined with the simplicity of proven technology and low capital investment requirements, can be successfully applied in the welding of heavy section CP titanium, without sacrificing the metallurgical quality associated with the GTAW process.[6]

ZuMing Liu et al. studied stable keyhole welding process on 8mm-thick stainless steel plates with different levels of welding current and made high quality welds. Welding parameters used were current of 485 A, voltage of 15.35 V with 352.5 mm/min Travel speed. They captured keyhole exit image in real time during the welding process with a CCD-based vision system. They founded that keyhole exit size, shape and position are all dynamic in K-TIG welding process. During the quasi stable keyhole process, keyhole exit was oval, deviates behind from the torch axis even the welding current is very large. Continuous open keyhole was achieved during the K-TIG welding without any unstable keyhole stage. As the welding current increases, keyhole dimensional size enlarger, ratio of length to width decreased, keyhole exit deviation distance got smaller in K-TIG welding process.[3]

ShuangLin Cui et al. experimented and evaluated keyhole behaviour in keyhole mode Tungsten Inert Gas (K-TIG) on 4 mm thick 304 stainless steel. They measured keyhole exit dimensional and positional parameters from the keyhole exit image sequence based on the vision system. The "one pulse one open keyhole" welding process is success-fully applied by using the square waveform pulse current. In the pulse waveform, peak current 350A, base current 60A, peak period 500 ms, pulsed keyhole welding processes are achieved when the base period is less than 200 ms. Stable welding process and acceptable quality welds were obtained with a relatively lower average welding current (285 to 310 A).[7]

Zhenyu Fei et al. presented the viability of keyhole tungsten inert gas (K-TIG) welding for joining armour grade quenched and tempered (Q&T) steel. Single pass full penetration was achieved on 9 mm thick plates at a speed of 280 mm/min without using any filler materials and edge preparation. Welding parameters used were current of 525, 545, 565 and 575 A, voltage of 16.58, 16.75, 16.99 and 17.31 V respectively with 280 mm/min Travel speed. In-depth investigation into the weld was conducted by optical microscope, scanning electron microscope, electron back-scattered diffraction, micro hardness and tensile test. Hardness distribution across the weld is higher than current practice, which would lead to improved ballistic performance. Although the joint efficiency of the weld is 65% due to reduction in weld metal hardness, it is still much higher than that produced via conventional fusion welding, which is not surpassing 50%.[8]

ZuMing Liu et al. Carried out the welding test to join the 16Mn steel with three different shielding modes, including no shielding, fully covered Argon gas, and backing jet flow Argon gas. They found that (1) it was hard to achieve a stable K-TIG welding process if the backside weld pool was exposed in the air; (2) stable keyhole welding process could be created in the current range of 410 to 450 A if the backside weld pool was covered with static argon gas; and (3) stable keyhole welding current range was increased to 420 to 560A if the argon gas jets directly flowed towards the backside weld pool.[9]

Fujii et al. developed an advanced activated Tungsten inert gas welding method for deep penetration of weld joint. Maragoni convection induced on the molten pool by surface tension gradient. In order to control Maragoni convection small amount of oxidizing gas was used. Welding process done with welding current 160 A, welding speed 0.75 mm/s, electrode gap of 1mm and Ar-O2 shielding gas. They observed that Maragoni convection changes from inward to outward and weld shape become wide and shallow.[10]

Vikesh et al. represented the effect of activated flux on TIG welding process. They focused on the effect of penetration in mild steel by TIG welding process. Compared to other arc welding processes it having small depth of penetration. An activating flux powder is used to avoid this problem. Taguchi optimization is used to optimize welding process parameters. They observe from experimental results that improves in depth of penetration at weld zone with increase welding current. Depth of penetration is inversely proportional to the travel speed.[11]

P Ravisankar have done optimization of TIG welding parameters using Taguchi technique for dissimilar joint of low carbon steel and aluminium. Welding speed, welding current and distance between work material and electrode were used as input parameters in three level for optimization of the process.[12]

Sanjeev kumar et al. explored the possibility for welding of higher thickness plates by TIG welding. Aluminium Plates (3-5mm thickness) were welded by Pulsed TIG Welding process with welding current in the range 48-112 A and gas flow rate 7 -15 l/min. Shear strength of weld metal (73MPa) was found less than parent metal (85 MPa). From the analysis of photomicrograph of welded specimen it had been found that, weld deposits are form co-axial dendrite micro-structure towards the fusion line and tensile fracture occur near to fusion line of weld deposit.[13]

Indira Rani et al. studied the mechanical properties of the weldments of AA6351 during the GTAW /TIG welding with non-pulsed and pulsed current at different frequencies. Welding was performed with current 70-74 A, arc travel speed 700-760 mm/min, and pulse frequency 3 and 7 Hz. From the experimental results it was concluded that the tensile strength and YS of the weldments is closer to base metal. Failure location of weldments occurred at HAZ and from this we said that weldments have better weld joint strength.[14]

Ahmed Khalid Hussain et al. studied 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 to 7200 mm/min. From the experimental results it was revealed that tensile strength increases with reduction of welding speed and strength of the weld zone is less than base metal.[15]

Tseng et al. studied the effect of activated TIG process on weld morphology, angular distortion, delta ferrite content and hardness of 316 L stainless steel by using different flux like TiO_2, MnO_2, MoO_3, SiO_2 and Al_2O_3. To join 6 mm thick plate they uses welding current 200 Amp, welding speed 150 mm/min and gas flow rate 10 l/min. From the experimental results it was found that the use of SiO_2 flux improve the joint penetration, but Al_2O_3 flux deteriorate the weld depth and bead width compared with conventional TIG process.[16]

Kumar and Sundarrajan investigated pulsed TIG welding of 2.14 mm AA5456 Al alloy using welding current (40-90) A, welding speed (210-230) mm/min. Taguchi method was used to optimize the pulsed TIG welding process parameters for increasing the mechanical properties and a Regression models were developed. Microstructures of all the welds were studied and correlated with the mechanical properties. 10-15% improvement in mechanical properties were observed after planishing due to or redistribution of internal stresses in the weld.[17]

III. FUTURE PROSPECTS AND CONCLUSIONS

Continuous experimental studies are going on in the field of TIG welding, in order to optimize the process to extend the range of materials it can weld. It was understood from the paper studied that most of the work has been carried out to improve mechanical properties by changing process parameter such as welding current, welding speed, torch stand of distances etc. As from literature survey it can be found that keyhole TIG welding is new process which can overcome earlier problems of high cost welding, also need of filler metal and flux can be eliminated. Limited research has been done in keyhole TIG process, so there is vast scope for keyhole welding for mid thickness plates of different material.

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