ENHANCING TIG WELD PERFORMANCE THROUGH FLUX APPLICATION ATIG AND FBTIG PROCESSES

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ABSTRACT

The penetration potential of TIG welding in one single run is limited, though the process itself generates high quality welds with good weld cosmetics. This is one of the main reasons, which has contributed to its development in high duty applications such as those encountered in aeronautical, aerospace, nuclear & power plant applications. For these applications, stainless steels, titanium & nickel based alloys are most often used. As these materials remain very sensible to weld heat input & atmospheric pollution, stringent processing conditions are imposed. For example welding of titanium alloys requires argon shielding of weld zone and for 5 mm thick plates multi-pass runs & filler additions are required. This multi-run operation not only raises the welding cost, but also increases defect risks. In recent years, extensive interest has been raised by the possibility to increase weld penetrations through flux applications & the process is designated ATIG-activated TIG, or FBTIG-flux bounded TIG. The improved welding performance of such flux assisted TIG is related to arc constriction and surface tension effects on weld pool. The research work by authors has lead to the formulation of welding fluxes for stainless steels & titanium alloys with ATIG Process. These fluxes are now commercialized & some applications in industry have already been carried out. FBTIG for aluminum has been proposed with silica application for AC mode TIG welding. The paper highlights the fundamentals of flux role in TIG welding and illustrates some industrial applications.

KEY WORDS

TIG, ATIG, activated TIG, FBTIG, Flux bounded TIG, Titanium, Stainless steel, Weld pool formation

1.Introduction

TIG, which stands for tungsten inert gas is one of the most currently used welding techniques in applications for aerospace, nuclear, petroleum & chemical industries. Besides being very simple and requiring low investment, the excellent end results regarding the weld quality with TIG processing have all contributed to its success in manual & automatic welding. Workpiece thickness of 3 mm, depending on material, can be welded in one pass without any joint preparation except that requiring a god fit between the faces. For higher thickness, multi pass welding with joint preparation through machining and hence the necessity of filler material during welding, reduces the attractiveness of Tig process. Not only the multi pass welding runs increase the welding cost, the risk of introducing defects through multiple operations on one job also becomes higher. This is particularly true for welding titanium structures where stringent requirements regarding weld and base metal protection against pollution from ambient air elements are imposed in different manufacturing specifications. Further, multi pass welding introduces higher heat inputs into the joint that contribute to excessive grain growth and residual stresses and deformations. Another factor affecting TIG process stems from the evolution of materials which become more clean and perturb the normal tendency of using data base information to establish process parameters on material and joint thickness. For example, stainless steels and titanium grades to a lesser extent are prone to bead-to-bead variations, notwithstanding a strict compliance to material specifications and real time control of weld parameters[1-4]. This problem is critical in TIG welding due to two main reasons: first the process is extensively used for stainless steels and titanium grades and secondly it is more often employed for welding of smaller thickness with a narrow flexibility of operating parameters. The two constraints of TIG welding mentioned above i.e., lower penetration capacity and bead variability with minor elements of material, have given incentives to further studies in recent years to find technological solutions. The ATIG or activated TIG process is based on the application of a complete flux cover, whereas FBTIG or flux bounded TIG concept rather uses two flux strips with a narrow non covered band around the joint as schematically shown in Figure 1[5],[6],[7]. FBTIG has been found particularly interesting for aluminum base alloys, which require AC-TIG welding for improved bead cosmetics[8],[9]. In fact, aluminum and its alloys are naturally covered with a relatively refractory oxide, which can only be fragmented in inverse polarity DC welding producing relatively shallower penetrations compared to straight polarity direct current welding. Thus, AC welding is a compromise between the cleaning and penetration actions of welding current. Further due to very high thermal conductivity of aluminum, high heat inputs are required and the resulting weld pool is often semi circular with very low depth (D) to width (W) aspect ratio. It is worth mentioning that ATIG process uses DC mode welding with flux cover to further enhance weld penetration, whereas FBTIG is well suited for AC welding so as to join the cleaning & the penetrating actions of the process.

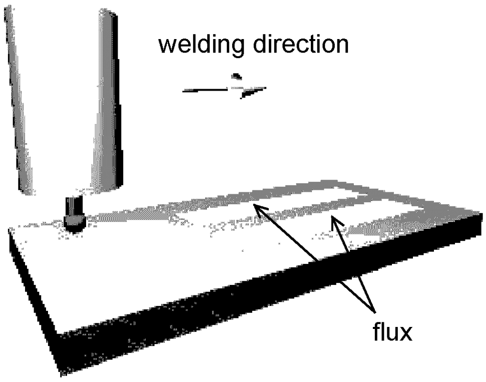
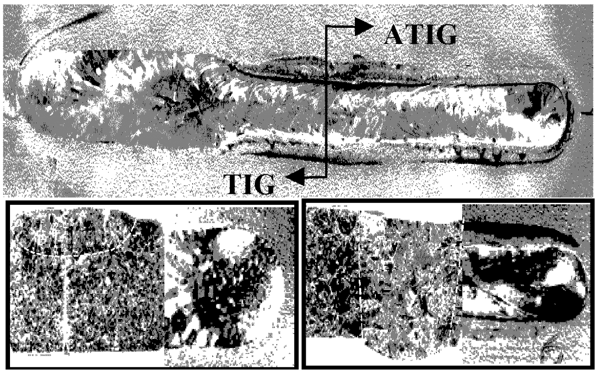


Fig. 1 FBTIG with two flux strips surrounding a bare joint zone. Total flux cover in ATIG



2. Weld pool formation

From fundamental point of view, instant weld pool volume depends on the balance between heat input and output through conduction in base metal. Increasing heat input through welding current, travel speed or better heat transfer from arc to workpiece would increase weld volume. However, from welding standpoint, it is more interesting to enhance depth of weld pool at constant volume, which also implies reduction in weld heat input for a given job with favorable benefits for weld distortions. The weld profile that is determined by weld pool dynamics and spatial energy distribution in the arc is very important quality criterion in welding.. The weld pool dynamics is determined by how heat is dissipated in the pool principally through convection. For instance, convection which results in inward metal and energy transport in the pool would generate deeper welds. This flow can be induced by positive surface tension temperature gradients in the pool through minor metal chemistry inoculations or Lorentz electromagnetic effect dominant at higher welding currents. Inward pool dynamics is generated by positive surface tension temperature gradients, subsequent to presence of some surface active species, such as sulfur, oxygen, bismuth, selenium etc in steels (Figure 4). In fact, surface tension which is a measure of cohesive forces normally decreases with increasing temperature and as such normally introduces outward melt flow in the pool suited for wider but shallower welds. Further, reducing arc contact surface with the workpiece i.e., arc constriction is propitious for enhanced penetration subsequent to increased power density for a given arc power. Thus any attempt to enhance weld penetration would normally require weld pool inoculation with surface active species favorably affecting melt flow or arc constriction or better their synergic action. From the foregoing aspects, the welding fluxes for ATIG or FBTIG are expected to play their role both in the arc and on the weld pool dynamics. Most of the welding fluxes are oxide, chloride or fluoride minerals which offer high extra electric impedance to the current flow in the arc. In fact, compared to metals, these minerals have very high intrinsic electric resistance, but this decreases with increasing temperatures. Had this not been the case, fluxes would have remained ineffective in welding. Through energy from arc, fluxes are melted, vaporized, dissociated and possibly ionized to modify current carrier density in arc itself. These fundamental state changes require extensive energy spending for the arc. The resulting arc voltage then changes to adapt the electric conductance to meet the imposed welding current. Depending on the dissociating energy and possibly first ionization potentials of the

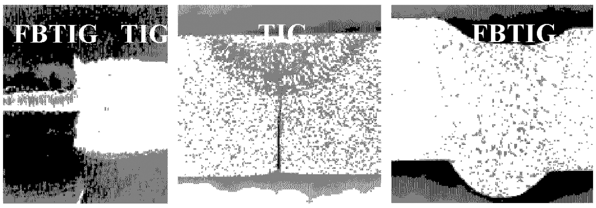


Fig. 3 Transition from TIG to FBTIG and corresponding weld cross-sections

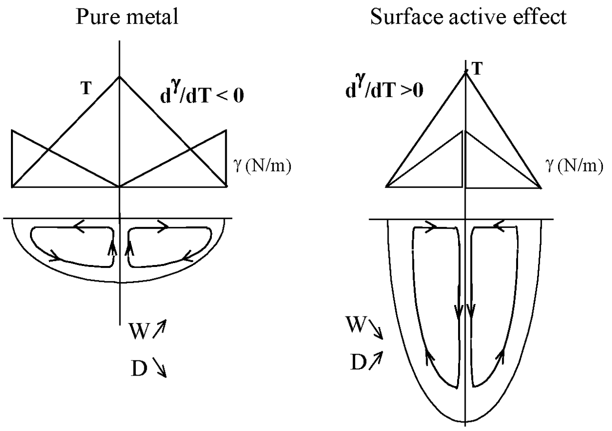


Fig.4 Effect of surface active species on the formation of a weld pool

species, voltage may increase or decrease. Further the presence of species from the flux would change spatial energy distribution. It is anticipated that arc, which is hotter in its central column would melt & vaporize the flux in the immediate vicinity of the joint. This central zone comparatively becomes more conducting which attracts arc current flow. It is then anticipated that the arc then become more constricted that leads to deeper weld penetrations. Beside this fundamental point, it has been suggested that some flux species with high electron capture cross-section would reduce electron density in arc periphery and hence increase the central charge carrier density, which also implies arc constriction[11]. The selective arc channeling in the most conducting zone of the workpiece forms the basis of FBTIG developments. Here, flux does not cover the totality of workpiece weld zone, instead a narrow uncovered workpiece strip around the weld is managed. It is, in fact, expected that this strip would constitute the preferential arc contact on the workpiece. Further arc ignition and stability would be improved compared to ATIG where the flux thickness and uniformity become important factors of process stability. In fact, so far the flux cover is applied on the workpiece by a simple brush after mixing flux ingredients in a solvent to make a paste. This basic technique or even a spray are not precise enough for uniform flux deposition. Different arc views from TIG and FBTIG process shown in Figure 5 strongly suggest increasingly hotter arcs with reduction in flux gap. The central bright zone is seen to expand in FBTIG with the flux gap of 2mm.

Sire et al [9] have investigated the effect of some potential mineral fluxes based on fluorides, chlorides and oxides for AC TIG welding of aluminum. Figure 6 in line with the results presented in Figure 3, shows the benefit of FBTIG with silica and aluminum fluorides. Compared to AC-TIG, the relative penetration factor D*, which is a ratio of FBTIG depth to conventional AC-TIG depth at constant process parameters, becomes as high as 2,5 particularly with silica. In practical terms, the application of silica with 2 mm gap increases the penetration potential by 250%, which represents a substantial gain in process performance. On the basis of the foregoing discussion on process characteristics and weld pool formation, improved weld penetrations with reduction in flux gap is also confirmed. These results are further confirmed in DC- FBTIG with silica (Fig.6, right). However, comparative to AC-FBTIG (Fig.3), direct current surface bead cosmetics is heavily degraded. It may be mentioned that due to high electrical impedance of silica coatings, arc ignition and stability at these

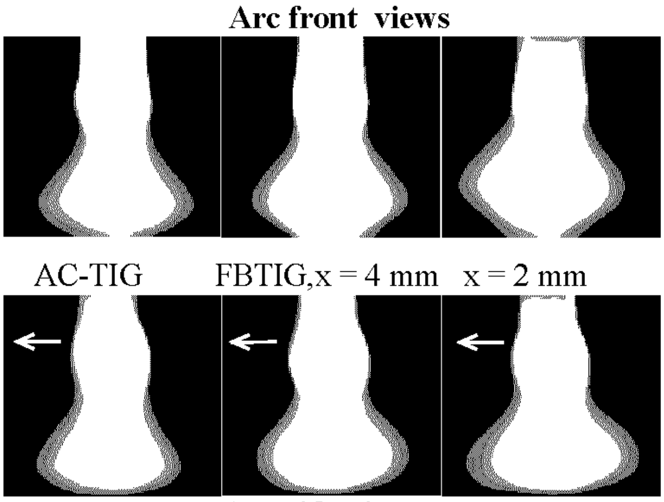


Fig.5 FBTIG compared to AC-TIG on aluminum 5086. Grey scales show arc brightness

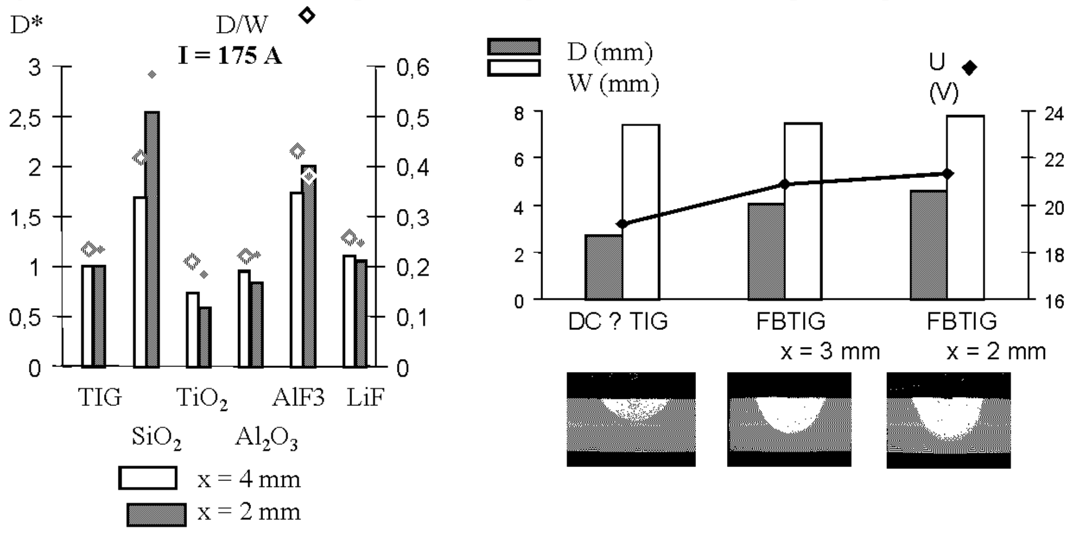


Fig.6 Effect of some coatings and gaps on D* (=D_{FBTIG}/D_{TIG}) in AC welding (left), DC welding (right) with silica on aluminim 5086 [9]

current levels is completely hypothetical in AC-ATIG configuration. Managing a very narrow uncovered strip in the flux cover over the workpiece allows arc ignition and stability. Further, as shown in Fig.6, silica application in FBTIG configuration generates higher voltage, which tends to further increase with reduction in flux gap, implying hotter arcs. This additional heat energy in FBTIG is preferentially used for producing deeper welds with high depth to width ratio, as weld width is only a little affected (Fig.6).

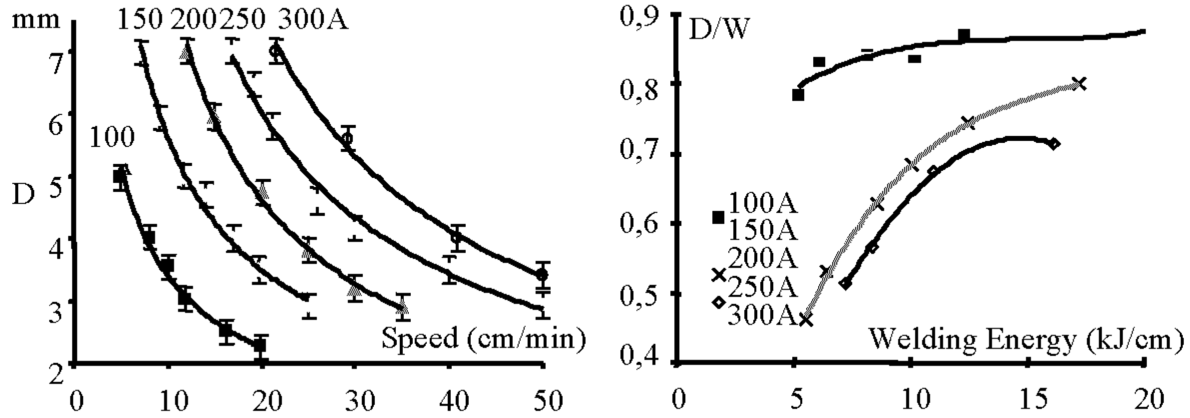


Fig.7 Depth of penetration and evolution of D/W with energy on titanium

For ATIG welding of titanium alloys, though the flux compositions are not precisely known, it seems that fluorides are potential candidates. The process performance with flux application is represented as depth and weld speed curves with different current levels. Thus,7 mm thick work-pieces can be easily welded at 150A and 10 cm/min., which can be handled by regular welders in manual welding. As expected, ATIG voltage is generally high compared to TIG, which means that higher energy at constant machine settings is being delivered to the work-piece. However, when D/W ratio is plotted versus theoretical arc energy, higher values are attained at lower currents. For example, maximum D/W is reduced from 0,85 to 0,7 by increasing the welding current from 100A to 300A. This is not surprising when arc views are monitored (Fig.8), which show increasing depressions and outgoing plasma streams from the pool with increasing ATIG welding currents. Though, the depression in the pool is propitious for deeper welding, the outgoing plasma streams spread the arc energy over the surface. This results in widening of the weld pool and probably accounts for observed reduction in D/W of ATIG welds. Perry et al[11] have shown that the melt cross-sections in TIG & ATIG welding depend only on arc energy, but D/W is comparatively higher in ATIG welding, i.e., energy utilisation is optimised from welding standpoint in ATIG welding (Figure 10).

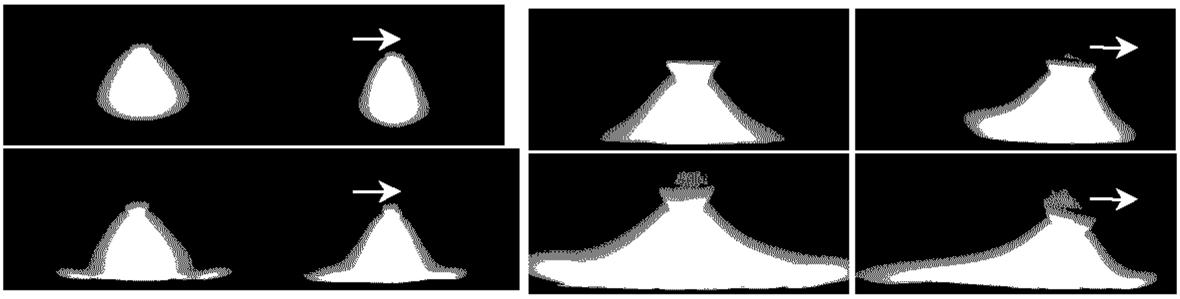

100A front 100A side **Views** 200A front 200A side

Fig.8? Arc views with and without prior flux application, TIG(Top), ATIG (Bottom)

That ATIG arc is comparatively hotter is further suggested by the treated images from TIG & ATIG arcs on a stainless steel (Figure 9 left), where the brightest zone representing the hottest region is further drawn towards the base metal and the arc is trailing on the retreating side of the welding direction. One of the possible reasons for arc trailing is related to the high electric impedance of the flux on the advancing front. The flux there has to be melted before its conductance can authorise arc advance. This is suggested by observation of the weld pool during transition from TIG to ATIG (Figure 9 right). For these observations, TIG arc is progressively moved from bare plate to a flux cover [13]. As the arc approaches the flux, its progression is slowed by the said high flux impedance and the weld pool instantaneously becomes wider on the retreating side, as schematically presented in Figure 9. The weld pool in ATIG thus becomes narrower and more elongated as further revealed by the end craters from ATIG welds (Fig.2). Spectroscopic measurements of ATIG arc show that it becomes more metallic like MIG arc and overall arc temperature rises in line with video captures and image analysis[14].

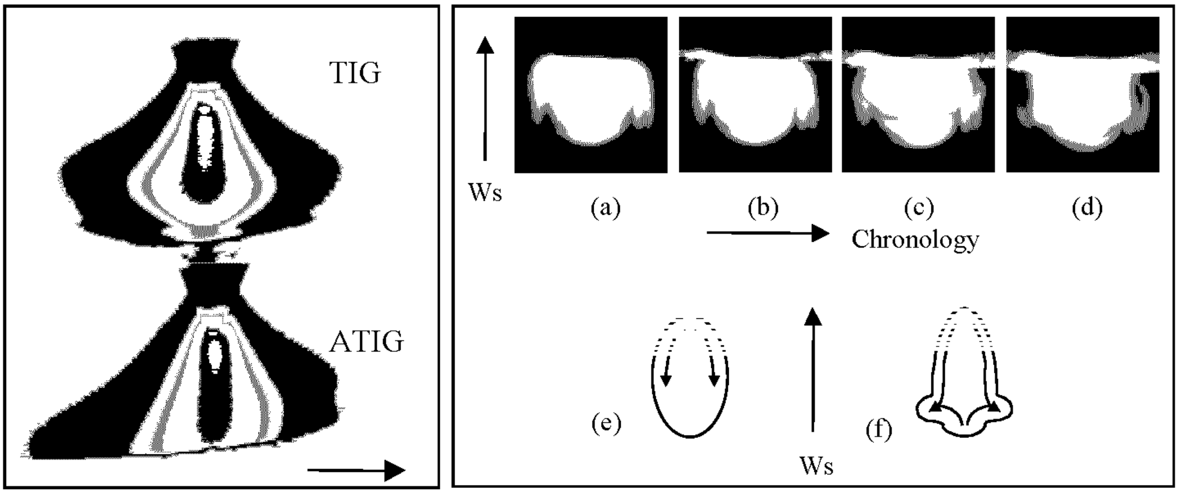


Fig.9 Arc image in scale suggesting hotter arcs in ATIG on a stainless steel, (right) weld pool viewed from the restreating side during transition from TIG to ATIG (a to d), e and f show schematic views,

3. Applications

As shown in Figure10, enhancement of weld penetration for a given welding energy is the most interesting advantage offered by ATIG. For welding of materials thicker than 3 mm in one welding run or for very clean materials, ATIG can be a major welding technique both for manual & automatic welding. For example, welding of 5 mm titanium requiring machining and five welding runs with filler additions has been successfully replaced by single pass total penetration welding followed by a second cosmetic pass, the total operation is very cost effective and productive. Figure 11 shows another welding configurations where ATIG in case of stainless steels can be a big advantage in production. One of the possible drawback of using fluxes in TIG welding however stems from flux adherence to the material, which needs to be removed for bead cosmetics. Though the mechanical & corrosion properties of the ATIG welds give very good results, fatigue behaviour needs to be still investigated. It is feared that in materials for which crack generation is the most important fatigue factor, poor bead cosmetics may be a handicap. Application of ATIG for the orbital welding applications are emerging, but due to high

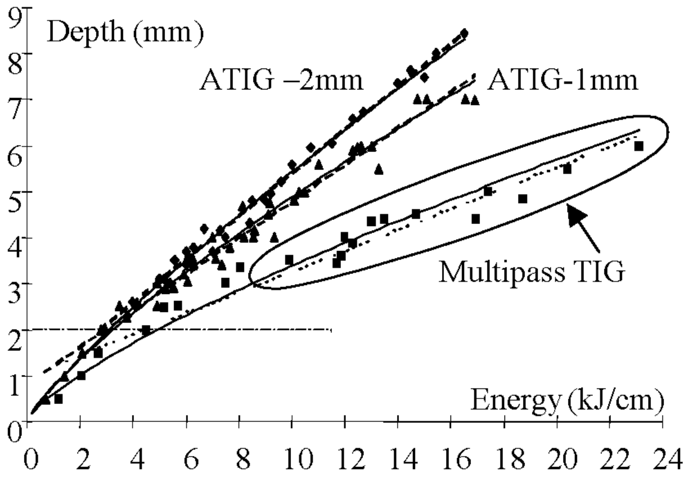


Fig. 20 Depth of weld pool in relation with welding energy

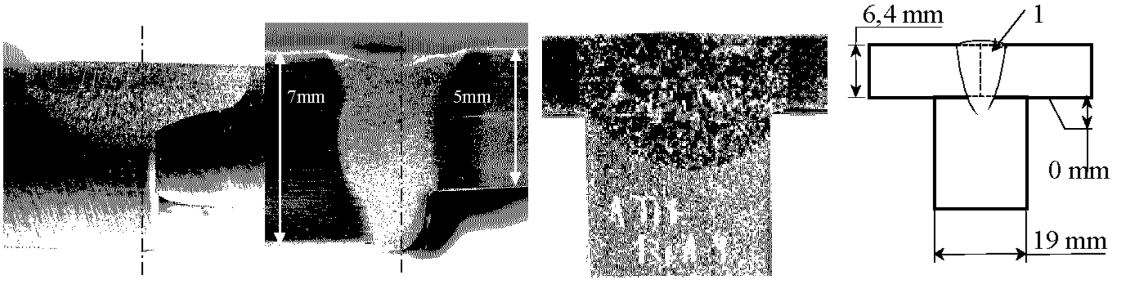


Fig. 11 from left to right, Welding of stainless steels with TIG, ATIG;Titanium ATIG and design for titanium

molten volume, bead profile on the root side is a big concern particularly in horizontal position. Orbital welding with tube in vertical position offers a greater flexibility in process management.

4 Conclusions

This paper describes the limitations of TIG welding and ways to improve weld penetrations and process efficiency by the selective application of some flux elements on the workpiece. ATIG or activated flux TIG can make 8mm and more thick weld joints in one single welding run. Flux bounded TIG or FBTIG is also based on the application of some flux minerals, but the flux application does not cover the immediate vicinity of the joint. In fact, two flux strips two to four mm apart are applied around the joint This process is based on the concept that as most of flux minerals offer very high electric impedance, arc would remain confined to the narrow conducting uncovered strip surrounding the joint. This has been demonstrated on aluminium 5086 in AC mode TIG welding with a view to join the cleaning action with that of flux to enhance weld penetration. The narrower the uncovered strip in FBTIG, greater is the weld penetration. Silica and aluminium fluorides have been found to be quite effective on aluminium 5086. DC –TIG also shows improved weld penetrations when flux is applied in FBTIG configuration, though the bead cosmetics is degraded. TIG arc with flux applications becomes hotter and voltage at constant current settings is found to increase both in ATIG and FBTIG set ups. This additional heat is used to preferentially increase weld depth rather than width. Weld pool is thus narrower and elongated compared to TIG weld pools. The improved weld penetration has been attributed to arc confinement -either to the narrow conducting strip in FBTIG or to the central melted flux coating in ATIG – and to possible inner surface tension induced melt flow due to flux application. Direct evidence is lacking, but various arc analysis and observations of the flux behaviour give sufficient support to their existence .

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