WELD POOL CHARACTERISTICS OF THE ATIG-WELDED JOINTS

János Dobránszky – Research Group for Metals Technology of the Hungarian Academy of Sciences, Hungary
Tamás Sándor – ESAB Hungary Ltd., Hungary
Adrian Nagy-Hinst – Budapest University of Technology and Economics, Hungary
Antal Géza Eichhardt – Budapest University of Technology and Economics, Hungary
László Gyura – Linde Gas Hungary Ltd., Hungary

ABSTRACT

TIG welding has a disadvantage against the substantially high productivity welding procedures. This is why there were continuously going on several trials to improve the productivity of the TIG welding. The Activated Tungsten Inert Gas welding (ATIG welding) is one of these trials. There were carried out welding experiments using silica powder as activating flux on 2205 type duplex stainless steel plates. The main problems, which appear when using the ATIG welding, are the choosing of tungsten electrode, the precious fitting of parts for the joining, the equal portioning of the activating flux. They are extremely important to apply the ATIG welding and the results will be presented in this work. In the second part of the paper there will be presented the shapes of the weld pool in function of few welding parameters. We investigated the weld pool geometry using metallographic methods. The first studied parameters were the shielding gas and the backing gas that are pure Argon or 95 % Argon + 5 % Nitrogen, the second parameters are the welding current and welding speed. Beside the shape of weld pool the ferrite content of weld metal was also determined.

KEYWORDS

TIG welding, ATIG welding, activating flux, penetration, weld pool geometry, Marangoni-effect, arc constriction

INTRODUCTION

Tungsten inert gas welding (TIG) is one of the cleanest and most important welding procedures for welding duplex stainless steels. The application of TIG welding started during the Second World War, when it became a real mass production procedure. But the relations of that time had been changing by the second third of the 20-th century thankful to the continuously presented new and higher productivity welding procedures (for example MIG, laser beam and electron beam welding). It is well known that the quality of TIG welding did not change any, only its productivity that caused the pushing in the background of the procedure.

Intention of stopping this progress and improving the productivity, several development and experimental procedure based on new suggestions were born. By grouping these procedure versions the classification may happen two main ways. The increasing of the bringing of the welding consumables' quantity into the joint is one of the ways and the improving the efficiency of the welding arc (resulting higher penetration) is the other way. Using of the activating fluxes for TIG welding also belongs to this last direction of the developments.

Considering the theoretical bases of the TIG process and these processes, in which activating fluxes are used – e.g. Activated TIG (ATIG) and Flux-Bonded TIG (FBTIG), which schema are seen in Fig. 1 – there are two significant differences. First, none of welding consumable is needed for ATIG welding. The second difference is the using of activating fluxes. As it looks well on the Fig. 1, the activating flux is very different from the powder of Submerged Arc Welding (SAW) because of the quantity that is in use and the mechanism of the effect.

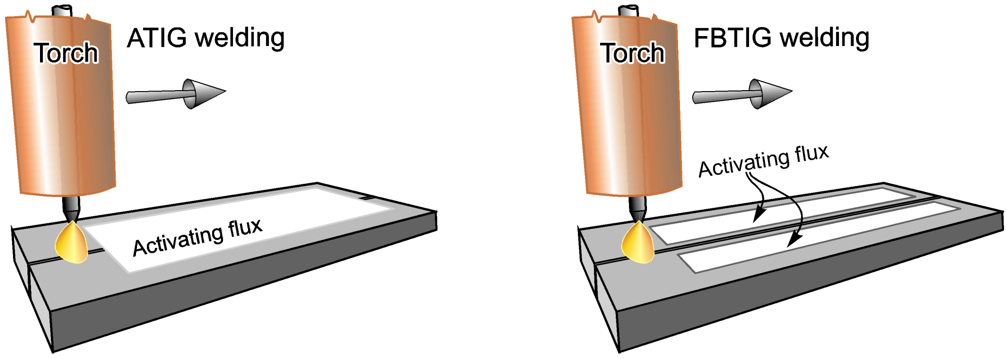

Fig. 1. Schema of ATIG welding and FBTIG welding

There is still not agreement today in the explanation of the mechanism of the activating fluxes. In the latest quarter century four different theories were published, which are made known in short forms in the following.

The theory of *Simonik* [1] said that oxide and fluoride molecules are present in the activating fluxes, which have affinity to chain the free electrons at the edge of the plasma of the arc. It is well known that the ions formed this way have substantially lower mobility than the free electrons. This leads to increase current density in the centre of the arc by means of the higher movement of the free electrons. This results better focus of the arc, which leads to the deeper penetration.

The theory of *Savitskij and Leskov* says that the activating fluxes decrease the surface tension of the weld pool, which makes able the arc pressure to cause a deeper invading in the pool. This invading helps the arc pressure to reach a deeper penetration [2].

Heiple and Roper explains [3] the high penetration with the inverse Marangoni effect [4]. The convective flow of the molten metal from the centre towards the edge is the phenomenon that is called (Gibbs-) Marangoni effect. It is working when the gradient of the surface tension of the weld pool is negative. This theory says that the activating fluxes changes the gradient of the surface tension from negative to positive that results that the convection turns in the opposite direction and flows towards the centre. This is how the deep penetration obtained by the inverse Marangoni effect.

Lowke, Tanaka and Ushio explains in his theory the deep penetration by the means of the higher electric insulation of the activating fluxes. Thankful to this the arc is able to break through the surface (and the flux on it) at a narrower area. This means that the focus of the arc increases which leads to higher current density in the arc spot and this causes the deep penetration [5].

For lack of uniform theoretical bases the experiences gained of very great importance. In fact it is unable to use the ATIG welding effectively without of this little knowledge [6]. The experiences in question led to make more and more experiments and put some brand new questions about the determinant factors of ATIG welding which are the followings:

– Joint gap
– Method of applying of activating flux
– Sensitivity for the measure of the activating flux
– Choosing of tungsten electrode
– Applicability of ATIG welding
– Comparison of TIG and ATIG welding procedure

The joint gap (used for butt-welding) has great importance from the point of view of gaining a faultless joint. If the gap is wider than a certain joint gap then inclusions will occur in the welded joint. When this property was realized the ATIG welding was kept a welding procedure that is applicable only with about zero joint gap. However this condition would query the industrial applications of ATIG welding.

The quantities of the applied activating fluxes (0,1–0,25 g/m [7] and 0,1–0,15 mm [8]) found in the literature of ATIG welding did not seem applicable in industrial environments, because these values are not controllable by the welder. This is why it was necessary the development of a suitable and practical applying method.

It is obvious that the human factor always contains the possibility of faults (not suitable measure of applied flux, overcovering, etc.). This is why the effects of not suitably applied flux had to be determined. Another important question was that how large deviation was allowed regarding to the measuring of the fluxes [9-12].

The ATIG welding needed generally 25 % lower amperage than the TIG welding when it was applied on 3 millimetres thick austenitic or duplex stainless steel plates with 13,5 cm/min welding speed by one root. Notwithstanding that the ATIG welding gave full penetration with 25 % lower current nevertheless the tungsten electrode got visibly higher heat load [13-14]. This would lead to faster electrode amortization. To prevent this other tungsten electrode choosing method had to be developed than is usable for TIG welding [15-16].

It was also realised that the ATIG welding is very sensible for the changing of the arc length so the first impression was that this procedure should be used by motorised. But what may be done when thick plates have to weld manually without joint preparation? We propose to use activating fluxes.

1. WELDING EXPERIMENTS

We used for the welding experiments Avesta 2205 type (1.4462) cold rolled duplex stainless steel, which cross section was 50×3 mm. The chemical composition of the examined steel is seen in the Table 1 and the microstructure of the base material in the Fig. 2. The welded joints were made from two pieces of length 200 mm. Before welding the contact surface of plates was rectified and it was not joint gap between the plates.

Table 1. Chemical composition of the investigated steel

C	Si	Mn	P	S	Cr	Ni	Mo	Nb	Cu	Co	N
0.017	0.40	1.40	0.019	0.001	22.41	5.33	3.19	0.003	0.11	0.08	0.181

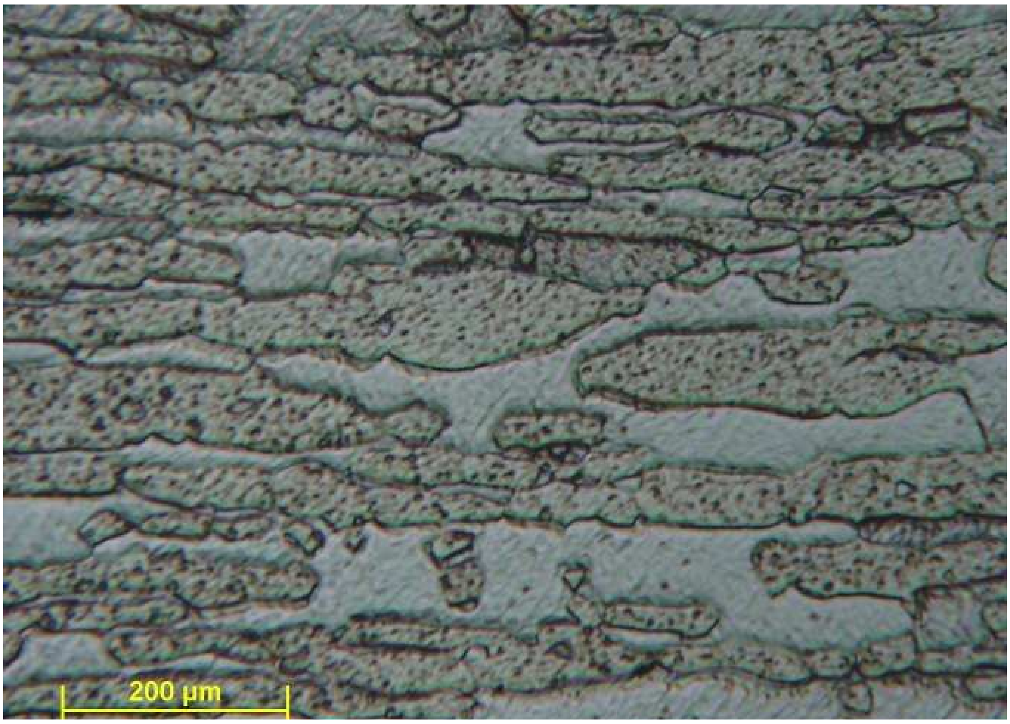

Fig. 2. Microstructure of the 2205 type duplex steel

A CaddyTig 200 type welding power source and a specialized torch moving system were used for welding. It was used WL-15 type La_2O_3 alloyed tungsten electrode of diameter 2,4 mm and ceramic nozzle of diameter 9,5 mm. The torch position was perpendicular to the surface and the arc gap between the tungsten electrode tip and the surface of base material was 3 mm. The torch moving system contains the base metal fixators and the backing gas channel too. The shielding gas and the backing gas type was one of the main investigated parameters; we used pure Argon and a gas mixture that contained 95 % Argon + 5 % Nitrogen. The shielding and backing gas consumption was 5 litre/minute and 2 litre/minute respectively. The Table 2 contains all welding parameters, which characterise the welding experiments. The activating flux was silica powder for all samples. Fig. 3 shows the sample 21 in the as welded state. The differences between TIG and ATIG welded parts are very spectacular.

Table 2. Parameters of the welding experiments

Sample	**Shielding gas**	**Backing gas**	**Welding current**	**Welding speed**
10.	Argon	Argon	90 A	13 cm/min
11.	Ar + 5 % N_2	Argon	90 A	13 cm/min
12.	Ar + 5 % N_2	Argon	90 A	13 cm/min
21.	Ar + 5 % N_2	Argon	150 A	21 cm/min
22.	Ar + 5 % N_2	Argon	150 A	21 cm/min
31.	Argon	Ar + 5 % N_2	150 A	21 cm/min
32.	Argon	Ar + 5 % N_2	150 A	21 cm/min
41.	Argon	Ar + 5 % N_2	90 A	13 cm/min
42.	Argon	Ar + 5 % N_2	90 A	13 cm/min

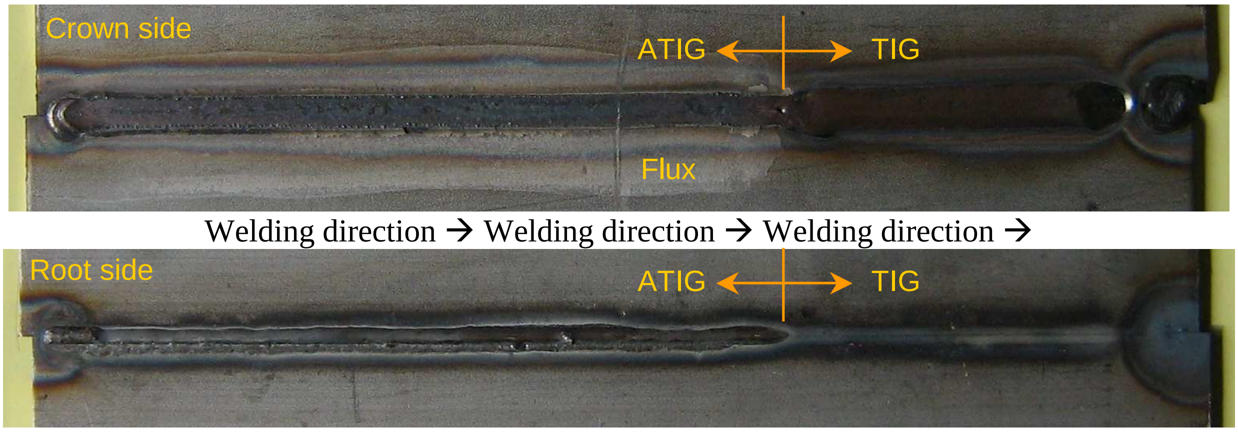

Fig. 3. Crown side and back side of the welded joint of the Sample 21.

2. CHARACTERISATION OF THE WELD POOL GEOMETRY

Main goal of our experiments was to clarify the effects of the shielding and backing gas on the weld pool geometry, and an other aim was to compare of TIG and ATIG process. Other experiments were made to answer the questions mentioned previously. The optimal parameters were always used as bases and changing were made according to the actual examined factor. By the course of these experiments the answers for the problems of other determinant factors were attained. These results, which are detailed in the followings help substantially the application of the ATIG welding.

For characterization of the weld pool shape we measured the weld penetration, the width of weld bead and root and the cross section of weld. These characteristics change significantly in function of welding current, welding speed and the nitrogen content of gases. The characteristic measures of solidified weld pool can be seen in Fig. 4. The geometry of weld pool was characterised by measurement of characteristic measures of weld metal, namely width at crown and root side (CW, RW), maximal height (H), penetration (P), deflection angle from vertical axe (φ) and the total area of weld metal cross section.

The weld pool geometry was investigated by optical microscopy. The macrographs of the weld cross section are presented in the Fig. 5. The pictures show clearly that the weld penetration at TIG-welded joint is much smaller then at ATIG-welded joints. The root is perfectly formed at ATIG-welded joints. Measured characteristics of weld metal are illustrated in Table 3.

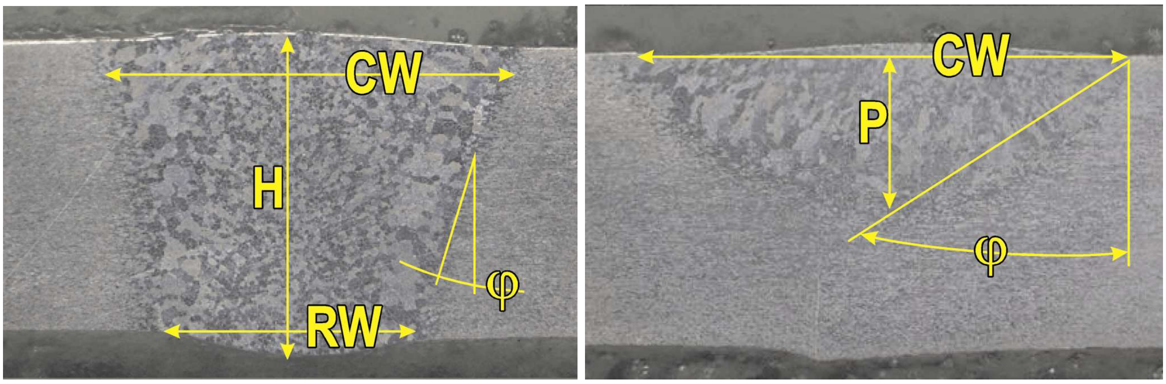

Fig. 4. Measures of weld metal geometry of ATIG-welded (left) and TIG-welded (right) joints.

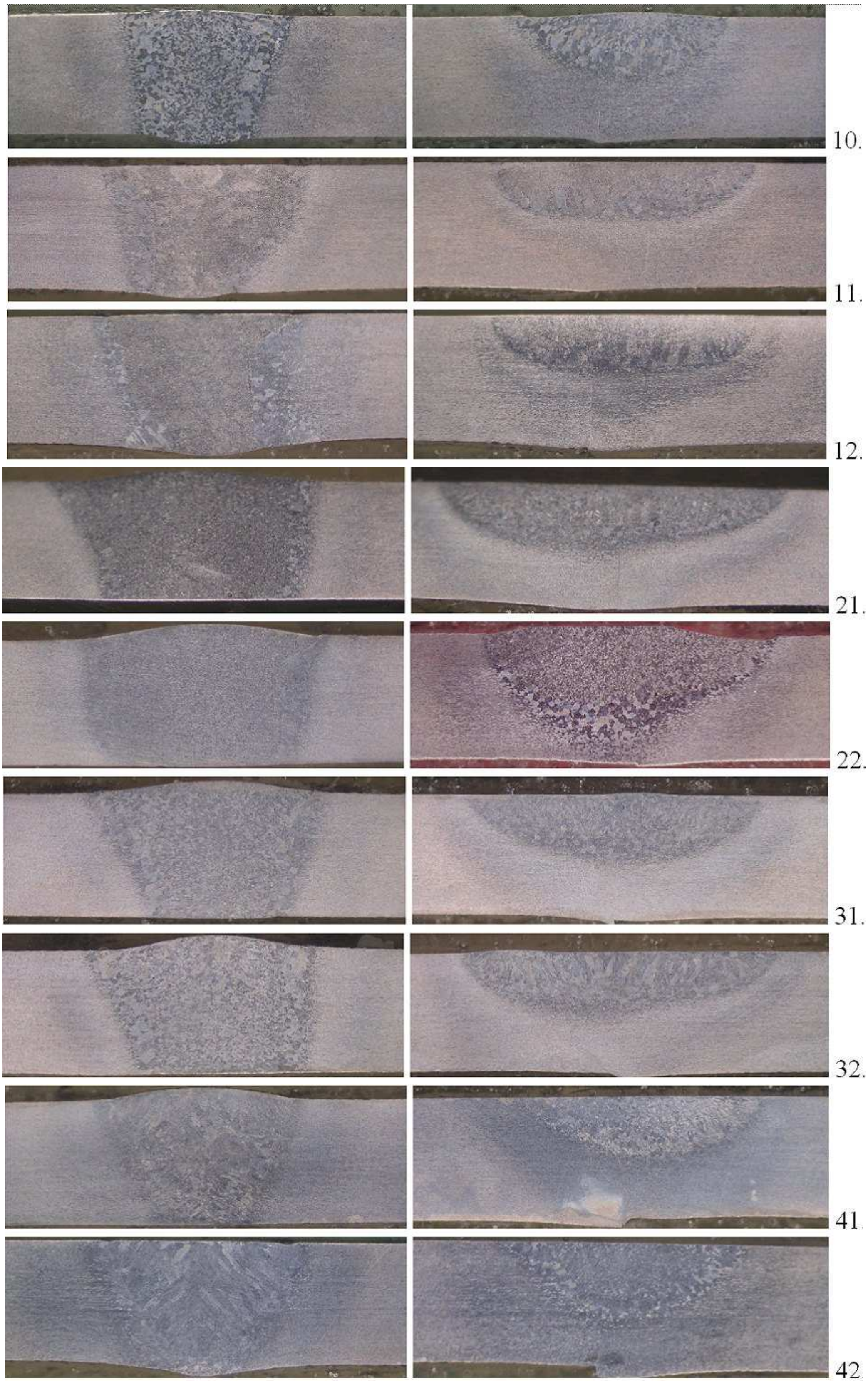

Fig. 5. Cross sections of seams welded by ATIG welding (left) and TIG welding (right). The plate thickness is 3 mm.

Table 3. Measured values of the weld metal geometry in function of welding parameters (H, CW, RW are in mm, φ is in degree, Area is in mm^2).

No.	ATIG welded joints					TIG welded joints					Gas		Welding	
	H	CW	RW	φ	Area	P	CW	RW	φ	Area	Shielding	Backing	Current	Speed
10.	3,38	4,43	2,60	17	11,20	1,61	5,15	–	59	6,30	Ar	Ar	90 A	13 cm/min
11.	3,42	4,46	4,38	17	12,91	1,33	6,23	–	66	7,10	Ar + N_2	Ar	90 A	13 cm/min
12.	3,25	4,97	2,27	21	12,27	1,21	6,33	–	68	7,32	Ar + N_2	Ar	90 A	13 cm/min
21.	3,35	6,72	4,89	19	18,43	1,75	9,07	–	69	11,95	Ar + N_2	Ar	150 A	21 cm/min
22.	3,39	5,56	3,92	14	16,82	2,49	6,80	–	54	13,15	Ar + N_2	Ar	150 A	21 cm/min
31.	3,40	5,69	3,28	22	14,84	1,65	7,48	–	65	9,92	Ar	Ar + N_2	150 A	21 cm/min
32.	3,39	5,49	3,61	13	15,13	1,49	7,80	–	68	9,41	Ar	Ar + N_2	150 A	21 cm/min
41.	3,36	4,51	1,66	20	10,77	1,46	6,09	–	62	6,51	Ar	Ar + N_2	90 A	13 cm/min
42.	3,37	5,13	2,75	21	12,10	1,84	6,16	–	58	7,72	Ar	Ar + N_2	90 A	13 cm/min

3. FERRITE CONTENT MEASUREMENTS

We applied two ferrite content analyser, both were developed in Hungary: the “Ferrite meter” [17,18] and the Ferricomp. The first is working at high frequency but the last instrument is working at a frequency of 50 Hz, consequently the analysed region is deep; this property is very useful for the determination of an average ferrite content of weld metal and the measured value is not disturbed significantly by the width of weld bead. Ferrite content of the base material was FEH = 53 % according to the certificate and we measured precisely the same value.

Table 4. shows the measured ferrite content values. It can be seen that when shielding gas contains nitrogen the delta ferrite content of weld metal is much smaller, then only pure argon is applied. This is caused by the reversed Marangoni convection that helps the get out of gases from the weld pool at its both side. These results were controlled by SEM-EDS and EBSD-measurements [19,20].

Table 4. Delta ferrite content of the weld metal

No.	ATIG	TIG	Shielding gas	Backing gas	Current	Welding speed
10.	65 %	67 %	Ar	Ar	90 A	13 cm/min
11.	49 %	64 %	Ar+N_2	Ar	90 A	13 cm/min
12.	41 %	56 %	Ar+N_2	Ar	90 A	13 cm/min
21.	45 %	64 %	Ar+N_2	Ar	150 A	21 cm/min
22.	41 %	56 %	Ar+N_2	Ar	150 A	21 cm/min
31.	65 %	66 %	Ar	Ar+N_2	150 A	21 cm/min
32.	69 %	80 %	Ar	Ar+N_2	150 A	21 cm/min
41.	68 %	65 %	Ar	Ar+N_2	90 A	13 cm/min
42.	68 %	70 %	Ar	Ar+N_2	90 A	13 cm/min

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4. DISCUSSION

Effect of the joint gap. It was considered that more the joint gap is closer to zero the better, but this is not realisable in practice. In industrial applications there is no possible to flatten the small geometrical defects, because of the productivity. The joints were made on V-form attached plates with zero gaps on one end and bigger on the other. This bigger gap was being got closer to the maximal allowable gap and finally the suitable gap size was found. It is ascertainable that if the maximum applicable gap does not exceed 0.7 mm for the 5 mm thick plates and 0.3 mm for the 3 mm thick plates then any welding insufficiency and inclusions will not occur. Simply there will not be enough base metal (because of the inaccurate joint preparation) to fill up the joint gap with molten metal.

Applying mode the activating flux. It was very important that an untrained person (for instance a welder) should be able to apply this flux properly. The suspension that is made of flux and acetone or ethanol absolute was found the most accurate for this aim. Suspension that is painted on the surface forms a thin, well-regulated, fast dryer, homogeneous and well adherer coating. By this applying method the regulating is reduced for proper mixing of suspension because the speed of painting must be sufficient. This assures that the accurate measure of flux shall be left on the joint’s surface after drying.

Sensitivity of ATIG welding for the quantity of flux. Does really the suspension applied by human produce a constant measure and homogeneity? During this experiment it was examined that whether the uncertainty of applying of flux (because of human chain-link) will fall into the interval that is proper for ATIG welding or not. As a result of this experiment it was stated that the changing of the suspension’s density by ± 50 % does not cause any detectable differences. It sounds well but do not forget the facts what measure belongs to this percentage. Because of the ± 50 % of the mentioned very small quantities the applying of fluxes suggested to be done by mechanised painter head.

Choosing tungsten electrode. The higher heat load of tungsten (compared to TIG) probably comes from the higher reflected heat that is caused by the good insulator activating flux. The tungsten electrode has to wear this higher heat load. Realised this phenomena the recommendation, which are in the Table 3 has been worked out for choosing the suitable size of tungsten electrode for ATIG welding applications.

Table 3. Recommendation for choosing of tungsten electrode for ATIG welding of 2205 steels

Plate thickness	**Tungsten electrode diameter**	**Welding current**
< 3,2 mm	2,4 mm	60… 100 A
3,2…5 mm	3,2 mm	80… 160 A
> 5 mm	4,0 mm	> 150 A

Automatic / manual ATIG welding. Besides that automatic application of ATIG welding is strongly suggested, some trials were made to weld manual. On the basis of these experiences it is presentable that ATIG welding is applicable to weld manually. But, of course, special practices and huge amount of skills needed for the welder for the successfully application. The plate thickness limit for manual ATIG welding strongly depends on the reflected heat load that the welder has to stand. This heat load was sometimes so high that the welder’s gloves burned out! This heat load depends on the amperage, which depends on the thickness. Finally it is standable that the manual ATIG welding is applicable until 5 mm thickness.

Comparison of TIG and ATIG welded joints. To compare correctly the two procedures proper plate thickness had to be found which was weldable by one root with both TIG and ATIG welding. Thickness of 3 millimetres was found the most suitable for this aim, because this size is the upper limit of the weldability (by one root) of TIG welding with acceptable productivity. The upper limit problem does not exist related to ATIG welding, because we do not know its upper limit of weldability (by one root). During experiments for austenitic stainless steels (before present work) the 8 mm plate thickness welding by one root butt-weld was attained. These joints were made by 220 A and welding speed of 8 cm/min.

5. CONCLUSIONS

The presented results show that the ATIG welding is applicable in industrial environments and it belongs to the high productivity welding procedures. Its application is suitable for mechanised welding of thick plates over 3 mm with one root (e.g. orbital welding of thick-walled pipes). Moreover the possibility of manual applications cannot be precluded based on the manually applied experiments especially at lower thickness (for instance field welding of tanks with wall thickness of 3-5 mm). Increasing the competence of the ATIG process, the welding of much thicker of plates, pipes is possible with one pass. This fact, and the moderate price, thanks to the simple composition of the activating flux altogether makes this method economical.

The reduced heat input was shown also in the size of the heat-affected zone: the HAZ is narrower. The investigation of the sensibility for the root gap proved, that the ATIG welding can be applied not only with zero gap. According to our experiences the maximal gap can be 10 % of plate thickness. This fact makes the ATIG-welding applicable in the industry.

Considering the mechanical properties – the strength and the toughness as well – both welding process resulted a quality up to the requirements. Thanks to the reduced/smaller heat input a more advantageous microstructure is formed in the ATIG welding, although in the mechanical examinations, better mechanical properties can’t be observed as a result of the finer dendritic structure of the ATIG-weld. The crown side of the TIG-welded seam is more esthetical, but use of silica-titania mixture as activating flux compensated the esthetical disadvantages of the ATIG-welded seam.

When the gases do not contain N_2, the ferrite content is the same for both, ATIG and TIG process. For the ATIG welding the weld metal ferrite content is significantly smaller when N_2 containing gas is applied as shielding and pure argon as backing gas, but the N_2 addition to backing gas does not have any influence on the phase ratio if shielding gas is pure argon. For the ATIG welding the delta ferrite content of weld metal (45 %) is significantly smaller than at TIG welding (average value is 60 %) when argon + nitrogen gas mixture is applied as shielding gas.

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REFERENCES

1) A.G. SIMONIK, Svar. Proiz., (1974:3), p.52.
2) M.M. SAVITSKIJ and G.I. LESKOV, Avtom. Svarka, (1980:9), p.17
3) C.R. HEIPLE et al., Weld. Res. Suppl., (1985:6), p.159.
4) G. M. Oreper, T. W. Eagar and J. Szekely, Welding Journal, 62, (1983) p.307.
5) J.J. LOWKE, M. TANAKA and M. USHIO, J. Phys.D: Appl. Phys., 38, (2005) p.3438.
6) N. PERRY, These de doctorat, Université de Nantes, 2000, N° ED. 82-452
7) P.C.J. ANDERSON and R. WIKTOROWICZ, TWI report 549/1996
8) N. AMES, M. HOLMQUIST and M.Q. JOHNSON, Proc. Duplex 2000 Conf.
9) M.Q. JOHNSON and CH.M. FOUNTAIN, US Patent 6707005 (2004)
10) J. CORNU, TIG and related processes. IFS Publications Ltd., Bedford, UK, (1988)
11) J.J. LOWKE, M. TANAKA and M. USHIO, Austral. Weld. J., 47, (2002)
12) R. Badji, Mater. Charact., (2007) in press
13) S. SIRE, S. MARYA, C.R. Mecanique, 330, (2002) p.83.
14) S. SIRE, G. Rückert and S. MARYA, Matériaux 2002, Tours, CM08006.PDF
15) P.J. MODENESI, E.R. APOLINÁRIO and I.M. PEREIRA, J. Mater. Proc. Tech., 99 (2000) 260.
16) T. PASKELL, C. LUNDIN and H. CASTNER, Weld. J., 76, (1997) p.57
17) J. NIAGAJ, Weld. Int., 17, (2003), p.257.
18) I. MESZAROS, Phys. B-Cond. Matter, 372, (2006), p.181
19) I. MESZAROS, P.J. SZABO, NDT & E Int., 38, (2005), p.517.
20) BERECZ T, SZABO PJ, Mater. Sci. Forum, 473-474, (2005) p.177.