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ACTIVATED TIG WELDING OF FERRITIC STAINLESS STEEL

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Abstract: - As a consequence of the enormous changing of the alloy surcharges of austenitic corrosion resistant steels in the last years more and more attention was focused on the cheaper ferritic stainless steels. Knowing the weldability problems of the ferritic stainless steels (sensitivity of grain growth during heat input, low ductility, etc.) it seemed the application of ATIG (Activated-TIG) welding with its lower heat input and focused arc may will provide advantageous results. This paper sums up the experiments that were done on ferritic steels with different thicknesses, different welding speeds and heat inputs. To strengthen our observations microscopic examinations also were done to compare the conventional welding methods and the ATIG welding.

Keywords: Activated TIG Welding, Ferritic Stainless Steel



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INTRODUCTION

In the last some years an enormous market stainless steels demand appeared .It is usual when we say “stainless” we mean “austenitic stainless steel” as the 80-90% of the total stainless steel production and consumption is austenitic. The advantages of austenitic stainless types are very well known: easy forming, very good weldability, good corrosion resistance, decorative outlook, and so on. An additional benefit is the very wide literature of the previously mentioned properties, which helps the user to find solutions for any problems that may occur during production.

In opposite with austenitic types the ferritic and martensitic types have several problems which did not help them to spread in the industry, but on the other hand in some specific areas these steels may be the unique solutions.

As the well sellable austenitic stainless steels contains 8, 12, 13, etc percent nickel, parallel with the increasing demand of austenitic stainless steels the demand of nickel also increased. This led to the substantial increasing of alloy surcharges and nickel prices.

The reaction of market did not wait too long time and soon began the developing of the low nickel content stainless steels. Among the duplex steels these types are called “lean duplex”. Parallel with these developments the focus of the market’s attention turned to the direction of elder and new ferritic stainless steels (FSSs). This work would like to represent the results of welding of the grain coarsening and intergranular corrosion sensitive FSSs by the Activated Tungsten Inert Gas (ATIG) welding.

The ATIG welding

The ATIG welding is the high productivity variation of the conventional TIG welding. When applying this hardly known welding process, the welding may be executed with substantially lower welding current and higher welding speed while the penetration is 2-3 times deeper as it is with conventional TIG welding. When ATIG welding is applied for welding of stainless steels the following rules must be kept:

- ATIG welding is applicable without bevelling. This decreases the cost and time of production and let the end-user easier fitting;
- Gap is not recommended when fitting the pieces, because it increases the possibility of porosity;

- One size bigger tungsten electrode should be used to resist the higher reflected heat;
- Electrode sharpening should be around 45° for longer life expectancy;
- Consistent active flux portioning is indispensable;
- Welding consumable is not added to the weld pool.

Generally about ferritic stainless steels

In spite of the advantageous properties of FSSs (similar mechanical properties to austenitic types, very good corrosion resistance to Cl-containing medias, high stress corrosion cracking resistance, low thermal coefficient and consequently low thermal fatigue tendency, strongly adhere oxide layer which is really prosperous at elevated temperatures and quite stable and low price) unfortunately the user should also be aware of some handicaps:

- In case of presence of carbon in the FSS the γ -loop opens which leads to formation of austenite and martensite (with appropriate cooling rate) (Figure 1);
- The presence of even a very small carbon content in FSSs also tend to form carbides in really wide variety (the most regular forms are $M_{23}C_6$ and M_7C_3 where M stands for Fe+Cr in FSSs) which finally results the high risk of intergranular corrosion (This is the so called sensitisation-effect);
- Aptitude to 475 °C embrittlement (especially when Cr-content is above 18%);
- σ -phase formation in the temperature range 500... 800°C (aptitude is increasing with Cr content);
- In the case of Nb or Ti stabilization knife-edge corrosion may occur in the heat affected zone (HAZ);
- Grain coarsening in HAZ;
- In pure ferritic types because of the lack of $\gamma \rightarrow \alpha$ transformation heat treatment is not possible to repair the grain-coarsened structure.

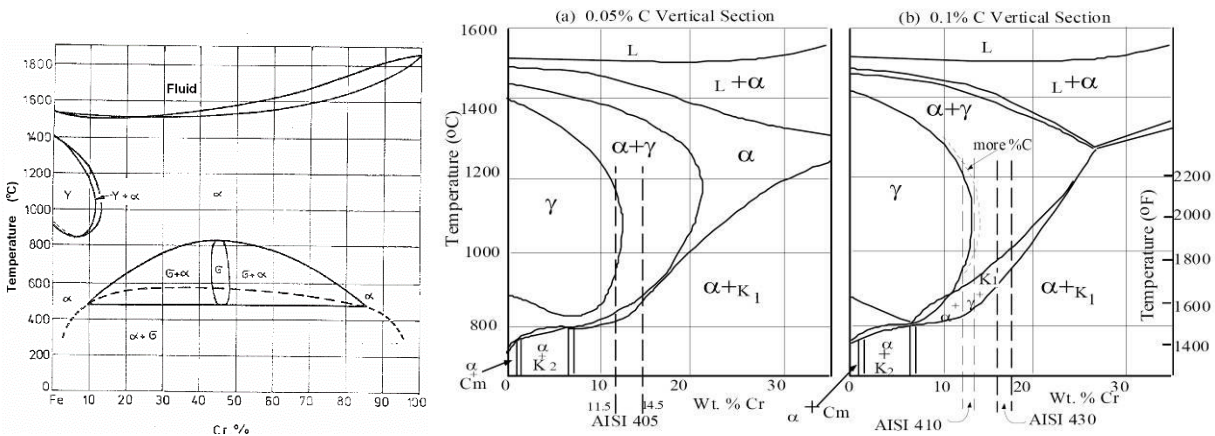


Figure 1. Fe-Cr binary system with <0.01%C content (left figure); Fe-Cr-C ternary system with 0.05%C content (middle figure); Fe-Cr-C ternary system with 0.1%C content (right figure). 1, 5

After solidification the FSSs keeps their body centered cubic lattice (bcc) until the room temperature. This explains why the regenerating heat treatment is not possible in FSSs, so consequently it may be stated that the biggest disadvantage of FSSs is the grain coarsening of HAZ. This phenomenon substantially decreases the mechanical and corrosion resistance properties. Moreover if C is present in the FSS the formation of carbides is almost unavoidable which finally leads to worse mechanical properties and decreased corrosion resistance.

In the following this paper would like to represent the effect of ATIG welding to grain structure of FSSs compared to TIG welding. 5, 7, 2.

EXPERIMENTS

The ATIG welding experiments were done in flat butt weld (PA) position without bevelling and fitted with no gap. Both shielding and backing gas were pure argon (T4.5). The arc length (the gap between tungsten electrode and the plate) was kept at 2 mm. The consistent arc length and welding speed was ensured with mechanised TIG torch moving table. Here the constant arc length parallel with analogue setting of welding speed with a potentiometer was also possible.

The base material was 430 type with the plate thickness of 8 mm (

Table 1).

Table 1. Chemical composition of investigated 430 type ferritic stainless steel according to inspection certificate 3.1.

C	Mn	Si	Cr	P	S
0.046	0.67	0.46	16.37	0.02	0.003

The cut edges were grinded manually and cleaned with alcohol to remove the possible grease or oil residuals from the proximate surrounding of the welding.

The welding parameters were optimised for ATIG welding to obtain absolutely perfect root penetration. The same parameters were applied for TIG welding afterward to ensure the same heat input. Thus the comparison of TIG and ATIG welding was possible from the point of view of heat input. The measured average grain size of base material was in the range of 30... 80 μm .

After parameter optimisation the following welding parameters were applied (Table 2).

Table 2. Welding parameters of TIG and ATIG welding of 8 mm thick 430 type ferritic stainless steel.

	Welding current (A)	Voltage (V)	Power (kW)	Arc efficiency (%)	Welding speed (mm/min)	Heat input (kJ/mm)
ATIG welding	250	20	5.00	75	70	3.214
TIG welding	250	20	5.00	75	70	3.214

Results of TIG welding

As the welding parameters of TIG welding were set to ATIG naturally perfect penetration was not expected. Thus only simple bead on plate welds were examined (Figure 2).



Figure 2. Cross section of bead on plate weld with TIG process.

As in the examined 430 type FSS the carbon content was 0.046% according to Figure 1. (middle figure) austenite and optionally martensite formation was expectable. Consequently the most interesting questions were how large mutation of grain size occurred due to the counted 3.214 kJ/mm heat input in the HAZ and how much austenite/martensite formed in the welded joint and in the HAZ.

Naturally the grain coarsening was befallen (Figure 3) in the HAZ. The average grain size increased to the range of 60... 120 μm in the HAZ.

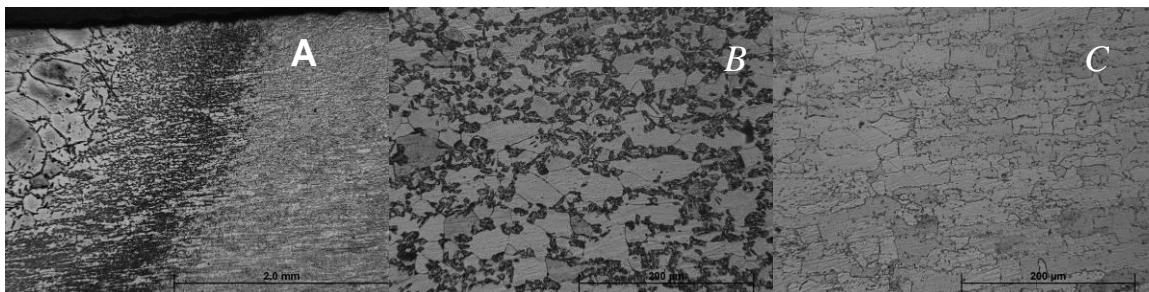


Figure 3. Macro- (A) and microstructure (B) of the HAZ of TIG-welded joint and microstructure of the base material (C).

The tremendous grain size increasing in the weld metal may have been improved with lower heat input but it was not the aim of this experiment. 6

Results of ATIG welding

The joints made with ATIG welding with the parameters stated in Table 2 resulted total root penetration (Figure 4).



Figure 4. Cross section of ATIG welded joint; plate thickness is 8 mm.

The cross section of the joints shows that the welding current could have been lower slightly. The little bit higher current was necessary to evade the root penetration faults that may originate from the not absolutely perfect fitting. The most interesting observation was between HAZ and welded joint of TIG and ATIG was that in case of ATIG welding the grain coarsening was a little bit moderate and the martensite formation was bigger. This originates from that the weld pool of TIG is more shallow (thus its volume is less) so the arc energy heats up to higher temperature the weld pool thus grains have more time to become larger in the HAZ as they are in the critical temperature range for longer time. In case of ATIG welding the weld pool is deeper and the volume of molten metal is bigger which flows faster. By this the arc energy does not heat up the weld pool overly. So the HAZ (with the weld pool) can cool down faster through the critical temperature interval, which results in finer grain structure there ⁸. If the previous statement is appropriate the faster cooling rate must be observed in the weld pool of ATIG welding too. The faster cooling rate increases the possibility of formation of martensite. The difference of formed martensite is shown on Figure 5.

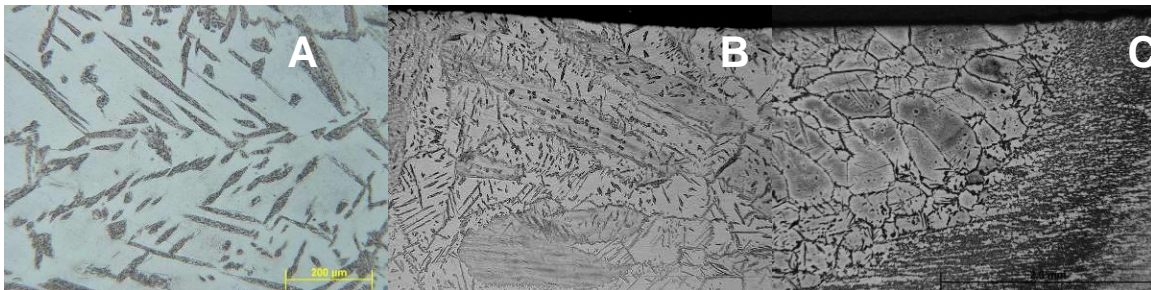


Figure 5. A.) Martensite in austenite matrix on the grain boundaries in the welded joint of the ATIG joint; B.) The microstructure of an ATIG joint; C.) The microstructure of a TIG joint.

The austenite/martensite ratio was examined by EBSD and micro hardness testing on the grain boundaries. EBSD stated that the austenite/martensite ratio was slightly bigger in TIG welded joint which represent its lower cooling rate while the martensite volume was bigger in ATIG welded joint. The micro hardness testing showed that in both cases the rest austenite decreased the hardness of the martensite. While inside the ferritic grain the hardness was 170-175 HV_{0.05}, in the grain boundaries it was only 270-320 HV_{0.05} (martensite is over 400-500 HV).

The grain size of both the welded joint and the HAZ can be decreased by reducing the heat input. The heat input lowering may be operated by welding current reduction or welding speed increasing. By applying these techniques, the penetration of the joint will not be enough for total root. To dissolve the problem of not perfect joint two-sided technique was applied.

RESULTS OF TWO-SIDED ATIG WELDING

The two-sided technique was applied with the same rules as they were established in the introduction. For the two-sided application had many benefits:

- no need of backing gas;
- no need of precise parameter setting (as there was no chance of weld pool holing);
- no need of accurate fitting of the plates.

In view of these points the following (Table 3) parameters were applied to obtain absolutely through melted joint.

Table 3. Welding parameters for two-sided ATIG welding.

		Welding current (A)	Voltage (V)	Power (kW)	Arc efficiency (%)	Welding speed (mm/min)	Heat input (kJ/mm)
Two-sided welding	ATIG	250	20	5	75	150	1.5

Most of the international literature stands that to avoid the grain coarsening of FSSs during welding the lowest possible heat input should be maintain. In some cases exact data is also stated. The highest recommended value is $q_{in} = 2.6$ kJ/mm (the same as for duplex stainless

steels). The heat input of one-sided experiments were higher (3.214 kJ/mm) than this value and the grain coarsening was really spectacular. The heat input of two-sided experiment (1.5 kJ/mm) is far below the 2.5 kJ/mm limit. 1

Thus naturally significantly lower grain coarsening was expected in both HAZ and welded joint. The two-sided ATIG joint went of well. None of welding defects appeared in the joint with special regards to the remelted zone (**Error! Reference source not found./A**).

The expectations were not completely fulfilled. As it is visible in Figure 66/B and C only a very slight decreasing could be gained concerning the wideness of the HAZ. Moreover the austenite + martensite formation also was not avoided.

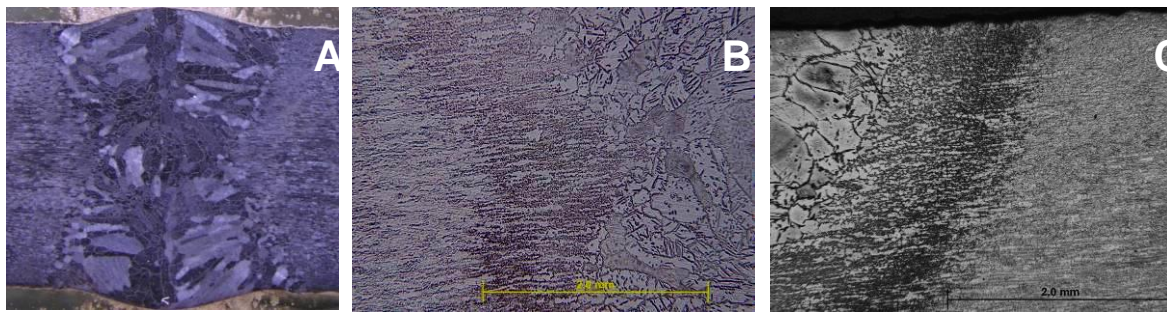


Figure 6. A.) The joint of two-sided ATIG joint; B.) HAZ of two-sided ATIG joint; C.) HAZ of TIG joint.

CONCLUSIONS

On the basis of the previously reviewed experimental work the following conclusions are stated:

- The lower heat input can not avoid the austenite, martensite and carbide formation in 430 type FSS.
- By application of ATIG welding with the same heat input faster cooling can be reached thus martensite is slightly more on grain boundaries in the formed austenite.
- One pass welding of 8 mm thick FSSs is not possible below ~3 kJ/mm heat input neither with TIG nor with ATIG welding.
- The heat input can be decreased and productivity can be increased substantially by two-sided welding where ATIG is applied.

- Further mechanical testing are indispensable to evaluate these results from practical point of view.

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