ATIG WELDING OF FERRITIC STAINLESS STEELS

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Abstract

As a consequence of the alloy surcharges of austenitic corrosion resistant steels in the last years more and more attention has been focused on the cheaper ferritic stainless steels. Knowing the weldability problems of the ferritic stainless steels, such as grain growth resulting in low ductility, for instance, the application of the activated TIG (ATIG) welding with its lower heat input and focused arc may provide certain advantages. This paper summaries the experiments performed on ferritic steels with various thickness, welding speeds and heat inputs. Microscopic examinations were also done to compare conventional welding methods and ATIG welding.

Introduction

In the last years an enormous market demand has appeared concerning the stainless steels. Here and usually when we say "stainless" one means "austenitic stainless steel" as 80-90% of the total stainless steel consumption is austenitic. The advantages of austenitic types are very well known: good formability, excellent weldability, good corrosion resistance, decorative outlook, and so on. An additional benefit is that these properties are well documented that helps the user to find out solutions for any problem that may occur during production.

Contrary to austenitics, the ferritic and martensitic types have several problems, which have limited their use. However, in some specific areas these steels may be unique solutions. The most common austenitic stainless steels contain 8-13% Ni. With increasing of alloy surcharges and nickel prices the interest in low-nickel content stainless steels has rapidly increased. Among the duplex steels these types are called "lean duplex". Parallel with these developments the focus of the market's attention has turned to ferritic stainless steels (FSSs). This work will present some results regarding the grain coarsening and intergranular corrosion sensitivity of FSSs as welded by the Activated Tungsten Inert Gas (ATIG) method.

ATIG welding

The ATIG welding method is a high productivity variation of conventional TIG welding. When applying this, so far an unfrequently used welding process, welding may be executed with substantially lower welding current and higher welding speed, even though the penetration is 2-3 times deeper compared to that with the conventional TIG welding. When ATIG welding is applied for welding of stainless steels the following should be noticed:

- ATIG welding is applicable without bevelling. This decreases the cost and time of production;
- A gap is not recommended, as it increases the possibility of porosity;
- One size thicker 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 important;
- Any filler metal is (usually) not added to the weld pool.

Main characteristics of ferritic stainless steels

Although FSSs offer many useful properties (formability, good corrosion resistance, high stress corrosion cracking resistance, low thermal coefficient and consequently low thermal fatigue tendency, and low price) unfortunately the user should also be aware of some handicaps:

- Many FSS pass through the γ-loop during cooling, which leads to the formation of austenite and subsequently martensite (Figure 1);
- The presence of even a very low carbon content in FSSs tends to form carbides that finally results in high risk of intergranular corrosion;
- Sensitive to 475°C embrittlement (especially when Cr-content is above 18%);σ-phase can form in the temperature range 500… 800°C (tendency increases with Cr);
- Knife-line corrosion may occur in the heat affected zone (HAZ) in grades stabilised with Nb or Ti;
- Significant grain coarsening in the HAZ decreases the ductility;
- In fully ferritic types, because of the lack of γ→α transformation, any heat treatment is not possible to refine the coarsened grain structure.

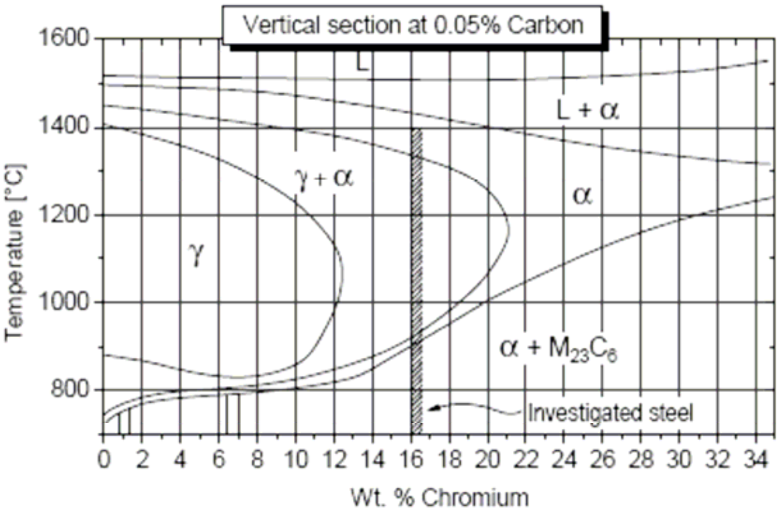


Figure 1. Fe-Cr-C quasi-ternary phase diagram with 0,05%C content [5]

After solidification the FSSs largely keep their body centred cubic lattice (bcc) until the room temperature. This explains why a grain refining heat treatment is not possible for them, and consequently it may be stated that a major disadvantage of FSSs is the grain coarsening in HAZ. This phenomenon substantially decreases the mechanical properties and corrosion resistance. Moreover, if C is present in FSSs, the formation of carbides is almost unavoidable that finally leads to worse mechanical properties and impaired corrosion resistance.
In the following this paper will present the effect of ATIG welding to grain structure of FSSs compared to obtained with the TIG welding. [5], [7], [3]

Experiments

The ATIG welding experiments were carried out in flat butt weld (PA) position without bevelling and without gap. Both shielding and backing gases used were pure argon (T4.5). The arc length (the gap between tungsten electrode and the plate) was kept at 2 mm. A consistent arc length and welding speed were ensured by using a mechanised TIG torch moving table. Here the constant arc length parallel with the analogue setting of welding speed with a potentiometer was also possible.

The base material was AISI 430 type (X6Cr17; 1.4016; UNS S43000) ferritic stainless steel, with the plate thickness of 8 mm. The chemical composition is given in

Table 1.

Table 1. Chemical composition of investigated 430 type ferritic stainless steel.

C	Mn	Si	Cr	P	S
0,046	0,67	0,46	16,36	0,02	0,003

The cut edges were ground manually and cleaned with alcohol to remove any grease or oil residuals in the vicinity of the joint.

The welding parameters were optimised for ATIG welding to obtain absolutely perfect root penetration. The same parameters were applied for TIG welding afterwards 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 welding parameters as follows 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	240	20,8	5,00	75	70	**3,2**
TIG welding	240	20,8	5,00	75	70	**3,2**

Results of TIG welding

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

Figure 2. A cross-section of bead-on-plate welded with TIG process; weld penetration less than 3 mm.

As in the 430 type FSS examined the carbon content was 0.046%, according to Figure 1 austenite and optionally martensite formation were expected. Consequently, the most interesting questions were how much the grain size increased due to the 3.2 kJ/mm heat input in the HAZ and how much austenite/martensite formed in the welded metal and in the HAZ. As expected, the grain coarsening was significant (Figure 3) in the HAZ. The average grain size increased to the range of 60…120 µm.

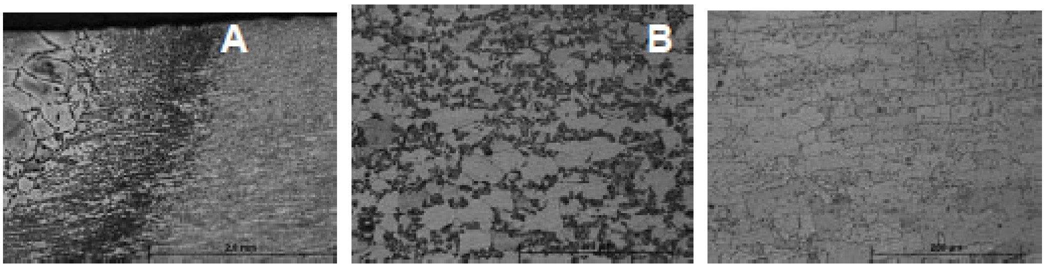


Figure 3. Macro- (A) and microstructure (B) of the HAZ of TIG-welded joint and the base material (C).

The tremendous grain size increase in the weld metal might have been less pronounced with a lower heat input, but this was outside the scope of this investigation. [6]

Results of ATIG welding

The joints made with the ATIG welding, using the parameters listed in Table 2, showed a complete root penetration (Figure 4).

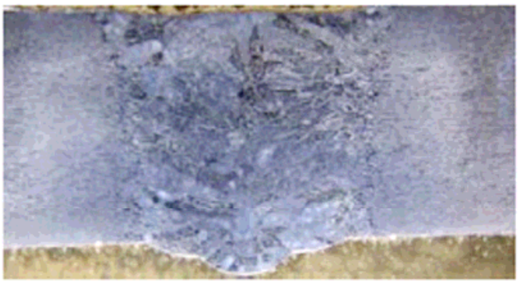
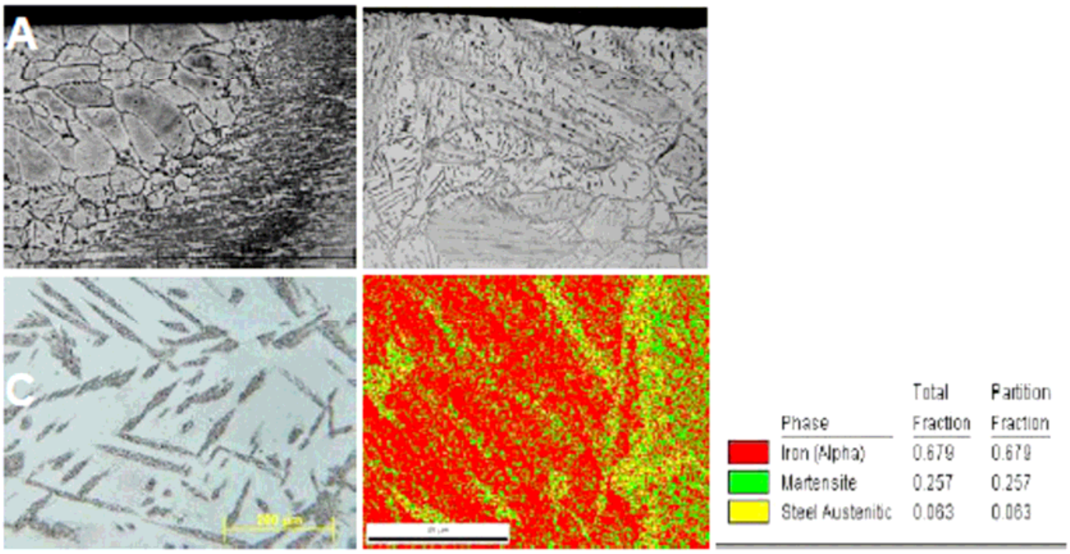


Figure 4. A cross-section of ATIG welded joint; plate thickness 8 mm.

The cross-sections of the joint indicate that the welding current used could be slightly lower. However, a somewhat higher current was necessary to avoid root penetration faults owing to a not absolutely perfect fitting. The most interesting observation when comparing HAZ and fused weld metals of TIG and ATIG was that in the case of ATIG welding less grain coarsening and more martensite formation were present. This origins from the fact that the weld pool of TIG is more shallow, so that the arc energy heats up the weld pool to a higher temperature. Therefore grains have more time to grow in the HAZ while they are in the critical temperature range for a longer time. In the case of ATIG welding the weld pool is deeper and the volume of molten metal is larger. Therefore the arc energy does not heat up the weld pool to the same extent and the HAZ (and the weld pool) can cool down faster through the critical temperature range, which results in a finer grain structure [8]. The faster cooling rate increases the possibility of formation of martensite. The difference in the martensite contents is shown in Figure 5.



	Phase	Total Fraction	Partition Fraction
🟥	Iron (Alpha)	0.679	0.679
🟩	Martensite	0.257	0.257
🟨	Steel Austenitic	0.063	0.063

Figure 5. Microstructures of ATIG (A) and TIG welded joint (B). Acicular plates in ferrite matrix of the ATIG welded joint (C) and phase map of an interior part of a plate (D)

EBSD analysis and microhardness testing on the grain boundaries were used to examine the austenite/martensite ratio. The EBSD stated that the austenite/martensite ratio was slightly bigger in the TIG welded joint, corresponding to its lower cooling rate, while the martensite fraction was bigger in the ATIG welded joint. The microhardness testing showed that in both cases the austenite decreased the hardness of the martensite. While the hardness was 170-175 $HV_{0,05}$ inside the ferritic grains, it was 270-320 $HV_{0,05}$ at the grain boundaries (the hardness of martensite is over 400-500 HV).

Reducing the heat input can decrease the grain size of both the welded joint and the HAZ. This can be achieved by reducing the welding current or increasing the welding speed. By applying these techniques the penetration of the joint will not be sufficient. Therefore, a two-sided technique was applied.

Results of two-sided ATIG welding

The two-sided technique was applied following the same guidelines as described in the introduction. Two-sided welding have many advantages:

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

In view of these points the following (Table 3) parameters were employed to achieve the full penetration.

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 ATIG welding	240	20,8	5	75	150	**1,5**

Most of the international literature states that to minimise the grain coarsening in FSSs during welding, the heat input as low as possible should be maintained. Thus, naturally significantly lower grain coarsening was expected in both HAZ and welded joint in two-sided welding. No welding defects appeared in the joint with special regards to the remelted zone (Figure 6A). However, the expectations were not completely fulfilled. As is seen in Figure 6B and 6C, only a very slight decrease of the HAZ width was achieved and the austenite + martensite formation was not avoided.

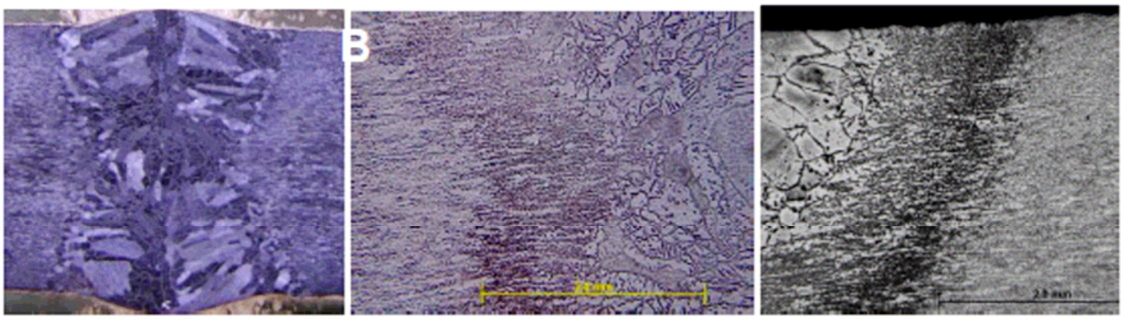


Figure 6. A) The joint of two-sided ATIG joint; B) HAZ of two-sided ATIG joint; C) HAZ of TIG joint.

Conclusions

On the basis of the experimental work the following conclusions can be stated:

- The lower heat input cannot avoid the formation of austenite, martensite and carbides in 430 type FSS. Hence, the welding of this type FSS is not recommended, not even by the ATIG process.
- By application of ATIG welding instead of conventional TIG with a given heat input, faster cooling can be reached producing slightly more martensite on grain boundaries.
- Single-pass welding of 8 mm thick FSSs is not possible using the heat input below ~3 kJ/mm, neither with TIG nor with ATIG welding.

- The heat input can be decreased and productivity can be increased substantially by two-sided welding applying the ATIG method.
- Further mechanical testing is required to evaluate these results from practical points of view.

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