PAPER • **OPEN ACCESS**

Researches for improving mechanical characteristics of high strength weld

To cite this article: L Zgripcea *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **477** 012008

IOP Conf. Series: Materials Science and Engineering 477 (2019) 012008 doi:10.1088/1757-899X/477/1/012008

Researches for improving mechanical characteristics of high strength weld

L Zgripcea, O Lupu, V Putan and C Birtok Baneasa

Politehnica University of Timisoara, Engineering and Management Department, 5 Revolution Street, Hunedoara, 331128, Romania

E-mail: laurentiu.zgripcea@student.upt.ro

Abstract. The current paper presents application domains of high strength weld, fabrication technologies and tests. High strength weld is used for assembly of high strength low alloyed steel (HSLA) where the same or greater mechanical properties must be obtained in weld line. The method presented in this paper is based on micro alloying inside the root of the weld, with minimum supplementary cost and keeping the same productivity for welding process. The applications of this method are realizations of storage pressure vessels, shields, crane arms and generally, all applications where high strength at a low weight are required.

1. Introduction

Alloy steels known as high-strength low-alloy (HSLA) can assure better strength per weight ratio compared with conventional low-carbon steels with an acceptable, additional price of 24% in average. Because HSLA steels are stronger, they can be used in thinner sections, making them particularly attractive for buildings, bridges and automotives, where weight reduction is important. HSLA steels are available in all standard rolled forms as plates, bars, structural profiles, and special profiles.

Regarding carbon content steel classification, HSLA steels are low-carbon steels with carbon content between 0.05–0.25 % (Table 1). Second important alloy element is mangan up to 1.5 % , strengthened by small additions of elements, such as niobium, vanadium or titanium.

Beside of chemical composition special rolling and cooling techniques are required. Controlled chemical composition improve the microstructure of HSLA steel by reducing the size of ferrite / perlite crystals. This fine precipitate acts as crystallization points which refines grains size and increases the material's strength. Usually, decrease the grains size by 50% double the yield strength. Precipitation strength also plays a minor role [1].

Another point to assure the mechanical properties of HSLA is reduction of phosphor and sulphur inclusion, by addition of calcium during vacuum degassing treatment

Table 1. Chemical composition of HSLA grades [2]

	percentage %									
grade	C	Mn	Nb	Mo	Ti	N	P	S	Si	Al
X80	0.06	1.65	0.03	0.24	0.01	0.01	0.00	0.00	0.00	0.00
HSLA 65	0.06	1.24	0.06	0.01	0.00	0.01	0.01	0.00	0.05	0.04
HSLA 90	0.05	1.65	0.07	0.20	0.02	0.00	0.01	0.00	0.03	0.03

From chemical composition table results the correlation between Niobium (which is the most effective microalloying element) and yield strength. Usually, every 0.01% Niobium addition bring 35 to 40MPa in yield strength.

There are two ways such steel of high strength and high toughness steels are produced:

- By micro-alloying: Adding small amount of alloys which form carbide and nitride crystallization points
- By thermo-mechanical rolling: very accurate control of the rolling temperature and cooling time called thermo-mechanically controlled process (TMCP)

The highest strength is achieved by a combination of the two methods. Final objective is to produce smaller again size as possible, finer grains assure the best yield and impact properties.

The additional benefit is the increased weldability of the material. Fast cooling of steel after welding can induce fragility if hardenability of the steel is high. To minimize this effect, usually carbon content is around limited around 0.05% .

Main effect of increasing the yield strength of low alloyed steel is reduction of steel thickness used in various assembled structures. Although economically is a very positive point, the drawback is always reduction of weld area used in these structures.

Reduction of weld area makes the weld line the weak point in whole structure, weld cannot follow the strength of HSLA steel and from this reason is necessary to redesign the structure, make it again ticker and canceling partially the advantage of HSLA steel.

Several best practices are key to achieving success when welding HSLA steels. Key points are clean material surface, proper preheating and interpass temperatures [3]:

- **Clean material surface**: clean surface is important before welding and between weld layers. Grease, water, dirt or other contaminants can be decomposed by arc temperature and form hydrogen. Steel has a high hydrogen affinity which once entrapped in crystal matrix can induce cracks due to pressure at low temperature. Hydrogen reaction with carbon can amplify the effect because methane resulted has a bigger molecule and can induce higher pressure. It is recommended to remove all contaminants and oxides buy grinding, using abrasive paper. grinding wheel or sand blast gunning machine
- **Proper preheating:** Hardenability effect can be decreased by control of cooling rate. This must be increased to the maximum allowed by welding process. Slower cooling rate has also reduce the content of diffusible hydrogen, allows it to dissipate from weld line and reduces risk of hydrogen cracking.

  Preheating reduces shrinkage stress and forms more favourable microstructures that increase mechanical properties.

  Preheating temperature depends by thickness and carbon content (type) of HSLA steel used. Best procedure is to use equivalent carbon formula which take into account effect of carbon together with other alloy elements. Another important point is to preheat base material on the both side of the weld line in order to assure a uniform thermal pattern inside of weld line and heat affected zone.
- **Maintain interpass temperatures:** This is an important parameter and must be correlated with preheat temperature when HSLA steel is welded.

  Low interpass time can bring too much energy heat which together with preheating energy can alter the grains structure, make them larger. Mechanical properties, especially Charpy impact is reduced.

  Long interpass time together with a poor preheating can bring fast cooling which will increase fragility of the weld.

2. New researches and production trials

On top of best practices regarding welding of HSLA steel, the paper present new methods and technologies implemented experimentally in crane arms production.

Main idea was to improve mechanical characteristics of the fusion zone by microalloying during welding.

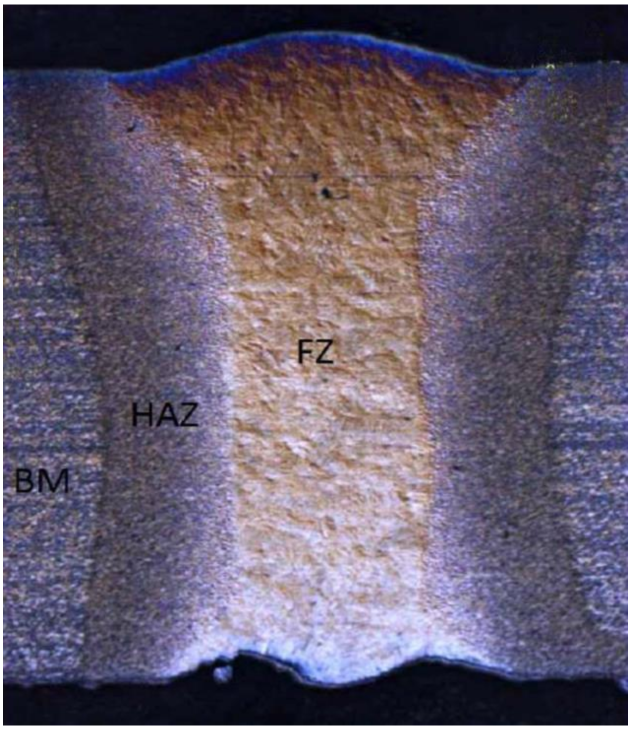


Figure 1. Weld transversal section

In the weld transversal section enhanced by acid attack are visible the 3 main zones (Figure 1):

- Bas material (BM) with fine granulation specific of HSLA steel
- Heat affected zone (HAZ)
- Fusion zone (FZ)

Trials were made using MAG welding technology for plates thickness between 3 and 10mm using an additional wire laid down in the weld root as in Figure 2.

In this case, during plates tack welding (red points) high alloyed wire was inserted (yellow color). Using this procedure only little supplementary maneuver is necessary and most important, does not change assembly technology in production line.

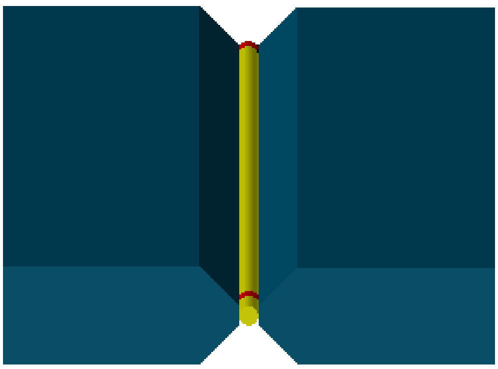


Figure 2. Alloyed wire position and fixation

Dilution of the welding wire is shown in Figure 3.

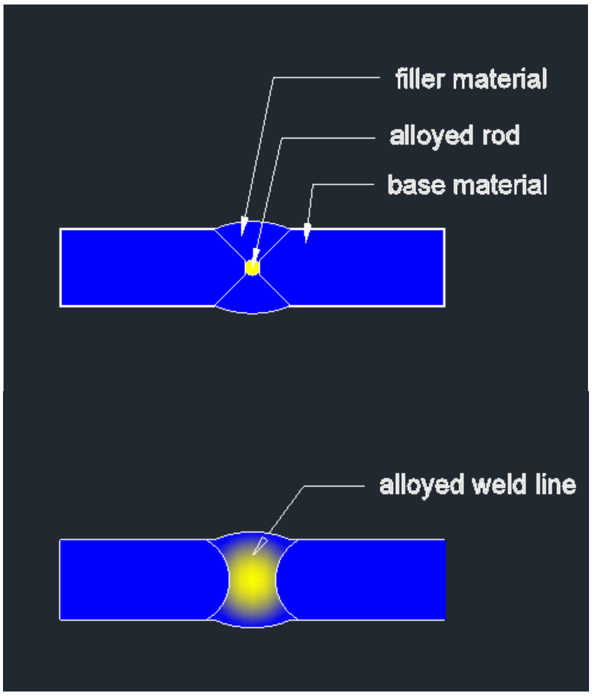


Figure 3. Dilution of alloyed element in fusion zone

Another important point was calculation of alloy element in fusion zone. For this purpose, was developed a calculation methodology and an excel spreadsheet calculation.

As input data, we consider plate thickness (s), alloy wire rod diameter (d) and concentration of alloy element in this wire.

Taking into account effect of various elements in steel we consider for first trial nickel element. Normally, around 1% nickel, provides a range of 60-ksi to 70-ksi tensile strength and has excellent toughness. Further increase of nickel content between 1.1% and 2.75% assure also high impact strength at low temperatures.

Joint was prepared in double V groove an welded on both sides as in Figure 4.

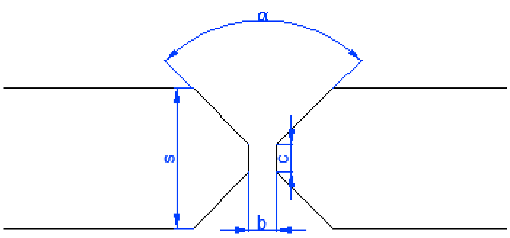


Figure 4. Joint bevel preparation

For calculation of alloying degree, first parameter is the geometrical area (A_g) of the bevel:

$$A_g = b \cdot s + \frac{1}{2}(c - s)^2 \cdot tg\,\frac{\alpha}{2} \tag{1}$$

For 10mm plate thickness case, Ag =75.4 mm^2

Because of 15% dilution rate (participation of base metal, melted by electrical arc) we define weld area (A_w):

$$A_w = 1.15 \cdot A_g \tag{2}$$

In this case, A_w=86.7mm^2.

In order to change the nickel content in fusion zone, we chose to weld plates with the same thickness (s=10mm) and use a nickel alloyed wire with different diameters, from 0.8mm to 3.2mm.

Regarding welding technology, aim is to keep as much as possible the layout of production line and not to be obliged to invest in expensive welding devices.

Main wire rod used for welding was classical 3GSi1 grade [4], and alloyed rod was Fe-Ni with 51% Nickel.

Welding procedure is metal activ gas (MAG) and sample was weld symmetrically on both sides with parameters [5] presented in Table 2.

Table 2. Welding parameters

Pass from-to	Welding position ISO6947	Pass type	Process	Filler diameter (mm)	Welding current (A)	Welding voltage (V)	Polarity	Wire speed (m/min)	Travel speed (cm/min)	Heat input (kJ/cm)
1	PA	side A	135	1.2	170	20	DC+	3.2	20	8.16
2	PA	side B	135	1.2	170	20	DC+	3.3	20	8.16

As a remark, versus classical weld additional energy is necessary to melt alloyed wire. In this case, if classical weld requires around 6kJ/cm, with alloyed wire the set point is 8.16 kJ/cm so 33% more heat.

Consequent trials with different alloyed wire diameter are presented in Table 3.

Table 3. Alloyed element percentage

wire diameter (mm)	0.8	1.0	1.2	1.6	2.0	2.5	3.2
wire section (mm^2)	0.5	0.8	1.1	2.0	3.1	4.9	8.0
weld area (mm^2)	86.7	86.7	86.7	86.7	86.7	86.7	86.7
Nickel content in alloyed wire (%)	51	51	51	51	51	51	51
Nickel content in weld (%)	0.3	0.5	0.7	1.2	1.8	2.9	4.7

The process is feasible for automation and. In case of high series of production and usage of welding robots, alloyed wire can be added automatically as second wire in the welding torch [4]. In this case, beside of high quality weld a higher productivity can be obtained.

Figure 5. New torch design for automatically alloying

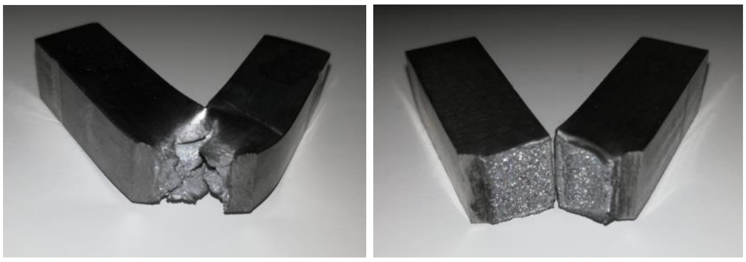
Figure 5 shows a modification of welding torch, by adding second wire.
Regarding electrical regime of alloyed wire is possible to adjust it for different situations:

- For thick plated alloyed wire is equal in diameter with main wire and makes the own electrical arc. This situation is called "tandem" and brings higher productivity.
- For medium thickness plates, alloyed wire is submerged in melted pool and its electrical arc is very short or even does not exist. A controlled current is heating the alloyed wire to compensate partially the energy needed for melting.
- For ultra-thin plate the best results are obtained with "cold" weld. In this case alloyed wire is smaller in diameter than main wire and is only immersed in melted pool.

3. Conclusions

Trials were made with same rod and different diameter.

- From yield point of view, nickel micro alloying improved weld fusion line. All samples during traction test did not breake in weld zone.
- Resilience of weld was improved almost in all cases. Best results were obtain with 1.6mm rod when fusion line has 1.2% Nickel and resilience improved by 18%. Increasing nickel content to 4.7% decreased drastically weld resilience and shows a fragile rupture (Figure 6).



Ni 1.2% Ni 4.7%

Figure 6. Resilience test

- Trials were made at 20 Celsius, but as an observation for negative temperature higher nickel content gives better resilience versus low nickel content.
- Nickel microalloy does not affect the weldability of HSLA steel [3], [7]. The measure for weldability is given by carbon equivalent formula and is satisfactory up to values of 0.35% [8], [9]:

$$CE\ (IIW) = C + Mn/6 + (Cr + Mo + V)/5 + (Ni + Cu)/15$$

As we observe in CE formula, Ni factor is divided by 15 and is minimal as influence for total CE.

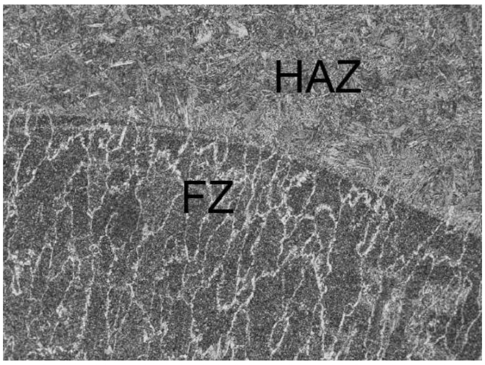


Figure 7. Microstructure, x100

- On microscopic structural analysis, fusion zone was carefully assessed. Structure is ferrite - perlite with acicular grains, fine enough to achieve better mechanical properties [1], (Figure 7).
- Weld micro alloying is suitable for industrial production. Alloyed wire is welded in points which usually are done during parts assembling, so no additional time is required
- Welding procedure modification is minimal, and alloy calculation can be done easy using excel files
- Method permit dosage of alloys in a large range, which is not possible for example by changing of filler material
- Dosage of alloys can target independently mechanic characteristics as resilience, toughness, behavior at low or high temperatures, or weldability
- Added cost with alloyed wire is minimal
- Method does not required changing of welding technology or procedures, so investments are minimal

References

[1] Lambert A, Drillet J, Gourgues AF, Stuel T and Pineau A 2000 Microstructure of martensite and austenite constituents in heat affected zones of high strength low alloy steel welds in relation totoughness properties, *Sci Technol Weld Join* **5**(3) 168e73

[2] ***ASTM A568 Standard specification for Steel, Sheet, Carbon, Structural and High-Strength General Requirements

[3] Omajene J, Martikainen J and Kah P 2014 Weldability of Thermo Mechanically Rolled Steels Used in Oil and Gas Offshore Structures, *The International Journal of Engineering and Science* 63-69

[4] Peters D J 1989 *Submerged arc welding consumables for HSLA-100 steel*, Massachusetts Institute of Technology

[5] Dunder M, Ivandic Z and Samardzic I 2008 Selection of arc welding parameters of micro alloyed steel, Metalurgia **47**(4) 325-330

[6] Buzduga R V, Constantin N and Lazar E A 2015 Research on uses plant ashes in processing powders for classical moulding of steel, *IOP Conf. Ser.: Mater. Sci. Eng.* **85** 012008

[7] Ragu Nathan S, Balasubramanian V S, Malarvizhi S and Rao A G 2015 Effect of welding processes on mechanical characteristics of high strength low alloy naval grade steel joints, *Defence Technology* **11** 308-317

[8] ***Equivalent carbon calculation, Atlas Steels, 2013

[9] Rucai V, Constantin N and Dobrescu C 2015 Experimental research program regarding the influence of thermo-time treatment of multicomponent ni-base melting on their properties in solid phase, *University Politehnica of Bucharest Scientific Bulletin, Series B-Chemistry and Materials Science* **77**(4) 359-364