# REPLACEMENT OF MANUAL GMAW WELDING BY FCAW SEMI-AUTOMATIC WELDING

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The article describes a replacement and benefits between manual gas metal arc welding (GMAW) with solid wire and semi-automatic flux-cored arc welding (FCAW) with metal flux-cored wire for a specific application of a welded steel compensator used for connecting piping systems to form larger units. For the replacement of the technologies and improvement of the welding efficiency and productivity a specific type of carbon steel mounting insert, DN300 PN16, was selected. Since these pressure parts are subject to the directive 2014/68/EU, both the welding processes have to meet the same welding quality requirements. In particular, they are the welding procedure qualification report (WPQR) and the welder's or welding operator's qualification in accordance with valid European standards. Based on this requirement, a sample was selected so that it would cover the widest possible range of carbon steel mounting inserts produced. This article describes the whole experiment including the selection of the right equipment and filler material, finding the ideal welding parameters, and the subsequent qualification of the welding procedure and the operator with emphasis on the largest possible increase in the welding speed and productivity for these specific weldments.

**KEYWORDS**

GMAW – gas metal arc welding, FCAW – flux cored arc welding, metal powder, WPQR – welding procedure qualification report, WPS – welding procedure specification, pWPS – pre-welding procedure specification, positioner, compensator, mounting insert.

## 1 INTRODUCTION

Due to lack of qualified staff, the basic requirement in each industrial sector is to implement automated production processes to the largest extent possible or possibly fully replace the manual processes with automated ones. The basic requirement in this experiment was also to increase the welding speed and productivity by employing full or semi-automatic welding processes while maintaining the required quality of the weld. For larger and complicated parts, it is better to invest in full automation or even robotic automation. In the case of smaller and less complicated parts, it is sufficient to invest in partial semi-automation as in the experiment described below. There are a number of possibilities of satisfying the requirements. One possibility is to replace the manual GMAW welding using solid wire on a rotator with semi-automated FCAW welding using flux-cored wire. We expect a reduction in the number of layers and an increase in the welding speed (productivity) by up to 30 %. This possibility is described and tested in the experiment. Another possibility could be replacing the standard single-wire GMAW torch with a twin-wire GMAW torch or with a tandem torch and thereby additionally increase the welding productivity as much as twofold. This possibility is not described or tested in this article and it could possibly be the subject matter of further study.

## 2 WELDED PART

For transporting liquids, gases or solid materials, piping of different dimensions is commonly used in industry. These materials often have to be transported over long distances. This requires the use of very long pipes. The pipes are not only affected by the transported substance but also by environmental influences, especially the air temperature and pressure and therefore, the piping expands and shrinks. On this account, tension and deformation may occur along the entire piping. One possibility of preventing these tensions is placing a compensator between the piping segments. The compensator can reduce or disturb dilatation changes.
For easier assembly and disassembly of the piping, a mounting insert can be used. The insert will enable easy replacement of fittings in the piping or definition of small longitudinal deviations. As the parts are made of steel, they are most often connected by welding to ensure the rigidity and strength of the product and thus its functionality. Examples of steel mounting inserts and compensators are shown in Table 1 and Figure 1.

| **Compensator** | **Diameter Nominal DN [mm]** | **Length Ls [mm]** | **Compression [mm]** | **Extension [mm]** | **Radial movement [mm]** | **Deviation Angle [±°]** |
|---|---|---|---|---|---|---|
| **GK** | 80 - 2200 | 200 - 510 | 13 - 20 | 10 - 15 | 5 - 12 | 3 - 6 |
| **GKB** | 100 - 3600 | 150 - 400 | 30 - 79 | 10 - 54 | 15-60 | 1 - 47 |
| **UK** | 40 - 500 | 375 - 760 | 50 - 150 | 50 - 150 | - | - |
| **Mounting insert** | **Diameter Nominal DN [mm]** | **Length Ls [mm]** | **Sset-up length [mm]** | | | **Operating pressure PN [bar]** |
| **MV3** | 40 - 2400 | 200 - 450 | ± 25 | | | 10 - 25 |
| **M20** | 40 - 1200 | 160 - 550 | ±5 - ±30 | | | 6 - 25 |

**Table 1.** Main dimensions of compensator and mounting inserts [1]

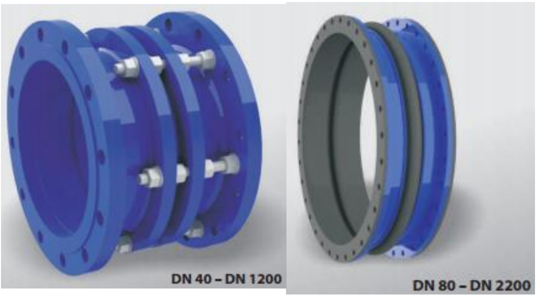


**Figure 1.** Design of steel compensator and mounting inserts

Steel mounting inserts and compensators consist of several parts. The main part of a mounting insert is a flange with a tube welded on to it. In the case of a mounting insert, this is a so-called body that forms a fixed support sleeve into which a sliding member is inserted, so-called piston. The distance between the flange body and the piston is secured and adjusted by distance bolts. The space between the tube body and the piston is filled with a rubber sealing wedge that prevents the transported medium from leaking. The wedge is pressed into the interspace by a sealing flange, which is supported by an independent nut. A steel compensator consists of connecting flanges, reinforcing tubes, and a rubber body that produces the compensation effect. The dimensions of mounting inserts and compensators are subject to the DIN 2501 standard and are divided according to the pipe diameter. For example, DN100 designates a mounting insert with the inner tube diameter of 100 mm. These dimensions could range from DN30 up to DN3600 for compensators and from DN40 to DN2400 for mounting inserts. Figure 2 shows a section through a DN300 PN16 mounting insert [1].

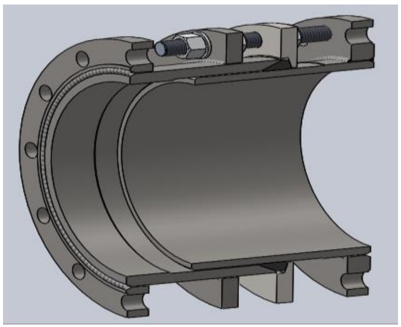

**Figure 2.** Cut from mounting insert DN300 PN 16.

The subject of this experiment is the body of the above-mentioned mounting insert DN300 PN16. Specifically, it is a fully penetrated 12V groove weld with a wall thickness of 9 mm. This weld is shown in Figure 3.

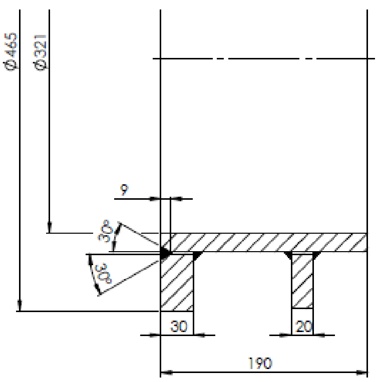


**Figure 3.** 12 V groove weld with wall thickness of 9 mm

## 3 BASE MATERIAL AND WELDING PROCESS

To weld the given weldment it is important to select a suitable welding method. This method should be economical, fast and suitable for both the base and filler material. When selecting the material, both the mechanical properties (the breaking strength and the yield strength) and the chemical composition are taken into account. These characteristics could have an impact on the functionality and stability of the structure and on the quality of the weld.

### *3.1 The base material used*

The mounting inserts and compensators are designed for pressure piping. Therefore, structural steel that can withstand high pressure had to be selected for the experiment. This structural steel, which is suitable for pressure vessels according to EN 10028: 2018, is designated P355N-TC1 according to EN 10027-1: 2017. The chemical composition of structural steel P355N-TC1 is shown in Table 2. Its mechanical and tensile properties are shown in Table 3.

| C | Si | Mn | Cu | Mo | N | Ni |
|---|---|---|---|---|---|---|
| Max | Max. | 0,90 | Max. | Max. | Max. | Max. |
| 0,20 | 0,50 | 1,70 | 0,30 | 0,08 | 0,02 | 0,50 |
| **Ti** | **V** | **Nb+Ti+V** | | | | |
| Max | Max | Max. | | | | |
| 0,03 | 0,10 | 0,12 | | | | |

**Table 2.** Chemical composition of structural steel P355N-TC1

| Condition | | $R_{eH}$ Yield stress [MPa] | $R_m$ Ultimate stress [MPa] | A Ductility [%] |
|---|---|---|---|---|
| Normalization | | 355 | 490 - 630 | 22 |

**Table 3.** Mechanical properties of structural steel P355N-TC1

### *3.2 The filler material used*

To weld this type of product more efficiently, a proper flux-cored wire filled with metal powder with a diameter of 1.2 mm was used. It was produced by Böhler Uddeholm CZ Ltd with the trade name of Böhler HL51T- MC. This flux-cored wire is suitable for welding steel structures, pressure vessels, piping, and pressure cross-connections from carbon steel. The wire has benefits especially for robotic welding. When welding more layers, it is not necessary to clean each layer from slag inclusions. The chemical composition and the mechanical properties of flux-cored wire are shown in Table 4.

| C | Si | Mn | P | S | | |
|---|---|---|---|---|---|---|
| Max | Max. | Max | Max. | Max. | | |
| 0,06 | 0,50 | 1,25 | 0,015 | 0,015 | | |
| **$Rp_{0,2}$ Yield stress [MPa]** | | **$R_m$ Ultimate stress [MPa]** | **$A_5$ Ductility [%]** | **KV Impact toughness (120J)** | | |
| 460 | | 530 | 20 | 47J / -40˚C | 47J / -60˚C | |

**Table 4.** Chemical composition and mechanical properties of filler material Bohler HL51T-MC.

### 3.3 *The welding process*

The main target is a maximum increase in the efficiency of the welding process. This should be achieved by using the Flux-cored Arc Welding (FCAW) method. In practice, numerical designation, 136 or 138, is more often used for welding by flux-cored wire according to the standard EN ISO 4063. The FCAW method is basically identical to the GMAW method as it is possible to use the same welding source and the same shielding gas. The only difference, and yet an essential one, between these methods is in the filler material. For the GMAW method, solid wire is used and for the FCAW method, flux-cored wire (tubular wire) is used as the filler material. The flux-cored wire can be filled with metal powder (welding method 138) or with rutile or basic (alcalic) powder (welding method 136). The main difference between solid and flux-cored wire is the style of melting the wire. Compared to the solid wire, in the flux-cored wire, the current is conducted through a significantly smaller profile (metal tube sheathing) and the powder inside the tubular wire provides considerable resistance for the current, which results in a higher current density. Thanks to this high current density, a non-spray shower arc with fine globular filler material is formed. Compared to the solid wire, a considerably wider arc occurs, which results in a wide profile penetration. A comparison of both arcs and metal transfers is shown in Figure 4. When using the flux-cored wire, it is also necessary to increase the wire speed while keeping the same ampere values. This results in a smaller heat input to the weld. Using the flux-cored wire has the following advantages [3]:

- deeper penetration, small spatter,
- increased weld quality,
- low susceptibility to porosity,
- possibility of alloying weld metal,
- higher burn-off (an increase of up to 40%),
- smaller heat input to the weld and base material.

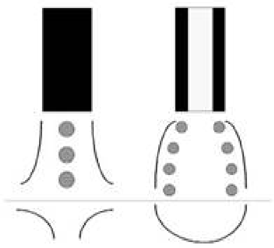

**Figure 4.** Metal transfer for solid and flux-cored wire [3]

### 3.4 *Welding machine modernization*

The first part of the implementation of the FCAW welding process is transition to a new welding power source. The Fronius TPS 500i power source was selected. The power source supplied in default set-up can easily be extended to a pulse welding source. Operating is controlled via a touch screen. An advantage of this power source is also preset welding programs based on the selected wire diameter and shielding gas. What follows is the basic technical data:
- Main frequency: 50 / 60 Hz, Welding current: 3 – 500 A
- Output voltage: 14.2 – 39.0 V, Off-load voltage: 71 V
- Weight: 38 kg

### 3.5 *Rotator modernization*

The second part of the semi-automatization of the FCAW welding is using a rotator. As they are rotary weldments with butt and fillet welds, a RWP MILLER 1050.1221 Mk. II rotator (Figure 5) by the HST Creative Company was used.

**Figure 5.** Rotator RWP Miller 1050.1221 Mk. II

It is equipment for welding rotary parts with the possibility of tilting the whole rotator unit, to which a self-centering chuck or a working board with radial grooves for weldment fixation is attached. The tilting ranges from 0° to 90°. Part of the rotator is also an air-controlled shoulder for holding the welding torch. The rotator is connected to the welding power source, which makes it possible to operate the whole welding process using the rotator control panel. Using the control system, it is possible to fluently control left and right rotation, control welding delay or set the angle of the shift spindle for exact cap or tack welds. The basic technical data for the rotator are shown in Table 5.

| Description | Value |
|---|---|
| Maximum load | 1 700 Kg |
| Turning moment on the main spindle | 2 585.5 Nm |
| Range of main spindle rotation | 0,01 – 2,8 rpm |
| Rotation of the main spindle | Controlled by program |
| Elevation of the main spindle | 0 – 90° |
| Current transmitted by spindle | 550 A |
| High x width x depth | 983 x 1 251 x 1 935 mm |
| Weight (without clamping unit) | 350 Kg |

**Table 5.** Technical data for rotator RWP Miller 1050.1221 Mk. II

## 4 THE EXPERIMENT

The welding parameters for the experiment were debugged from synergic lines (another wire diameter program). The debugged welding parameters were tested on a test piece (test coupon). After internal tests took place, qualification of the welding process and also welding operator qualification were performed. Figure 6 shows the welding process. The operator performed a proper weld at three layers. Table 6 contains the welding parameters for each layer. Table 7 contains the calculated welding speed and heat input for each layer.

**Figure 6.** FCAW welding in the experiment

| Layer of Weld | Current [A] | Voltage [V] | Wire Speed [m/min] | Length of Weld [mm] | Welding Time [s] |
|---|---|---|---|---|---|
| 1st Root | 220 | 28,1 | 0,45 | 1 125 | 255 |
| 2nd Filler | 250 | 28,6 | 0,5 | 1 130 | 400 |
| 3rd Cap | 250 | 28,6 | 0,5 | 1 140 | 370 |

**Table 6.** Record of the FCAW welding parameters in the experiment

| Layer of Weld | | 1st Root | 2nd Filler | 3rd Cap |
|---|---|---|---|---|
| Welding Speed | [$mm\cdot s^{-1}$] | 4,41 | 2,83 | 3,08 |
| Heat Input | [$kJ\cdot mm^{-1}$] | 1,21 | 2,02 | 1,86 |

**Table 7**. Welding speed and heat input during an experiment of FCAW welding

## 5 EXPERIMENT EVALUATION

The subject of this experiment was a tendency to perform welding more effectively. It was done on specific weldment of the metal compensator and assembly mounting insert mounted to the piping system. To achieve required welding effectivity, a new welding machine (new power source) and new rotator were acquired, which makes possible partial automatization of the welding process. In the next step, a flux-cored wire filled by metal powder was chosen as filler material. Flux-cored wire with metal powder compared to solid wire could achieve at the same welding parameters as high as 40 % higher deposition rate. For the introduction of a new welding process to the production, it is necessary to qualify new WPQR. Therefore, were issued pWPS (Pre-Welding Procedure Specification), according to these, a butt-weld with thickness 16 mm was FCAW welded using the semi-automatic machine. Qualification of the weldment procedure was performed according to EN ISO 15613: 2005 standard that prescribes visual and penetrant testing, evaluation of macrostructure and hardness measurement on a weld. All these testing and evaluation were done with good results. The picture after penetrant testing is shown on the Figure 7. Consequently, sample was cut (Figure 8) for mechanical testing in the laboratory, for the evaluation of macrostructure and hardness measurement.

**Figure 7.** Picture after penetrant testing.

**Figure 8.** Cut sample for mechanical testing

The macrostructure evaluation of the FCAW seam without defects is shown in Figure 9. A comparison of the macrostructure and the hardness measurement of the GMAW seam was not performed (tested). For verification welding process was measured hardness in root area of HAZ by one line of indents. The maximum measured hardness value in root area of HAZ was 251 HV 5. It is considered satisfactory according to the standard EN ISO 15614-1: 2018, which establishes the maximum hardness value to 380 HV. The hardness measured indents on the macrostructure picture and graph are shown in Figure 10 and Figure 11.

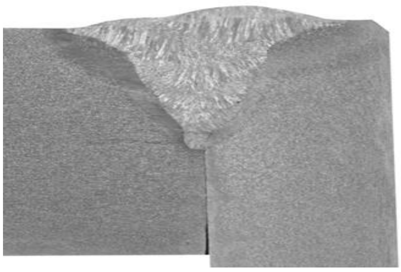

**Figure 9.** Macrostructure evaluation

**Figure 10.** Indents of hardness evaluation in root area of HAZ

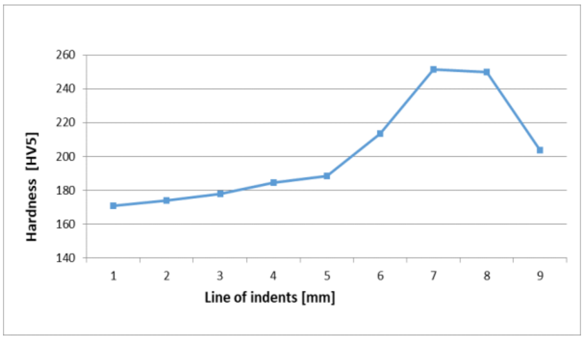


**Figure 11.** Graph of hardness evaluation in root area of HAZ

## 6 MANUAL GMAW WELDING REPLACEMENT

The same type of weld was subsequently welded manually following the normal welding process (GMAW). The same welding power source TPS 500i and a solid wire with a diameter of 1.2 mm with classification G3Si1 were used. To make the required weld, five layers of weld were made - specifically, a root, two fillers, and two cap layers. The record of the welding parameters is shown in Table 8. Table 9 contains the calculated welding speed and heat input of each layer. A comparison of both the technologies, the manual GMAW welding and the semiautomatic FCAW welding, is summarized in Table 10.

| Layer of Weld | Current [A] | Voltage [V] | Wire Speed [m/min] | Length of Weld [mm] | Welding Time [s] |
|---|---|---|---|---|---|
| 1st Root | 192 | 26,6 | 6,3 | 1 125 | 212 |
| 2nd Filler | 212 | 26,7 | 6,7 | 1 130 | 337 |
| 3rd Filler | 234 | 26,8 | 7,2 | 1 135 | 343 |
| 4th Cap | 250 | 26,5 | 7,3 | 1 140 | 409 |
| 5th Cap | 250 | 26,7 | 7,3 | 1 140 | 423 |

**Table 8.** Record of GMAW welding parameters

| Layer of Weld | | 1st Root | 2nd Filler | 3rd Filler | 4th Cap | 5th Cap |
|---|---|---|---|---|---|---|
| Welding Speed | [mm·s$^{-1}$] | 5,31 | 3,35 | 3,31 | 2,79 | 2,7 |
| Heat Input | [kJ·mm$^{-1}$] | 0,77 | 1,35 | 1,52 | 1,90 | 1,98 |

**Table 9.** Welding speed and heat input during manual GMAW welding

| Manual GMAW | Heat Input | Welding Time | Semiaut. FCAW | Heat Input | Welding Time |
|---|---|---|---|---|---|
| | [kJ·mm$^{-1}$] | [s] | | [kJ·mm$^{-1}$] | [s] |
| Sum | 7,52 | 1724 | | 5,09 | 1025 |

**Table 10.** Comparison GMAW and FCAW welding

The results in Table 10 clearly show that the weld was welded faster by the semi-automatic FCAW welding process, namely 1025 seconds. Using the semi-automated FCAW welding, the seam was performed in three layers, whereas the manual GMAW welding in five layers. Lower numbers of layers are achieved, above all, by a higher deposition rate of the weld metal during the FCAW welding. Since during welding on this rotator the welding torch is only set to one welding position and it is not possible to move or oscillate the torch, efficiency must be achieved in different ways.

The following changes are recommended:

- acceleration of the rotator turning and correction of the arc length; reducing the number of weld layers by using flux-cored wire with a diameter of 1.6 mm
- modification to the weld surfaces
- a smaller bevel opening, which means closing the bevel to 45°
- cleaning the welding torch from spattering by applying spray against spatter; eliminating the slag falling from the torch into the weld pool.

## 7 CONCLUSIONS

The article describes an experiment including a verified process of making the welding process more efficient using a specific weldment, namely the steel compensator (mounting insert) DN300 PN16. By introducing simple semi-automatization and FCAW welding instead of normal GMAW welding, the number of weld layers was reduced from five to three. The welding time was reduced by about 12 minutes for this DN300 PN16 compensator. It is assumed that all types of mounting inserts and steel compensators will be welded using this semi-automatic machine. The amount of the welding time saved will be considerable compared to the manual GMAW welding. The money invested in the new semi-automatic welding machine and the qualified WPQR for the FCAW process will quickly return to the cooperating firm. To achieve higher efficiency and productivity of welding, some recommendations were offered to the cooperating firm. The recommendations include: increasing the welding parameters using a bigger diameter of the flux-cored wire, thereby reducing the number of weld layers, adjusting the weld bevels to obtain a smaller bevel opening, and also cleaning the weld interlayers, protecting the welding torch from spatter, and more frequent cleaning of the welding torch.


## ACKNOWLEDGMENTS

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