INFLUENCE OF 8% CO_2 AND ARGON SHIELDING GAS MIXTURE ON MAG WELDING OF HIGH STRENGTH STEEL (650 MPA) IN SPRAY ARC

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Abstract. It is more complicated to weld low alloyed high-strength steel materials than standard structural steel. The chemical composition of these materials makes the process harder as it is important to keep the high strength properties of the steel even after the process is done. An important influence in MAG (Metal Active Gas) welding of such steels makes the choice of the welding wire, welding parameters and shielding gas composition. Appropriate choice of the welding wire and shielding gas is an important issue in welding of low alloyed high-strength steel. Change of the welding parameters changes the heat input, type of welding wire transfer and the welding process in general. Shielding gas can influence the stability of the welding parameters. The influence of shielding gas has been investigated for structural steels (till 275-355 MPa). There are also articles about very high strength steel (900-1000 MPa) MAG welding where the shielding gas influence on the welding joint was investigated. As these investigations show that the influence of Argon mixture with 8% Carbon dioxide (CO_2) is much better than mixtures with higher CO_2 content, the authors have stated that the same influence can be on low alloyed high strength steel (550-650 MPa) MAG welding. High welding parameters can also influence the welding process. Lower heat input is an important issue in welding of high strength steels. Because of the previously mentioned reasons the influence of 8% CO_2 mixture in Argon on MAG welding of low alloyed high strength steel at high welding parameters was investigated. Better results in combination of penetration + inclusions + hardness were reached with lower welding parameters.

Keywords: MAG welding, high strength steel, spray arc, shielding gas.

Introduction

High strength steel constructions are becoming more common nowadays. Welding of high strength steel is a challenge for many steel manufacturing companies. MAG welding is the most popular welding technology that is used in production of different kind steel constructions. Which shielding gases should be used better and how the welding parameters will influence welding are only some of the questions that appear during the production process. In recent years new welding equipment with high welding parameters is available in the market to increase the productivity and the efficiency of welding.

The aim of this investigation is to find out how the welding parameters that afford the spray arc transfer mode in Ar + 8% CO_2 shielding gas can influence welding of low alloyed high strength steel. Welding equipment form previous generations can afford welding with short arc parameters. Nowadays the equipment has become more powerful and gives the opportunity to increase the productivity and welding speed in total. Latest welding machines provide the opportunity to increase the parameters like electrode wire feed. It is important to control and keep the welding process stable.

Higher welding parameters bring changes into the welding process in general [1]. Higher welding wire feed rate increases the arc temperature but decreases the heat input as the traveling speed is higher [1]. The welding wire is melting faster and creates small droplets instead of bigger ones [2]. Short arc effect on the welding process is less. There are less spatters during the welding process, too. Higher traveling speed decreases the time of the welding pool liquid phase. The melted metal is turning solid again much faster. All these changes of the process influence the chemical composition and mechanical properties of the welding joint [3; 4].

An important role on the welding process is played by the shielding gas. The role of the shielding gas in the welding process is not only to protect the welding pool from access of oxygen and to prevent the formation of pores in the seam. Shielding gases can also stabilize the arc and improve the metal transfer type in arc welding [3; 5; 9]. The shielding gas not only affects the properties of the weld, but also determines its shape, penetration and alloy quality. During welding, the shielding gas also interacts with the welding wire to determine the strength, hardness and corrosion resistance of the welded metal. Shielding gas also affects the content of various inclusions such as hydrogen, nitrogen and oxygen in the weld [6]. The quality, efficiency and overall compliance of the welding process with the standard

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requirements are highly dependent on the shielding gas, as it significantly affects the metal transfer mode [7; 8].

As it was stated in a recent study about extremely high strength steel (MPa 1000) material welding, Ar + 8% CO_2 mixture provides better shielding properties in the welding process [10]. Three different welding parameters with this gas mixture were tested in this investigation. It was done to find out if this shielding gas also provides good results in welding of lower strength steel (MPa 650) and which parameters show better results of the weld. Filler material was used the same for all experiments. Gas consumption was set even for all trials.

Experimental Procedure

Experiments were carried out by using the base metal STRENX®650MC that is low alloyed high strength steel. The chemical composition of the material is given in Table 1.

Table 1

Material composition of base and filling material, in %

Composition	C	Si	Mn	S	Cr	Mo	Ni	Al	Nb	Ti	V
Base material	0.0581	0.157	1.56	0.0162	0.0451	< 0.0030	0.0251	0.0191	0.0416	0.102	0.0165
Electrode wire	0.075	0.63	1.63	0.007	0.28	0.22	1.42	0.006	0.002	0.001	0.09

A 10mm thick plate was laser cut into welding pieces of 100x200mm. They were stick together creating a T-joint with two spot welds on the opposite side of the welding experiment seam. No extra preparation was done on any of welding specimens. Welding equipment from company FRONIUS® TPS500i (Figure 1) and the welding tractor Fronius® FlexTrack 45 Pro (Figure 2) were used to create smooth movement of the welding torch and regular welding joint.

Fig. 1. **Welding machine Fronius®MIG500i [18]**

Fig. 2. **Welding tractor Fronius® FlexTrack 45 Pro**

The welding wire electrode was used according to the base material properties with higher manganese content. The chemical composition of the welding wire is given in Table 1. The diameter of the electrode was chosen 1.2mm that gives higher deposition rate. It also gives a possibility to increase the welding speed that helps decrease the heat input during the welding process.

The welding process was done according to EN ISO 6947 in PB (Plate Horizontal Vertical) position and created a welding seam with a height of 5mm (a = 5). Figure 3 shows the welding setup of the experiments.

Investigation was carried out with Argon mixtures with CO_2 at constant flow rate 15 $l \cdot min^{-1}$. The composition of these gases: gas – MISON®8, Ar – 92%, CO_2 – 8%.

The welding parameters were set to reach the spray arc conditions in the study: 280 A, 320 A and 360 A at 28V. The traveling speed was set for each experimental weld accordingly: 350; 400 and 450 $mm \cdot min^{-1}$. The welding parameter matrix was chosen by using a special welding modeling application WeldConnect (Figure 4).

Fig. 3. **Welding setup of the experiments**

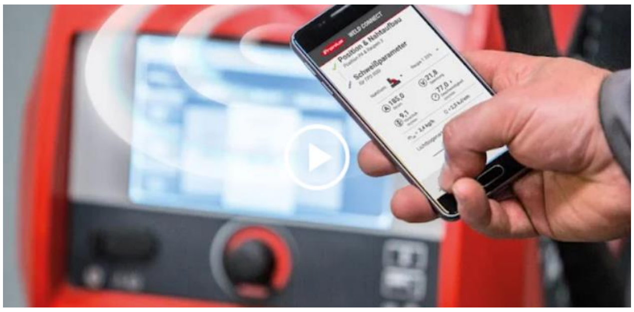

Fig. 4 **WeldConnect Application [19]**

The arc stability was checked after setting the welding parameters before each block of experiments (At 280 A, 320 A and 360 A). The stick-out of the welding wire electrode was set 19mm before each weld.

After welding of each specimen, they were photographed, cut into pieces of 10mm and prepared according to procedures described in referenced studies [11,12]. There were also pictures made of the prepared specimens. Photomicrography was used to identify microstructural changes for each weld. Each specimen for the microstructure test was taken from the middle of the welding joint. Chemical composition of the welding joints was made using the optical spectrometer PMI-MASTER Pro2. Finally, the tests of mechanical properties (hardness) were carried out by using Mitutoyo Micro Vickers hardness tester HM-210D. Testing of the hardness was made using the multi-step punctures starting from the base metal, passing the HAZ (Heat Affective Zone) and into the welding joint. Photographs of all puncture lines were captured to evidence and measure the HAZ width for each specimen.

Results and Discussion

Three different studies were conducted in this investigation. First, the change of microstructure of the weld with different spray arc parameters. Second, the effect of shielding gases and parameter change on the chemical composition of the weld. Third, mechanical properties of the welding joint were evidenced influenced by changes of the shielding parameters in the spray arc conditions, as three different heat inputs were achieved during the welding process.

Welding Seam and Penetration

The welding parameters can influence the formation of the welding pool and the form of the welding joint. Shielding gas can influence the form of metal transfer of melted electrode and arc stability. It is also stated that the amounts of spatters are affected by the stability of the welding process [13]. It is visible in figures of the welding joints that all shielding gases show rather good stability of the arc (Fig. 5). There were no spatters observed on all samples.

Fig. 5. **Amounts of spatters on welding seams with different welding current:**
a – 280 A; b – 320 A; c – 360 A

It appeared to be harder to keep the shape of the welding seam as the temperature of the welding pool became hotter, as the parameters were increased over 300A (Fig. 6).

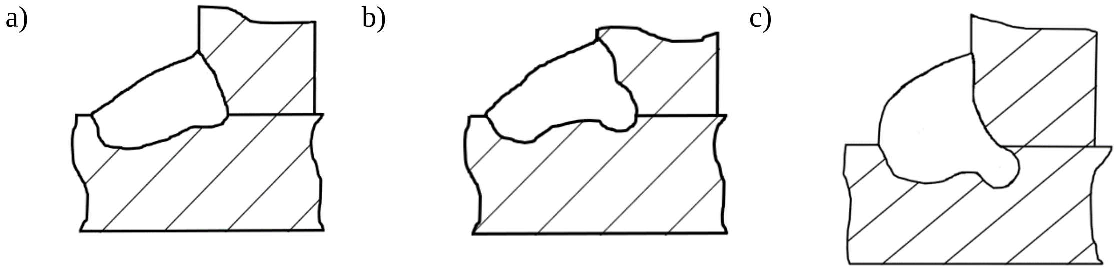

Fig. 6. **Welding seam form and penetration of welded samples:**
a – 280 A; b – 320 A; c – 360 A

All samples were treated with a liquid of 9% nitrogen acid after polishing. It is then possible to see the form of weld penetration. The shape of the penetration was changing according to the parameters for the samples that were welded with Argon and 8% CO2 mixture. (Figure 6). As current was increased the form of the welding pool became unregular. It can be explained with higher temperature of the welding pool that melted the base material not only where the electrode was directed, but also on the horizontal base plate away from the corner.

It is clearly possible to see the forming of, so called, Argon finger in welded samples at the parameters of 320 A and 380A. More import was the form of the rest of the penetration in the welding seam. The best result and more even penetration on both base plates were observed on the specimen welded with 280 A parameters.

Microstructure

Microstructure of all welded samples was captured by optical microscope. One of the defects that is possible to recognize are the inclusions in the welding joint. According to Figure 7, it appears that more inclusions but in smaller size were captured in welding joints in the samples created with less current. As the current grows, the inclusions become less, but the size increases.

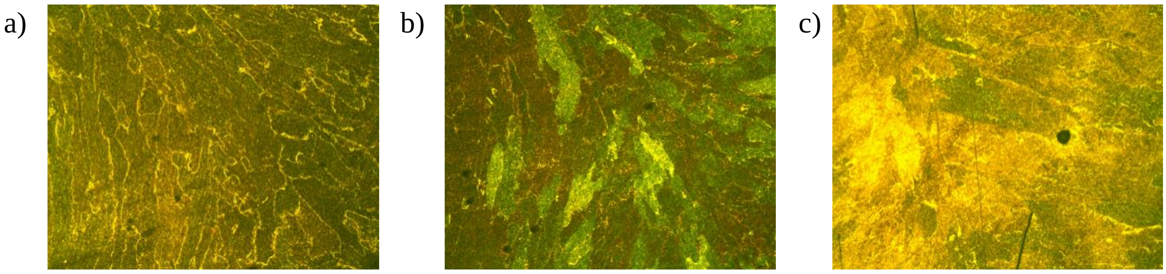

Fig. 7. **Structure of welding joints (50x)**: a – 280 A; b – 320 A; c – 360 A

The structure of finer-grained ferrite cells with cementite inclusions, which form the grain boundaries, is observed in the structure of the sample welded at 280 A. In the specimen welded at 320 A, the structure of the perlite is mixed with the ferrite, but the grains of the perlite predominate. The ferrite grains are forming small boundaries and form larger grain structures than in the previous sample. The sample welded at 360 A shows ferrites, but now with larger grains of cementite. They are located between ferrites and form larger boundaries. The grain size of ferrites is larger than that of the welded specimen with the current of 280 A (Fig. 8).

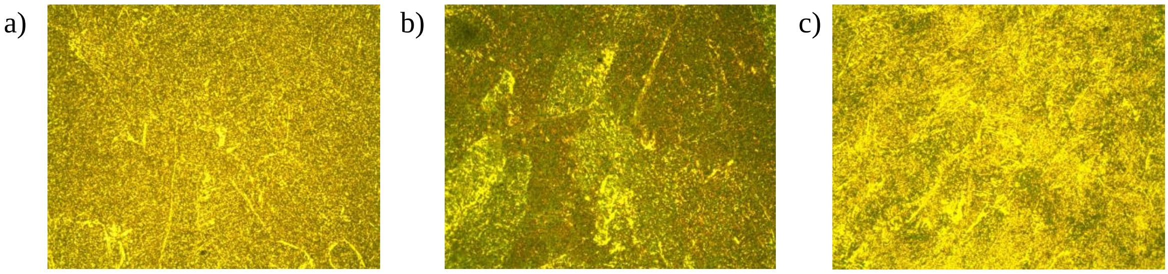

Fig. 8. **Sample microstructure (200x)**: a – 280 A; b – 320 A; c – 360 A

Chemical composition

Investigation of the chemical composition of all welds was carried out. Shielding gas can influence the amount of alloys that might be burned out from the welding joint as it was stated in the previous research [14; 15]. Manganese (Mn) is one of the most important alloying elements that is responsible for the hardness properties of the high strength steels [17]. This investigation shows how the welding parameters influence the chemical composition of the weld. The graphs in Fig. 9 show the changes of Mn content in the welding joint at all three welded parameters.

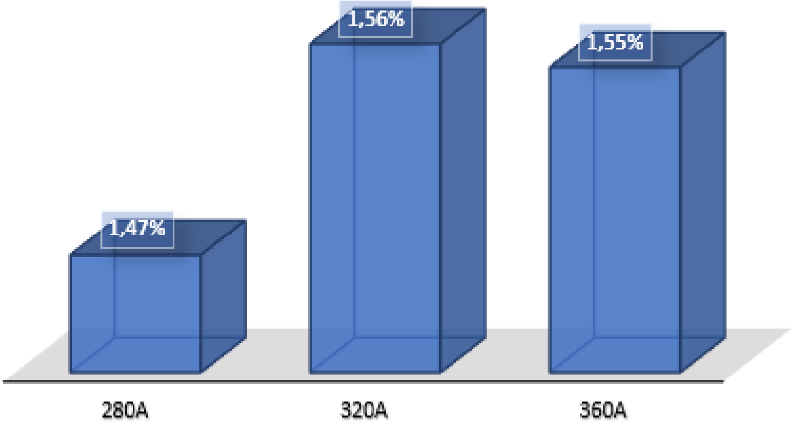

Fig. 9. **Chart of Mn content in welding joints**

Smallest amount of Mn in the welding joint was achieved with the welding parameters at 280 A. Decrease of 10% against the wire and 6% against the base material was observed when welding was carried out with these parameters. As the parameters increased to 320 A, the shielding gas Ar + CO_2 8% mixture showed the best result in this investigation. Manganese content in these welding joints was decreased only by 2% against the wire material and no changes against the base material. Almost similar results were achieved also with welding at 360 A parameters.

Hardness

High strength steel is used due to its properties. The main one is the hardness. It is important to keep this property also after welding. All welded samples were tested with the automated hardness testing machine Mitutoyo Micro Vickers hardness tester HM-210D (Fig. 10).

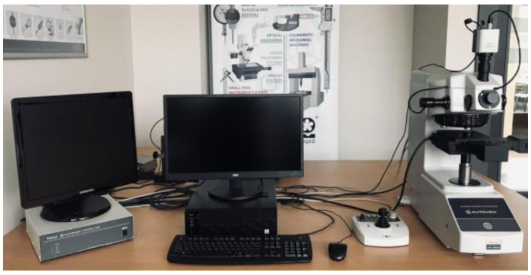

Fig. 10. **Mitutoyo Micro Vickers**

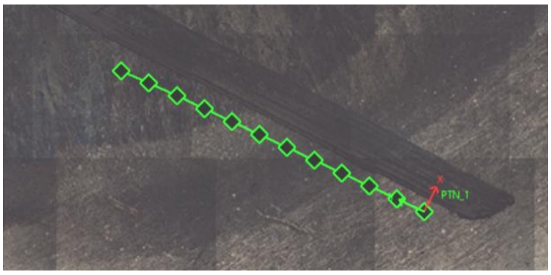

Fig. 11. **Hardness measuring tester HM-210D procedure (Sample 280 A)**

Twelve stitches one by one after 0,5mm were made into every specimen covering the base material, HAZ (Heat Affective Zone) and the weld seam (Fig. 11). It is possible to find the changes in hardness of the material in the welding joint after welding from the charts in Fig. 12.

Each parameter set was highlighted separately with the graph that shows the tested hardness of the samples. From these graphs it appears that the hardness in HAZ is almost the same for every welded specimen. The difference is visible only in the welding pool. Hardness was the highest in the samples welded with 280 A parameters. It might be explained by the smaller grain structure (Figure 8a) that appears in this sample. In this case, even after loss of Mn content in the welding joint it still keeps the properties of hardness high. The time of hardening and cooling rate of the welding pool appears to be longer then with other samples that keeps the possibility to create a smaller grain structure similar as in welding of 950 MPa class steel [16]. It was also observed that hardness of the welded metal was reached similar to the base metal in one point of the welding pool.

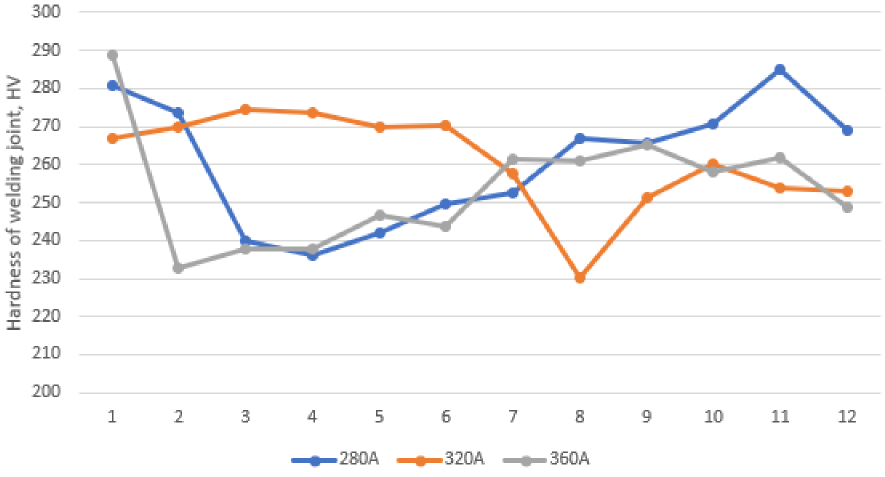

Fig. 12. **Welding joint hardness parameters (HV) for each sample:**
sample numbers along the X-axis – Base material- > HAZ- > Weld metal

As the parameters were rising, the hardness of the weld did not reach the same values as the base metal. In this case Mn content was almost the same in both samples welded with 320 A and 360 A parameters, but the grain size was observed bigger than in 280 A sample. It can be also explained with the shorter hardening time of the welding pool [16]. It appeared that HAZ was shorter than in the samples with higher and lower parameters.

Conclusions

1. Higher welding parameters make it hard to control the creation of the shape of the welding seam.
2. The typical “Argon finger” penetration shape appears in the welding parameters at 320 A and 360 A. This phenomenon is not so expressed and observed in the sample welded at 280 A.
3. The sample welded at 280 A shows a smoother, finer grain structure in the welding seam. This kind of structure looks closer to the base metal structure.
4. Manganese content was higher in the welds that were made with higher parameters (320 A and 360 A).
5. Hardness values were reached higher in the sample welded at 280 A parameters.

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Author contributions

Conceptualization, methodology, investigation, data curation, writing—original draft preparation, funding acquisition, D.Avišāns; writing—review and editing, I.Boiko and A.Avišāne; visualization, A. Avišāne, project administration D.Avišāns and I.Boiko. All authors have read and agreed to the published version of the manuscript

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