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Analysis of Shielding Welding Gas Composition Effects on the Final Microhardness of the Fillet Joints Made With Use Of MAG Technology

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--***ABSTRACT***--
The article aims to analyze the impact of the composition of the shielding welding gas to the quality of welded joints, which were made by technology MAG (Method 135 - STN EN ISO 4063). MAG welding is characterized by the use of technical gases, which are essential to the proper functioning of the process, ensure reliability, productivity and influence the final properties of the weld. For the experimental part, three types of shielding gases were used, namely gases: Ferroline C18, Ferroline C6X1 and Ferroline He20C8. Mentioned are shielding gases from company Messer Tatragas s.r.o. The S235 J2G3, 10 mm thick material (according to EN 10025-94) was used as the welded material for the welded samples, where, with the addition of filler material OK Autrod 12.51 (wire diameter - ϕ 1.2 mm) in the above mentioned shielding gases atmospheres were made experimental fillet welds. Experimental fillet welds were made on a welding machine ForMIG 389FW. After the samples were made, visual inspection of the weld joints according to STN EN ISO 17 637 was carried out. In the end, the microhardness of the welded joints evaluated according to STN EN ISO 9015-2 is evaluated using a Vickers hardness test on machine Shimadzu HMV 2 with a load of 0.9807 N for 15 seconds. The microhardness of each analyzed sample is measured in the areas of the base material, the heat-affected zone, and the weld metal.
KEYWORDS *– welding, MAG, shielding gas, microhardness*

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I. INTRODUCTION

Welding is one of the most used engineering manufacturing technologies. Welding is used in the production of almost all kinds of engineering products, from micro-parts and small parts to large load-bearing structures. At present, a large number of different welding processes exist, which is a natural consequence of the development new welding materials and technologies. [1]

The largest share of the world market involves gas metal arc welding (GMAW). GMAW is divided to subtypes: metal inert gas welding (MIG) or metal active gas welding (MAG). These methods are most used for welding non-alloy and low-alloy steels, which make up the largest percentage of world production in the metal-working industry. The main mechanism of MAG welding is the burning arc between the base material and the melting electrode in the form of a wire. This whole process takes place in the protective atmosphere of the shielding gas. [1,2]

An important factor in the welding process is the metal transfer from the electrode to the weld, more precisely the welding pool. The transfer is affected by the welding parameters and the shielding gas composition. For the welding of thin metal structures, we use an arc of the short type, contrariwise for the thicker structures we use a shower arc. The behavior of the arc changes depending on the used welding currents.

Drops of metal during the welding process have a temperature between 1700 and 2500 °C and the welding pool temperature is between 1600 and 2100 °C depending on the used technology, the chemical composition, material properties, welding parameters and shielding gas atmosphere used. [3]

The MAG method is a type of welding where the gas is forming a shielding atmosphere actively participates in chemical reactions in welding pool and helps to finish the weld. The method is characterized by high productivity, low welding costs and ease of welding process management. [2,4]

The aim of this paper was to investigate the effects of the shielding gases used in the MAG method on the resulting properties of the weld joints. In an article for the individual experiments are used mixture of gases Messer Tatragas company.

II. USED SHIELDING GASES AND CHEMICAL REACTION IN THE WELD POOL

MAG welding is highly used due to its technical advantage, where we can use cheaper gases or a mixture of gases for welding lower quality materials. The welding pool is protected by the active gas atmosphere or a mixture of active gases atmosphere from the negative effects of nitrogen and oxygen (from air). An ideal amount of shielding gas depends on a number of factors, such as the type of joint, welding parameters, but also weather conditions when welding is done outdoors and in poorly insulated rooms. The excellent protection of the welding pool is at 12 to 17 liters / min of shielding gas used. Massive steel structures and other devices are most often made from non-alloy or low-alloy steels. For welding these types of materials we need just carbon dioxide (CO_2) or mixed gases, which can contain two to four mixed gases (Tab.1). The most common gases of these mixtures are active gases such as carbon dioxide and argon (Ar). While choosing the protective gas we must consider the chemical composition of the weld metal, more precisely its carbon, silicon and manganese content. [1,4]

During welding, chemical reactions occur in several locations of the welding process. The basic reactions are the metallurgical reactions, the reaction of the protective gas with the droplets of the molten electrode and the reaction of the protective atmosphere with the surface of the weld pool.

Table 1 Gas mixtures used in MAG welding method [3,4]

Gas type	Composition	Use
CO_2	CO_2 (99,9%)	Welding of thin sheets in short metal transfer in arc, high mixing with base material, considerably spatter
Ar + CO_2	Ar + CO_2 (8-20%)	Stable arc, low spatter, good mixing with base material, universal use
Ar + CO_2 + O_2	Ar + CO_2 (5-13%) + O_2 (1-5%)	Smooth and clean welds, suitable for mechanized welding, gradual transition of the weld into the base material
Ar + He + CO_2 + O_2	Different	Shipbuilding, rail vehicles, heavy machinery, high welding speed with little spatter

The gases forming the active protective atmosphere can be divided by the action on weld metal to oxidation, reduction and carburizing. The oxidizing gas includes a mixture of oxygen gas with a reducing effect on the weld pool. [5]

Substantial metallurgical reactions are deoxidizing and oxidizing, which occur in drops of melting electrodes and in molten weld metal. Their action we change the shape of the arc and weld surface. Overall, they affect the internal purity of the weld, the shape of the welding bead and the transition from welding bead to the base material. The size of the reaction is mainly determined by the amount of dissociated oxygen which is subsequently combined in the melt with other elements. [5]

Each element has a typical character that affects the result of welding. By mixing Ar and He we can protect the weld before starting the chemical reaction by the presence of an electrode and a weld pool. An important effect on metal transfer during welding has CO_2 with O_2. [6]

The presence of higher CO_2 content in mixed gases causes a decrease of arc stability. In this case, the thermal conductivity is high, which is related to the loss of heat by conduction. Therefore, a higher voltage is required with the same current intensity to stabilize the arc. A lower CO_2 content predisposes that the inner weld area is warmer than its marginal area. In the case of O_2, the arc temperature is increased in those mixtures which have a higher O2 content. [7]

III. EXPERIMENTAL METHODOLOGY

The S235 J2G3 base material (according to EN 10025-94) for making experimental fillet welds. This steel can be characterized as non-alloy structural with fine-grained structure. In terms of welding (up to 300 °C) it is suitable for the construction of cranes, parts of machines and also pressure bottles with limit pressure. Experimental material had an initial size of 150 x 310 mm and a thickness of 10 mm. Chemical composition detected by the spectral analysis is described in Tab. 2 and in Tab. 3 and the values of the mechanical properties of base material S235 J2G3 are given by the material data sheet. [8,9]

Table 2 Chemical composition of S235 J2G3 steel

Fe [%] 98,69	**C [%]**	**Cr [%]**	**Si [%]**	**Mn [%]**	**Mo [%]**	**Ni [%]**	**Co [%]**
	0,125	0,059	0,186	0,602	0,051	0,09	0,045
	V [%]	**Ti [%]**	**Nb [%]**	**Cu [%]**	**Al [%]**	**S [%]**	**P [%]**
	0,017	< 0,002	0,029	0,08	0,012	<0,002	0,006

Table 3 Mechanical properties of S235 J2G3 steel [8]

Tensile strength Rm_{min} [MPa]	**Yield strength Re_{min} [MPa]**	**Ductility A_{min} [%]**	**Impact strength KC_{min} (20°C) [J]**
340	215	24	35

As the filler material OK Autrod 12.51 (ϕ 1.2 mm) wire made on Mn-Si basis was used. Wire is made by ESAB Company for MAG welding of non-alloy steels with possibility of use on steel structures, pressure vessels or shipbuilding. It can be used for welding with pure CO_2 or in combination with Ar + CO_2. Tab.4 shows a summary of chemical elements and Tab.5 gives information on the mechanical properties obtained from this filler material. [9,10,11]

Table 4 Chemical composition of filler material OK Autrod 12.51 [10,11]

C [%]	**Si [%]**	**Mn [%]**
0,09	0,9	1,5

Table 5 Mechanical properties of filler metal created in M21 welding atmosphere [10,11]

Gas atmosphere	**Tensile strength Rm [MPa]**	**Ductility A_5 [%]**	**Impact strength KC (20°C) [J]**
M21 (Ar/CO2)	560	26	130

The samples were formed using three kinds of mixed gases (Table 6), which was supplied by Messer Tatragas company. These are two- and three-component gases used in MAG processes to make joints for two types of steels - unalloyed and low-alloyed steels. [9]

Table 6 Chemical composition of used mixed gases [12]

Shielding Gas	**Ar [%]**	**CO2 [%]**	**O2 [%]**	**He [%]**
Ferroline C 18	82	18		
Ferroline C 6 X 1	93	6	1	
Ferroline He 20 C 8	72		8	20

The next step was to design welding procedures, based on Fig.1 below, where are shown semifinished products of 10 mm thickness with root beads (1,5) and cover welding beads (2-4,6-8) for produce samples. [9]

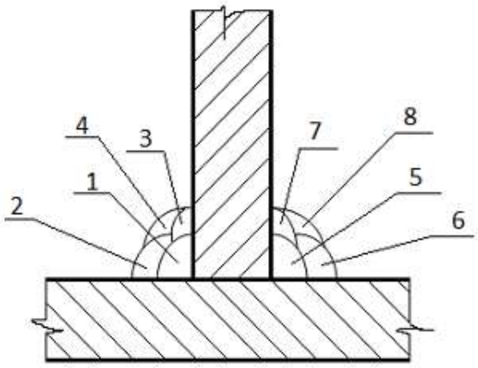

Figure 1 Assembly of semi-finished and placement of root (1,5) and cover (2-4,6-8) welding beads [9]

The parameters used in the welding procedures for individual fillet welds are described in Tables 7, 8 and 9. The welding method was chosen MAG – method 135 (STN EN ISO 4063), filler material - OK Autrod 12.51 by ESAB company with wire diameter of 1.2 mm using three different shielding gases atmospheres. Protective gases are classified into categories based on their chemical composition. The gas flow in the experimental measurement was the same for all three shielding gases, 16 liters per minute, welding current and voltage are recorded in the tables.

Table 7 Welding parameters of two-sided fillet weld with usage of Ferroline C18 shielding gas (Sample No.8)

Weld bead No.	Welding method	Welding position	Electrode diameter [mm]	Welding voltage [V]	Welding current [A]	Polarity	Welding speed [cm/min]	Shielding gas atmosphere	Gas flow [l/min]
1	135	PB	1,2	24	220	DC +	48-55	M 21	16
2	135	PB	1,2	24	240	DC +	48-55	M 21	16
3	135	PB	1,2	25	220	DC +	48-55	M 21	16
4	135	PB	1,2	25	220	DC +	48-55	M 21	16
5	135	PB	1,2	23	220	DC +	48-55	M 21	16
6	135	PB	1,2	24	230	DC +	48-55	M 21	16
7	135	PB	1,2	25	230	DC +	48-55	M 21	16
8	135	PB	1,2	25	230	DC +	48-55	M 21	16

Table 8 Welding parameters of two-sided fillet weld with usage of Ferroline C6X1 shielding gas (Sample No.9)

Weld bead	Welding method	Welding position	Electrode diameter [mm]	Welding voltage [V]	Welding current [A]	Polarity	Welding speed [cm/min]	Shielding gas atmosphere	Gas flow [l/min]
1	135	PB	1,2	24	230	DC +	48-55	M 24	16
2	135	PB	1,2	24	240	DC +	48-55	M 24	16
3	135	PB	1,2	24	230	DC +	48-55	M 24	16
4	135	PB	1,2	25	225	DC +	48-55	M 24	16
5	135	PB	1,2	23	220	DC +	48-55	M 24	16
6	135	PB	1,2	24	235	DC +	48-55	M 24	16
7	135	PB	1,2	24	230	DC +	48-55	M 24	16
8	135	PB	1,2	24	230	DC +	48-55	M 24	16

Table 9 Welding parameters of two-sided fillet weld with usage of Ferroline He20C8 shielding gas (Sample No.12)

Weld bead	Welding method	Welding position	Electrode diameter [mm]	Welding voltage [V]	Welding current [A]	Polarity	Welding speed [cm/min]	Shielding gas atmosphere	Gas flow [l/min]
1	135	PB	1,2	23	230	DC +	48-55	M 20	16
2	135	PB	1,2	24	240	DC +	48-55	M 20	16
3	135	PB	1,2	24	240	DC +	48-55	M 20	16
4	135	PB	1,2	24	248	DC +	48-55	M 20	16
5	135	PB	1,2	23	220	DC +	48-55	M 20	16
6	135	PB	1,2	24	235	DC +	48-55	M 20	16
7	135	PB	1,2	24	240	DC +	48-55	M 20	16
8	135	PB	1,2	24	240	DC +	48-55	M 20	16

Samples (Figure 2) were created using ForMIG 389FW welding machine. From a construction point of view, the device is equipped with a portable feeder, which is characterized with the water cooling of the burner. It is suitable for applications in organizations using gas mixtures, as well as a separate CO_2.

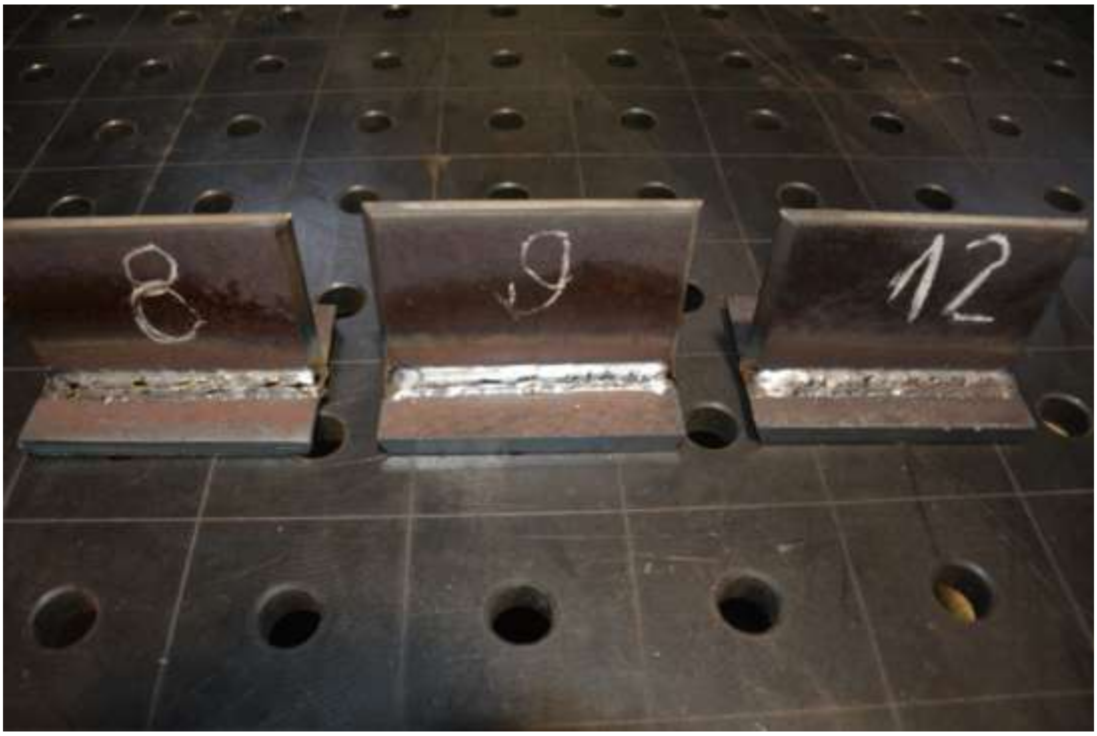

Figure 2 Experimental specimens of fillet welded joints

Visual inspection of weld joints was carried out according to STN EN ISO 17 637. Surface of welded joints were vision checked, when it was illuminated with 500 lux lighting. The presence of surface defects such as ignition, surface pores, floating roots, over-welding, welding deformation, and the like were analyzed.

IV. MICROHARDNESS EVALUATION OF WELDED JOINTS

The microhardness of the welded joints was evaluated in accordance with STN EN ISO 9015-2 standard using the Vickers hardness test on Shimadzu HMV 2 device. The procedure was based on the pressing of the identor - square-based diamond pyramid with face angle of 136° with a load of 0.9807 N for 15 seconds. The microhardness of the analyzed samples was measured at multiple locations of base material, heat-affected zone and weld metal to compare hardness changes. The following photodocumentation (Fig. 3) was created using a Keyence VHX 5000 microscope, where the overview of the analyzed macrostructures is prior to the hardness test itself. Further, Figure 4 shows the locations of the indentations for detecting and assessing the microhardness of the samples.

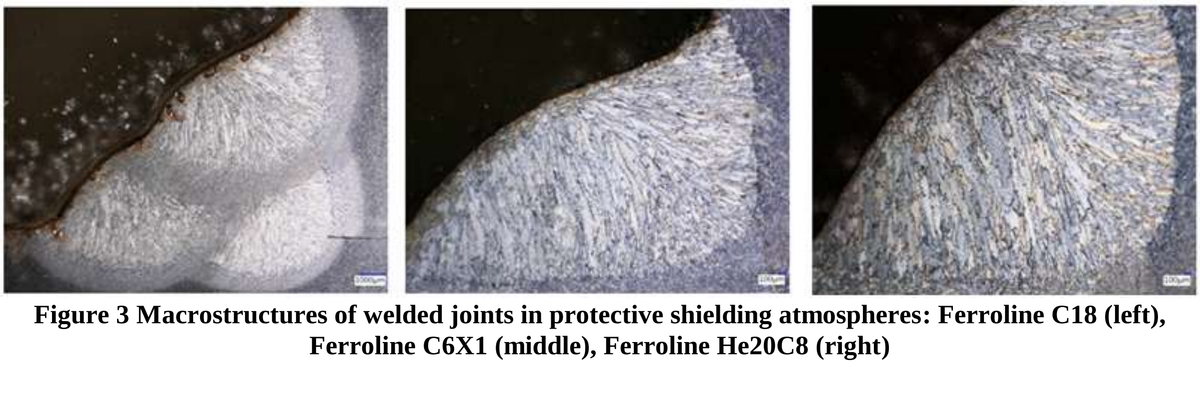

Figure 3 Macrostructures of welded joints in protective shielding atmospheres: Ferroline C18 (left), Ferroline C6X1 (middle), Ferroline He20C8 (right)

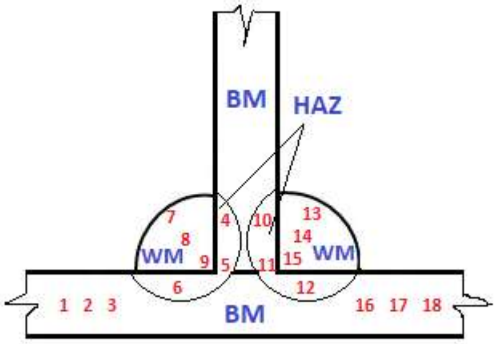

Figure 4 Scheme location of the indentations for measuring the microhardness of fillet welds [9]

For sample No. 8, where the Ferroline C18 shielding gas was used, the measured values of weld metal microhardness in the range of 169 HV to 199 HV were obtained. The values measured in the area of the heat-affected zone had values from 155 HV - 171 HV. Measurement results for base material were 139 HV - 169 HV. The graph of the measured values is shown on Fig. 5.

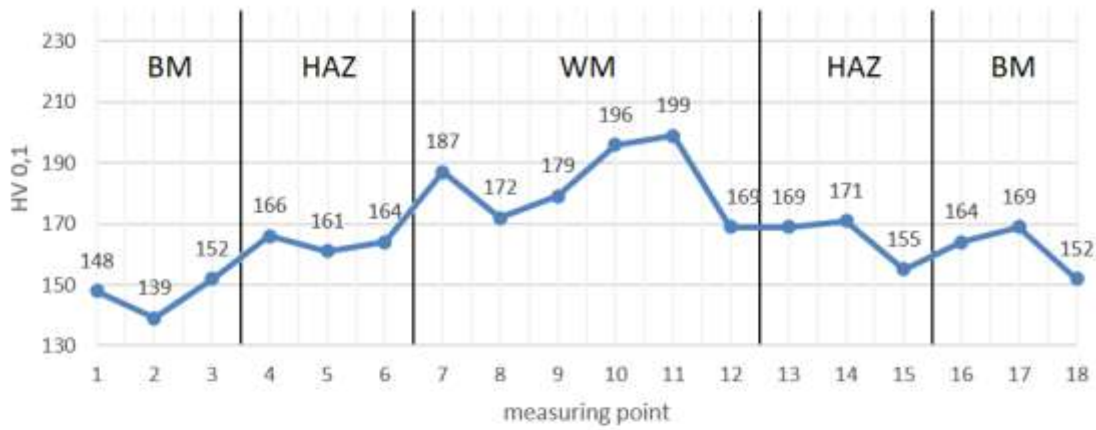

Figure 5 The graph of the measured values of the sample No. 8 (shielding gas Ferroline 18)

The second graph with fillet weld sample no. 9 (shielding gas - Ferroline C6X1) shows microhardness of the weld metal in the range 163 to 231 HV H (Fig. 6). After welding metal, it had the highest values of microhardness of the heat-affected zone. It ranged from 151 HV to 186 HV. The smallest measured values had a base material of 143 HV to 167 HV.

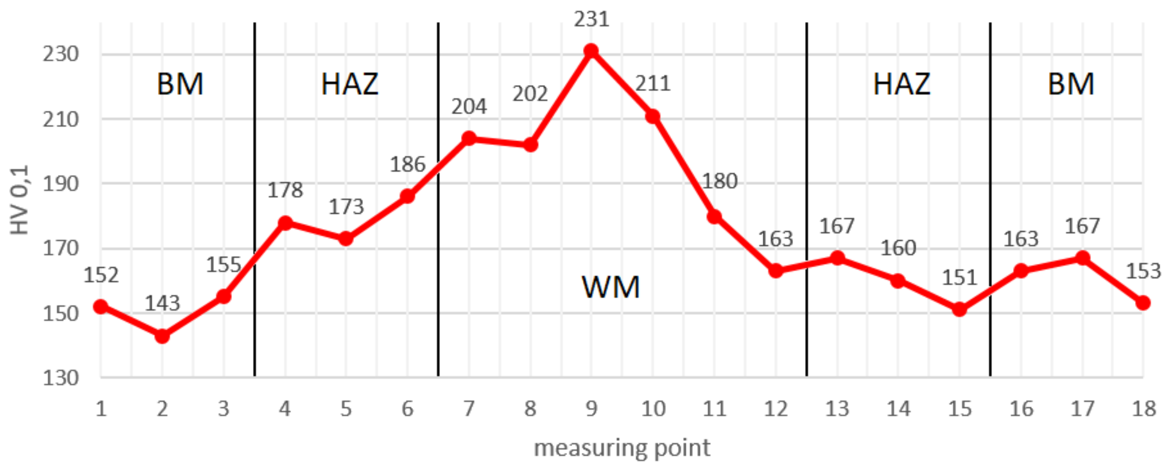

Figure 6 The graph of the measured values of the sample No. 9 (shielding gas Ferroline C6X1)

The results of the evaluation of fillet weld sample no. 12 (shielding gas - Ferroline He20C8) also had the highest values of microhardness in the weld metal area, reaching values ranging from 172 HV to 232 HV (Fig. 7). The values of microhardnees in heat-affected area were in the range from 151 HV to 181 HV. In the area of the base material, values from 138 HV - 173 HV were measured.

Figure 7 The graph of the measured values of the sample No.12 (shielding gas Ferroline He20C8)

V.CONCLUSION

A summary graph (Fig. 8) was designed to evaluate all measured values in the base metal, welded metal and the heat affected zone between each other in the individual fillet weldings using the various shielding gases by Messer Tatragas Company.

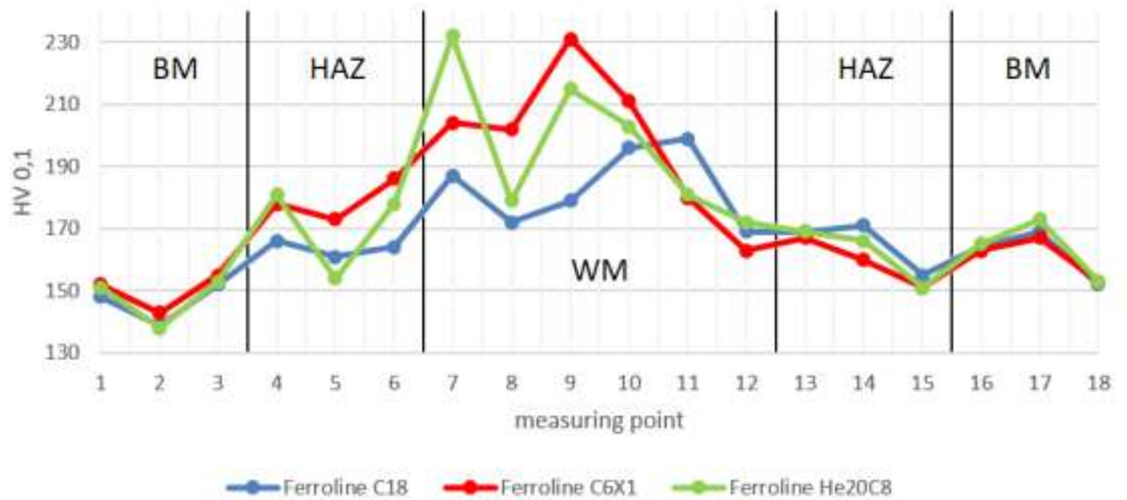

Figure 8 Overall graph of measured values of microhardness of samples No.8 (shielding gas Ferroline 18), No. 9 (shielding gas Ferroline C6X1), No.12 (shielding gas Ferroline He20C8)

From the measured values of microhardness of the fillet welds it is obvious that the highest microhardness value was achieved in the area of weld metal. If the values measured in welding metal are compared with each other, the highest measured value of microhardness reached sample no. 12 (232 HV). The second, in the order of the highest measured value of weld metal, was sample no. 9 (231 HV). The lowest values were measured on sample no. 8, which was welded in a protective atmosphere in Ferroline C18 gas (Ar 82% + CO2 18%).

The measured values of microhardness in the heat-affected zone of the fillet welds show that the highest value had sample no. 9 (186 HV) and the second highest in the order of the samples was sample no. 12 (181 HV). The resulting graphs have shown that the protective atmosphere used had only a minimal effect on the microhardness values in heat-affected zone.

The most significant differences were measured in the weld metal, where important factor in the welding process is the transfer of metal from the electrode to the weld, more precisely the welding bath. The transfer is affected by the composition of the shielding welding gas, because the MAG method is the type of welding where the gas forming the shielding atmosphere actively participates in the chemical reactions in the welding pool and helps to shape resulting weld. Used gases affect the internal cleanliness of the weld bead and the transition from weld metal to the base material, therefore the greatest difference on microhardness was measured in weld metal.

Samples were different by the type of protective atmosphere used with the same filler material OK Autrod 12.51 (1.2 mm) from ESAB Company. The gas flow in the experimental measurement was the same for all three shielding gases, 16 liters per minute, other values as welding current and the voltage are listed in the tables above (Tab. 7, 8, 9).

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