

Research regarding the influence of the preheating temperature on the welding dilution

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Abstract Due to high costs generated by the replacement of certain products components, currently, specialists in the field seek for solutions to develop some technologies dedicated to recondition the affected areas. In industry, there are many applications where the component that comes in touch with the operating environment must be made out of different characteristics material layers – one designated to resist corrosive conditions and the other to increase the resistance. These components are usually the result of depositing appropriate layers by welding. The paper presents the results obtained during the experiments carried out in order to establish the influence of the preheating temperature on the dilution resulted from metal active gas welding deposit (GMAW). A number of experiments are carried out by using different preheating temperatures, keeping constant the welding deposit parameters: deposit speed (v_d), welding current (I_s) and arc voltage (U_a). The results are presented in tabular form, macroscopic or graphic images through which can be set quantitatively and qualitatively, valid for the experimental conditions, the effects of the pre-heating temperature on the dilution but also on other geometric parameters of the weld bead such as the width of the weld bead, the penetration, the reinforcement or the final crater.

1. Introduction

The welding deposit of a material on another material is made in order to increase durability and corrosion proof, restore the initial geometrical shape or obtain intermediate layers designed to make the connection between two incompatible materials [1, 2].

Regardless of the welding deposit purpose, the chemical composition of the deposited layer depends on the chemical composition of the filler and base material but also on the participation coefficients of the two materials mentioned above. For example, the chemical composition of the deposited layer will be more influenced by the base material as its participation coefficient will increase.

A physical model designed to determine the chemical composition of the beams obtained by welding deposit (1a) or welding (1b), is presented in figure 1. The analytical predetermination of the medium chemical composition that a seam will have is important in terms of rational choice of the filler materials and some parameters of the welding process in order to achieve a welded seam having the desired characteristics [3, 4].

Denoting by γ the participation coefficient of the filler material/deposited material and by δ the participation coefficient of the base material, it can be noticed that they can be determined using the equations (1) and (2) respectively:



$$\gamma = \frac{D}{B+D} = \frac{D}{C} \quad (1)$$

$$\delta = \frac{B}{B+D} = \frac{B}{C} \quad (2)$$

Given the relation between the two coefficients, see equation (3):

$$\gamma + \delta = 1 \quad (3)$$

Considering a seam of equal length with the unit and writing the mass balance for each element the following is obtained, equation (4):

$$m_c E_c = m_d E_d + m_b E_b = C E_c = D E_d + B E_d \quad (4)$$

where m_c , m_d , m_b represents the mass of the seam, the filler material and the base material and E_c , E_d , E_b represents the concentrations of the general chemical element E in these areas.

Dividing by C and considering the relations defining the participation coefficient, it results, equation (5):

$$E_c = \gamma E_d + (1 - \gamma) E_b \quad (5)$$

Using equation (5), the chemical composition of the seam can be calculated if the chemical compositions of the filler material, base material and the participation coefficient of the deposited material are known.

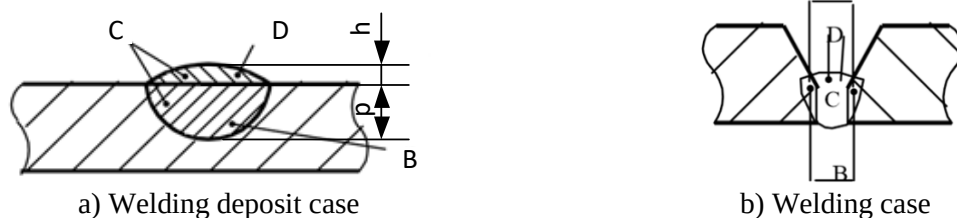


Figure 1. Physical model designed to determine the chemical composition at welding [3]

B – base material; D- filler material; C – metal welded seam; h – reinforcement; p – penetration.

As previously mentioned, the dilution is defined as the mixing degree, during welding, between the filler material and the base material. In order to obtain optimal properties of the welding deposit layer, the dilution must be maintained as low as possible.

Since the dilution degree depends not only on the welding process used but also on the specific welding method, it must be designed in such a way as to obtain the desired value [4, 5, 6, 7] taking into account the following elements:

- Welding speed, meaning that welding/ depositing at low speed increases the value of the dilution;
- Welding current type - the use of direct current leads to low dilution, while the use of alternating current leads to high dilution;
- Heat input - the higher the heat input value, the higher the dilution;
- The welding technique - the layers deposited by weaving leading to higher dilution compared to the layers deposited with no pendulation;
- The welding position;
- The number of layers - with their increase decreases the dilution;
- The free length of the wire - greater length leads to lower dilution.

A wide range of steels, undergone welding processes or welding deposit, are predisposed to different problems, of these the worst effect is given by the appearance of cracks, in general and cold cracks, in

particular. Cold cracking is mainly due to the coexistence at the same time in the welding / welding deposit area of three factors: tensions, structure and hydrogen [8].

For the cracking phenomenon not to occur, the welding technology designers foresee some technological measures, including the application of a preheating temperature (T_{pr}) which aims at lowering the cooling rate and increasing the time in which the amount of hydrogen decreases.

Preheating involves heating the base material, entirely or only in the joint area, up to a temperature resulted from computations or standards, before welding [9].

In order to obtain the results necessary to determine the dependence between the preheating temperature and dilution, the following steps were taken:

- The analysis of the base material used in the experiments;
- Settling the welding deposit parameters;
- Depositing a seam on the base material found at a temperature equal to the ambient temperature;
- Depositing the next seam, 10 mm distance from the other, after the first seam reached 25°C in the initial deposition area;
- After the previous seam reached 50°C in the initial deposition area, the next seam is deposited;
- The process is repeated for the initial 75°, 100°, 125° and 150° temperatures;
- Measuring parameters like seam width and reinforcement;
- Cutting the samples in the middle area of the seam;
- Macrographic processing of the samples after cutting;
- Chemical attack of the samples;
- Taking macroscopic images;
- Processing the images from the previous stage in order to determine B, C and D areas;
- Making calculations in order to determine the dilution values and the participation coefficient of the base and filler material.

2. Experiment input data

2.1. Base and filler material

The base material used in the experiments is S235JR steel, a steel type whose chemical composition is indicated in table 1. Other properties associated with this steel are presented in table 2.

Table 1. Chemical composition of S235JR material according to EN 10025-2:2004.

Chemical element	C [%]	Mn [%]	P [%]	S [%]	N [%]	Cu [%]
Value	max 0.20	max 1.4	max 0.04	max 0.04	max 0.012	max 0.55

Table 2. Other characteristics associated to S235JR steel.

Characteristics	Value
Young's module [GPa]	201
Poisson's ratio [-]	0.3
Shear module [GPa]	80
Density [Kg/m ³]	7800
Average CTE 20-300°C [µm/m ⁰ K]	12
Specific heat capacity 50/100° [J/Kg ⁰ K]	460-480
Thermal conductivity at 20°C [W/m ⁰ K]	40-45
Electrical resistivity at 20°C [µΩm]	0.20 – 0.25

The plate sheets on which the seams were deposited had 200 x 100 x 6 mm dimensions. The filler material was G3Si1 having Φ1.2 mm diameter and a chemical composition indicated in table 3.

Table 3. Chemical and mechanical characteristics of the filler material - G3Si1.

Chemical composition		Mechanical properties	
C	0.1 %	Yield strength [MPa]	440
Si	0.9 %	Tensile strength [MPa]	530
Mn	1.5 %	Elongation [%]	26
Charpy V			
		Temperature [°C]	Value [J]
		+20	130
		-20	90
		-30	70

The welding parameters recommended by the manufacturer are presented in table 4. The welding deposit was made using a reversed polarity DC source; CO₂ shielding gas (C1).

Table 4. Common values of the parameters.

No.	Parameter	Value
1	Diameter [mm]	1.2
2	Arc voltage [V]	18-34
3	Welding current [A]	120-380
4	Weight of weld metal [Kg welded metal/arc time]	1.3-8.0
5	Wire feed rate [m/min]	2.3-15

2.2. Welding parameters

The parameters used in the experiments and their values are indicated in table 5.

Table 5. Welding deposit parameters values.

No.	V _a [m/min]	I _s [A]	U _a [V]	V _d * [cm/min]	E _l [kJ/cm]	T _{pr} [°C]
1	7	210	24	45	6.05	25
2	7	210	24	45	6.05	50
3	7	210	24	45	6.05	75
4	7	210	24	45	6.05	100
5	7	210	24	45	6.05	125
6	7	210	24	45	6.05	150

* ensured by using a mechanical driving device

2.3. Conducted experiments

The samples on which the seams were deposited, having 200 x 100 x 6 mm dimensions, were undergone cleaning operations in order to remove impurities, grease and rust.

A seam was deposited and the sample was left to cool until it reached 25°C temperature in the starting area of the seam. This seam was deposited with the purpose of ensuring the 25°C preheating temperature necessary for depositing the first layer from the experimental program. It is specified that the temperatures were determined using a non-contact pyrometer, Fluke 60 brand. The seam deposited with T_{pr}=25°C was left to cool until it reached 50°C, when the second seam from the

experimental program was deposited. The procedure was repeated in order to obtain seam 3 and 4, with $T_{pr}=75^{\circ}\text{C}$ and $T_{pr}=100^{\circ}\text{C}$.

In order to obtain seam 5 and 6, two adjacent seams were deposited. The sheet plate was left to cool until it reached $T_{pr}=125^{\circ}\text{C}$ and then seam 5 was deposited. After the sheet plate reached $T_{pr}=150^{\circ}\text{C}$ seam 6 was deposited.

After depositing all 6 seams, they were cut mechanically and processed for macroscopic analysis. In the interest areas, the seam width (B) and reinforcement (h), were measured using an electronic caliper.

An overview of the experimental stand, taken over during the experiments, is shown in figure 2.

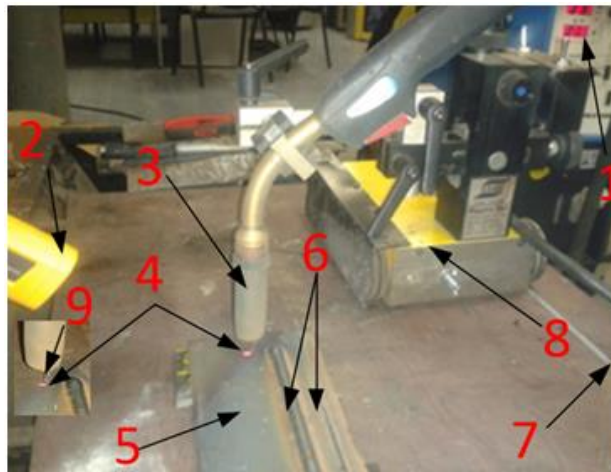


Figure 2. Experimental stand
1 - welding source with electronic display; 2 - pyrometer; 3 - welding gun; 4 - temperature measurement point before seam 2 was deposited; 5 - base material; 6 - welded seams; 7 - welding tractor runway; 8 - welding tractor; 9 - welding wire.

The temperature measurement technique is presented in figure 3.



Figure 3. Temperature measurement
A1 - the beginning of the seam previously deposited, A2 - the middle area of the seam previously deposited, A3 - the ending area of the seam previously deposited, B1 - the beginning area of the following seam.

3. Results and interpretation

After each deposited seam, after 10 seconds, the temperatures in 3 different areas were measured - figure 4. The preheating temperatures in the start and end area of future deposits, as well as the temperatures measured 10 seconds after depositing are presented in table 6.

Table 6. Temperature values.

No.	Temperature[°C]			
	Before depositing		After depositing*	
	The beginning of the seam ** (B1)	The beginning of the seam ** (A1)	Middle area of the seam **(A2)	Ending area of the seam **(A3)
1	25	51	201	295
2	50	67	227	302
3	75	97	230	375
4	100	136	246	383
5	125	147	267	401
6	150	162	280	420

*measured 10 seconds after extinguishing the electric arc

** - according to figure 3

The resulted welded seams are presented in figure 4.



a) The welded seams resulted from 1, 2, 3, and 4 experiments



b) The welded seams resulted from 5 and 6 experiments

Figure 4. Resulted samples.

The macrographic images obtained after the NITAL 2% chemical attack are indicated in figure 5.



a) Macrographic image - sample 1



b) Macrographic image - sample 2



c) Macrographic image - sample 3



d) Macrographic image - sample 4



e) Macrographic image - sample 5

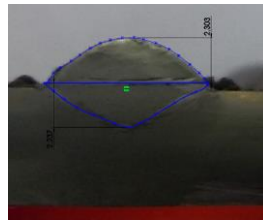


f) Macrographic image - sample 6

Figure 5. Macroscopic images of the welded seams.

The macroscopic images were introduced in a specialized software by means of which areas B,C, D, reinforcement (h) and penetration (p) were determined. On this bases, the filler and base material participation coefficients were established.

An image generated by the software is presented in figure 6.

**Figure 6.** Macrographic image dimensioning

The values generated by the software for B, C and D areas are presented in table 7.

Table 7. B,C,D areas, filler material participation coefficient γ and base material participation coefficient values δ .

No.	B [mm ²]	D [mm ²]	C [mm ²]	δ * [-]	γ ** [-]
1	195.85	298.73	494.58	0.396	0.604
2	200.33	296.34	496.67	0.403	0.597
3	214.21	277.98	492.19	0.435	0.565
4	215.52	276.18	491.7	0.438	0.562
5	228.79	260.66	489.45	0.467	0.533
6	233.87	247.32	481.19	0.486	0.514

* calculated using relation 1

** calculated using relation 2

The dimensions of the geometrical elements p, h and B of each welded seam are presented in table 8. It is specified that the geometrical parameters h and B were determined with the help of an electronic caliper and the geometrical parameter, p, was determined by introducing the macrographic images in the same software with which B, C and D areas were determined.

After visually testing the welded seams, notable differences could be noticed between the characteristic dimensions of the final crater for each welded seam, as can be seen in figure 7 and table 8.

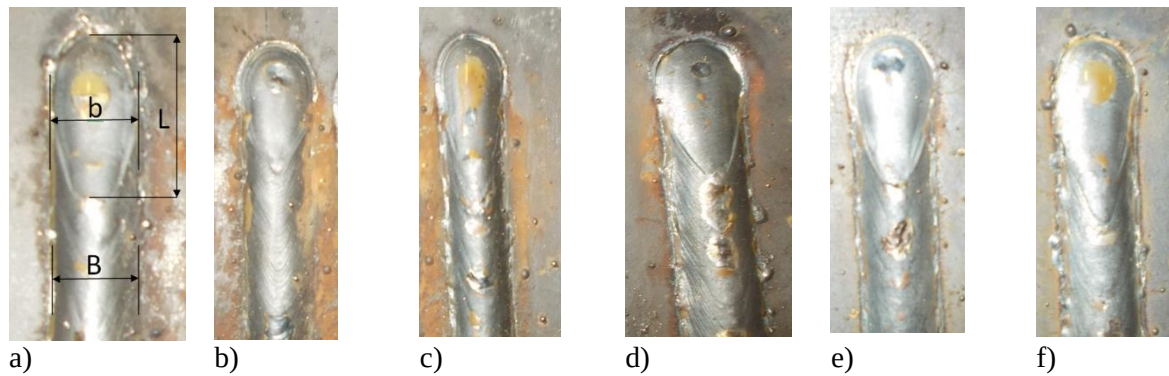


Figure 7. Final crater for each deposited seam

a) Final crater - sample 1; b) Final crater - sample 2; c) Final crater - sample 3; d) Final crater - sample 4; e) Final crater - sample 5; f) Final crater - sample 6.

Table 8. Geometrical parameters values of the welded seams.

No.	L_c [mm]	p [mm]	B [mm]	h [mm]	Final crater	
					L [mm]	B [mm]
1	174	1.852	8.35	3.06	19.12	9.69
2	158	1.926	8.67	2.72	18.7	10.28
3	154	2.209	9.09	2.67	17.78	11.08
4	156	2.236	9.12	2.63	17.48	11.27
5	152	2.27	9.92	2.33	16.54	11.67
6	154	2.665	9.94	2.32	16.5	11.98

Based on the values indicated in the table 8 above, the graphs representing variation of penetration, width, reinforcement and also length and width variation of the final crater were drawn up - figure 8 and 9.

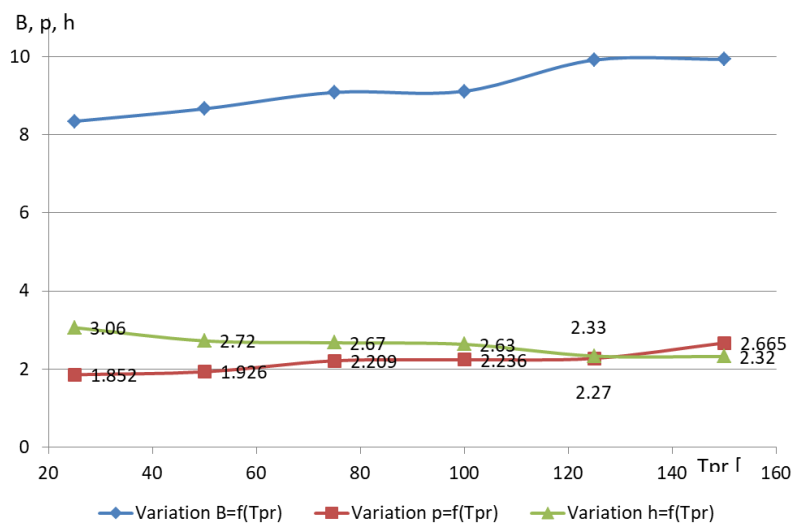


Figure 8. The geometrical elements variation of the welded seams (B , h , p) depending on the preheating temperature.

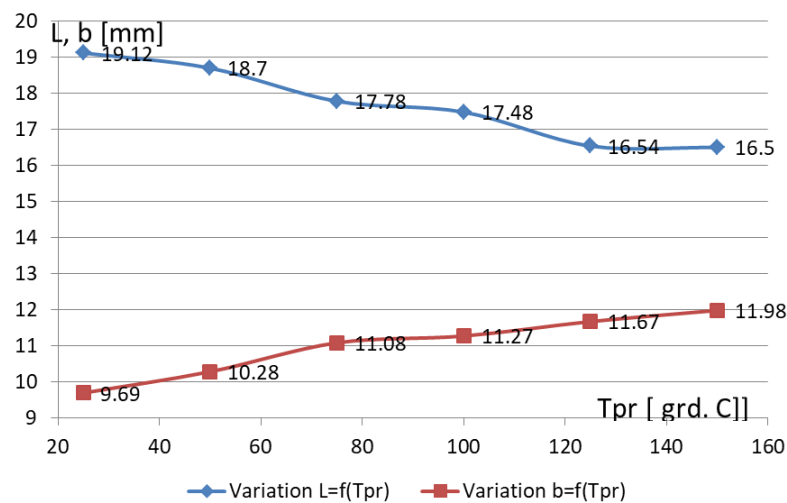


Figure 9. Dimensions variations of the final crater (L, b) depending on the preheating temperature

Based on the values indicated in the table 8, the participation coefficient variation for the filler and base material was drawn - figure 10.

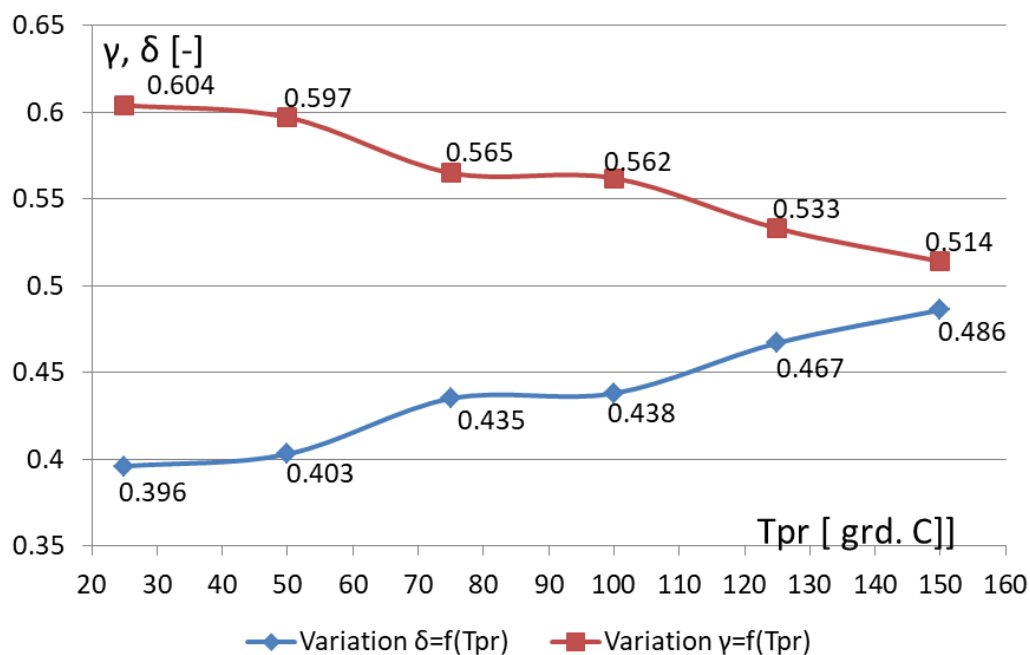


Figure 10. Base and filler material participation coefficient variation depending on the preheating temperature.

4. Conclusions

From the carried out experiments the following conclusions can be drawn concerning the geometrical elements of the welded seam:

- The preheating temperature applied influences the geometrical parameters of the resulted welded seams;
- By increasing the T_{pr} values, B and p parameters will increase and h parameter will decrease;
- The increase with 125°C of T_{pr} led to an 0.81 mm increase of the penetration, 1.59 mm increase of the seam width and a 0.74 mm decrease of the reinforcement.

Concerning the final crater, it could be noticed:

- An increase with 125°C of the T_{pr} leads to the decrease of the final crater length with 2.62 mm.
- An increase with 125°C of the T_{pr} leads to the increase of the final crater width with 2.29 mm.

The final conclusion is that with the change of the initial temperature in the area where the deposition or welding is carried out, there is a change in the filler and base material participation coefficient and also in the chemical composition of the welded seam.

5. References

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