Innovation in the MIG/MAG Process: Productivity analysis and Fume Emissions

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Abstract

In a more competitive industry there is a constant search for new solutions, where a balance between productivity, quality, costs and safety is always present. In metal working companies where welding is significantly used the solution includes specific situations that this work approached.

In this work new welding processes were studied, processes that are derivatives from the traditional MIG/MAG process: FastRoot, Surface Tension Transfer (STT) and Cold Metal Transfer (CMT). These processes were analyzed through the study of its wave forms and through the study of the welds performed. This work approached two subjects, the productivity of the welding processes, and the fume formation that results from those welding processes.

The present work pretends not only to study these processes but also show them in a more profound way, confirming at the same time some of the advantages associated with those welding processes.

Keywords

Welding; Productivity; MIG/MAG; FastRoot; CMT; STT; Welding Fume Formation

Introduction

The initial concept of the MIG/MAG welding process was first introduced in the 1920's, but its first commercial appearance will only happen in the 1940's [1], where an aluminum electrode was continuously fed and protected by a gas formed by 100% of Argon [2]. Only in 1951 with the introduction of a gas mixture of oxygen and argon, was possible to weld steel [3]. But only in the last 20 years this welding process began to dominate the industries of welded constructions [4]. Since it appeared in the late 1940's until now, the MIG/MAG welding process suffered successive upgrades improving the productivity of the process and the safety of the welder. Those constant improvements were responsible for the great flexibility characteristic of this process, where a large range of materials and thicknesses can be welded.

The welding fumes that result from the MIG/MAG process have been studied since 1975 [5], specifically their nature and the factors that control the formation rate, as well as solutions to reduce the welding fumes produced. Just recently the Welding fumes began to gain more importance due to several law suits in the United States regarding illnesses that might be related to a long exposure to welding fumes. Some of those cases concern manganese [6].

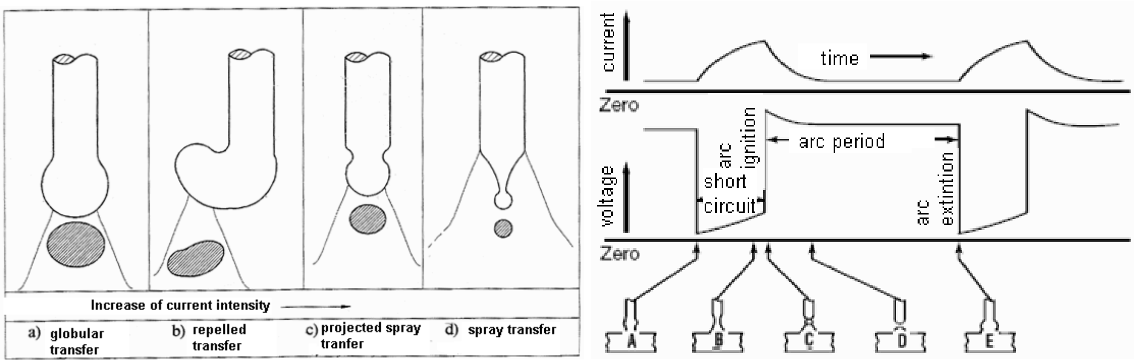
Theoretical Background

Metal transfer

The MIG/MAG welding process uses a consumable electrode, continuously fed to the weld pool. If the fusion of the electrode is balanced by the electrode's speed towards the piece to weld, then the process will function in a continuous and stable manner.

One of the ways to classify the transfer modes is dividing them into two groups [11]:

- free flight transfer
- dip transfer (short circuit)



a) b)

Figure 1 – Transfer modes:a)free flight, b) dip transfer [11]

There are another types of metal transfer know as “controled transfer”:

- controlled dip transfer
- pulsed transfer

The controlled dip transfer concept was adopted in the development of new welding processes derived from the MIG/MAG process. They are: Surface Tension Transfer, Fast Root e Cold Metal Transfer.

Variants of the MIG/MAG Process

Fast Roost

FastRoot is a modified short-arc welding process, where the power source's current and voltage parameters are digitally controlled. The process controls the welding parameters and monitors the formation of a short circuit during welding, so that the weld droplets fall off the end of the welding wire into the molten weld pool at precisely the correct moment, making it easier to control the arc and significantly reduce the formation of spatter.

The Fast Root principle is as follows:

- During short circuit period a droplet from the filler wire is produced;
- The material transfer occurs on a low current value, leading to a arc with reduced spatter;
- After the material transfer starts the arc period with higher current(open arc);
- The open arc is forming a weld puddle and bringing energy to the base material→penetration;
- One complete section lasts approximately 5-6 ms.

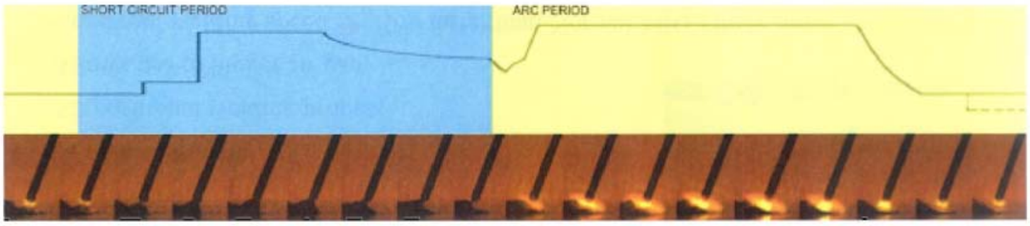


Figure 2 – Diagram of current wave form and series of high speed photos

Surface Tension Tranfer (STT)

Surface Tension Transfer (STT) welding is a MAG controlled short circuit transfer process which uses current control the heat, independent of wire feed speed, so changes in electrode extension do not affect heat generation. Those changes occur according to real parameters of the arc. The source instantaneously reacts to all phases of weld metal transfer to the weld pool in accordance with real situation of arc. Figure 3 shows how current and voltage are controlled during the welding process. Spatter and fumes are reduced because the electrode is not overheated

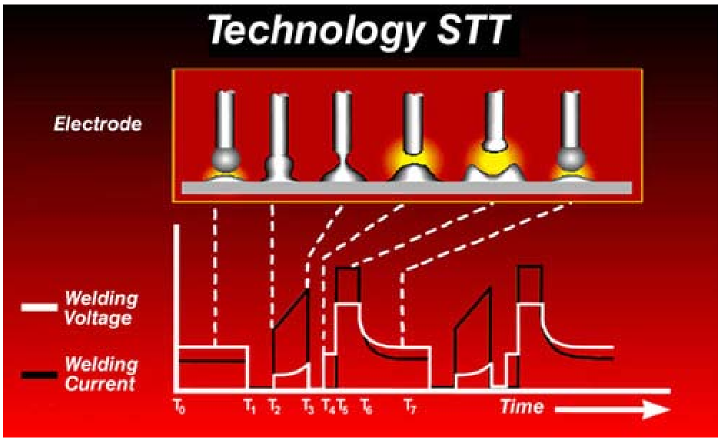


Figure 3 – Relation between current and voltage in a STT power source

In STT the welding cycle comprises the following phases:

- During the arcing period STT produces a uniform molten ball and maintains it until the "ball' shorts to the puddle.
- When the "ball" shorts to the puddle, the current is reduced to a low level allowing the molten ball to wet into the puddle.
- Automatically, a precision pinch current wave form is applied to the short. During this time, special circuitry determines that the short is about to break and reduces the current to avoid the spatter producing "explosion".
- STT circuitry re-establishes the welding arc at a low current level.
- STT circuitry senses that the arc is re-established, and automatically applies peak current, which sets the proper arc length. Following peak current, internal circuitry automatically switches to the background current, which serves as a fine heat control.

Cold Metal Tranfer (CMT)

CMT (Cold Metal Transfer) can be described as a GMAW process where heat input is low as when compared to the conventional dip arc process. The CMT process is characterized on the innovative solution for the weld drop detachment. Unlike in a conventional pulsed arc, the droplet is not shed by a current impulse, rather it is a defined rearward motion of the welding wire which brings about controlled droplet detachment (figure 4).

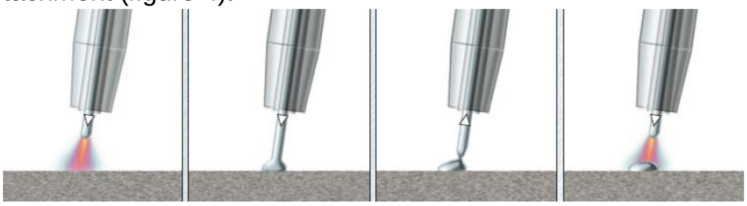


Figure 4 – The principal phases in the new CMT process (from left to right)

In figure 4 are represented the different phases that characterize this process:

- During the arcing period, the filler metal is moved towards the weld-pool.
- When the filler metal dips into the weld-pool, the arc is extinguished. The welding current is lowered.
- The rearward movement of the wire assists droplet detachment during the short circuit. The short-circuit current is kept small.
- The wire motion is reversed and the process begins all over again.

The principal innovation is that the motions of the wire have been integrated into the welding process and into the overall control of the process. Every time the short circuit occurs, the digital process-control both interrupts the power supply and controls the retraction of the wire. This forward and back motion takes place at a frequency of up to seventy times per second (70 Hz). The wire retraction motion assists droplet detachment during the short circuit.

Fume Formation

Welding fumes are formed by two mechanisms, from the evaporation in the detached droplet, and from the spatter that results from the welding process (figure 5).

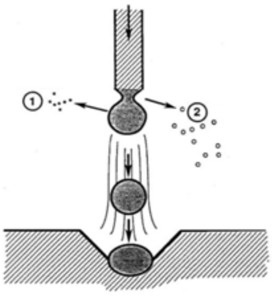


Figure 5 – Responsible factors for the welding fumes formation: 1) evaporation in the detached droplet; 2) Spatter

There is also fume formation in the level of the weld, specifically in the weld pool, but the quantity produced is not significant [5].

Fume formation from the detached droplet is going to depend of its characteristics, i.e., from the temperature at the surface of the droplet, and also from the geometry of the droplet itself (dimension). These characteristics vary for different types of metal transfer.

Experimental Approach

Productivity tests

For this work the base material used was carbon steel, St52 that normally is used in welded constructions. Its composition is shown in table1.

Composition	C [% max]	Si [% max]	Mn [% max]	P [% max]	S [% max]
St52	0.2	0.55	1.5	0.05	0.05

Table 1 – Material base composition

The welding wire used is this work was the EN 440 G3Si1 with the following composition:

Composition	C [% max]	Si [% max]	Mn [% max]
EN 440 G3Si1	0.1	0.9	1.5

Table 2 – Welding wire composition

The St52 steel was used in this work in the form represented in figure 6.

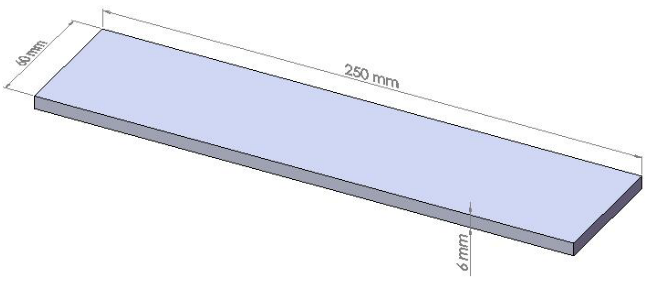


Figure 6 – Dimensions used

In this work four different welding equipments were used:

ESAB
LUC 400

Figure 7 – MAG machine

FRONIUS
TPS 4000 CMT

Figure 8 – CMT machine

Kemppi
FastMig Synergic

Figure 9 – FastRoot machine

Lincoln Electric
Invertec STT

Figure 10 – STT machine

In the productivity tests, a welding speed of 0.23 m/min was adopted. The only changeable parameter was the current intensity. The voltage and wire feed speed were controlled by the welding equipment itself as an approximation of the industrial reality.
The shielding gas used for these tests was Argon+8%CO_2.

Fume emission tests

In the tests concerning the fume formation analysis, it was necessary to build a fume chamber that would be according to the existent standard [19]. A fume chamber was then built according to the norm – figure 11.

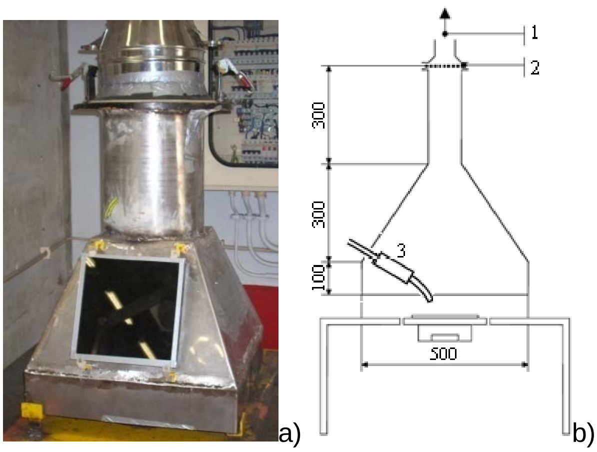


Figure 11 – Fume chamber (a); drawing taken from the norm (b) [19]: 1 – fume exit; 2 - filter

In these tests was also used the St52 steel with a EN 440 G3Si1 welding wire.

Procedure

Productivity tests

In order to study these processes some parameters had to be calculated. The heat input was calculated so that the quantity of energy transferred to the material base could be known. The heat input was calculated by the following equation:

$$Q=\eta\times\frac{V\times I\times 60}{WS\times 1000}\ [J/m]\ ,\ (1)$$

where η is the efficiency associated with to the welding process, *V* is the voltage, *I* is the current and *W* is the welding speed. The efficiency associated to the traditional MIG/MAG process varies between 66% and 85% [8]. Not having the efficiency for the equipment used, it was considered the worst case scenario, in this case 66%. This was the efficiency value considered in the calculations.

From the base and deposited material a new parameter can be calculated, the Dilution Rate. The equation to calculate the Dilution Rate is:

$$D.R=\frac{M_b}{M_b+M_a}\times 100\ [\%],\ (2)$$

In order to measure the areas of the base material (Ma) and the deposited material(Mb), the welded samples were prepared, cut, polished and contrasted with NITAL (5%).

Also the penetration (p) and width (a) were measured directly from the welded samples (figure 12).

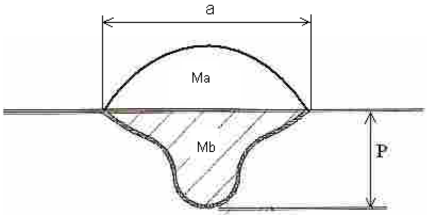


Figure 12 – Parameters measured directly form the welded samples

For the three new processes, STT, CMT and FastRoot, there are no efficiency values, but due to the fact that these processes are very similar to the traditional MIG/MAG, it’s to be expected that also the efficiency varies between 66% and 85%. Also for these three equipments the worst case scenario was adopted, i.e., 66% of efficiency was the value used.

Fume emission tests

The fume emission tests were performed using a fume chamber according to the EN ISO 15011-1 norm.

Fibber filters were used to collect the fumes that resulted from the welding process. The filters were scaled before and after each test in a precision scale. From these results the Fume Formation Rate could then be calculated:

$$FFR=\frac{m_f-m_i}{t}\ [g/min],\ (3)$$

Where *FFR* is the fume formation rate, m_f is the final weight of the filter, m_i is the initial weight of the filter and *t* is the welding time in minutes.

Results and Discussion

Through the bead on plate welds a study to compare the welding characteristics of the different processes will be carried out, specifically the penetration and the width of the weld, dilution rate and melted area of the welds. Through the study of these characteristics it is expected to prove that these new processes will bring some advantages in some applications when compared with traditional MAG.

These new processes are mainly used in the welding of thin sheet metal and root passes because they are associated to low heat inputs and better controlled metal transfers. It is expected that the controlled dip transfer will lead to a more stable process, with less spatter without the lack or excess of fusion in root passes.

Processes	MAG	CMT	STT	FastRoot
Weld				

Figure 13 – Example of the weld profile of the different processes, 200 A and Ar+8%CO_2 as shielding gas

In figure 13 profiles of the welds performed can be seen. On the MAG and CMT process the “finger tip” penetration stands out. This type of penetration is a characteristic of the shielding gas that is mainly composed by argon. But in the case of STT and FastRoot this type of penetration is not present despite the use of the same shielding gas (Ar+8%CO2). In fact these processes present a more uniform penetration.

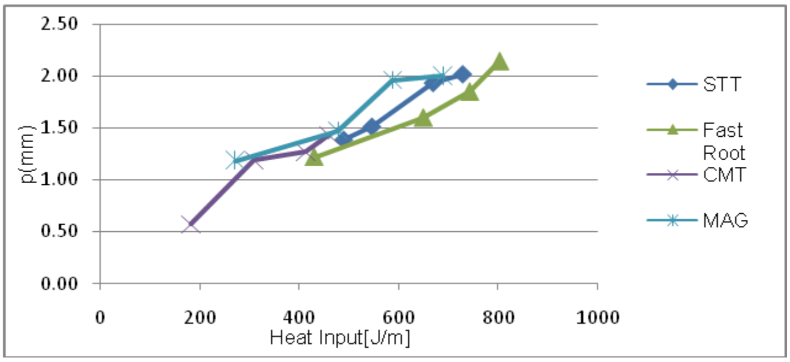


Figure 14 – Penetration of the different processes as a function of the heat input

In what concerns the penetration on the bead on plate welds, it can be seen from figure 14 that the MAG process in general presents higher penetrations, only the FastRoot process has bigger penetration than the MAG, mainly because this process achieved a higher heat input. From figure 14 it can also be seen that the CMT is the process that presents the lowest penetration values, mainly because of the also lower values of its heat input.
The process that presents the higher heat inputs is the FastRoot process (apart from the first test, where STT has a higher heat input because of the higher current used – table 2), where in the sequence of tests made for each process (made on the same conditions) of table 2, it can be seen that the FastRoot process has the higher heat inputs.

Welding Process	Welding speed [m/min]	I [A]	V [volt]	Heat Input [J/m]	Dilution Rate [%]	Deposited Area [mm2]
FastRoot	0.3	164	19.86	348.59	38.49	4.61
	0.23	170	22.15	648.32	48.54	4.92
	0.23	200	21.53	741.38	50.21	6.36
	0.23	230	20.24	801.50	51.88	6.95
STT	0.3	200	18.54	489.46	37.09	7.09
	0.23	200	15.85	545.79	37.59	7.15
	0.23	214	18.14	668.37	42.53	7.05
	0.23	220	19.21	727.64	46.23	7.08
MAG	0.3	130	15.80	271.13	20.65	9.73
	0.23	170	16.30	477.09	23.05	15.83
	0.23	203	16.80	587.18	26.59	18.89
	0.23	222	18.00	688.01	29.74	20.73
CMT	0.3	133	10.40	182.58	11.61	9.36
	0.23	170	10.60	305.12	14.39	15.76
	0.23	205	11.70	412.96	15.37	19.42
	0.23	225	11.90	461.00	15.95	21.64

Table 3 – Sequence of values of the different tests performed

From table 3 it can be seen the reason for the differences between the heat inputs. Considering the test with a current of 200A, it can be seen that the only parameter that is changing is the voltage, and because the voltage is higher in the case of the FastRoot process, this process is the one with higher heat inputs. In the case of the CMT process, because it functions with lower voltages, it has the lower heat inputs.

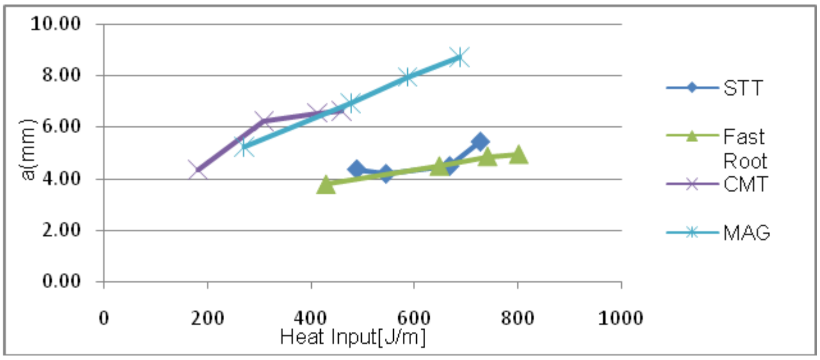


Figure 15 – Width of the weld as a function of the heat input

Concerning the width of the welds in figure 15, it can be seen a gap between the processes CMT, MAG and STT, FastRoot. There is a clear difference between the processes that use the controlled dip transfer and the normal dip transfer. Only the CMT process, with a controlled dip transfer mode, goes against this premise, obtaining values similar to the MAG. This fact can be explained by the lower voltage values used by this process, which leads to a wider weld [2]. The larger deposited area, similar to the MAG process (figure 17), can also explain these width values for the CMT process.

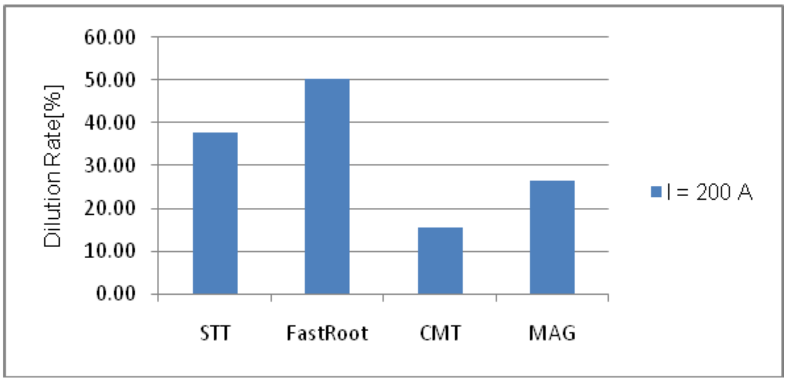


Figure 16 – Dilution Rate for each process

In figure 16 is represented the dilution rate of the performed tests, that is directly connected with the heat input. It can be seen that for the same current value (200 A) the FastRoot process presents the higher dilution rate. This is because the FastRoot process has the higher heat inputs. Despite the fact that the STT and MAG processes have similar heat inputs, from figure 16 it can be seen that STT presents a higher dilution. Has for the CMT process, it presents the lower dilution value of al the processes, because is the process with the lower heat input.

In table 3 are presented the values of all the dilutions calculated and their heat input. It can be seen that the STT and FastRoot processes have the dilution values always bigger than the ones from the MAG process, where even with bigger heat inputs from the MAG process, it presents lower dilutions than the ones from the STT and FastRoot processes. This fact comes to prove not only the quantity of transferred energy is important, but also the way how that energy is transferred (controlled dip transfer). As for the low dilution values of the CMT process, these can explained by the lower heat inputs that characterise this process, but the “push and pull” mechanical system of this process can also have some influence in this issue, even though this fact can’t be proven in this work.

Figure 17 represents the area of deposited material for a current intensity of 200 A. The tests present in the figure were all done with the same welding speed, therefore conclusions can be made concerning the deposition rate of the processes studied. There is a clear difference between the obtained values for the CMT, MAG processes and for the STT and FastRoot processes, where the last ones present lower deposition rates than the ones from the CMT and MAG processes.

Is due to the fact that the FastRoot and STT processes present lower areas of deposited material (lower deposition rates), that lower values of width were obtained. This is because the width of the weld is directly connected with the deposition rate of the processes, since it is a direct consequence of the deposited material.

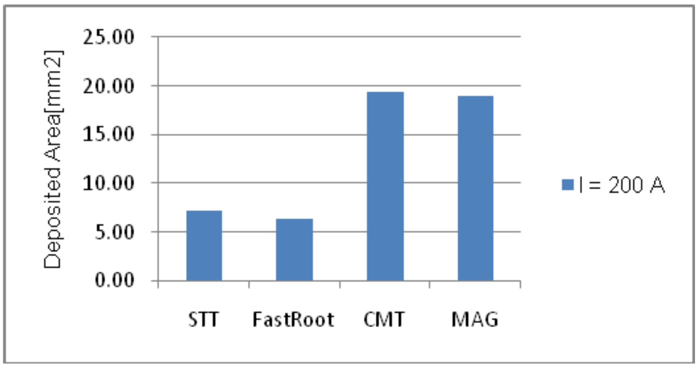


Figure 17 – Area of deposited material for each process

Comparison between the CMT and MAG processes concerning fume

Figure 19 represents the fume formation rate for the CMT and MAG processes, and has it can be seen the difference between the two is high. This can also be confirmed through figure 18 that shows the filters obtained, where it's shown a clear difference between the colorations of the filters obtained.

a)  b)

Figure 18 – Different coloration of the filters after the tests: a) MAG; b) CMT

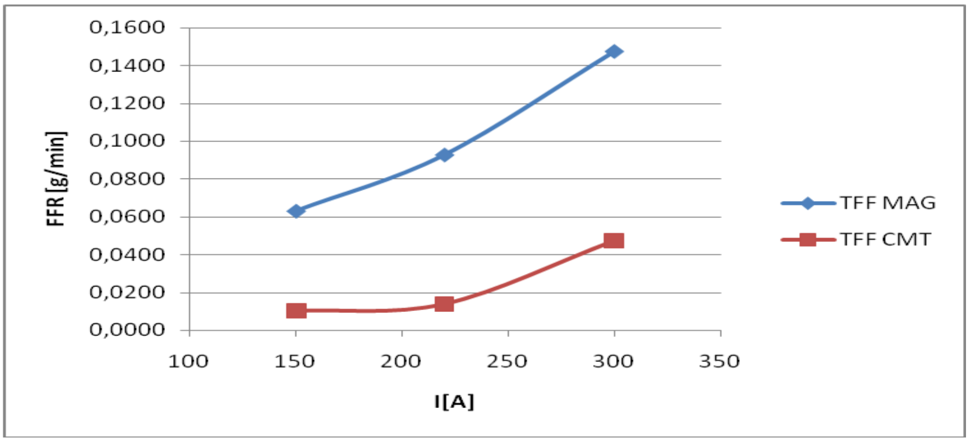


Figure 19 – Comparison between FFR of MAG and CMT

The observed difference in the fume formation rate between the two processes is mainly because of the way how the current is controlled in both processes. In the CMT process the metal transfer mode is the controlled dip transfer. This fact leads to a more stable process, with less spatter, which leads to the production of less welding fumes for the CMT process.

In this work no study was preformed regarding the fume formation rate of the FastRoot and STT processes, but due to the fact that these processes also have a controlled dip transfer mode, the spatter formation is reduced, and because of that it is to be expected that these processes also present fume formation rates lower than the ones obtained for the MAG process and similar to the ones obtained for the CMT process.

Conclusions

Through the results presented here, the following conclusions can be drawn:

– The FastRoot and STT processes are the ones that presents the better results for the penetration, because despite the fact they have similar values to the ones obtained for the MAG process, they have a more uniform penetration, making them indicated for applications where the quality of the penetration is an important fact (root passes).

– Due to the fact that the STT and FastRoot processes present lower deposition rates, their applications in thin sheets of metal might be advantageous because the quantity of deposited material would be smaller. But because these processes have higher heat inputs, that fact could lead to an excessive distortion of the sheet.
– The CMT, from all the processes studied, it is the one that presents the lower heat inputs. This characteristic might be advantageous in the case when thin sheets of metal have to be welded, because it might reduce considerably the distortion normally associated with these types of welding. This process might also be advantageous for root passes, in a way that due to its low heat input there will be no excess of fusion, and because this process also presents deposition rates similar to the MAG process more material will be deposited, making in just one pass, a sufficient weld height to continue the filling of the weld with high productivity processes (ex. Tandem Welding and Submerged Arc Welding).
– The spatter generated during welding have a great influence in the fume formation rate. That is one of the reasons why the CMT process has a lower fume formation rate, making it a more "clean process".
– The use of these processes is more expensive than the use of traditional MAG (the purchase price is higher), so the use of these processes by the industry has to depend on other factors, like the need for more quality and safety, that has seen before they can achieve it.

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