STUDY OF THE EFFICIENCY OF A VISION SYSTEM FOR MONITORING AND DEVELOPMENT OF ARC-WELDING PROCESS

Carolina Pimenta Mota, cpimentamota@gmail.com
Marcus Vinícius R. Machado, mvrmachado@gmail.com
Diandro Bailoni Fernandes, diandro@mecanica.ufu.br
Louriel Oliveira Vilarinho, vilarinho@mecanica.ufu.br
Laprosolda – Centro para Pesquisa e Desenvolvimento de Processos de Soldagem, Universidade Federal de Uberlândia, MG, Brasil.

Roberto Mendes Finzi Neto, robertofinzi@hotmail.com
Universidade Federal de Goiás, Departamento da Ciência da Computação, Catalão, GO, Brasil.

Abstract. *Vision, the human being's favorite sense, and its great capacity to catch, to process and to interpret great amount of visual nature data has been throughout the years a great inspiration for development of techniques and technological devices that reproduce it into a computational system. In welding processes, vision can supply information in inspection and welded joint's quality, in the parameters' monitoring, in trajectory correction and even, finally, in the study of the phenomena involved in the process. However, the luminosity/radiation emitted from the weld arc represents a barrier for these visual studies.*
One of the forms currently used to visualize the process, without the interference of the arc's light, consists of illuminating the process with the near infrared light and, using band pass filters, around this exactly wave length, during the acquisition of the images. A solution for the near infrared illumination, of increasing application, involves the use of laser diodes of high power, with low cost and less complex installation than conventional lasers.
Therefore, this work aims to perform a comparative study of the arc near infrared emission in one of the two most used processes: GTAW and GMAW, focusing on the influence of welding parameters, such as current and shielding gas. Through a luminous sensor and the use of an optic lens system, experiments were carried out by acquiring the light spectra emitted by the welding arc. It's possible, using the arc results – arc energy value - obtained and following the same methodology proposed, to know the quantity of infrared energy, and its luminosity, needed to overlay the arc during the image acquisition.

Keywords*: vision, welding, monitoring, near-infrared.*

1. INTRODUCTION

Welding is one of the main manufacturing processes used on industry for materials' union, mainly metals, and it's being more necessary and used nowadays. With this knowledge, the necessity of productivity and quality's guarantee of the involved processes is in an increasing demand. As a special process, with interdependent parameters, many research works are developed with the intent of better understanding of the phenomena involved in the process.

One of the forms greatly applied nowadays to help these studies of welding processes are vision systems. Using cameras, of high or low speed, can give much useful information to the researchers, which aren't possible to obtain only with electrical signals monitoring, like current or voltage. Each type of vision system can provide specific information about the occurring process: the *shadowgraphy* technique, or back-lighting, which consists in projecting in a plane surface the shadow of the elements in weld region, illustrated in Figure 1, visualize the drop transference as a form of studding the metal transfer (BÁLSAMO *et al.*, 2000), while new vision systems has as intent the direct visualization of the melted metal and of the weld joint itself, with a variety of applications going trough studies of the phenomena in weld pool until joint trackers or online controllers of welding parameters.

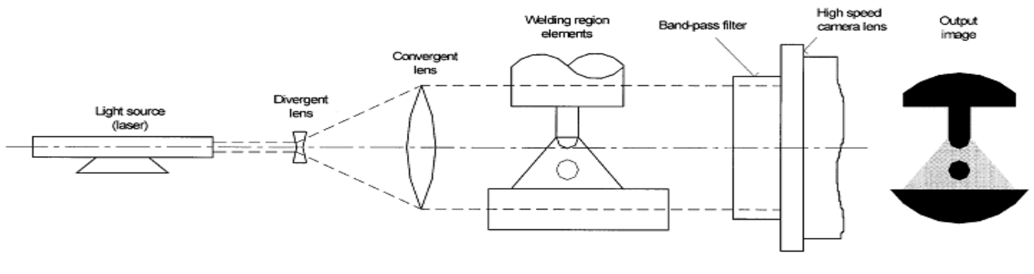

Figure 1. View of metal transfer by back-lighting technique (BÁLSAMO *et al.*, 2000)

The visualization of the melted pool can provide information about many aspects of the weld. Many studies (ZHANG *et al.*, 1995; ZHANG *et al.*, 1996; BASKORO *et al.*, 2008; VILARINHO, 2009) prove that the observation and control of the melted pool, and its main characteristics, can result in desired penetration and mechanic proprieties, while another study (HARA e SUGA, 2008) proposed a penetration control system monitoring natural frequency and width of the melted pool. In addition to that, the applications of a vision system can go much further than the control of penetration in welding process. A clear view of the melted pool surface and its deformation hold important information of many basic phenomena, like Marangoni's flux and the pressure drop caused by the metal vaporization, among others (DUFFEY *et al.*, 1995).

The voltaic arc in the welding processes emits, further than the visible light radiation, in practically all wavelengths, including ultraviolet and infrared. The light intensity emitted, however, in wavelengths bigger than 850 nm is low when compared to the visible spectrum. One of the techniques of visualization of the process is the use of long pass filters in this region of emitting, with the intent of decrease the arc's light present during the image acquisition. This technique, despite being efficient, isn't sufficient to overlay completely the arc, Figure 2, and the luminosity left affects the precision and sharpness that the melted pool can be observed and not being sufficient in major precision applications.

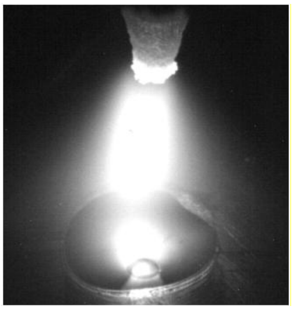

Figure 2. GTAW in carbon steel, Argon, 100 A, with a optic long pass filter in 850 nm (VILARINHO, 2009).

For the arc's luminosity not be a problem during the images acquisition, it's used the technique named as Laser Illuminations with Spectrum Filtering. According to the authors (HOUGHTON *et al.*, 2007), the principle of this technique is decrease or eliminate the arc's light that reaches the camera by illuminating the weld area with the light of a laser. To minimize the requirements of light intensity, the light's source wavelength must be selected where the arc's intensity is low. A band pass (interference) filter is required to eliminate the arc's light and only the laser's light will be capable of reaches the camera, as it show in Figure 3.

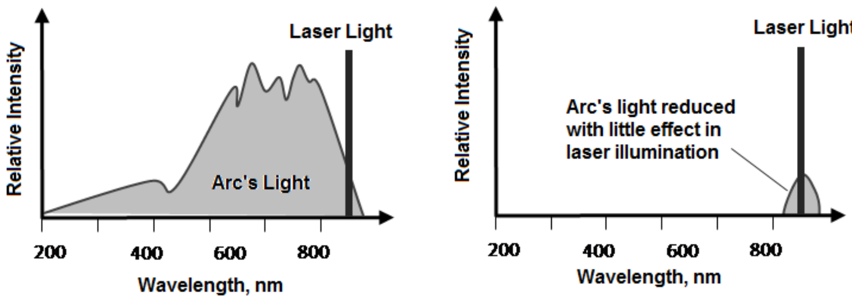

Figure 3. Principe of Spectrum Filtering (HOUGHTON *et al.*, 2007).

The shutter (exposure) time of the camera also has influence in the quantity of light that is obtained during de image acquisition. So, is possible to decrease the arc's light intensity by decreasing the exposure time of each acquired frame. Pulsing the laser inside each exposure time result in a minimum power necessary to achieve a overlay of the arc's radiation, as long as the pulse is situated inside of the exposure time in each frame acquired, as show in Figure 4.

Three different sources of illumination can be used to illuminate the melted pool: lasers systems, LED diodes and laser diodes. The laser systems like Nd-Yag, produce sufficient power to illuminate the melted pool. However, these systems are expensive and have lower flexibility. LED diodes are low cost products and have a large variety of products commercially available, but, according to studies (ABDULLAH *et al.*, 2007), they can't produce enough light power to illuminate the melted pool. On the other hand, the laser diodes have many characteristics that determinate their utility as an alternative source to the laser itself, having lower cost and enough power when used in groups, as show in Table 1.

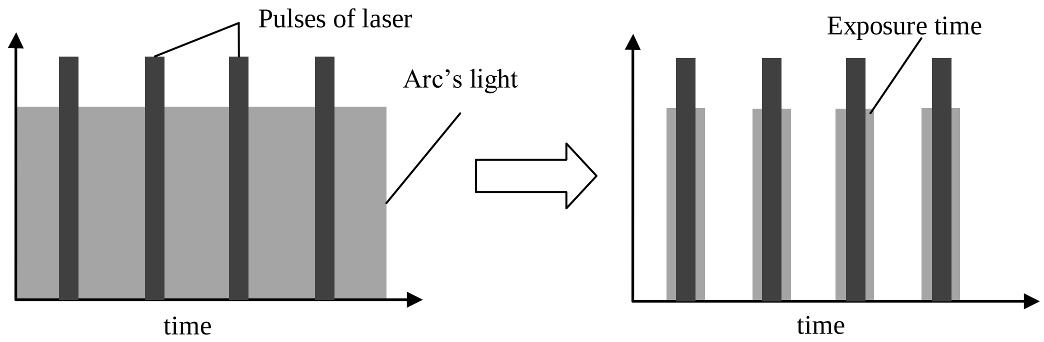

Figure 4. Exposure time adjusting to minimize the power applied to the laser.

Table 1. Characteristics of LED diodes and Laser diodes (ABDULLAH *et al.*, 2007).

Characteristic	LED Diode	Laser Diode
Current	50 a 100 mA	5 a 40 A
Power	Less than 1 W	50 W a 250 W
Beam divergence	More than 40º	10º a 25º
Available Wavelength	0,66 a 1,65 µm	0,78 a 1,65 µm
Spectrum Width	Broad (40-190 nm FWHW)	Narrow (7-10 nm FWHM)
Cost	Less than £2	£15 a £400
Pulse Width	Bigger than 100 µs	Less than 100 ns

Recent works (VILARINHO *et al.*, 2009; VILARINHO *et al.*, 2010) show the applicability of using vision systems for welding process with high power laser diodes in the near infrared. The light intensity emitted by arc welding in infrared wavelengths above 850 nm, is low compared to the visible spectrum.

Therefore, a vision system was designed and developed for the illumination and monitoring of welding processes, using high power laser diodes in the near infrared with a specific wavelength at 905 nm (MOTA, 2011). This vision system consists of a set of 19 high-power laser diodes, which when used together with a lens system capable of spreading the spot lighting, a high power circuit and a programmable MCU (microcontroller) is capable of generating light pulses in the near infrared spectrum for synchronization with images acquisition. The vision system itself is capable of controlling the acquisition of images through a trigger output that is connected to the camera directly.

Through the use of electrical resonant circuits theory and *snubbers*, it's possible to build a topology capable of driving the laser diodes with higher energy efficiency than an ordinary circuit switching (MOTA *et al.*, 2010). Putting in a simple way, the drive circuit receives two subsequent pulses in a given frequency (25 frames per second in default mode) and, through a resonant topology, causes the first set of laser diodes (8 of them) to reach a current pulse with duration of 800 ns and, after its end, the second set of laser diodes (11 of them) receive a current pulse with the same duration, as show in Figure 5.

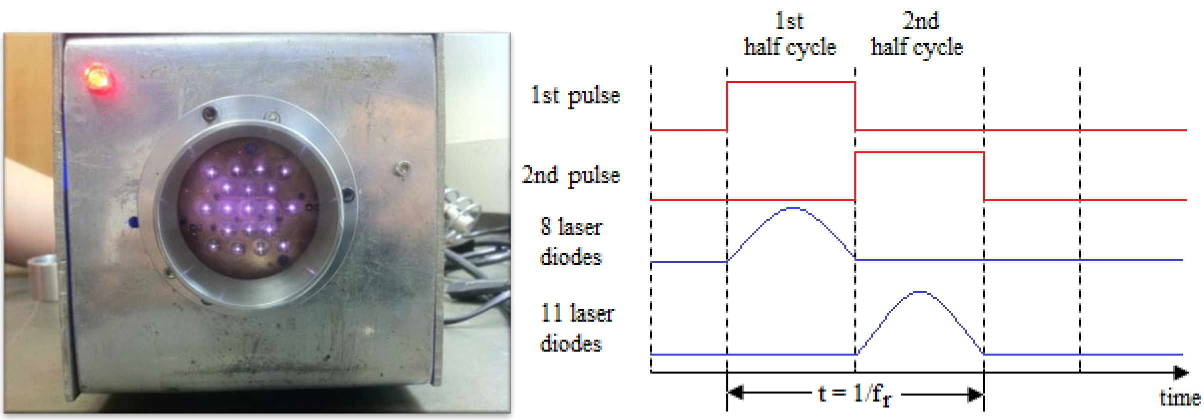

Figure 5. Vision system: set of 19 driven laser diodes (left) and schematic functioning of the circuits (right).

In this contest, is important to know the arc behavior in relation to its light emission, mainly in near infrared. In this way, the proposal of this work was a comparative study between the welding arc's emissions in the near infrared (next to 905 nm) in GTAW and GMAW processes, evaluating the current intensity and shied gas composition influences and the emission of a vision system constructed with high power laser diodes. The results can confirm, or not, if this diode laser system is capable of overlay the arc's light during the image acquisition.

2. EXPERIMENTAL METHODOLOGY

In order to achieve the objectives of this work, a standard methodology of work was elaborated, ranging from the choice of welding parameters of two different processes, including the manufacturing and sensor adjustment of brightness, to the development of a program for obtaining and interpretation of the spectrum of arc welding. The standardization of all steps involved in this experiment allowed the comparison and discussion of results.

A portable spectrometer was used, as a light sensor, for obtaining the spectrum of the arc, USB model with 0.3 nm in resolution of wavelength, SMA905 fiber optic input, CCD detector of 2048 pixels. In addition to its portability and versatility (use of a fiber with higher resolution or larger light gathering), its communication by USB interface facilitates its programming in platforms such as LabView®, making it independent of its original software. The optical fiber used, with diameter of 600 micrometers and a length of 2 meters, captures the radiation and leads to the spectrometer.

To focus the point of light emission, a support with a system of converging and diverging lenses was used, Figure 6, and an optical band pass filter at 905 nm (wavelength of emission of the laser diodes in the vision system used). The necessary distances between the lenses so that the focused arc could be entirely captured and sent to the optical fiber were calculated, as illustrated in Figure 7. Importantly, the diverging lens (focal length of -12 mm) and subsequent convergent lens (focal length 54 mm) are aligned with its focus coincident and fiber optics is in the vicinity of the focal point of the last convergent lens (with a length 54 mm focal length). The distance between the pinhole (Ø = 10 mm) and arc welding (D) determines the size of the object seen by the spectrometer.

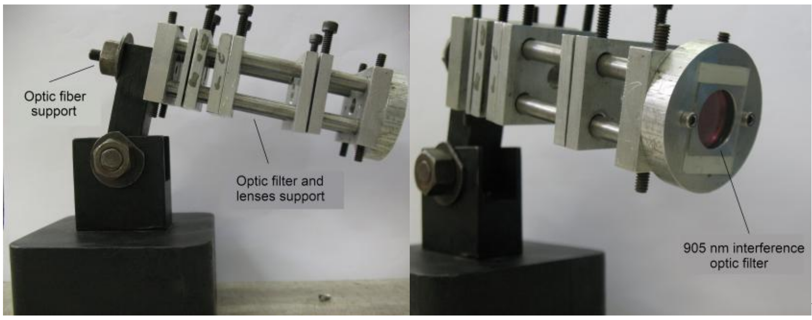

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Figure 6. Support to optic fiber and lenses (left) and detail to the band pass filter (right).

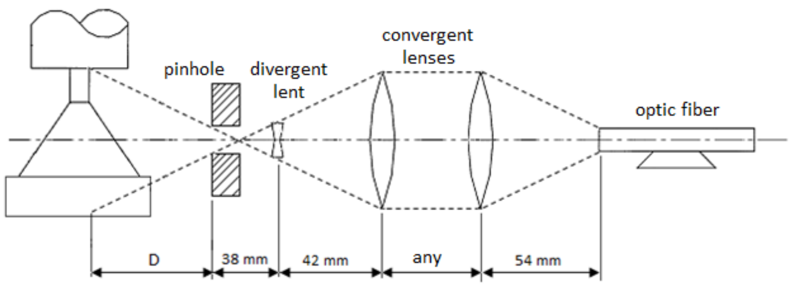

Figure 7. System of lenses used to focusing the arc in the optic fiber.

2.1. For Welding Processes

All tests were performed with the aid of a torch attached to a robotic arm without relative movement to the spectrometer. The optical fiber and the lens supports were positioned so that only a region surrounding the test plate and the welding torch was focused by the lens system, without causing any complete saturation of the sensor, with a straight-line distance between them (D) of 795 mm. The test plates were placed on a table with velocity control and handling of welding carried out towards the support (table moving in the opposite direction) to avoid the torch passing halfway the focused region and the sensor.

The arc radiation and spectrum were acquired through a program in LabView® environment with calibration and libraries provided by the manufacturer of the spectrometer. The user must enter four data to the acquisition during the experiments: the integration time, time that the spectrometer CCD remains open to obtain a signal, the number of averages, number of times that the sensor makes the calculation for a cycle, the time interval between two samples and the number of samples of spectrum to be recorded. This work used the values, for the welding processes, of 40 ms, 5, 10 and 200 ms, respectively. By clicking the "Save" button the program automatically saves LVM files of the vector of light intensities.

The table shown below, Table 2, lists the welding parameters used in the tests for acquiring the spectrum of the welding arc. Two arc processes were used, GTAW and GMAW, and the shield gas and the intensity of current were varied. Still, in each case, the other parameters were set to obtain a spray type metal transfer (there isn't almost any variation in the emission of radiation over time) and an arc length roughly similar among the tests. Finally, all tests were performed using the band pass filter at 905 nm, except for one test each process for the purpose of comparison between the spectra.

Table 2. Used parameters for the experiments in welding processes.

Test	*Process*	*Current (A)*	*Wire Feed Speed (m/min)*	*Travel Speed (cm/min)*	*Shield Gas*	*Gas Flow (l/min)*	*CTWD / DEP⁽¹⁾ (mm)*	*Filter 905 nm*
1	GTAW	150	-	20	Argon	13	4	NO
2	GTAW	150	-	20	Argon	13	4	YES
3	GTAW	200	-	20	Argon	13	4	YES
4	GTAW	250	-	20	Argon	13	4	YES
5	GMAW	200	19(2)	25	Argon	15	22	YES
6	GMAW	250	22(2)	25	Argon	15	18	YES
7	GMAW	275	7,8	25	Argon	15	22	NO
8	GMAW	275	7,8	25	Argon	15	22	YES
9	GMAW	390	12,5	35	Argon	15	22	YES
10	GMAW	275	7,8	25	Ar+8%CO_2	15	22	YES
11	GMAW	390	13,2	35	Ar+8%CO_2	15	22	YES
12	GMAW	275	7,8	25	Ar+5%O_2	15	22	YES
13	GMAW	390	13	35	Ar+5%O_2	15	22	YES

*(1)**Note 1:** CTWD is the distance between the contact tip and work piece in GMAW and DEP is the distance between the electrode and GTAW welding piece. (2)**Note 2:** The tests 5 and 6 were performed with a 0.8 mm wire.*

Follows a list of equipment and consumables used during the tests:
- Welding Power Source Fronius TRANSPLUS Synergic 5000 for GMAW;
- Wire ER70S6 with 0.8 mm diameter for tests 5 and 6;
- Wire ER70S6 with 1.2 mm diameter for other tests in GMAW;
- Welding Power Source IMC MTE Digitec 300 for GTAW process;
- Electrode EWTh-2 with 2.4 mm diameter;
- Shielding gases: Argon, Ar +8% CO2, Ar +5% O2;
- Carbon steel plates with a thickness of ½";
- Support for lenses with adjustable distances;
- Diverging lenses (-12 mm) and convergent (54 mm);
- Optical Filter Comar 905 IH 25;

2.2. For the Vision System

To determine the power of light emitted by set of nineteen laser diodes in the vision system and, qualitatively, its ability to overlay the near infrared emission from welding arc, a study in the near infrared emission of the high power laser diodes was also realized. As the technique of direct illumination configuration was chosen initially as the use of vision system, ie the near infrared illumination is projected onto the joint region and reflected to the camera, to obtain the spectra of laser diodes was performed the study by reflection of the beam light on a sanded steel plate, as illustrated in Figure 8.

To enable the comparison of emission spectra of laser diodes and the emission in the same wavelength of welding processes, the distance between the spectrometer and sanded plate, D = 795 mm, was the same used in tests for welding processes . The carbon steel plate was sanded to provide more reflexivity, maximizing the energy of near infrared light coming from the vision system that reaches the CCD spectrometer.

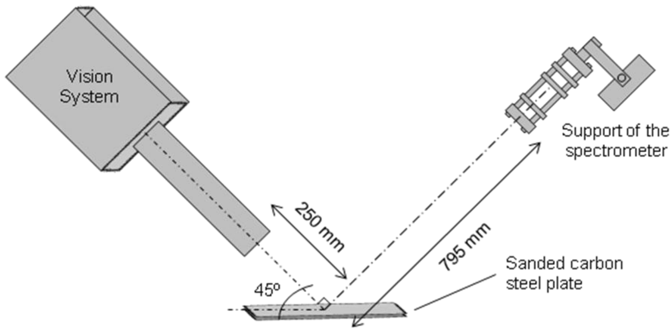

Figure 8. Experimental setup to study the emission NIR of the vision system with laser diodes.

It should be noted that both systems were at an inclination of 45 degrees of the reflection plane of the plate, and the vision system is established in the working distance that was previously established to its use in tests with welding processes (250 mm). Proper alignment between the vision system and the spectrometer is essential to obtaining the emission spectrum and any change in the assembly can significantly alter the results.

To obtain the reflected emission spectrum, the program in LabView® environment presented in the study of emission from welding processes was also used, with the following input data: integration time of 1000 ms, just one average, 1000 ms of time interval between two samples and 10 samples to be recorded.

The vision system was programmed to send 40 driving pulses per frame, at a frequency of 25 Hz. In this way, throughout the opening time, or integration time, of the spectrometer CCD (1 second) are therefore the spectra summed of 1000 pulses with a duration of 1.6 µs (800 ns per half cycle), ie, equivalent to a total of 1.6 ms continuous emission of laser diodes. By way of comparison, the welding processes were purchased from opening time of 40 ms continuous, so 25 times higher than the time captured by the emission spectrometer for the vision system.

2.3. Interpretation of the results

For the interpretation of the light intensities vectors collected during the experiments, a program was developed in MATLAB®. The algorithm runs through all the file folders contained LVM in a given directory, lists the intensity vector versus the calibration vector of wavelengths, calculates the average values for each point in length, print the vectors and their average on a chart and calculates the integration of the average spectrum obtained through an algorithm of trapezoidal numerical integration (CHENEY e KINCAID, 2007). All spectra were subtracted from the DC value corresponding to zero emission, to calculate the integration value and this will be used as a comparison factor between tests of the welding, and between the welding results and the vision systems results.

It should be emphasized that the values obtained, like the light intensity at each point of the spectrum obtained and the integral value calculated are only relative, dependent on numerous factors such as integration time, the number of averages, the position of spectrometer in relation to welding and test conditions. Therefore, the results obtained here are useful only when used to make a comparison with tests performed exactly as described here and it is not possible conclusions outside the scope of this experimental methodology.

4. RESULTS AND DISCUSSION

4.1. Welding Experiments

The values of numerical integration in the wavelengths range of 890 to 930 nm, obtained after the collection and interpretation of the spectra, the average monitored voltages and currents during the processes are listed in Table 3. On the tests of number 1 and 7 the optical band pass filter at 905 nm was taken off for acquiring the full spectrum of the arc and the was performed integration of the entire range of lengths.

A first analysis can be discussed by comparing the number of tests 8 to 13, Figure 9. An increasing current, keeping the same type of shielding gas, result in an increase of the value of integration of the spectrum, ie, an increased emission of near infrared radiation. The increase in current, keeping the same arc length, increases the arc energy delivered by the agitation of present atoms and, therefore, increasing the number of ionized particles. It is known that part of the infrared radiation is due to atomic emission in form of radiation when an electron belonging to an excited atom releases luminous energy to return to its original position and, therefore, the greater is the number of ionized particles, the greater is the light energy emitted by the return of electrons to its natural state. For the same level of current, GMAW welding had higher infrared radiation when compared to the GTAW process.

Table 3. Experimental results obtained for welding processes.

Test	*Process*	*Current (A)*	*Filter 905 nm*	*Current Monitored (A)*	*Voltage Monitored (V)*	*Integration*
1	GTAW	150	NO	151	14,7	2,28E+07
2	GTAW	150	YES	151	15,2	4,05E+04
3	GTAW	200	YES	202	16,1	5,22E+04
4	GTAW	250	YES	253	17,8	7,90E+04
5	GMAW	200	YES	202	31,5	7,15E+04
6	GMAW	250	YES	250	33,5	9,74E+04
7	GMAW	275	NO	275	29,6	3,50E+07
8	GMAW	275	YES	275	29,6	3,23E+05
9	GMAW	390	YES	393	33,5	5,65E+05
10	GMAW	275	YES	267	26,6	2,39E+05
11	GMAW	390	YES	394	31,7	4,43E+05
12	GMAW	275	YES	268	24	1,71E+05
13	GMAW	390	YES	390	28,7	2,84E+05

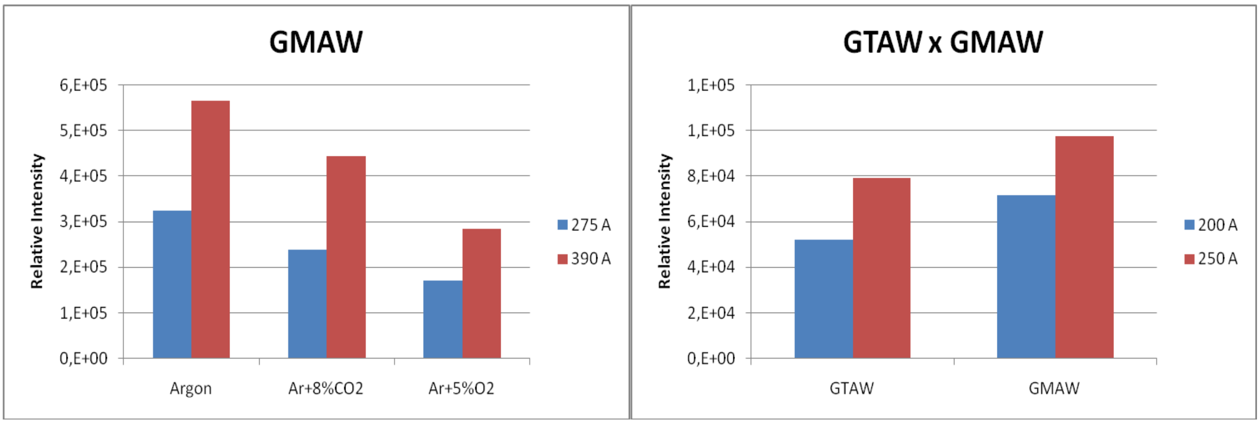

Figure 9. Comparison of tests 8 to 13 (left) and between GTAW and GMAW (right).

Another interesting analysis of withdrawal of these same tests (8-13) is the influence of shielding gas on the infrared emission. We can observe that for any current, the numerical integration presented the higher values with argon protection, intermediate values with addition of dioxide carbon and, finally, lower values with addition of oxygen to argon. By comparing the average spectra obtained, Figure 10, it's possible to note the differences between the spectra of shielding gas: the argon test showed a peak around 914 nm, with addition of carbon dioxide showed smaller peaks below this value and, finally, the test with the addition of oxygen showed a smaller peak around the same 914 nm.

It is known that the spectrum acquired in the region around the arc is formed by the blackbody thermal radiation - due to the high temperature reached - corresponding to the lower area of the spectra obtained, and the atomic emission spectrum - when an electron belonging to a excited atom releases energy to return to its original position - corresponding to the peaks present. According to the National Institute of Standards and Technology (NIST, 2010), the excited atoms in the different gases used (argon, carbon and oxygen), have emission peaks in the range of wavelengths filtered, as shown in Table 4, and are, therefore, responsible for the peaks in the spectrum acquired.

The higher relative intensity of the radiation emitted by Ar I results in peaks around 914 nm, greater protection for Argon, intermediate for Ar +5% O 2 and, finally, lower for Ar +8% CO2. For the addition of oxygen, there is an addition of radiation emitted by the excited atom O I at the peak existing Ar I and, for the addition of carbon dioxide is observed two distinct peaks near 910 nm. The difference between the values of lengths where the peaks occur may be related to problems in calibration of the spectrometer.

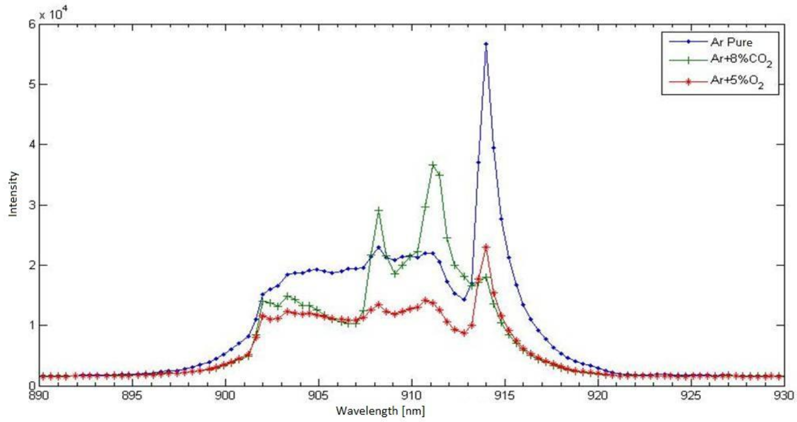

Figure 10. Comparison of the spectra of tests 8, 10 and 12 (275 A).

Table 4. Peaks of emission from excited atoms present in the shielding gas (NIST, 2010).

Element	*Excited Atom*	*Wavelength (nm)*	*Relative Intensity (%)*
Argon	Ar I	912,2967	100,0
Carbon	C I	909,483	45,0
		911,180	30,0
Oxigen	O I	915,601	23,5

These peaks are proportional to the percentage of atoms and therefore the excited atoms present in the argon arc. It is believed that this proportionality has a direct relationship with the electrical conductivity of each component of the composition. According to authors (SCOTTI e PONOMAREV, 2008) the higher the electrical conductivity of the element is in the temperature of the plasma region, the greater the portion of current, in percentage, which passes through them. In the case of Ar +8% CO2, for example, it is expected that a greater percentage than the variation of argon (8%) circulating through the ionized atoms of CO2.

According to the Planck distribution the emission magnitude increases with increasing temperature (INCROPERA *et al.*, 2002). Therefore, besides having a higher relative intensity of ionized elements, test with argon had a higher blackbody radiation, indicating higher temperatures in the region measured by the spectrometer (joint and melted metal).

4.2. Vision System versus Welding

The average spectrum obtained by emission of reflected laser diodes and its comparison to the spectra obtained in welding processes are shown in Figure 11.

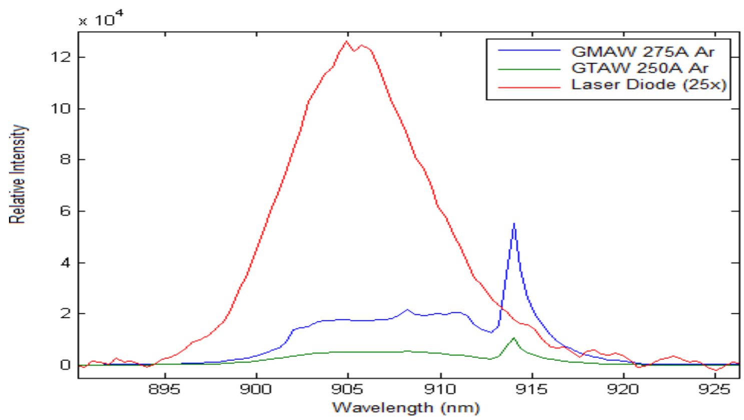

Figure 11. Comparison of the spectra of welding processes and the vision system.

The corrected profile of the spectrum emitted by laser diodes - multiply the profile found for 25 to simulate a continuous 40 ms light - it is superior to the spectra of welding processes with shielding gas of pure argon (higher emission spectrum allowed by band-pass filter) and with currents above 250 A.

In an extreme condition of over switching, it's possible to drive the diode laser power about 18 times per frame with an interval of 4 ms between them in order to increase the sum of light from the vision system to the excessive exposure time camera (100 µs) and without affecting the operation of the resonant topology. Thus, is has effectively 28.8 µs of added time in emission of the set of laser diodes.

Therefore, for overlay the welding arc's light, which emits continuously throughout the exposure time (shutter) of a frame, the light energy emitted by the set of laser diodes must overcome the energy of the arc in at least three times the energy of that. That is, the integrated spectrum of laser diodes should be 3 times larger than the integral of the welding process. For the spectra illustrated in Figure 11, the values of light energy are shown in Figure 12.

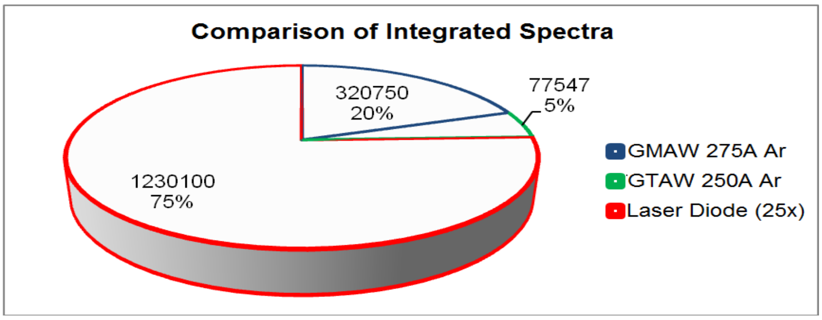

Figure 12. Comparison of light energy (integrated spectra) of welding processes and the vision system.

Through comparing the studies of infrared emission by welding processes and by the vision system, it's possible to conclude that the light that is emitted by the system is strong enough to overlay the arc's light in GTAW process (about 15 times greater) and GMAW (about 3.5 times higher) in the condition of over switching the resonant topology and 100 µs of exposure (shutter) time of per frame acquired.

Finally, a very important point observed during the testing of reflective emission was that the welding masks with auto darkening were sensitive to the near infrared light of the diode lasers. Namely, when the vision system was turned on, the operator using the welding mask has its display darkened even without being directly in front of the vision system. Qualitatively, it's possible to conclude that the light from laser diodes is as much as or stronger than the brightness of the arc for triggering the automatic closure of the welding mask. This observation is also important in enhancing the vision care operator, whose eyes can suffer damage (burns) if it's not used the appropriate PPE.

4. CONCLUSIONS

A study of the near-infrared emission and radiation in arc welding processes was proposed in this work, in particular, GTAW and GMAW, also focusing how its influenced by parameters such as welding current and shielding gas used. A similar study of the near infrared emission of a vision system was made. By using a USB spectrometer, combined with a lens system for focusing the arc and an algorithm for acquiring the spectrum, it was possible to perform a quantitative comparison between the processes and the vision system used.

For both processes, the increase in current intensity resulted in increased infrared emission. The growing voltages over an arc of equal length, increases the blackbody radiation in the near infrared emission and the return of electrons to their natural state by the ionized particles. For a given current intensity, the GMAW process has a higher emission and infrared radiation when compared to the GTAW process, due to the physical nature of the arc.

The acquired spectrum format provides important information about the welding arc. Peaks indicate the composition of shielding gas used and the reached temperature influences the emission of black body. The sum of these two plots characterizes the total emission of the arc. Based on the results obtained, it is possible to obtain quantitatively the light intensity necessary to overlap the arc during image acquisition.

Through comparing the studies of near infrared emission by welding processes and the vision system, it's possible to conclude that the light that is emitted by the vision system with high power laser diodes is strong enough to overlay the arc's light in GTAW process (about 15 times greater) and GMAW (about 3.5 times higher) for the conditions of over switching in the resonant topology and 100 µs of exposure (shutter) time of per frame acquired.

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