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ANALYSIS OF THE OXIDATION LEVEL AND SURFACE CURVATURE ON EMISSIVITY USED IN INFRARED PYROMETRY

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Abstract. *In several manufacturing and quality control sectors present in the industry, non-contact temperature measuring instruments stand out as an important tool. Among these instruments, infrared pyrometers are widely used. Infrared pyrometers are temperature sensors that intercept and measure the thermal radiation emitted by an object with a fast response time. In this context, the emissivity of the object is an important parameter in determining its surface temperature, being influenced by the wavelength, temperature and surface conditions of the object. Therefore, like any other measuring device, temperature values measured with infrared pyrometers are also susceptible to errors. The increase in oxidation on the surface of metals, when submitted to heating cycles as is the case of welding processes, can significantly alter the emissivity of the material, in addition, the surfaces available for measuring the temperature do not always present the desired flatness, therefore, adjusting the emissivity of the material to be measured by the infrared pyrometer becomes a complex task. Therefore, the present work has the objective of assessing the effect of the surface curvature and the level of oxidation on the emissivity of the material. For this purpose, a methodology was used to analyze the emissivity of specimens, which consists on assessing the measured values of temperature with an infrared pyrometer and comparing them with the values obtained with a type K thermocouple, as well as the technique of partial blackening of the surface of specimens. Furthermore, tests were performed on oxidized carbon steel specimens in order to analyze the effects of oxidation on temperature acquisition. The specimens have the geometry of cylindrical bars, with a diameter varying from 2.5 to 8mm, in addition to a flat surface with thickness of 6.5mm. For different cross sections of the specimens, their surface was standardized by chemical pickling and the heating was accomplished by Joule effect, at temperature levels from 100 to 800°C. As a result, it was found that the increase in temperature and, consequently, the increase in surface oxidation, promotes an increase in the emissivity of the specimens. The emissivity stabilization trend was observed until it only represents the emissivity of the oxide layer. Furthermore, it was verified that the effect of the surface curvature has no significant effect on the emissivity values of the material.*

Keywords: *Infrared Pyrometer, Oxidation, Surface Curvature.*

1. INTRODUCTION

In the industrial environment, measurement and quality control are essential to the search for better results regarding the use of resources, performance and safety. In this context, temperature acquisition is included. The temperature of an object can be measured with or without physical contact with the object. For Lacerda (2015), non-contact thermometry makes it possible to measure the temperature of fragile objects, as well as those that are in motion or difficult to access. Furthermore, it is a form of temperature measurement with fast response time.

Instruments that allow non-contact temperature measurement, such as infrared pyrometers, stand out as an important tool and are widely used in the most diverse sectors of the industry. These instruments consist of temperature sensors that intercept and measure the thermal radiation emitted by an object.

A blackbody is defined as an ideal thermal radiator, that is, a body capable of absorbing all the radiation incident on it, at a given wavelength at a given temperature, and emitting as much thermal radiation as possible. However, in a real body, thermal radiation is absorbed, transmitted and reflected, therefore, the emission of thermal radiation is lower than that of a black body. Therefore, the blackbody is used as a reference in determining its thermal emission. In this context, the emissivity of the object is an important parameter in determining its surface temperature. It is determined that the ratio of thermal radiation emitted by an object to the thermal radiation of a black body at the same temperature as emissivity. Therefore, emissivity represents the ability of a real body to emit energy. It is influenced by the wavelength, temperature and surface conditions on which the object is located.

Like any other measuring device, temperature values measured with infrared pyrometers are also susceptible to errors. Materials when subjected to heating cycles such as welding are affected by oxidation. For correct temperature measurements, adjusting the emissivity of the material to be measured by the infrared pyrometer becomes essential. However, increased oxidation on the surface of metals can significantly change the emissivity of the material (Bauer *et al.*, 2013; Somveille, 2018).

In this context, Somveille (2018) states that during the heating of a metal, its emissivity increases with the increase in the thickness of the oxidation, even if the oxide layer partially covers the metal's surface. Interference in the emissivity value of the metal can be observed until the oxide layer becomes too thick and then the emissivity tends to a constant value and represents the contribution of the oxide emissivity alone. Therefore, when measuring the temperature of a metal that is subject to oxidation, the consequent increase in emissivity would induce errors in the measurement with an infrared pyrometer.

The influence of the growth of the oxide layer on the surface of a metal on the emissivity of a material was also studied by Bauer *et al.* (2013). The authors report that the emissivity value changes with increasing oxidation thickness, due to the relationship with the wavelength of the metal's thermal radiation. At the onset of oxidation, emissivities at short wavelengths become higher compared to estimated values of the bright metal at room temperature. And with the increase in the thickness of the oxide layer and interferences in the emissivity values, there is a shift towards longer wavelengths for metals. Therefore, it is necessary to pay attention to the working spectral range of the infrared pyrometer used so that it is possible to carry out correct measurements of the temperature of metals.

The relationship of the oxide layer growth and the emissivity value with the metal's thermal radiation wavelength was also evaluated by Roebuck *et al.* (2005). The authors state that during the initial phases of oxide growth, there is a wide variation in emissivity, caused by radiation interference between the metal surfaces and the growing oxide film. One of the materials studied by the authors was carbon steel, and the temperature of the metal was changed between 700 and 1100°C. In tests for characterization of surface oxidation of metals with two-color pyrometers, the authors used one thermocouple and two two-color pyrometers to acquire temperatures. The authors observed a significant increase in emissivity from 0.4, before oxidation, to about 0.7-0.8 after oxidation, in specimens kept at 900°C for one hour. Furthermore, they concluded that the carbon steel specimens analyzed showed a difference in the indicated temperature between the pyrometer and the thermocouple during heating, since the temperature values obtained by the pyrometer were influenced by the effects of the increase in the oxidation layer, as observed by Figure 1.

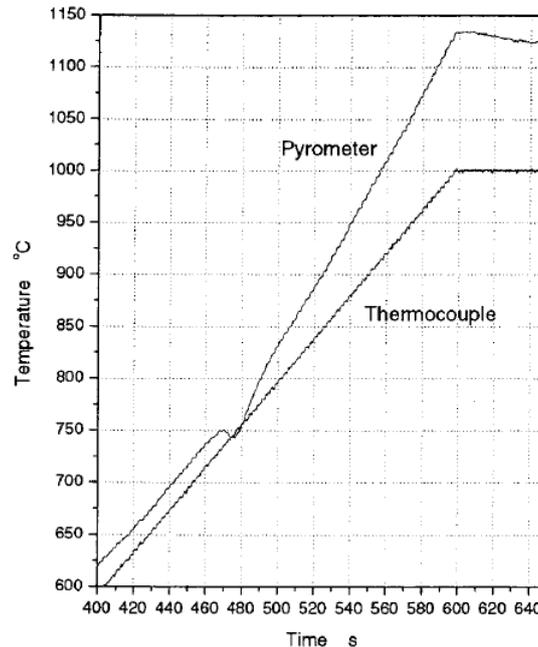


Figure 1. Comparison between temperatures obtained by Roebuck et al. (2005) with pyrometer and thermocouple.

The acquisition of the temperature of an object can also be performed through contact thermometry, in which thermocouples are widely used, temperature sensors composed of two different metallic conductors. For Keltner and Beck (1983), the most significant causes of errors in the use of thermocouples arise from the thermal constriction of the object to which the thermocouple is connected, from imperfection in the contact between the sensor and the surface of the object, in addition to heat loss from the thermocouple for the environment. In addition, Araújo (2008) states that another source of error in the use of thermocouples is related to the type of thermocouple joint, therefore, the contact between the thermocouple wires must be as close as possible to the object for which the temperature is to be measured, as well as a

reduced volume of the joint. Manso (2013) states that temperature variation of the thermal source, electromagnetic interference, mechanical stresses or deformations, non-homogeneities, oxidation and alloying effects of the sensor material are considerable causes of error in temperature measurement with thermocouples.

The studies presented above showed the importance of emissivity and how this parameter is influenced by temperature. Furthermore, emissivity is also influenced by body surface conditions. The most varied surfaces, with different cross-sections and roughness, are present in various sectors of the industry. Therefore, the effect of surface curvature on material emissivity was searched in the literature, but without success.

Since during the execution of the welding operations, the surfaces of the materials reach high temperatures and, therefore, the increase in oxidation is something inherent to the process, and that the surfaces available for taking the temperature do not always have the desired flatness, the This work aims to evaluate the effect of curvature and surface oxidation level on the material's emissivity.

2. MATERIALS AND METHODS

Tests were carried out and the IMPAC IPE 140 Infrared Pyrometer from LumaSense Technologies, model MB 10 was used. The equipment has a temperature range of 30 to 1000 °C and presents the technical specifications, as shown in Table 1.

Table 1. Technical specifications of the IMPAC IPE 140 infrared pyrometer.

Technical specifications	
Spectral range [μm]	3-5
Emissivity measurement range [%]	10-100
Emissivity increments [%]	0.1
Minimum measurement diameter [mm]	2.9
Minimum focal length [mm]	370

Considering the temperature operating range of the IMPAC IPE 140 pyrometer, it was defined that for the tests to be carried out, the specimens would be heated at different temperature levels, from 100 to 800°C. For this, heating by the Joule effect was used through the passage of an electric current in the specimens. Cylindrical carbon steel specimens of 100mm in length and diameters ranging from 2.5 to 8.0mm were used. In addition, a 100mm x 6.5mm x 6.5mm square section test piece was also used.

A device was developed to make it possible to fix the specimens and heat them by the Joule effect. The low cost of its construction and the ability to support specimens of different cross sections during the tests were defined as the design premise of the device. To carry out the tests, a test bench was designed consisting of two welding power sources, connected in parallel, temperature data acquisition system model SAT from *IMC Welding*, infrared pyrometer with magnetic fixation base, pyrometer acquisition system, sources voltage and device for fixing and heating the test specimens developed, as can be seen in Figure 2. In the device for fixing and heating the test specimens, the wood assembly and the porcelain sindal connector act as insulators, as does the terminal electric used for fixing the current cables and the test piece.

Knowing the importance of the material's emissivity, as well as the influence of the object's surface conditions, on the emissivity and, consequently, on the temperature measurement with an infrared pyrometer, a treatment was carried out on the specimens in order to standardize the conditions of its surface. For this purpose, the chemical pickling of the specimens was carried out with a 10% hydrochloric acid solution, in order to remove impurities, oxidation and surface encrustations. This procedure consisted of submitting the specimens, before the performance of each test, in solution for 50 minutes, and then quickly rinsed in running water, dried and subsequently cleaned with 70% alcohol.

Since the specimens have different cross sections, it was necessary to carry out preliminary tests in order to identify the currents needed to heat the specimens to the desired temperature levels. Still, for each of the specimens, it was necessary to identify the temperature stabilization time, since this was influenced by the cross-section of the specimens. Table 2 lists all current values used for heating the specimens used in this work.

As a reference, temperature measurements obtained with a type K thermocouple were used. Before each test, the thermocouple was fixed in the center of the specimens by capacitive discharge. Thermocouple signal acquisition was performed with the SAT temperature acquisition system. As mentioned before, the tests were performed at temperature levels from 100 to 800°C, assuming a 5% upper or lower limit for each temperature plateau for the acquisition of SAT temperature.

One of the techniques used to adjust the emissivity of the specimens consisted of comparing the value obtained with the pyrometer with that obtained with the thermocouple (contact thermometer). Thus, the emissivity adjustment was carried out in the IMPAC IPE 140 pyrometer until the temperature in the device was close, considering a difference of at most 5%, to that indicated in the SAT temperature acquisition system.

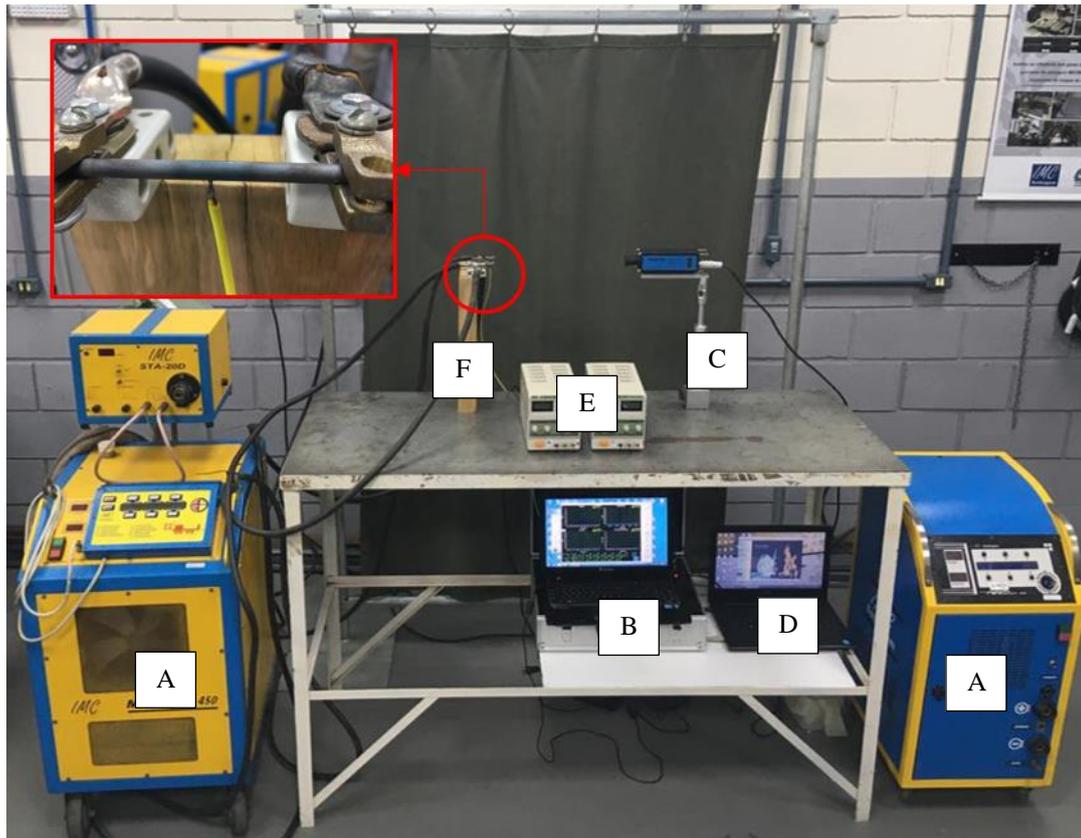


Figure 2. Test bench consisting of (A) welding power sources, (B) SAT temperature data acquisition system, (C) infrared pyrometer with magnetic base, (D) pyrometer acquisition system, (E) voltage sources and (F) device for fixing and heating the specimens.

Another technique used in the present study was the partial darkening of the surface of the specimen. For this purpose, only the square section specimen was used. For greater reliability of the temperature results and as a comparison parameter, the temperature with the type K thermocouple was also obtained in the region without the paint. Only one face of the specimen was painted with black paint and the thermocouple was fixed on the opposite face. Mundial Prime black high temperature spray paint with a matte finish and resistant up to 600°C was used. In these tests, the emissivity of the infrared pyrometer was adjusted to 100%.

In both techniques used, temperature acquisitions were performed twice for each specimen. In addition, the test of specimens already oxidized was carried out to analyze the effects of this oxidation in the acquisition of temperatures. For this analysis, specimens of cylindrical bars with diameters ranging from 3.5 to 6.1 mm were used. In these tests, the emissivities imposed on the pyrometer were the same used during the study of the comparison technique with a contact thermometer to adjust the emissivity of the specimens.

Table 2. Current values used for heating the specimens.

Temperature level [°C]	Current value used to heat the specimen [A]					
	Ø2,5mm	Ø3,5mm	Ø4,7mm	Ø6,1mm	Ø8,0mm	Square section test piece
100°C	38	57	93	120	157	120
200°C	51	76	127	167	225	167
300°C	56	82	140	200	275	200
400°C	60	89	153	220	305	230
500°C	64	93	166	240	335	265
600°C	67	97	174	260	351	280
700°C	69	99	181	266	380	300
800°C	71	106	189	283	400	320

3. RESULTS AND DISCUSSION

Figure 3 shows the average temperature values obtained as a function of the heating current, as well as the adjusted emissivity at each temperature level for each diameter of the specimens studied.

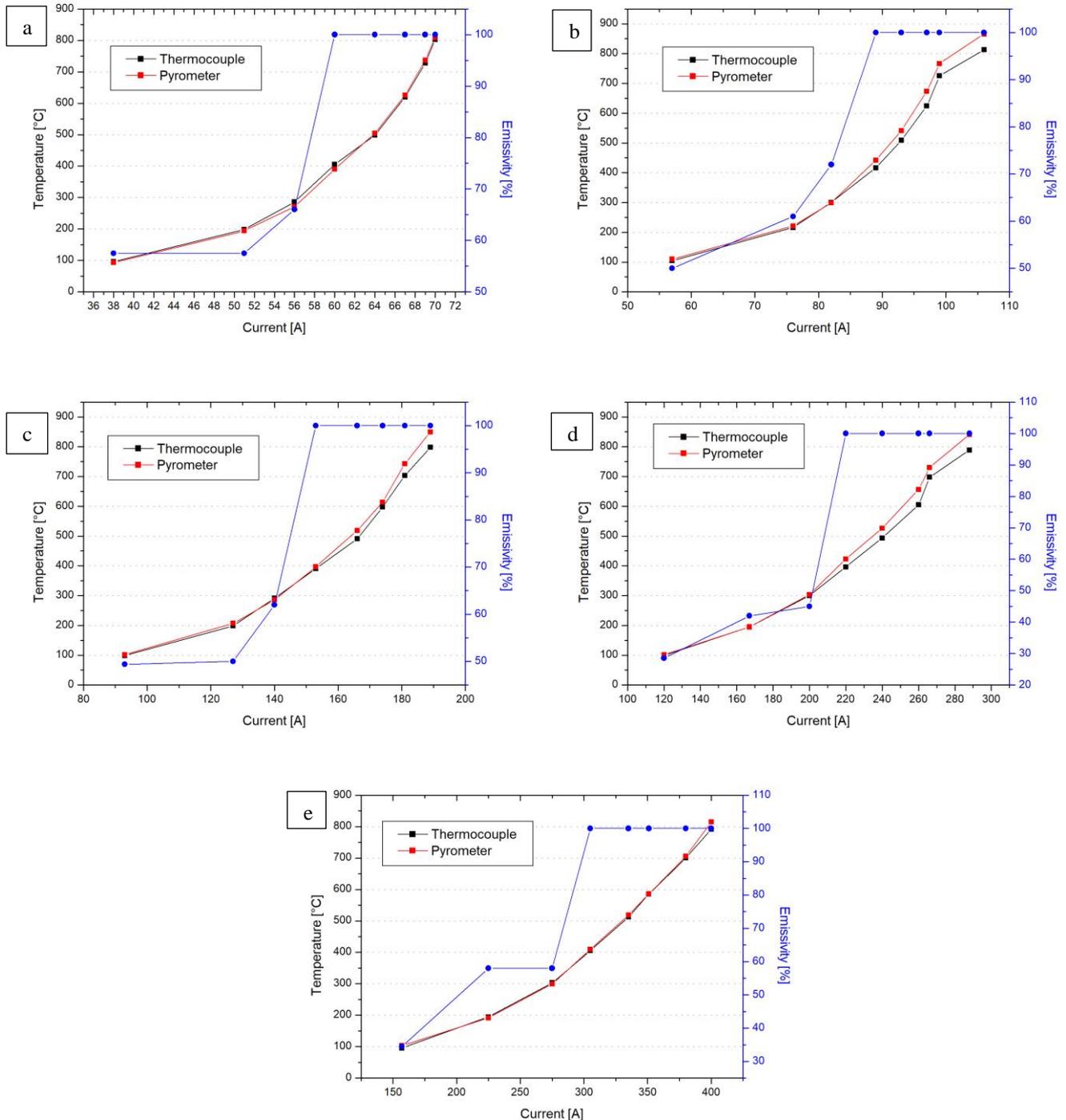


Figure 3. Temperature and emissivity as a function of heating current for specimen diameter: (a) 2.5mm; (b) 3.5mm; (c) 4.7mm; (d) 6.1mm; (e) 8.0mm.

As expected, it was found that there was an increase in emissivity with increasing temperature, as well as an increase in temperature for all diameters of the tested specimens. In addition, when analyzing the emissivity curve, it is verified that for the temperature value above 400°C it was necessary to adjust the emissivity in the pyrometer by 100% in order to ensure the smallest possible differences between the temperatures obtained with the thermocouple and the pyrometer. Naturally, this is attributed to the appearance of oxidation on the surface of the specimens during heating by the Joule

effect during the tests. In this regard, it was noticed in all test specimens tested that the surface oxidation layer appeared in the central region of the specimen, and with the increase in temperature levels, the areas affected by oxidation increased towards its edge. After submitting the specimens to a temperature level of 800°C, the complete oxidation of the surface of all tested specimens was verified. This result is consistent when considering that at the ends of the specimens there is a greater loss of heat by conduction for the electrical connections, thus resulting in a temperature gradient along its length. In Figure 4, it is possible to observe the oxidation level of the 6.1mm diameter specimen before and after the test for temperature acquisition, in which Figure 4(b) is an example of the surface condition after the test for all analyzed specimens.



Figure 4. Specimen of 6.1mm diameter (a) before and (b) after the test for temperature acquisition.

It is possible to notice, from the graphs presented in Figure 3, differences between the average temperature values obtained by the thermocouple and the infrared pyrometer. Therefore, these are described in percentage in Table 3. These differences become more significant after the 400°C temperature level, with the highest temperatures obtained by the pyrometer. Similar results were obtained by Roebuck et al. (2005) (Figure 1), in which they obtained a difference in the indicated temperature between the pyrometer and the thermocouple during the heating of the metal. The authors attribute this to the effects of increasing the oxidation layer on the surface of the material. In fact, during the tests, it was found that the effect of increased oxidation on the surface of the material alters its emissivity value. This fact is evidenced in the emissivity values obtained in Figure 3. This occurs until the emissivity reaches a constant value equal to 100%. Somveille (2018) states that the change in the emissivity value of the metal is observed until the oxide layer becomes very thick and then the emissivity tends to a constant value and represents the contribution of the oxide emissivity only. This resulting, for example, in differences between the temperature values obtained by the thermocouple and the pyrometer, at 800°C, of 6.4%, 6.5% and 6.7% for the diameters of 3.5mm, 4.7mm and 6.1mm, respectively.

Table 3. Measurement errors with infrared pyrometer.

Temperature level [°C]	Differences between temperature values obtained by the thermocouple and the infrared pyrometer [%]				
	Ø2,5mm	Ø3,5mm	Ø4,7mm	Ø6,1mm	Ø8,0mm
100°C	3,4	5,2	3,2	2,8	7,7
200°C	2,3	2,6	4,3	0,2	1,6
300°C	5,3	0,4	1,7	1,2	1,2
400°C	3,7	6,3	1,5	6,8	1,0
500°C	1,1	6,3	5,7	6,7	1,3
600°C	1,0	7,9	2,7	8,4	0,1
700°C	1,3	5,7	5,6	4,6	0,7
800°C	0,7	6,4	6,5	6,7	3,0

According to Bauer *et al.* (2013), during the material's oxidation process, the emissivity at short wavelengths becomes higher, so it is necessary to consider the working spectral range of the infrared pyrometer used so that it is possible to carry out correct measurements of the temperature of the metals. Therefore, a possible solution to reduce measurement

errors with the infrared pyrometer to adjust the emissivity of the specimens would be the use of a pyrometer with a greater spectral range than the pyrometer used in the present work.

A characteristic of the infrared pyrometer used in the present work is its minimum measuring diameter of 2.9mm. In order to determine the possible measurement errors associated with an object smaller than the minimum measuring diameter of the pyrometer, it was decided to use the 2.5mm diameter test piece. As a result, through the graph in Figure 3(a) and Table 3, it is observed that there were no such significant differences when comparing the pyrometer temperatures with the thermocouple measurements. Since for 100°C, an error of 3.4% was obtained between the temperature measured by the pyrometer and that of the thermocouple, the latter being taken as a reference. For the 200°C level, the error was 2.3%, for 300°C of 5.3%, for 400°C of 3.7%, for 500°C of 1.1%, for 600°C of 1.0%, for 700°C of 1.3% and for 800°C of 0.7%.

The specimens of 3.5mm, 4.7mm and 6.1mm diameter already tested were submitted to a new round of tests in order to verify the influence of oxidation from low temperatures. The results are shown in Figure 5. Therefore, from the temperature information obtained, Figure 5 presents the temperature graphs as a function of the heating current, in addition to the emissivity adjusted in the temperature thresholds for each diameter of the studied specimens. The emissivity values are the same as those set above and are illustrated in Figures 3(b), (c) and (d).

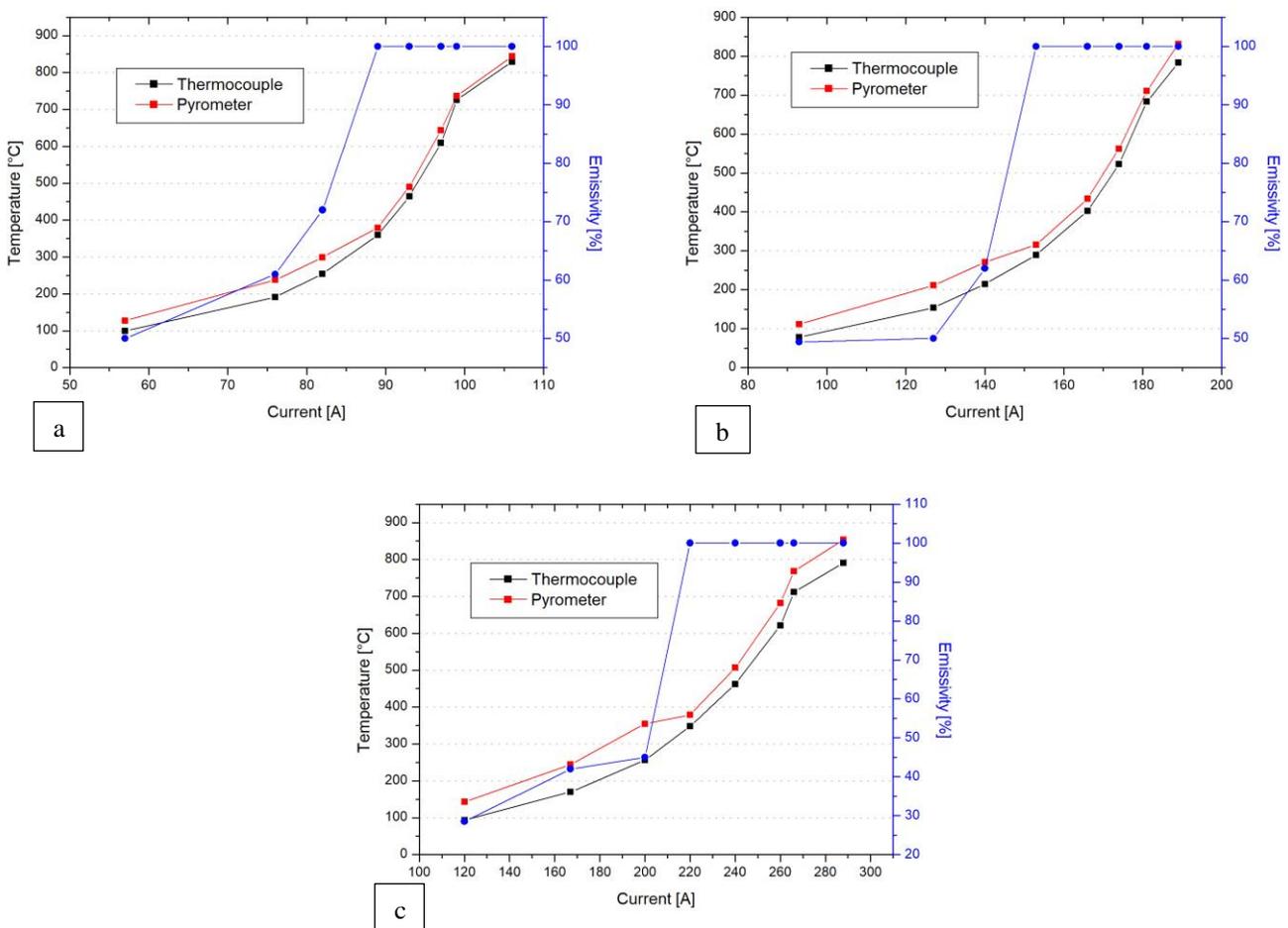


Figure 5. Graph of temperature and emissivity as a function of current for retested specimen of diameter: (a) 3.5mm; (b) 4.7mm; (c) 6.1mm.

When analyzing the temperature values obtained in Figures 3(b), (c) and (d), used as a reference, and those presented in Figure 5, differences are verified both for the temperatures obtained by the type K thermocouple and by the pyrometer in all temperature thresholds. Again, the causes of measurement errors obtained with the pyrometer are related to the presence of oxide films on the surface of the material. The temperature values acquired with the pyrometer were more significant in this second round of tests, since the specimens had already been subjected to long periods of exposure to high temperatures, being, therefore, strongly affected by oxidation. Furthermore, the differences in the values of the temperature measured with the pyrometer at the level of 100°C, between the reference test (Figure 3) and that with the already oxidized specimens (Figure 5), are 16%, 10% and 40%, for the diameters of 3.5mm, 4.7mm and 6.1mm, respectively. When performing the same analysis for the temperature values measured with the thermocouple, the

differences are 5%, 21% and 6% for the same specimens, respectively. These divergences in values were maintained at all temperature levels (Table 4), which reaffirms the influence of oxidation on the measurement of temperature and emissivity of a metallic material by both an infrared pyrometer and a thermocouple. It is supposed that the differences in the temperature values obtained with the thermocouple are due to the presence of the oxidation layer on the surface of the tested objects before the thermocouple fixation by capacitive discharge. This may have significantly interfered with the thermocouple-part coupling. These results are compatible with other studies on temperature acquisition by thermocouples in the literature. In this context, Keltner and Beck (1983) state that imperfection in the contact between the sensor and the surface of the object is one of the most significant causes of errors in measuring with thermocouples. Still on the sources of error in the measurement of thermocouples, Manso (2013) certifies that the non-homogeneity and presence of oxidation on the surface of the object to be measured, as well as the variation in the temperature of the thermal source, cause changes in the measured temperature values.

Table 4. Temperature measurement errors in specimens between reference tests and those already oxidized.

Temperature level [°C]	Differences between temperature values obtained by the specimens in the reference tests and those already oxidized [%]					
	Infrared Pyrometer			Thermocouple		
	Ø3,5mm	Ø4,7mm	Ø6,1mm	Ø3,5mm	Ø4,7mm	Ø6,1mm
100°C	16,0	10,0	40,0	5,0	21,0	6,0
200°C	7,0	2,0	25,0	12,0	22,1	13,0
300°C	0,0	5,0	17,0	15,0	26,0	15,0

The effect of surface curvature on the emissivity of the material was analyzed for the temperature levels of 100°C to 300°C (Figure 6), since at the level of 400°C to 800°C it was necessary to adjust the emissivity in the pyrometer to 100 % in order for the smallest possible differences between the temperatures obtained with the thermocouple and the pyrometer.

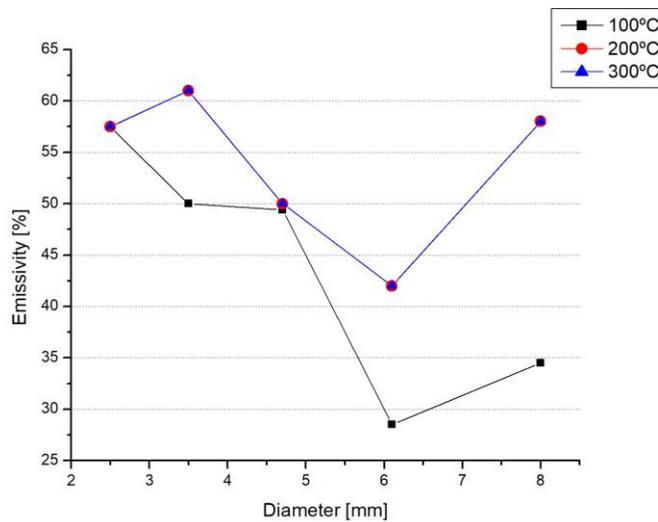


Figure 6. Effect of surface curvature of cylindrical bars on material emissivity.

It appears that there was a discrepancy in the behavior of the emissivity curve for the diameter of 3.5mm, for two temperature levels analyzed. Since for temperatures of 200°C and 300°C, the emissivity value was equal to 61%, while for 100°C the emissivity value was 50%. It is noticed that for the temperature plateau of 100°C, there is a tendency for the emissivity value to fall with the increase in the diameter of the specimen and, from the diameter of 6.1mm, there is a change in the behavior of the curve, increasing the emissivity value. The curves, for the 200°C and 300°C levels, follow the same behavior for its emissivity value. For a better understanding of the effect of the curvature of a surface on the emissivity value of the material, it is suggested that in the future a study be carried out with specimens with diameters above 8.0mm in order to verify the behavior of the emissivity value. In the present work, due to limitations with the work cycle of the welding sources and the time required for temperature stabilization for each diameter of the analyzed specimens, it was not possible to carry out tests for diameters greater than 8.0 mm. Furthermore, in order to mitigate the

effect of oxidation on the emissivity value, it is suggested to carry out the tests in environments with a controlled atmosphere.

Another technique evaluated in the present work consisted of the partial darkening of the surface of the specimen. With the temperature data a graph of temperature as a function of the heating current was prepared. It is noteworthy that at this stage of the tests, the emissivity was maintained at 100% to make it possible to study the technique of partial darkening of the specimen. Figure 7 presents the graph with the temperature values obtained in the tests using, for this purpose, the square section test piece.

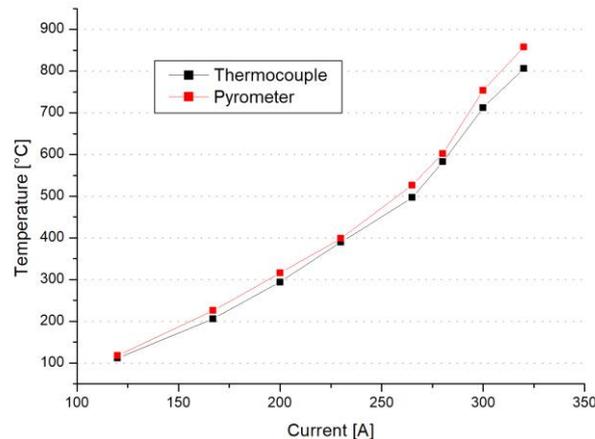


Figure 7. Graph of temperature versus current for square section test piece.

It was verified that from the temperature plateau of 200°C onwards, smoke appeared, while at the level of 400°C, the beginning of the degradation of the paint applied on the surface of the specimen in order to promote the darkening of the object. The differences in temperature values measured by the thermocouple and the pyrometer are 5.1%, 9.6%, 7.6%, 2.2%, 6.1%, 3.3%, 5.9% and 6.5% for 100°C, 200°C, 300°C, 400°C, 500°C, 600°C, 700°C and 800°C, respectively. It is understood that these differences in temperature values are related to the presence of smoke during the tests due to paint degradation. Considering that the infrared pyrometer operation manual used in the work informs that smoke is a source of interference in the measurements performed by the pyrometer. Furthermore, the differences in temperature values should also be influenced with the beginning of the degradation of the paint on the surface of the specimen, making the effect of the oxidation layer more relevant in the acquisition of temperature with the pyrometer.

4. CONCLUSIONS

In view of the results obtained throughout this work, it is possible to achieve that:

- The emissivity of carbon steel is strongly affected by the presence of an oxide layer on its surface.
- When comparing the desired temperature results of the temperature obtained with the pyrometer and the thermocouple, considering the diameters of 2.5mm, 3.5mm, 4.7mm, 6.1mm and 8.0mm, there is a difference of 3, 4%, 5.2%, 3.2%, 2.8% and 7.7%, respectively, at the level of 100°C. For a temperature of 200°C, the differences are 2.3%, 2.6%, 4.3%, 0.2% and 1.6% for the respective diameters of the specimen studied. At 300°C we have errors of 5.3%, 0.4%, 1.7%, 1.2% and 1.2%. For 400°C, the differences are 3.7%, 6.3%, 1.5%, 6.8% and 1.0%. Agreement at a temperature of 500°C, error values equal to 1.1%, 6.3%, 5.7%, 6.7% and 1.3% were noted. For a temperature of 600°C, the differences are 1.0%, 7.9%, 2.7%, 8.4% and 0.1% for the respective diameters of the specimen studied. At 700°C we have errors of 1.3%, 5.7%, 5.6%, 4.6% and 0.7%, respectively. And finally, for 800°C we have error values equal to 0.7%, 6.4%, 6.5%, 6.7% and 3% for the respective specimens. In this way, demonstrating the effect of the oxide layer on the surface of the material on the temperature values received and, consequently, on its emissivity.
- In the specimens that were submitted to a second round of tests and, again, the influence of oxidation, differences were noted in the measurement of temperatures obtained with the pyrometer and thermocouple when comparing these results with the reference ones. At the level of 100°C, the differences with the values obtained by the pyrometer between the reference tests and with the specimens already oxidized are 16%, 10% and 40%, for the diameters of 3.5mm, 4.7mm and 6.1mm, respectively. When performing the same analysis for the temperature values measured with the thermocouple, the differences are 5%, 21% and 6% for the same specimens, respectively. For a temperature of 200°C, the differences for the values obtained with the pyrometer are 7% 2% and 25%, while with the thermocouple they are 12%, 22% and 13%. As for 300°C, the errors in temperature obtained by the pyrometer are 0%, 5% and 17%, and for the

thermocouple, 15%, 26% and 15%. These divergences in values reaffirm the influence of oxidation on the measurement of temperature and emissivity of carbon steel by both an infrared pyrometer and a thermocouple.

- As the temperature increases and, consequently, the surface oxidation of the material, the emissivity increases until it tends to a constant value and represents only the emissivity of the oxide layer.
- There is, for a temperature plateau, the tendency of the emissivity value to fall with the increase in the diameter of the specimen and, from the diameter of 6.1mm, there is a change in the behavior of the curve, increasing the value of the emissivity.

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