DEVELOPMENT OF AN INSTRUMENTED GRIPPER FOR ROBOTIC SHIELDED METAL ARC WELDING

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Abstract. *In the present, the shielded metal arc welding process (SMAW) is typically manual. Therefore, the weld quality and repeatability is limited. The use of semi-mechanized devices solves in part these problems, however restricts the bead geometry, which is determined by the mechanism assembly. A more appropriated solution would be the process robotization. However, the melting rate of the shielded electrode is not constant during the welding. This is due to the fact that the welding current crosses all the electrode length, promoting its heating by Joule effect. This increases the melting rate as the electrode is consumed. Thus, the knowledge of the melting rate behavior is indispensable to the process robotization, since manipulator trajectories and velocities are function of this behavior. Recent researches demonstrate that the determination of the melting rate can be made by monitoring the temperature in the uncoated region of the electrode. The present work describes the development of a gripper with connected thermocouples in the contact points with the electrode. The sensors are connected to a data acquisition board that will provide sufficient information, enabling the development of a data base that will direct the robot controller. The temperature was measured in three different points simultaneously and the influence of the gripper in the temperature measurements and the thermocouples location was determined.*

Keywords*: robotization, SMAW, covered electrode gripper.*

1. Introduction

The shielded metal arc welding process (Welding Handbook, 1991) is quite simple, since the necessary equipment to its execution and the regulation of the parameters itself are unmistakable (ABM, 1979; Juers, 1993). This manual process allows a good control of the welding variables by the welder, providing a large range of microstructure and allowing an extent of applications. However, this process has a huge disadvantage in comparison to others. While other procedures are already robotized, the SMAW is still manual, since the process variables are difficult to be controlled. Despite this fact, welding with covered electrode is still one of the most used processes due to its advantages. Even so, it is interesting to promote the SMAW robotization.

It is common the use of semi-mechanized devices, as the equipment that executes the welding by gravity (Pessoa, 2003). However, this equipment can be used exclusively to execute horizontal welding, in joints of simple geometry.

One of the problems to promote its robotization is that the electrode length is limited and can not be continuous, hence the robot is obligated to change the electrode all the time. But the preeminent problem is the variation of the melting rate during welding. The melting rate of the electrode is a measure of its instantaneous consumption. In the course of the welding, the current flows from the contact point between the electrode holder and the electrode to the arc, causing its heating by the Joule effect (I^2R). Since the resistivity is intensified with temperature growth, the resistance increases and consequently the melting rate increases during welding (Wilson, Claussen and Jackson, 1956). Hence, as the electrode is consumed, the melting rate is increased.

Since the manipulator trajectories and velocities are function of the melting rate behavior, the knowledge of this variable as a function of time is a requisite to the process robotization.

In practice, the melting rate behavior depends on the welding parameters such as welding current, melting temperature, thickness and chemical composition of coating and bare diameter, among others (Ter Berg and Larigaldie, 1952). The relations of those parameters and the melting rate are complex, but recent researches (Felizardo, 2003) demonstrate that the determination of the melting rate can be made by monitoring the temperature in the uncoated region of the electrode.

This work describes the development of a gripper with connected thermocouples in the contact points with the electrode. The sensors are connected to a data acquisition board that will provide information to the robot controller.

In this stage of the research, the electrodes used in the experiments are part of the same batch, since Oliveira (2000) demonstrated that small differences in the chemical composition of the electrodes may change the welding variables.

2. Materials and methods

Previous work (Ter Berg and Larigaldie, 1952; Waszink and Piena, 1985; Coutinho, 1998; Felizardo 2003) has demonstrated that the temperature growth modifies de melting rate.

Felizardo (2003) has shown the development of a computational model that simulates the temperature distribution along the shielded electrode (Figure 1). It was observed that the temperature profile along the electrode is practically constant, and in the region close to the fusion front there is an abrupt temperature increase, until the melting point. Felizardo (2003) demonstrated that the temperature profile along the electrode is influenced by the electrode holder, which removes part of the heat from the electrode. It was noticed that the maximum temperature in the uncoated region of the electrode, for a 40 seconds welding, would be only of an 100 °C. Without the electrode holder, the maximum temperature in the simulated profile would reach 1200 °C.

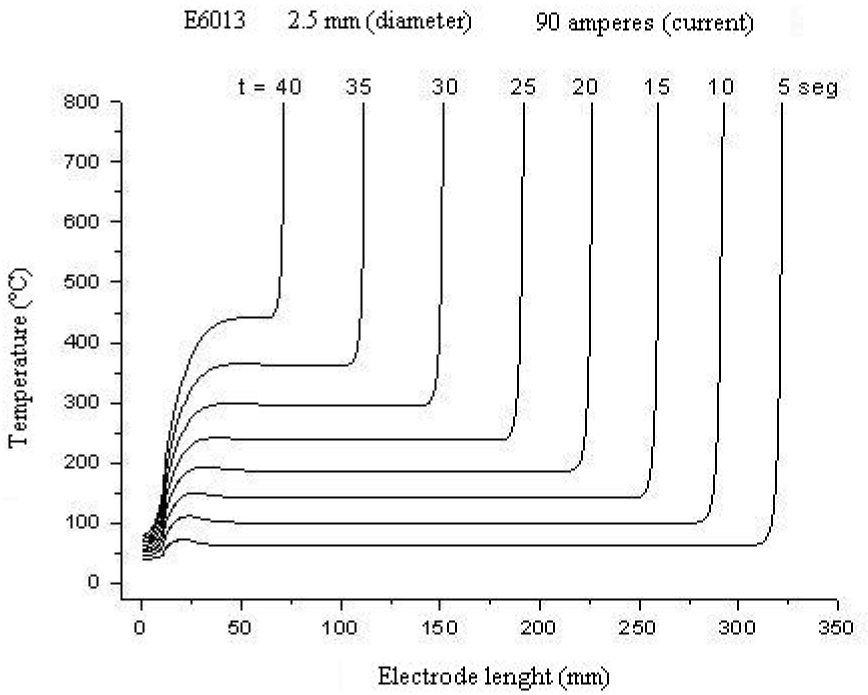

Figure 1. Diagram of temperature versus electrode length for a type E6013 electrode with 2.5 mm diameter. The current used was 90 amperes and the polarity was negative.

The temperature measurement can be made by a large extent of sensor types. However, for this application the most appropriate instrument would be the thermocouple. This sensor type has an adequate range, a satisfactory uncertainty and is not expensive. Since thermocouples are small sensors, they can be easily incorporated to the gripper. As a consequence, the control of the temperature measurement in the robotic process is adequate with this kind of sensor.

The temperature in the coated region of the electrode is difficult to be measured and it is impracticable in a robotic process. The temperature in the uncoated region of the electrode is simple to be measured, however it is expensive, since each electrode used in the robotic process would require an individual sensor. From the temperature profile in the electrode length and the instantaneous temperature in the uncoated region of the electrode, using Felizardo's model it is possible to determinate the instantaneous melting rate.

The temperature growth in the electrode resulting from the Joule effect is a function of resistivity and current. Since resistivity is a function of material type and the current is determined from the electrode type and diameter, there is a distinct model for each consumable type and applicable current. Therefore, the procedure carried through here must be executed for several conditions, providing sufficient information for the development of a database, which will guide the manipulator controller during the welding.

Since the electrode have to be changed just before the total consumption of the coated region, it will be necessary to monitor when it will have to be changed, allowing the complete robotization of the process. This can not be made by monitoring the temperature, as the temperature measurements are made in the uncoated region of the electrode. The temperature measurement will provide information about the melting rate, but not about the remaining portion of the electrode. This situation can be solved by calculating the instantaneous electrode length by integration of the melting rate.

It was decided to use a tri-jaw chuck as an electrode-holder (or gripper), since the chuck has three equidistant jaws with efficient contact area. A sufficient contact area will promote a low contact resistance between the electrode and the jaws and will permit a correct temperature measurement. The chuck holds electrodes of diameters varying from 1.5 mm up to 13 mm.

Two jaws were perforated with a two millimeters diameter drill, to accommodate the thermocouples (Figure 2). One jaw was pierced in the middle point and the remaining one was pierced near the tip of jaw. The objective was to analyze qualitatively if the thermocouples locations in the jaws have a considerable influence on the temperature measurement.

The jaws and the body of the tri-jaw chuck were manufactured with temperate steel. As a consequence, it was necessary to normalize the jaws before perforate them.

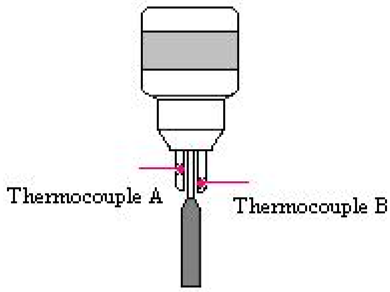

Figure 2. Location of the thermocouples in the jaws.

Type K thermocouples of the same batch were used to monitor the temperature during the welding. To ensure a good contact between the thermocouples wires, they were previously welded using the oxyacetylene flame process. Subsequently, the thermocouple was located in the hole and a weld between the thermocouple and an electrode was carried through a capacitive discharge. An adhesive for high temperatures was used and the weld connecting the electrode and the thermocouple was disarranged, allowing the setting of the thermocouples and a good contact point between it and the electrodes. This process was executed for the both punctures.

3. Experimental procedure

The experiments were executed using the thermocouples confined in the jaw middle puncture (Thermocouple A) and near to the tip (Thermocouple B). Furthermore, each electrode used in the experiments had in the uncoated region a thermocouple (Thermocouple C) welded by a capacitive discharge (Figure 3). The intention was to analyze the influence of the tri-jaw chuck on the temperature measurement, since the electrode heat is dissipated in the gripper. The positioning of the thermocouples in the electrodes was executed in a way that the sensor was aligned to Thermocouple A when the gripper was closed.

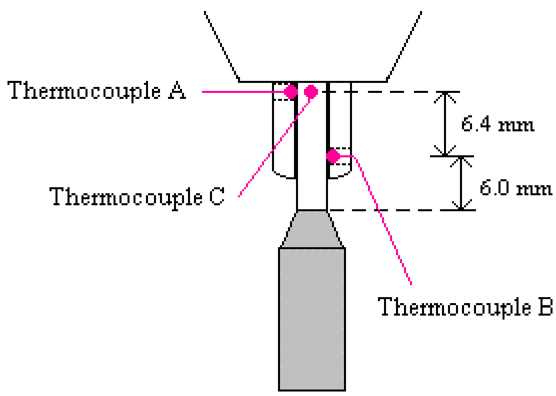

Figure 3. Thermocouple location in the electrode.

The thermocouples were connected to extensions wires and them to a signal transducer system, which produces a linear signal and compensates the cold junction temperature. Moreover, this system prevents the data acquisition board against electric discharges that can occur in the course of the welding process. The signal output was acquired by a data acquisition board and them was received by a computer program at a rate of an 100 samples per second. The data acquisition system (thermocouples, cables, signal transducer, channels connectors, and computer board) were calibrated for the experiments.

In this work, type E6013 electrodes with 4 mm of diameter were used, every one of the same batch. The welds were performed with a current of 150 ampere. This value is in the foreseen range by the manufacturer.

All experiments were carried out in the flat welding position. The power source was a current-controlled type.

Figure 4 shows a picture of a weld carried through with the gripper:

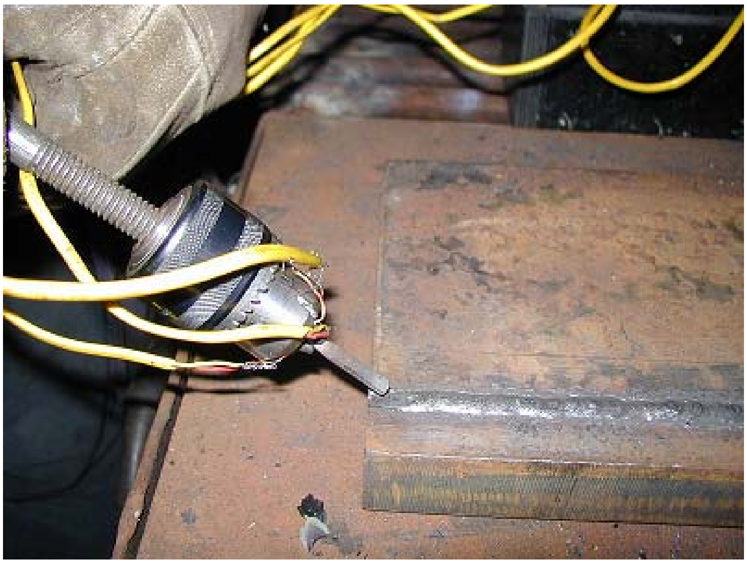

Figure 4. Weld bead carried through with the tri-jaw chuck.

4. Results and Discussion

The temperature in the uncoated region of the electrode was measured as a function of time during 20 weldings carried through by a qualified welder, improving the repeatability of the process. Between the execution of the welds pauses were made to ensure that the gripper temperature would not interfere in the process. A regular behavior was observed (Figure 5). Owing to the simplicity, the plot shows only the fitted curves.

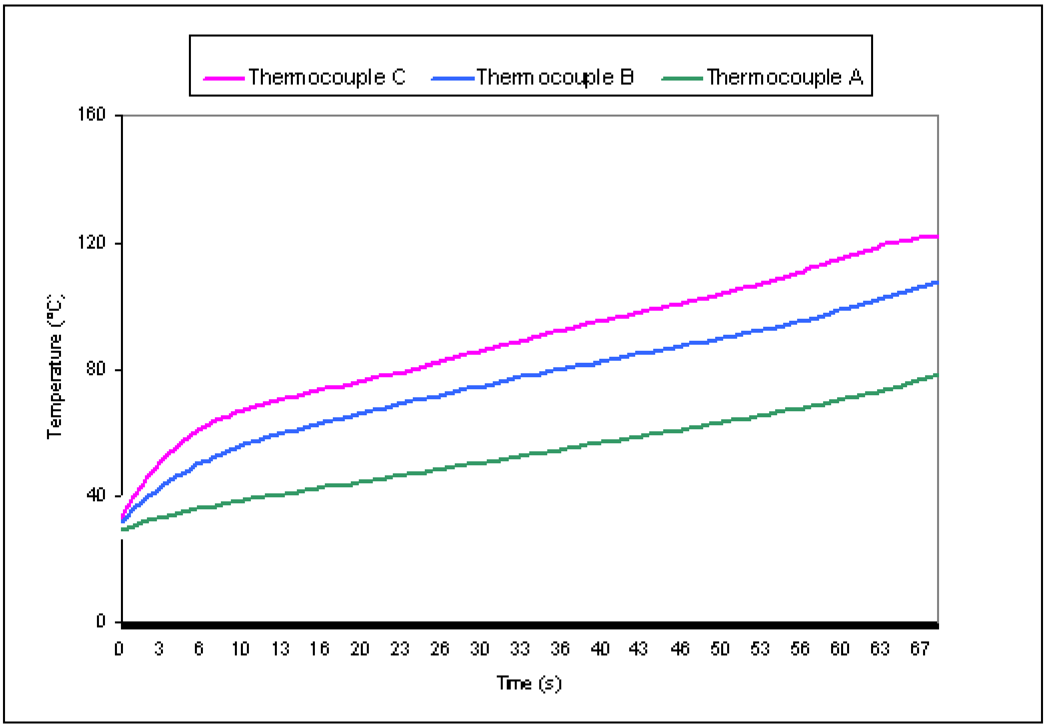

Figure 5. Measured temperatures during the welds.

It can be observed that the temperature in the uncoated region of the electrode (thermocouple C) is always higher then the temperature in the jaws (Thermocouples A and B). This is due to the fact that the temperature measured directly in the electrode is only affected by the heat loss by convection and radiation. In the jaws, the heat loss is a result of convection, radiation and conduction. Nevertheless, it is essential to attempt to the fact that the temperature behavior is practically the same for the three thermocouples locations.

The position of the thermocouple in the jaw affects the measurement of the temperature. In the tip of the jaw (Thermocouple B) the temperature is measured before the dissipation of the heat, in contrast with the temperature measured by Thermocouple A.

It is important to notice that the profile temperature in the electrode consider the use of an electrode holder, but the measurement of the temperature was executed in the electrode. Thus, it is important to know the temperature in the uncoated region of the electrode. Since the temperature behavior is regular, it is possible to obtain experimentally the difference between the temperature measured by the thermocouple in the electrode and the thermocouple in the jaw. This variation added to the temperature measured in the jaw could be used during the robotic welding to determine the electrode temperature and then the instantaneous melting rate. The only constraint is that since the temperature variation is referent to a thermocouple location, it is interesting to stipulate only one position, and if possible a position adjacent to the tip of the jaw, where the temperature difference is the minimum.

5. Conclusion

In this work the implementation of an instrumented gripper for the robotic SMAW process was presented. A tri-jaw chuck was used and the temperature of each electrode was measured with type K thermocouples in three different locations. The temperature measurement during the welds was acquired by a data acquisition board. These measurements will provide sufficient information for the robot controller, allowing the manipulator to execute the correct trajectory and velocity.

The plot of the temperature as function of time confirms the influence of the thermocouple location in the temperature measurement. It was observed that the variation of the temperature is a regular phenomenon, and will provide information to the instantaneous melting rate determination.

6. Acknowledgment

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