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PRELIMINARY CHARACTERIZATION OF THE THERMAL AND ELECTRICAL BEHAVIOR OF STUD WELDING.

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Resumo. *O processo Stud Welding, inicialmente empregado durante a segunda guerra mundial, é amplamente utilizado na indústria atualmente, encontrando aplicabilidade nos setores da construção naval, construção civil, além do setor automotivo. Neste contexto, o objetivo do presente estudo é avaliar de forma preliminar o comportamento térmico e elétrico do processo Stud Welding para fixação de pinos roscados empregados no setor off-shore em estruturas metálicas. As análises foram realizadas por meio da técnica de termografia para medir a temperatura máxima no verso de chapas de ½ polegada de espessura e pinos de 10 e 20 mm de diâmetro, soldados na posição plana, além de medição dos sinais elétricos, como corrente, tensão e potência do processo por um sistema portátil de aquisição de sinais elétricos de soldagem. O estudo verificou a temperatura máxima atingida no verso das peças, a evolução do comportamento térmico e os oscilogramas do processo Stud Welding por arco retraído. O pino M10 apresentou temperatura máxima equivalente a 105°C. Por outro lado, o pino M20 apresentou temperatura máxima equivalente a 206,6°C. Os resultados deste estudo preliminar sugerem que o risco iminente para componentes que permanecem no verso das estruturas metálicas, como pintura ou isolantes é baixo, devido principalmente ao reduzido tempo de exposição ao calor mais elevado no verso das chapas.*

Palavras chave*: Termografia infravermelha. Soldagem off-shore. Arco retraído. Soldagem de pinos.*

Abstract. *The Stud Welding process, initially employed during World War II, is widely used in the current industry, finding application in shipbuilding, civil construction, and automotive sectors. In this context, the objective of this study is to preliminarily evaluate the thermal and electrical behavior of the Stud Welding process for fastening threaded studs used in metallic structures in the off-shore sector. The analyses were carried out using the thermography technique to measure the maximum temperature on the back of ½ inch thick plates and 10 and 20 mm diameter studs, welded in the flat position, in addition to measuring the electrical signals, such as current, voltage and power of the process by a portable welding electrical signal acquisition system. The study verified the maximum temperature reached on the backside of the pieces, the evolution of the thermal behavior and the oscillograms of the Stud Welding process by drawn arc. The welding of the M10 stud showed a maximum temperature equivalent to 106.6°C, with a cooling time of approximately 25 seconds after the beginning of the process. On the other hand, welding the M20 stud resulted in a maximum temperature equivalent of 208.3°C, with cooling of approximately 150 seconds to near room temperature. The results of this preliminary study suggest that the imminent risk to components that remain on the back of metal structures, such as paint or insulation is reduced, due mainly to the higher heat exposure time on the back of the sheets.*

Keywords: *Infrared Thermography. Offshore Welding. Drawn Arc. Stud Welding.*

1. INTRODUCTION

The Stud Welding (SW) process was developed shortly before the Second World War and was employed exclusively by the US Navy. According to the actual manufacturer of the first equipment, the process was invented by Edward Ted Nelson, a US Navy contractor. The need of the time, months before the war, was the proper fixing and installation of wooden decks on submarines, battleships and aircraft carriers [Stanley 2022]. However, stud welding is fundamentally based on welding stud-shaped or similar metal parts onto other metal parts. It should be noted that there are different variations of this welding process, such as capacitive discharge and short cycle, but the present work will focus on the study with the drawn arc version. In stud welding, the operator uses a gun to place the stud against the base metal (A). When triggered, an electric solenoid in the gun raises the stud to a preset height from the base metal (stud retraction) opening an electric arc that melts the base of the stud and the base metal, creating a melt pool (B). The gun then forces the stud into the melt pool and the molten material is held in place with the aid of ceramic ferrule (C) until the weld is formed (D) (Stanley, 2020).

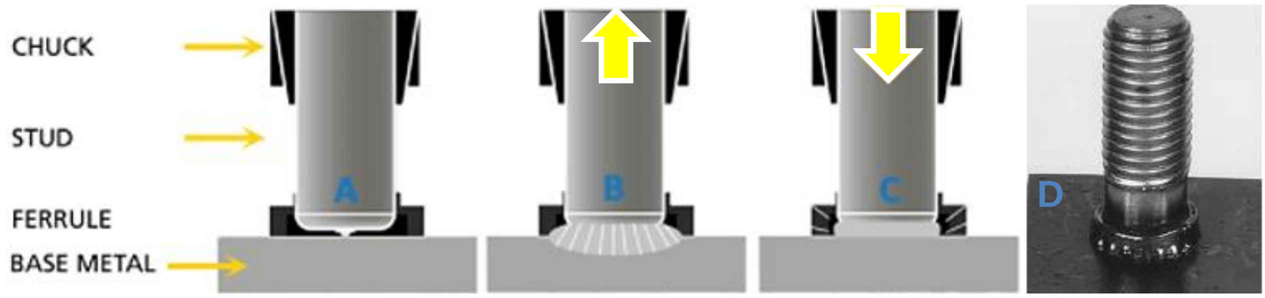

Figure 1 - Principles of the Stud Welding Process with Drawn Arc. From Stanley (2020)

Before the invention, the navy used through bolts to fix the wooden decks on its ships. Today the technology is widely used in industry in various applications such as welding components in the shipbuilding and construction sectors (Chambers, 2001), as well as the automotive sector (Ramasamy, 2002). Thus, SW is characterized as a well-established process for attaching studs to a variety of material thicknesses and coating combinations (Abid Al-Sahib, 2009). Hsu and Mumaw (2011) presented a study of the use of stud welding for various advanced high strength steels (AHSS) as well. According to Chambers (2001), more than 100 million stud welds per year, of all types, are made using the Stud Welding process worldwide, and their quality is essential for the performance of structural members, fittings, and connections. The importance of the standardization of the process and the proper selection of standardized stud and part materials can be accessed in AWS D.1.1 - Structural Welding Code Steel. In addition, the ISO 14555- Welding - Arc Stud Welding of Metallic Materials also presents important factors for inspecting the welding of studs. As per the technical standards, the quality of a stud weld depends not only on strict compliance with the specification of the welding procedure, but also on the correct function of the drive mechanism such as the welding guns and the condition of the accessories and power supply (ISO 14555, 2014).

In some application cases, many structures do not allow access to the opposite side or have finishes on the back, whether they are paintings, polymeric textures or other components such as acoustic, thermal insulation or chemical means like a fuel tank for example. The present study is situated in a context of maintenance activities on offshore platforms, where situations have been identified where the fixation of components can represent a significant reduction in risk, time, and, consequently, costs. One of them is related to the use of load handling devices, such as monorails, rails, and eyebolts, which are fixed by welded studs, simplifying the service and reducing execution time. Another application considered to be the riskiest, is related to works and services that involve welding with restricted heating on the back of a part, either due to the risk of explosion in equipment in operation or due to possible degradation of the internal coating, besides the restricted access to the back. It is important to emphasize that during the welding process of pins, which can normally be from 3 to 25 mm in diameter and welded by fusion to the base metal, high welding currents are employed, between 200 to 2500 A in up to 1s of welding time depending on the diameter (Nishikawa, 2003). In this sense, from the practical point of view of the process, even without the need to access the back of the plate to fix components such as threaded studs, the heat generated by the electric arc during welding can be a limiting factor even during the manufacturing stage as well as in maintenance and repair operations, either by risk of degradation or by risk of explosion of the internal medium. In these cases, infrared thermography, described as an advanced technique to identify and assess thermal behavior, is widely used to perform predictive maintenance on industrial equipment. In addition, thermography is being widely used in welding for various evaluations and processes such as non-destructive testing of welded joints (Meola, 2004) and is already used even for monitoring thermal deviations of non-conventional welding processes such as hybrid Laser-TIG (Huang et al. 2007), Laser-MIG (Matteï, 2009) and resistance spot welding (RSW) (Lee, 2011).

In this context, the present work proposes to study the Stud Welding (SW) process for fastening threaded studs used in the off-shore sector by investigating the thermal behavior, especially maximum temperature reached and cooling time on the backside of steel plates during the welding of studs used in the context. The tests intend to obtain quantitative and qualitative information regarding the heating generated by welding on the backside of the pieces by means of the thermography technique, synchronized with the acquisition of electrical signals from the process.

2. Methodology

The experimental tests were conducted using 10 and 20 mm diameter threaded studs (M10 and M20) that were welded to 800 x 100 x 12.7 mm thick ASTM A131 AH36 steel plate in the flat position. The welding source employed for all tests was a SOYER/BMK-16 equipped with a SOYER/PH-3N stud welding gun. A FLIR/T1030sc thermographic camera was used to obtain the maximum temperature and cooling curves. K-type thermocouples were used prior to the study, for verification and calibration purposes of the emissivity (ε) value, set at 0.90. To record the thermal behavior of the process, the thermographic camera lens was positioned under the part at a distance of 500 mm between the lens and the back of the part. Similarly, the process electrical signals were measured and recorded using a portable welding electrical signal acquisition system (IMC/SAP.v4). This system allows signals such as voltage and current to be obtained for analysis and welding monitoring purposes. To validate the measurements made, all tests were repeated to check the results. The main welding parameters used that are significant to this study are described in Table 1 and come from welding procedure qualification tests.

Table 1. Welding parameters

	M10	M20
Current (A)	790	970
Arc Time (ms)	350	920

3. RESULTS AND DISCUSSION

3.1. Welding the M10 Threaded Stud

Figure 2 illustrates the evolution of the thermal behavior of the weld at three different times before and after welding the stud on the backside of the 12.7mm plate. The temperature data were also plotted as a graph as a function of time (Fig. 3). Figure 2a, illustrates the instant captured by the camera immediately after opening the arc in the SW process. It is possible to verify that, at this moment, the thermographic camera registers a temperature of approximately 50°C, where it is already possible to identify that the piece is being heated by the action of the electric arc. Two other moments of welding are registered to enrich the visual analysis of the thermal behavior of the process. Figure 2b, illustrates the exact moment when the piece reaches the maximum temperature during the procedure, with a temperature of 105°C being registered in the camera. At this instant it is also possible to see the heat distribution along the part. The isothermal lines show the temperature gradient at different levels and connect regions of the same temperature along a surface. During the procedure, the central region of the weld shows the highest temperature isotherm and decreases slightly from the center to the edges.

Furthermore, it is also evident that the region heated by the arc shot is concentrated in a relatively small region considering the stud diameter as reference (10 mm) and dissipates quickly. Figure 2c, illustrates the result of the temperature measurement 60s after the end of the procedure and the temperature gradient on the back of the plate. In this picture, the camera registers a temperature of approximately 41.5°C. As experienced after the test, at this temperature the part can already be handled without the need for burn protection for the human body. To complement the understanding of the thermal cycle in this procedure, the graph in Figure 3, allows following the evolution of the temperature on the back of the plate, which relates the temperature by the welding time during 60s, illustrating the same points of the thermographic filming (a), (b) and (C).

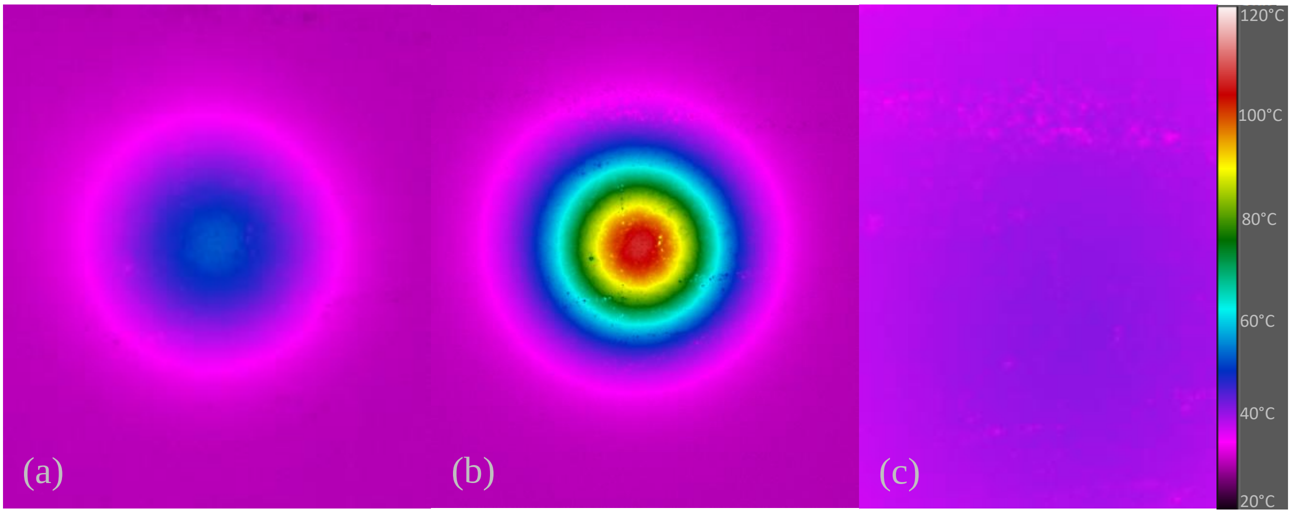

Figure 2 - Images captured by the thermographic camera on the back of the 12.7 mm thick plate during welding of M10 stud. (a) during opening of the arc, (b) during obtaining the maximum temperature (c) instant after 60s

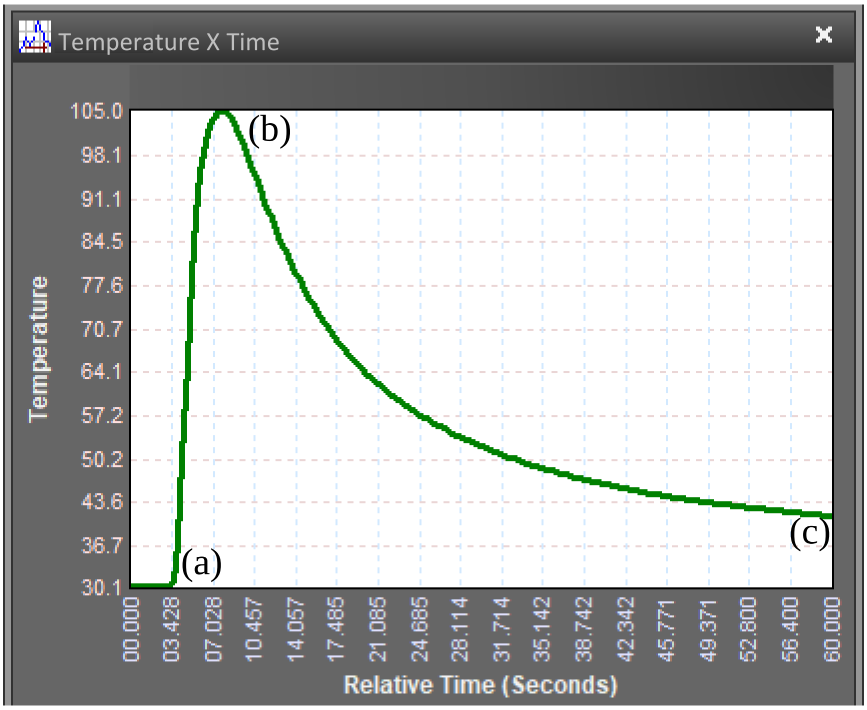

Figure 3 - Stud welding thermal cycle for M10 threaded studs in 12.7 mm thick carbon steel plate (Power 24184 W)

Simultaneously with the thermal filming, the acquisition of the electrical signals of the process was also performed. Figure 4 shows the electrical signals obtained during welding and plotted in the measurement system software in the form of voltage and current oscillograms by time. This type of analysis contributes to a better understanding of the effects involved in the welding process where one can concatenate essential information of the correct operation of the machine and guarantee of adequate values of the parameters involved. In addition, it contributes to the survey and exploration of the parameterization. In this case, the average current measured was 794 A, voltage 30.5 V, and power 24184 W. The measurement results of the electrical signals also allowed the identification of the waveform, in direct current, inherent to this type of welding source, which in turn operates with the gun connected in negative polarity of the machine. The final result of the weld can be seen in Figure 5. Considering only the visual inspection, according to the technical standard, the weld presented complete fusion with the base metal, without the occurrence of any apparent defect and was considered adequate.

Figure 4 - Current and voltage osilograms obtained from monitoring the welding signals during the M10 stud welding procedure

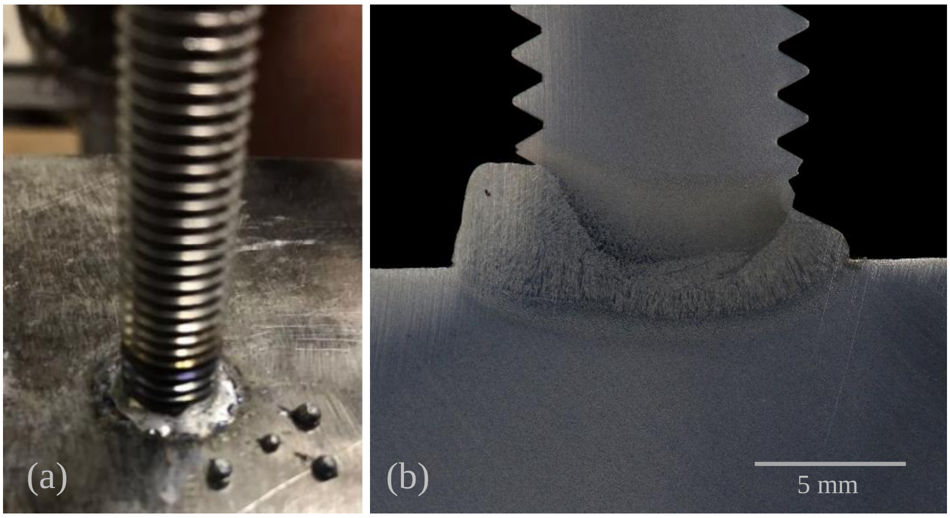

Figure 5 - Final result of the M10 stud welding procedure on 12.7mm plate. (a) stud welded into the workpiece (b) macrography of the weld

3.2. Welding the M20 Threaded Stud

The welding of the M20 stud showed similarity to the procedure performed with the M10. Figure 6 illustrates the evolution of the thermal behavior of the procedure, also in three different moments before, during and after welding the stud on the back of the 12.7 mm plate. In this case, the temperature data were also plotted in the form of a graph as a function of time (Fig. 7). Figure 6a, illustrates the instant captured by the camera immediately after opening the arc. It is possible to verify that, at this moment, the thermographic camera registers a temperature of approximately 70°C, where it is possible to identify that the part is already being heated by the arc's heat transmission. Similarly, to the procedure with M10, Figure 6b shows the instant at which the part reaches maximum temperature during the procedure, with a temperature of 206.6°C being recorded on the camera. It can be seen that, regardless of the diameter of the stud being twice the diameter of the previous stud, the central region of the captured image presents the highest temperature region, which possibly coincides with the central region of the welded stud. Precisely because the stud has a larger diameter, and also uses a higher current level, the area represented by the temperature isotherms in the image of Figure 6b, is also larger than the temperature distribution of Figure 2b.

Figure 6c, illustrates the result of the temperature measurement 60s after the end of the procedure and the temperature gradient on the back of the plate. In this picture, the camera records the temperature of approximately 63°C. Unlike the previous part, 60s after the shot, the part still had a relatively high temperature to be handled without protection. The graph in Figure 7, allows following the evolution of the temperature on the back of the plate welded with M20 studs, which relates the temperature by the welding time during 60s, illustrating the same points of the thermographic shooting (a), (b) and (C). Unlike the M10 studs, the M20 studs showed a high cooling time. The 100 mm wide plate was entirely heated due to the high current density and welding time for welding the M20 stud. In a synchronized manner with the thermal filming, the electrical signals of the welding process of the M20 studs were also obtained. Figure 8 displays the electrical signals obtained during welding and plotted in the measurement system software in the form of voltage and current oscillograms by time. The average process current was 979 A, voltage 35.3 V, and power 34461 W. It is important to note that in the case of welding the larger diameter studs (M20) the power value increased by approximately 1200 W, resulting in a 42% increase in the power required to weld a stud with twice the diameter. The final result of the weld performed can be seen in Figure 8. Considering only the visual inspection, according to the technical standard, the weld presented complete fusion with the base metal, without the occurrence of any apparent defect and was considered adequate. Despite this, even so, the maximum temperatures measured do not influence the degradation of materials that will be exposed on the backside of the metallic parts that will be welded by the Stud Welding process, such as waterproofing, for example. According to a study conducted by Bodstein (2006), pigments specified for high temperature, used in industrial structures, can withstand temperatures of up to 600°C without showing apparent degradation. This fact is an indication that the welding procedure of the two stud models used could be employed in situations with these requirements. However, further studies with different types of pigments, or insulators, directly installed on the parts are suggested to be performed and analyzed after the procedure.

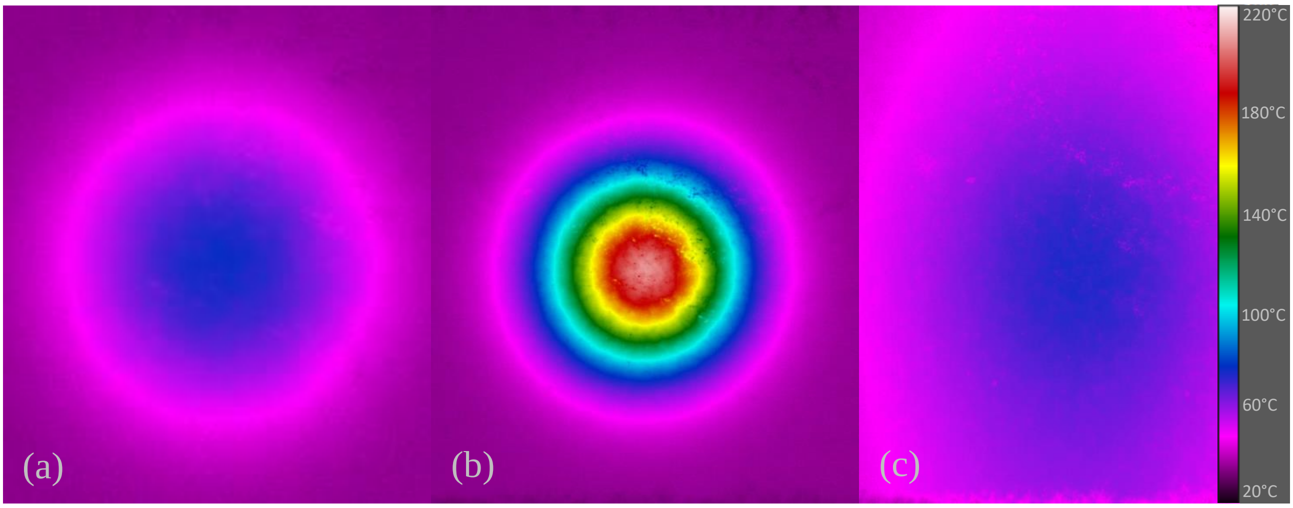

Figure 6 - Images captured by the thermographic camera on the back of the 12.7 mm thick plate during welding of M20 studs. (a) during opening of the arc, (b) during obtaining the maximum temperature (c) instant after 60s

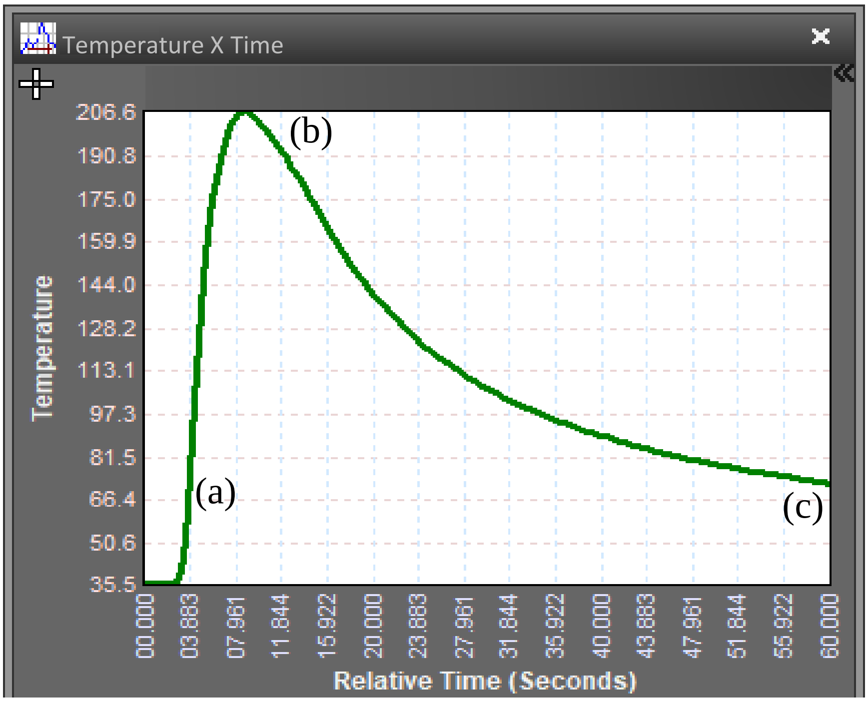

Figure 7 - Stud welding thermal cycle for M20 threaded studs in 12.7 mm thick carbon steel plate (Power 34461 W)

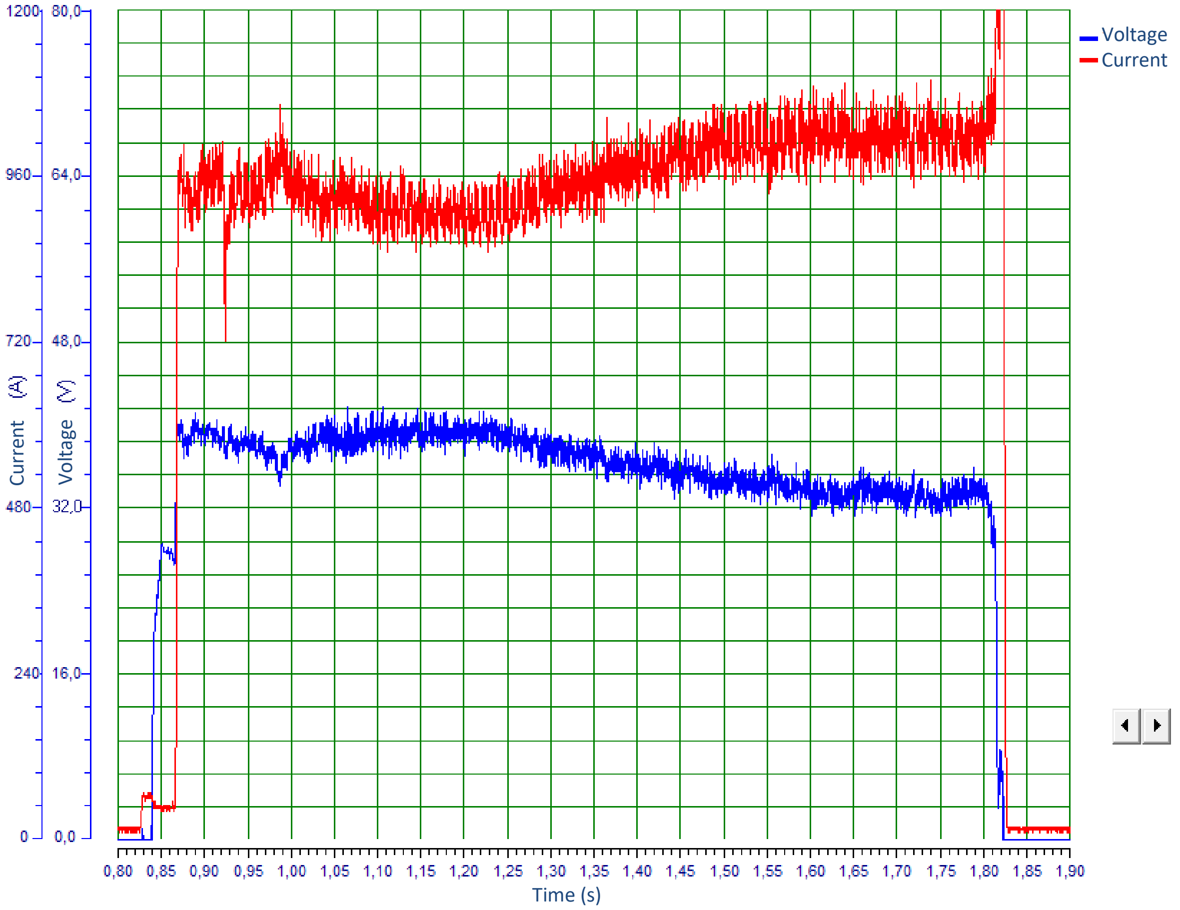

Figure 7 - Current and voltage osilograms obtained from monitoring the welding signals during the M20 stud welding procedure

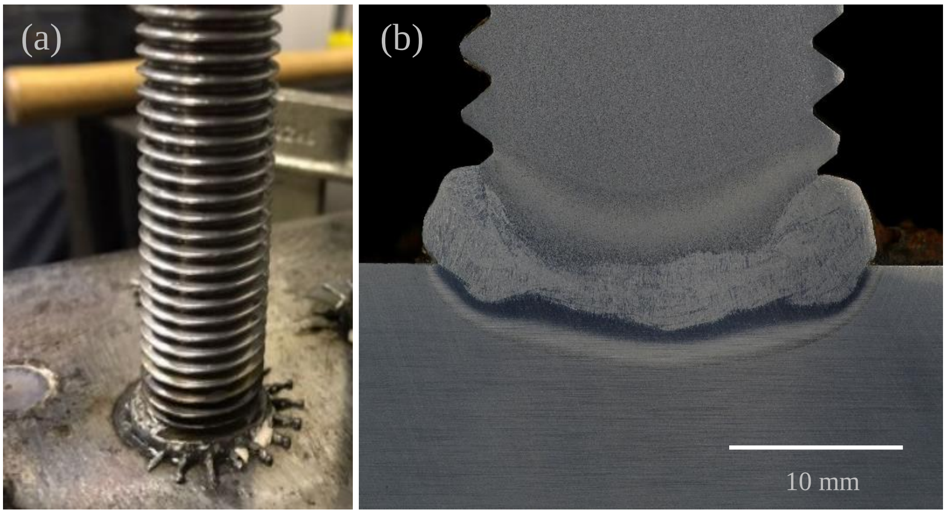

Figure 8 - Final result of the M20 stud welding procedure on 12.7mm plate. (a) stud welded into the workpiece (b) macrography of the weld

4. CONCLUSIONS

The present work preliminarily evaluated the thermal and electrical behavior of the SW process by means of thermography and monitoring of electrical signals. The main results obtained in the work suggest the viability of using this process in welding procedures of industrial structures that use sheets with medium wall thickness. The maximum temperature values measured on the back of the 12.7mm plate were 105°C and 206.6°C for the M10 and M20 studs, respectively. The temperatures obtained after the 60s cooling time, for example, allowed the full handling of the parts by the operator, i.e., without the need for protection such as anti-thermal gloves for the M10 studs and partial handling for the M20 studs. It was found that the temperature of the backside of the plate welded with the M20 could be handled without protection after 130s. This fact shows itself as a strong indication that the textures used in the metallic structures that will be welded with the two stud specifications used in this work will not suffer apparent degradation, but it is emphasized that specific tests are still needed for such application. In general, the temperatures obtained on the back of the plates for both the M20 and the M10, (two studs widely used in the field for fastening) do not seem to present potential risks to the structures fastened on the back of the plate, since the cooling time proved to be relatively high at a non-high temperature. In addition, the procedure time is very short compared to other conventional arc welding processes, which offers an advantage and greater flexibility of use for the Stud Welding process.

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5. RESPONSIBILITY FOR INFORMATION

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