Flash electron beam welding of stainless steels 1.4510 and 1.4511

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The electron beam technology allows a rapid scanning along a defined trajectory. When a properly controlled input of energy is applied, it could be used for the manufacturing of a whole weld joint at once. This technology, called flash welding, represents an alternative to common continuous welding.

The aim of the paper is to describe the development of the procedure for a given weld joint geometry and the effect of the welding parameters on selected properties of the weld joint. The circle welds were manufactured on the samples of materials 1.4510 and 1.4511 by using the electron beam facility K26 from ProBeam. The properties of the welds were examined by the light microscopy and the microhardness testing. Final results were discussed based on analysis of EB elding conditions and weld joint parameters.

Мигновенно електроннолъчево заваряване на неръждаема стомана 1.4510 и 1.4511 (Ю. Матлак, И Шипула, В. Щраус, И. Длухи). *Електроннолъчевата технология позволява бързо сканиране по определена траектория. Когато се приложи един правилно подбран енергиен вход, може да се произведе целия шев едновременно. Тази технология, наречена мигновено заваряване, представя една алтернатива на съвременното непрекъснато заваряване.*

Цел на работата е да опише развитието на процедурите за дадена геометрия на заваръчното съединение и ефекта на заваръчните параметри върху избраните свойства на заваръчния шев. Кръгови шевове бяха получени на образци от стомани 1.4510 и 1.4511, използувайки устройството K26 на ProBeam. Свойствата на шевовете бяха изпитани със светлинен микроскоп и микротвърдностни изпитания. Крайният резултат се дискутират на основата на ЕЛ заваръчните условия и параметрите на електроннолъчевия шев.

Introduction

A. Flash electron beam welding

Electron beam (EB), together with laser, is one of the most modern technologies used for precise welding. Both methods have similar characteristics, nevertheless, there are clear differences determining the proper choice. The EB technology enables a rapid deflection of electron beam and allows a homogenous distribution of the energy supply at an adequate programming of the whole welded area. Moreover, EB allows the increase of a local energetic density within a given trajectory. This is advantageous for welding of dissimilar materials. The welding itself is realised by one short energetic pulse of the electron beam distributed to the whole welded area. Flash welding possesses many disadvantages like the necessity of the whole trajectory to be visible from one point with minimal distance differences, small welds depth etc. On the other hand, there a tiny heat affected zone (HAZ), minimal thermal distortion, no movement during welding process etc. belongs to highest advantages. [1 – 4]

Properties of the weld and weld joint can be directly controlled by process parameters. The total supplied power rate is controlled by a combination of the accelerating voltage „HV“, the electron current „SQ” and the pulse duration „TIME”. This energy is distributed to the whole area with the dimension parameters „SWX“, „SWY“ set together with the scanning frequency „FRQ“ (Fig. 1). Usually, some beam defocusing „Offset“ is set up. That can be realized by a shift of the focal plane either above the quenched surface (positive value) or below the surface (negative value). There is no movement of the treated components during flash EB welding. [4 – 5].

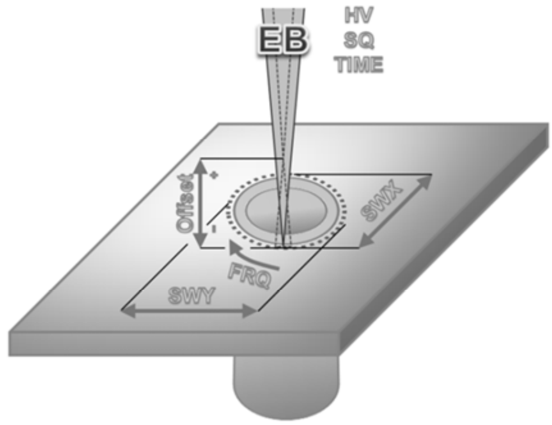

Fig.1. Flash electron beam welding parameters scheme

Experimental material and methods

A. Experimental material

Material 1.4510 (X3CrTi17), high-alloyed ferritic stainless steel with chemical composition of (wt%): C 0.04, Mn 1.00, Si 1.00, Cr 17.2 and Ti 0.7 is used for production of an inner tube. Plates are manufactured from 1.4511 (X3CrNb17) high-alloyed ferritic stainless steel with the chemical composition of (wt%): C 0.04, Mn 0.90, Si 0.95, Cr 17.00 and Nb 0.32. These materials are resistant in a weakly corrosive environment and are used for applications requiring weldability and resistance to intergranular corrosion. Dummy testing samples (Fig. 2) represent the real welding geometry of a manufactured product. Nowadays, joining is realised by a rapid continuous laser welding from the inner side through the wall of a tube. However, from time to time, some part is necessary to reject after the tightness test. Flash electron beam welding seems to be an adequate alternative technology having potential of higher reproducibility a reliability of weld joints [6–8].

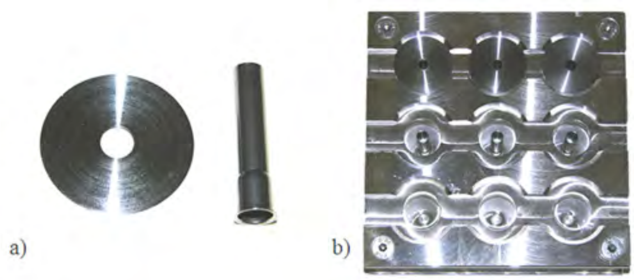

Fig.2. Parts of dummy testing sample (a) and sample mounted in welding fixture (b)

B. Experimental methods

Flash electron beam welding of the dummy testing sample was performed on PROBEAM K26 equipment, adopting the electron beam technology with maximum beam power of 15 kW and the accelerating voltage from 80 to 150 kV. The size of the oscillation figure scanned by EB was set up slightly larger (SWX = 7.1 mm; SWY = 7.1 mm) than the diameter of the welded geometry was (6.8 mm). A constant accelerating voltage HV = 120 kV was used for the experiments and the electron beam current SQ was subsequently optimized. Three pulse times TIME = 20, 40 and 80 ms were chosen in the range of limits of the machine command (from 2 to 100 ms). The speed of the scanning beam was set up with the frequency FRQ = 400 Hz and the beam was defocused (Offset = 25.0 mA).

The tightness of the welded parts was tested by the tailor-built pressure testing stations. In the first step, the parts with a large leakage were excluded, based on the test with the pressured air (MKS – Universal airflow station). The parts having satisfactory tight during the pressurised air test were further tested for their tightness with helium where the leakage of helium was detected by a mass spectrometer. The macroscopic observation of a surface quality was performed by a stereo magnifier.

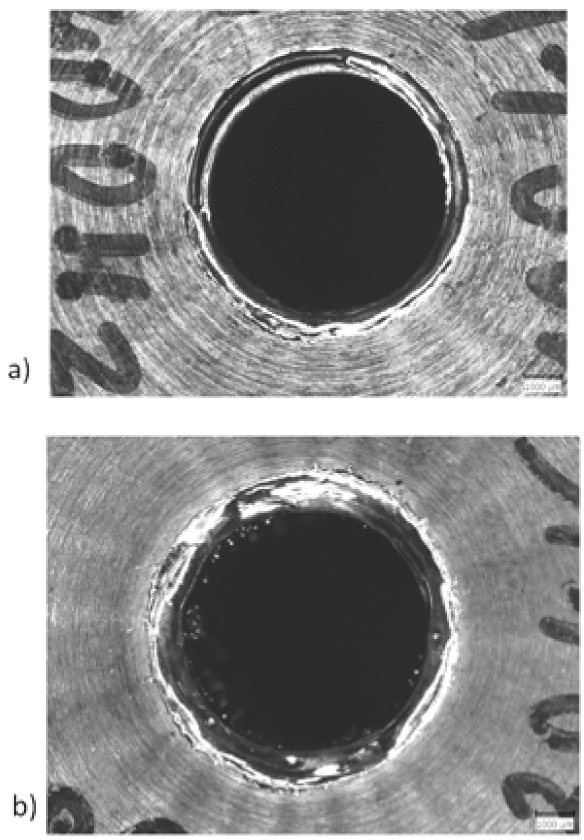

Fig.3. The macroscopic overview of a weld with the insufficient EB current SQ (a) – TIME = 80 ms, SQ = 35 mA) and with the adequate SQ (b) – TIME = 80 ms, SQ = 40 mA)

Fig.4. Example of the microstructure (LOM) of a weld for TIME = 80 ms, SQ = 40 mA (a) or for TIME = 80 ms, SQ = 45 mA (b)

Welds were cut by a metallographic cutter and the metallographic specimens prepared by the standard procedures were analyzed by the light microscopy (Carl Zeiss Axio Observer Z1m). LECO LM 247 AT microhardness tester was also used to analyze changes in the HV hardness.

Results

Circular welds were processed by flash electron beam welding under parameters above described. For each flash duration TIME, more samples were used to determine the optimal range of the electron beam current SQ. From the macroscopic point of view, the EB current SQ was found to be considerably insufficient because some parts were not welded along the whole trajectory (Fig. 3).

With the use of the LOM, the ferritic structure of the tube material (1.4510) and the plate material (1.4511) was observed. Samples were etched in the Villela Bain agent and tinny colour differences among separate grains were revealed due to a different orientation of the grains. The base material of a tube exhibits the average hardness of 230 HV0.2. Its microstructure is uniform and fine-grained with the average grain size of 17 µm. The microstructure of the plate material was typical by wrought coarse-grained morphology with the grain size of 55 µm and 600 µm in the direction of forming. Due to the coarse-grained structure, the average hardness was lower than 170 HV0.2. Welding caused a slight grain coarsening of the grained material, namely in the HAZ (Fig. 4).

No significant hardness changes were observed in the hardness profiles within the melted material through HAZ to the base materials (Fig.5).

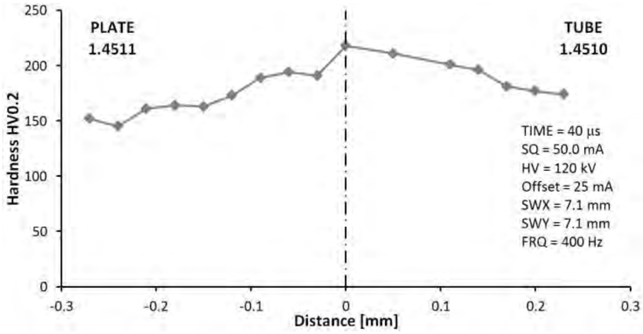

Fig.5. Example of hardness profiles HV0.2 measured in plate base materials through weld area to tube base material.

All samples were tested for their tightness, but most of the samples were excluded as not satisfactory in the first step of the pressure test with the compressed air. The leakage was so high (minimal reached value 4.2 $mm^3 \cdot min^{-1}$) that it was not necessary to perform the test with helium for these samples anymore. The remaining samples were tested for helium tightness and all of them passed. Helium leakage was determined less than $1.2 \cdot 10^{-6}$ $mbar \cdot dm^3 \cdot s^{-1}$ by pressure 1 bar abs. The tightness of a weld is a key parameter for determining compliant parts. The optimum range of welding current SQ therefore was determined by the tightness test. The optimized parameters for the tested welding times are given in Table 1.

Table 1

Optimal parameter SQ for flash electron beam welding of the investigated geometry

TIME [ms]	SQ [mA]	Not tested constant parameters
20	——	HV = 120 kV Offset = 25 mA SWX = 7.1 mm SWY = 7.1 mm FRQ = 400 Hz
40	45.0 – 50.0	
80	40.0 – 45.0	

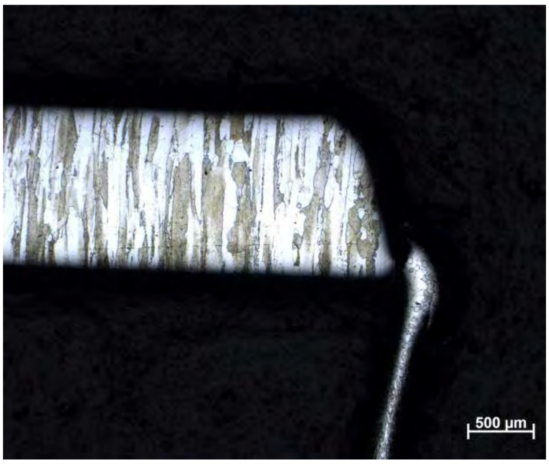

Fig.6. Evaporation and spattering of welded material in the case of a higher welding current SQ (TIME = 80 ms; SQ = 50 mA)

Shortest flash duration TIME = 20 ms has been proven to be unsatisfactory because the samples were not tight enough. Probably, the density of the distributed energy was too high, causing evaporation, leaking and spattering of the base metal. The time for welding was too short to create a homogenous melted pool joining both materials without pores. While applying longer time and higher current SQ, a considerable part of a tube was melted (Fig. 6) and the metal was leaked, evaporated and spattered. Too high energy density led to a high porosity and a low quality of a weld. Welds with the optimal parameters were created over the gap 40 – 100 µm (manufacturing and assembly tolerance) and welds were 130 – 230 µm high.

Conclusions

The main goal of the research applied on provided samples of 1.4510 and 1.45111 steels was to examine the possibility of the flash electron beam welding application. This technology appears to be the alternative to the currently used continuous laser welding with the possible potential of a more stable and reliable processing. The optimal parameters leading to the joining of both materials over the gap 40 – 100 µm and the height of a weld 130 – 230 µm were determined. The ferritic microstructure was changed only slightly under these conditions. There was a slight coarsening of the grains in the heat affected zone of the tube material. There were no substantial changes observed of the microhardness across the weld joint. It was found that too short welding time does not lead to a tight joint as well as too high value of the welding current.

Acknowledgements

The works have been supported by the project NETME centre plus (Lo1202), project of Ministry of Education, Youth and Sports under the "national sustainability programme".

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