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Mechanical and technological analysis of AISI 304 butt joints welded with capacitor discharge process

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ABSTRACT

In the present work, the capacitor discharge welding process (CDW) applied on AISI 304 circular bars was studied. The CDW process is essentially an electrical resistance welding technology, realized through current pulses of high intensity and discharged by large capacitors; the process allows to reduce stress concentration effects at the weld toe, obtaining thin welds and achieve good material integrity.

CDW process characteristics lead to conceive the idea to investigate on the interaction between the weld technological aspects and the related mechanical properties.

In this research activity, 150 cylindrical specimens with bore diameter 6 mm and different igniter dimensions were machined in AISI 304 austenitic stainless steel; a special equipment was designed to clamp specimens and to assure perfect electrical continuity.

The main CDW welding parameters (energy input P, applied forces and igniter dimensions) were studied in order to optimise the welding process. The static and fatigue properties were finally analysed for the welded bars and the results were correlated to process parameters; mechanical tests give good results with respect to base metal if the proper welding parameters are used, despite the fact a brittle character was observed for the welded joints.

1. Introduction

The capacitor discharge welding process essentially consists of high-intensity current flow, discharged onto one small cylindrical igniter, positioned between the parts to be welded; it is generally used for rapid welding of dice and bolts of small dimensions [1]. The igniter, fused into a plasma state by Joule effect, melts narrow layers of base metal at the joining surfaces, to achieve the final welded joints with the forging forces [2,3].

CDW process is a potentially powerful mean to produce butt-welds with accurate jointed profiles and narrow weld beads; the current densities are higher than traditional resistance processes and the discharge times are extremely short, in the order of milliseconds [3,4]. In addition, filler material is not needed for the weld to take place. The pressure applied during the welding phases between the parts completes the weld by a forging mechanism. The CDW process gives cooling rates greater than 10^6 K/s, to be attained with Electron Beam welding or Laser welding, among welding technologies [5,6].

The advantages of both rapidly solidified microstructure and extremely narrow Heat Affected Zones are assured; solidified material without losing meta-stable crystalline structures, with good grain refinement and reduced segregation are also achieved. It is also worth pointing out the welding profile deformations induced by this process are negligible, reducing the subsequent machining and control costs [7–9].

The CDW method provides improved technological advantages and additional positive features of the CDW method are:

- Absence of significant local deformations of the original profile.
- Small HAZ extension with limited defectiveness and porosity.
- Narrow welded layers with little amount of material expulsed from the welded zone [4].

All these factors make this technology attractive in relevant applications, even that the initial investment cost and the delicate operating conditions are the main drawbacks.

The CDW machine is to be sufficiently robust to bear electromagnetic forces and components deformations; an hydraulic system ensures compressive forces to perfectly hold the pieces before and during welding. Large batteries (8320 μF) are connected to discharging pulse transformers for the secondary welding circuit working at 10–15 V.

Critical process characteristics are the contact conditions, the calibrated pressure between the parts, as well as the electrodes gripping system.

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Before applying CDW technology on hollow shafts, turbine blades or other components in valuable materials, cylindrical specimens made with AISI 304 stainless steel were produced to deeply analyse the process characteristics with the weld mechanical properties. Material choice is given by the necessity to study the parameters influencing the process, exempt by metallurgical transformation during welding [10].

Poor specialist literature concerning CDW process dictates the maximum welding area should not exceed 6 mm diameter [4]. This limit doesn't seem to be connected with the maximum available power; in fact with larger surfaces the molten material cools down and stuck weld defects occur with lack of penetration.

150 specimens with bore diameter 6 mm and different igniter dimensions were machined according to the ASTM standards (Fig. 1); a different igniter geometrical ratio h/d and volume was used according to the results achieved in a previous work [11], as displayed in Fig. 2. Preliminary investigation on the process parameters (energy input P, applied force F) and geometry effect were analysed.

Specimens were initially welded with different welding parameters, in order to reduce internal defectiveness and most over to increase the extension of the welded area.

Static and fatigue tests at room temperature were executed to correlate the results to the welding parameters; micrographic analyses were finally performed for the more significant welded joints and the welding mechanism in terms of shape and distribution of the weld bead can be established. The main aim is to provide an exhaustive characterisation of the CDW process for butt-welded joints of cylindrical metallic components for industrial applications.

2. The CDW process applied on cylindrical bars

In CDW Process, the discharged current flows from a capacitor bank through an electrical circuit with impulse transformers (Fig. 3a). An arcing effect is produced at the igniting tip, properly machined onto the cathode. The tip melts and vaporises so that the metal vapours heat and melt the welding surfaces, completing the weld by action of the upsetting force. The CDW welding cycle for the welding tests is realized in four successive steps (Fig. 3b); the two parts are connected with the machine electrodes by means of special gripping tools; then they are placed in contact through the igniter. Successively, a constant pressure is applied and the capacitor stored energy is released with high electrical density to provoke the instantaneous igniter fusion. Finally, the surfaces are molten, metal solidifies and a welding junction occurs with a forging force to build a thin and continuous welded layer between the parts.

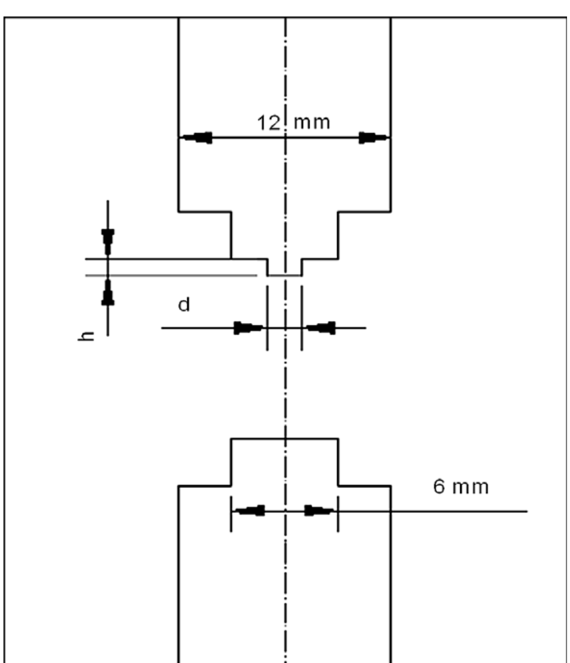

Fig. 1. The igniter geometry.

Fig. 2. CDW specimens with different igniter dimensions.

In order to perform CDW welding on cylindrical bars, a special welding device was purposely designed(Fig. 4). It serves several functions: to clamp the specimens into the machine, to apply calibrated loads and to ensure perfect electrical continuity at the electrodes, avoiding coaxial defects and energetic dispersions; finally, it allows the removal of the welded piece (Fig. 5a).

Four supporting copper plates (of which one is movable) are connected with robust electrical wires to the main machine; a calibrated and adjustable contrast spring system is fixed to the movable plate through special steel sliding guides, parallel to the specimen axis, in order to control the welding depth and the material deformability. Plastic insulators are placed between the parts; two flexible gripping components with external conical surfaces (Fig. 5b) are finally inserted into the plates by a dedicated threaded mechanism, to facilitate specimen placement and ensure electrical conductivity. Most of the components are copper made, the rest is common steel.

The specific equipment was designed to allow the CDW application on cylindrical elongated parts; the tools allow electric conductivity to be increased near the welding zone, providing good contact conditions and geometrical alignment.

Up to now only small surfaces were successfully welded, but no data besides the authors [11,12] concern the mechanical and fatigue behaviour of the welded joints; defects such as porosity and lack of welding uniformity are presents and repeatability is critical, since the process can be unstable due to electro-mechanic interactions.

On the bases of these presuppositions, it was decided to experiment CDW circular specimens, using a great specimens number to select the best welding parameters and enhance the weld characteristics.

No heat treatments were done on the parts prior and after welding, whilst a gas shielding transparent chamber with Argon gas was used to prevent oxidation. The welding trials were executed on annealed/aged AISI 304 steel specimens, separated in 15 classes; different energy input and applied force values were applied (Table 1).

The primary aim of this activity is to isolate the optimal process parameters ranges, in order to produce good mechanical characteristics; the fundamental process characteristics emerged, both regarding the process dynamics and the solidification structure.