

High-voltage electric pulse welding of magnetic cores made of rings of magnetic soft alloy 49K2FA

A V Yudin, E G Grigoryev, S S Bashlykov and V I Goltsev

The laboratory of advanced technologies for creation of new materials, National Research Nuclear University MEPhI, Kashirskoe shosse, 31, Moscow, Russia, 115409

E-mail: Artem.Yudin@icloud.com

Abstract. This research analyses the influence of the parameters of high-voltage electric pulse welding on microstructure of weld seams and mechanical parameters of samples. Special tooling was developed for the process of high-voltage electric pulse welding, allowing welding of ring samples. The method of determination of mechanical characteristics of toroidal samples was developed. An influence is established of parameters of high-voltage electric pulse welding, such as current density and applied pressure, on microstructure of a weld seam and density of a weld joint. The study of magnetic parameters of samples is conducted.

1. Introduction

Various types of welded joints and welding processes are currently used for production of solid devices. Conventional welding methods can not always meet the requirements of the welding joints. Consequently, the modernization is required, as well as development of new methods with wider potential [1]. One of the promising directions of welding is the high-voltage electric pulse welding.

A high-voltage electrical pulse passing through the welded parts causes a significant change in the state of the contacting surfaces. Intense alternating magnetic field and the applied pressure affect the blank details simultaneously with the ohmic heating in the zone of contact of details. This leads to a firm joint (good quality of welding) of details.

Depending on the initial state of the contacting surfaces, current pulse parameters and the applied pressure, both forming of a firm joint (at the optimal parameters values) and explosive destruction of the contact zone are possible [1]. Earlier studies [2] discovered that initial roughness of surfaces of welded parts has a substantial effect on the welding process. Experiments showed that the maximum strength of the T-type welding joints (core - disk) in the analyzed range is obtained at the value of roughness of surface (R_z) 20 μ to 40 μ . This achieves the maximum energy release and the maximum heating of the contact surfaces of the welded parts.

The high-voltage pulse welding method uses special high-voltage process equipment, which allows providing controlled pulse electric power impact on the joined parts. This equipment has been designed and created in the Interdepartmental laboratory of advanced technologies for creation of new materials of National Research Nuclear University MEPhI for implementing advanced electric pulse technologies of development of new materials and products made them, with unique structure and properties unattainable by other methods. A more detailed description of the equipment can be found in articles [3-5].

Modern mechanic engineering widely use various systems of electromagnetic energy conversion. The technical and operational characteristics of such systems are determined by the magnetic



parameters of the permanent magnets and magnetic cores, made of soft magnetic material, in which capacity the 49K2FA precision alloy is used in Russian instrumentation engineering. The improvement of magnetic properties: an increase of saturation induction and the maximum magnetic permeability and a decrease of coercive force significantly affect the quality of the products, which use details made of this precision alloy.

The objective of this paper is to investigate the influence of technological parameters of the high-voltage electric pulse welding (the current pulse amplitude and the applied pressure) on the joint efficiency of the elements in the reference samples, compare the characteristics of magnetic circuits made of thin rings of soft magnetic alloy 49K2FA to the characteristics of the glued magnetic cores.

2. Experiment

A special tooling has been developed to carry out the high-voltage electric pulse welding process. The welding of toroidal samples of the alloy 49K2FA was conducted on the system shown in Figure 1a, with the tooling shown in Figure 1b. The high-voltage electric pulse welding system consists of a high-frequency pulse generator (1) and a executive unit (2). The technological tooling includes a brass rod (1), a central laminate liner (2) and a brass electrode punch (3).

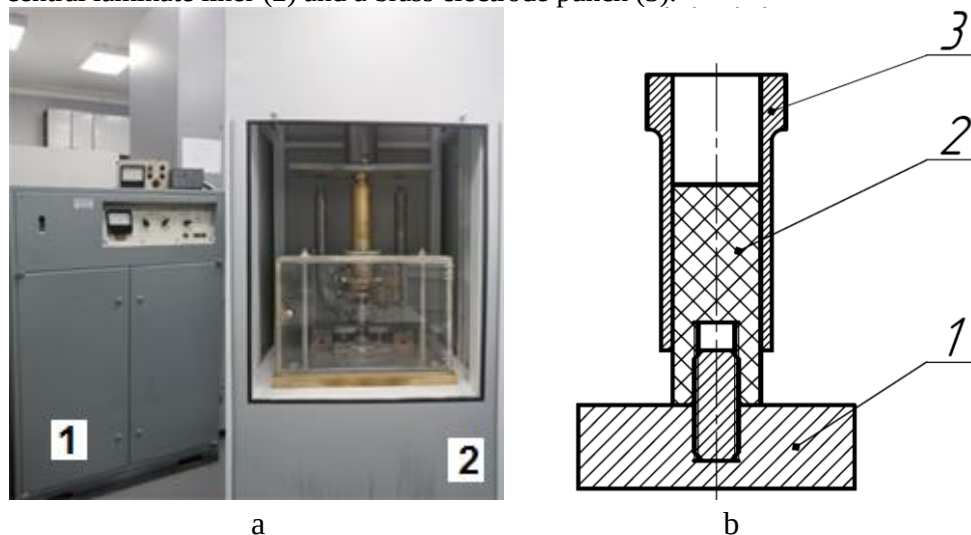


Figure 1. Used equipment (a) and tooling (b).

Toroidal samples of 10 mm height were produced by welding at different technological modes of thin rings with thickness of 0,2 mm cut out of a sheet of 49K2FA precision alloy. In a high-voltage electric pulse welding process the main variables are the value of the ring (disks) compression force and the value of current density through the blank sample, as well as the number of pulses passed through the blank.

Changing the current density was carried out by changing the voltage on the capacitor bank, and changing the compression force was carried out by changing the pressure in the pneumatic system.

The testing is proposed of the ring samples by compression in a ring plane. Compression testing of a ring sample allows simplify the process of loading the sample and its destruction as fully as possible and determining not only the mechanical characteristics of the material, but also the quality and reliability of the joints of elements in cases when the produced sample is made of thin ring elements by the method of high-voltage welding. Essentially this realizes a lateral bending of a beam places on two supports (Fig. 2).

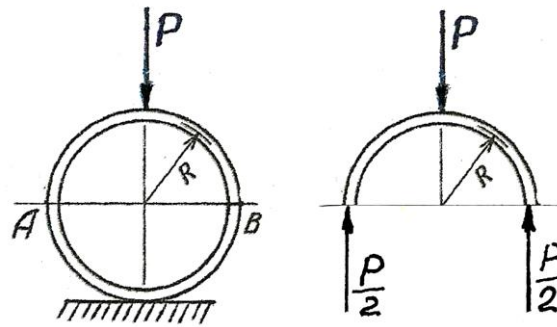


Figure 2. Schematic diagram of a compression test of the reference samples

Considered are three possible types of sample failure under a compressive loading by the scheme presented in Figure 2:

- brittle fracture on the plane of load application
- plastic deformation of the ring up to its flattening (without a fracture or with formation of cracks in the external side surfaces or internal along a plane coinciding with the plane of the loading);
- delamination of the produced ring on separate elements (exposed to weld joint) followed by loss of stability of these thin elements.

If the material of finished product is brittle, than the sample failure occurs along the plane of load application, where the maximum bending moment applies, bending strength is determined by the formula:

$$\sigma_B^u = \frac{3P_k D_{ad}}{2bh^2} \quad (1)$$

where P_k – recorded loading at the sample failure;

D_{cp} – average ring diameter;

b – ring width;

h – ring thickness.

Expected significant variation of the test results is typical for brittle fracture and may require a statistical processing.

If the material is plastic, a gradual flattening of the ring occurs with a possible formation of cracks on the external or on the internal surfaces of the ring. In this case the deformation (the deflection of the sample) at the moment of the crack appearance is determined as well a characteristic of the strength of the material resistance to the initial appearance of plastic deformation – the yield bending strength, determined by the formula:

$$\sigma_T^u = \frac{3P_T D_{ad}}{2bh^2} \quad (2)$$

where P_T – the value of loading, corresponding to load corresponding to the maximum relative deformation of the sample 0,002 (determined by the diagram of loading-deflection of the sample);

D_{ad} – average ring diameter;

b – ring width;

h – ring thickness.

If during the loading of the ring sample delamination and subsequent loss of stability of the individual elements occurs, it does not mean that the strength of material joint in the weld is insufficient. It is important to establish at which stage of loading the delamination occurs. Ensuring the

strength of the sample and the reliability of the element joint is achieved under optimal conditions of high-voltage welding.

3. Experimental results and discussion

A study of microstructure of the sample produced by a single pulse of 2 kV and the pressure of 88.5 MPa, revealed a rather large gaps between the rings. The weld seam is a spot weld of size about 50 μm (see Fig. 3 a). Conducting mechanical test allowed determining that the sample is degrading by delamination of the finished product into the separate elements with a consequent loss of stability of these thin elements. The delamination of rings occurs at the pressure equal 43.2 MPa and the displacement value equal 0.17 mm (Fig. 3 b).

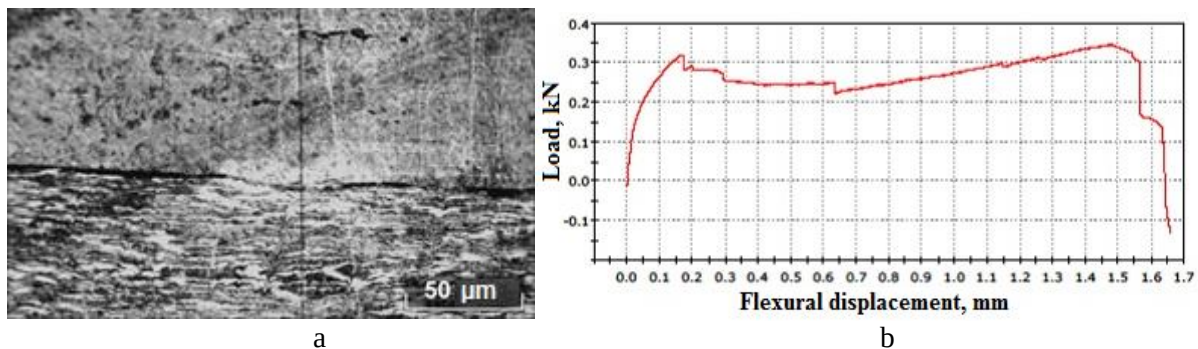


Figure 3. Characteristics of the sample produced by a single pulse of 2.0 kV

The microstructure of the sample welded by a single pulse of 3.5 kV at the pressure equal 88.5 MPa is characterized by smaller gaps between the disks, at the same time the size of the weld seam remained nearly the same (about 50 μm). Mechanical tests showed that the pressure value at the sample failure amounts to 67.5 MPa, and deformation equals 1.1 mm. The character of the destruction also changed with no delamination of the rings and it proceeded by the scheme of plastic deformation of the ring.

Next samples were made by two high-voltage pulses of 3.0 kV at the pressure of 88.5 MPa. At these parameters of the high-voltage electric pulse welding the gaps between the disks are practically nonexistent and the size of the weld seam amounts to 70 μm to 100 μm (Fig.4, a), and the failure pressure increased to 185.5 MPa, with the maximum deformation equal 2.6 mm. The failure also proceeded by the scheme of plastic deformation of the ring, with no sharp declines of load value leading to the delamination of the rings from the sample (Fig.4, b).

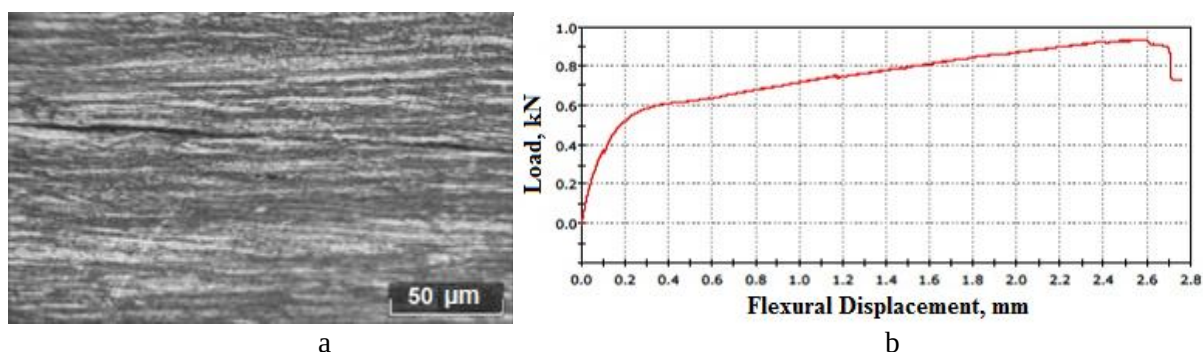


Figure 4. Characteristics of the sample produced by two pulses of 3.0 kV

Next set of samples was produced by passing two high-voltage pulses of with an amplitude of 4.0 kV at the pressure equal 88.5 MPa.

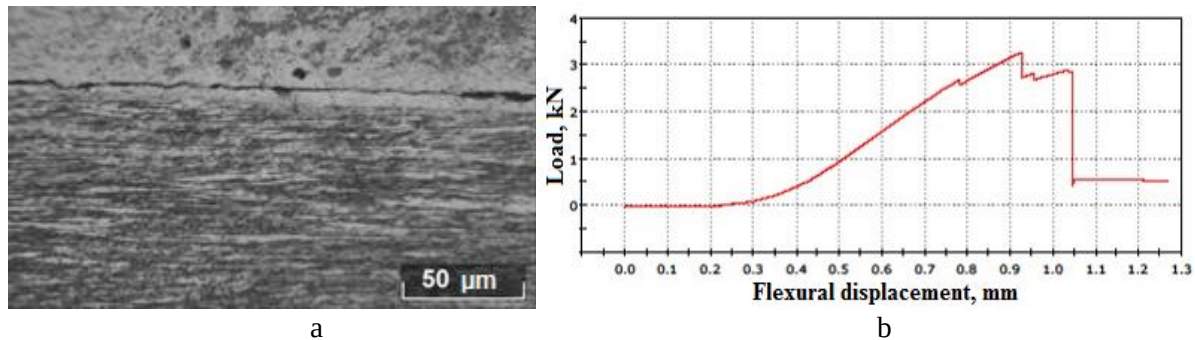


Figure 5. Characteristics of the sample produced by two pulses of 4.0 kV

As is evident from the photograph of the microstructure there are no gaps between the discs and the size of the weld seam amounts to more than 100 μm (Fig. 5 a). Concurrently the ultimate strength amounts to 351 MPa, the deformation equals 0.77 mm, but the character of the failure has changed. In this set of samples the brittle failure is prevalent (Fig. 5 b).

Consequently, the overall analysis of sample loading diagrams and recorded stepwise images of the process leads to the conclusion that the delamination of ring samples starts outside of the elastic initial loading zone and is reflected in the diagram in the form of steps.

The study of magnetic properties of the samples showed that with this method of joining rings into the magnetic core there is no deterioration of the magnetic characteristics of the material. E.g. for the sample produced by two pulses of the amplitude 4.0 kV, the following magnetic characteristics were obtained: $B = 2.26 \text{ T}$, $H_c = 50 \text{ A/m}$, $\mu = 15000 \text{ G/Oe}$.

4. Conclusions

The research proposes a method of strength testing of weld seam quality. Such strength testing allows simplifying the process of loading the ring sample and its failure as fully as possible and determining not only the mechanical characteristics of the material, but also the quality and reliability of the joints of elements. The comparison of the microstructure and strength properties of welded joints showed the following:

- the strength the weld joint depends on the distance between the plates in the sample, the shorter the distance the greater the strength;
- the use of two high-voltage pulses increases the weld zone (weld seams), which also increase the strength of joint;
- the location of weld seams between the plates depends on the roughness of the welded surfaces, which define the contact zone
- An optimal mode of obtaining quality weld seam is suggested: two high-voltage pulses with a voltage value of 4,0 kV.

References

- [1] Grigoryev E G 2011 High voltage electric pulse welding of titanium with stainless steel *International Scientific Journal Machines. Technologies. Materials* **8** 8-11
- [2] Gurevich S M 1990 *Reference book on welding of nonferrous metals* (Kiev, Naukova Dumka)
- [3] Grigoryev E G, Bazanov V N 2008 Electric current pulse welding of titanium VT1-0 with stainless steel 12X18H10T *Moscow State University of Education J.: Natural Sciences* **2** 84-88
- [4] Grigoryev E G, Bazanov V N 2010 Electric current pulse welding of titanium with 18-10 STAINLESS STEEL *Advanced Materials Research* **83-86** 1251
- [5] Grigoryev E G 2011 Welding of titanium with stainless steel by high-voltage electric-current pulse *Proceedings of the 2011 International Conference on Powder Metallurgy and Particulate Materials, "PowderMet 2011"* 642-646