Innovative solutions for ultrasonic joining

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1. Introduction

Ultrasonic welding is increasingly used in various sectors of activity. One of the main reasons that led to the extension of the applicability of ultrasonic welding to the disadvantage of classical joining processes was the fact that the joining of the materials is done without added material. Numerous research items focused on the development of new materials and innovative technical solutions for ultrasonic tools [1], [2], [3], [4], [5], [6], [7] , [9], [10].

Figure 1 shows the principle scheme for ultrasonic welding of metallic materials.

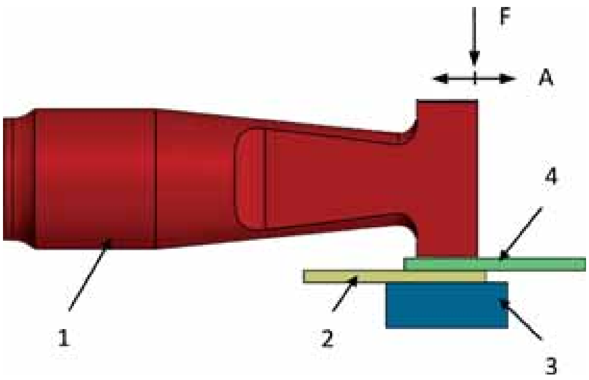

Figure 1. Scheme of principle for ultrasonic welding:
1 - sonotrode; 2 and 4 - joining parts; 3 - anvil; F - welding force; A - amplitude of ultrasonic microvibrations.

The main aim of the paper is to present new innovative solutions for the execution of sonotrodes for ultrasonic welding of metallic, polymeric and composite materials. At the same time, the characterization elements of the sonotrode are presented, as the results from the simulations using specialized software.

The two proposed innovative solutions can be applied to ultrasonic welding of materials in technical fields such as:

- Eco-Nano - Technologies and Advanced Materials (New Generations of Ecological and Energy-Efficient Vehicles and Technologies);
- Advanced materials and technologies for the niche application of the economy.

2. Description of the innovative solutions

Conventional sonotroods for ultrasonic welding are usually made in monoblock construction (Figure 1), and innovative solutions of sonotrodes with removable head (Figures 2 and 3) represent part of the research carried out in the project PN 16 08 102/2016 – "Research regarding the development of innovative ultrasonic tools and environmentally friendly joining technologies for industrial applications". These have been registered by the State Office for Inventions and Trademarks (OSIM) under the number A00160 / 15th.03.2017.

Figure 2 presents an innovative solution of sonotrode and anvil for ultrasonic processing with interchangeable heads, made in a monobloc variant, used for ultrasonic welding of metallic, polymeric and composite materials, and in the Figue 3 an innovative solution of sonotrode and anvil is presented with interchangeable heads in the construction version with the body made of two parts, assembled by means of a threaded nipple; for replacing the interchangeable ends the sonotrode is disassembled, and the subassembly comprising the working head or heads is subjected to the fretting process, in order to accomplish the possibility of replacing the working head or heads with other parts dedicated to the application to be made.

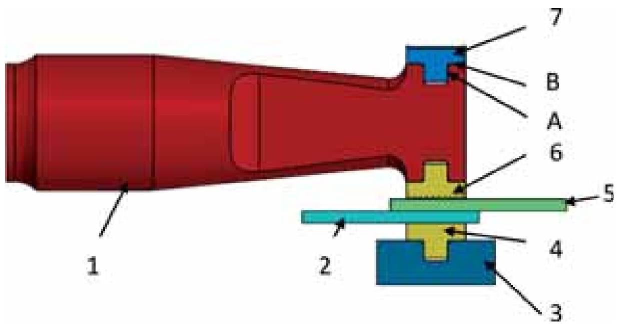

Figure 2. Sonotrode with removable active zone: 1 - sonotrode; 2 and 5 - parts to be joined; 3 - anvil body; 4 - positioning zone of the part to be welded at the anvil level; 6 and 7 - active welding zones; A - fixation and transfer surface for ultrasonic microvibrations; B - laying surface.

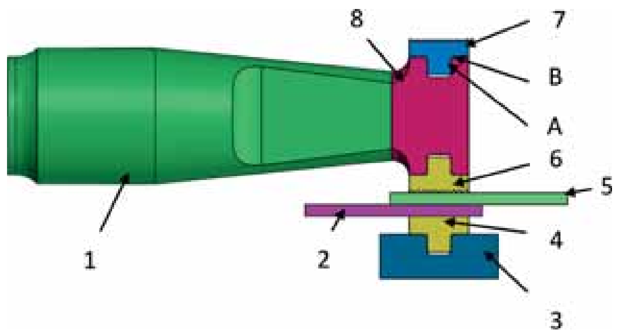

Figure 3. Sonotrode with removable head and removable active zone: 1 - sonotrode body; 2 and 5 - parts to be joined; 3 - anvil body; 4 - positioning zone of the part to be welded at the anvil level; 6 and 7 - active welding zones; 8 - sonotrode head;
A - fixation and transfer surface for ultrasonic microvibrations;
B - laying surface.

The novelty element of the two solutions presented is that it allows the production of specialized sonotroods for given applications by constructive solutions for replacing the active working zone with other subassemblies made according to each application. Thus, specialized sonotrodes for different welding parts with different configurations can be used.

In the same way, the technical problem is presented for the anvil dedicated to each application, by using the constructive solution to replace the active area, when appropriate.

At the same time, by the proposed solutions welded joints can be made from a wide range of materials (polymeric, composite, metallic), the hardness of which can be much higher than that of the sonotrode body, by simply replacing the active zone, made from material imposed by the welding application, having economic effects, by reducing the fabrication cost of the sonotrode. It will also be possible to increase productivity by reducing the unit work time.

These solutions will provide the possibility of obtaining new configurations of active tools (sonotrodes) for ultrasonic welding, depending on a given application, simply by replacing the sonotrode head, respectively the active zone.

Interchangeable-headed sonotrode solves the above-described technical problems in that it is composed of a sonotrode body on which the head of the sonotrode with the active zone is fixed, by a removable joint having the necessary shape for each application, depending on the application's specificity. Similarly, the anvil will be obtained if the application also requires such solution for the anvil.

The anvil shown in the Figures 2 and 3 is subject to the same fretting process, in view of changing the component called positioning zone of the part to be welded at the anvil level.

With respect to the interchangeable "active zone" we can see the surface "A" through which the transfer of the microvibrations occurs and the surface "B" for laying the two components.

In the Figure 3, in the joint zone of the sonotrode head with the sonotrode body, the contact area is remarked that is to be processed for both parts with the assembling precision of an intermediate shrinkage fitting at the A zone level and with the flatness in the field 2.5 ÷ 4 µm at B zone level.

Regarding the processing mode, to avoid the occurrence of stress concentrators, as well as for a correct laying at the level sonotrode-active zone, the joints of the surfaces are made with "R" connection rays that for the body have values higher than the values of the rays (r) at the level of the active zone. These values have to be met in all the variants of parts called interchangeable "active zone".

It is noted that for the anvil all information presented previously is valid and must be complied with for welding operations according to the technical documentation. As for the active form of the welding heads, they will be made according to both the application requirements and the welding technology.

Sonotrods can be made with one, two or more interchangeable active zones, as appropriate.

The assembling of the two subassemblies, the sonotrode and the active zone, is performed by fretting. The heating of the sonotrode (Figure 2) or the sonotrode head (Figure 3) takes place without its dismantling, according to Figures 2 and 3; it is carried out in inert gas media, to prevent the formation of oxides at the contact surface between the sonotrode and the active zone, a phenomenon that occurs when heating metal surfaces by flame. At the same time, by the solution proposed in the Figure 3, the head of the sonotrode, which may be with one, two or more active zones, is also interchangeable, allowing the fretting assembly to be performed only at the head of the sonotrode.

The physical effect of the heating is the expansion of the sonotrode head, hence of the head place or places, too, as the case may be. This makes it easy to mount the active zone of the sonotrode. After cooling, a non-demountable assembly is obtained and the ultrasonic welding process can take place.

Execution of a new application or, depending on the case, replacement of the active area as a result of wear can be achieved by fretting, heating appropriately the sonotrode used, extracting the active zone used for the previous application and making the sonotrode head assembly with an active zone for the application that's next to happen.

It is mentioned that the same procedure is applied with the anvil used for the welding operation, by heating the anvil body by flame in an inert gas environment and assembling the anvil head, i.e. the laying zone with the anvil body, which is in the dilated condition at the moment of assembly. The type and size of the anvil laying zone is imposed by the welding application.

In the dimensional processing of the surfaces of the two subassemblies, the sonotrode head and the active sonotrode area, an intermediate shrinkage fitting will be made, in such a way that the sonotrode assembly behaves during the welding process as a solid, uniform body in terms of structure.

In the same way, it must be done for the anvil assembly, i.e. the anvil body and the anvil head (the laying zone of the part to be welded).

The two constructive variants presented can be achieved for the whole range of frequencies used in the technique.

The sonotrode form, which also takes into account the mechanical properties of the material from which it is manufactured, must be chosen so as to provide a working value of the microvibration amplitude specific to the welding application.

A lower or higher amplitude of the ultrasonic microvibration can be achieved, additionally to the sonotrode form, by using an intermediate wave amplifier (booster) with an amplification factor different from 1: 1 and / or directly from the control panel of the ultrasonic equipment.

The Figure 4 presents the theoretical characterization elements of the sonotrode with interchangeable heads corresponding to the resonance frequency of 20 kHz, and the Figure 5 shows the temperature-dependent sound speed variation diagram for the W12842 (90MnCrV8) material.

Simulation with specialized programs allows the knowledge of the state parameters of the sonotrode, resonator gain, node position, amplitude, variation curves for loss and internal stress of the sonotrode.

The characterization elements of the sonotrode obtained after the simulation are presented in the Table 1.

Table 1. Sonotrode characterization after simulation

Material	W12842 (90MnCrV8)
Sound speed [m/s]	4741
Sonotrode length [mm]	121.5
Frequency [kHz]	20
Horn gain	1.65
Largest axial stress MPa/x	2.2/79.5
Half-wave node [mm]	59.8
Power dissipated [Watt]	$4.6x10^{-3}$

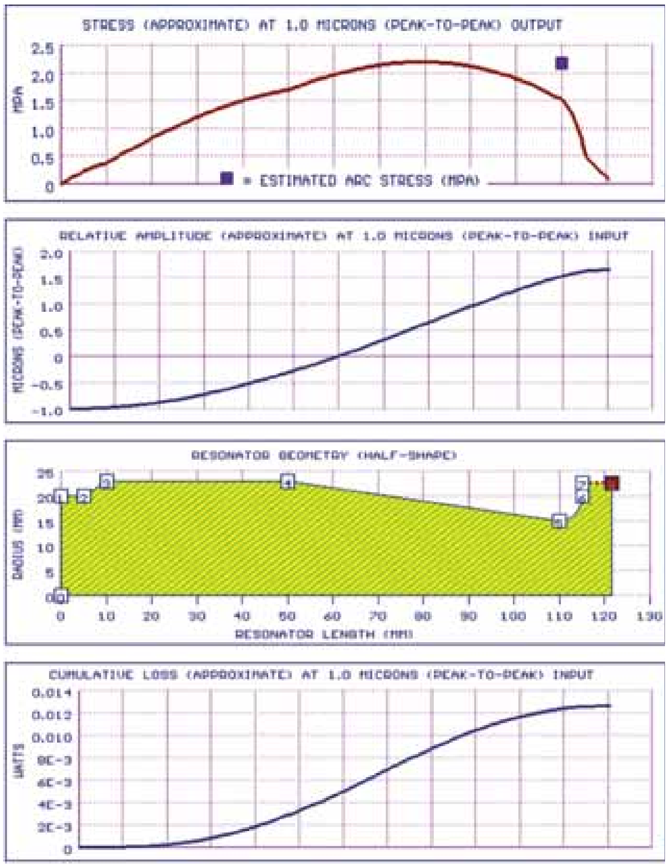

Figure 4. Theoretical characterization elements of the sonotrode with interchangeable heads, related to the 20 kHz resonance frequency: a - variation of the internal stress condition along the sonotrode; b - variation of the amplitude along the sonotrode; c - the variation of cumulative losses.

Figure 5. Temperature-depending sound speed variation diagram for material W12842 (90MnCrV8).

4. Conclusions

The two constructive variants presented can be realized for the whole range of frequencies used in the technique, and by using the proposed solutions a number of advantages can be highlighted. The main advantages of the two proposed solutions (Figures 2 and 3) related to the classical solution (Figure 1) are:

- the wear of the active zone does not involve the replacement of the whole sonotrode, but simply the replacement of the removable head, which also contains the active zone;
- a new ultrasonic welding application is carried out by simply replacing the removable zone (Figures 2 and 3) or, as the case may be, by replacing both the removable zone and the head of the sonotrode (Figure 3);
- obtaining material savings by using removable heads;
- increased productivity by reducing the auxiliary times, respectively replacement time for the sonotrode, as a consequence of the active zone wear, or because of the need for a new application.

In the next stage of the project, the two solutions presented above will materialize. Experimental attempts will also be made to validate welding technologies for various types of materials, as metals, polymers and composites.

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