

Optimizing ultrasonic joining technologies of composite polymer materials

N.A. Sîrbu, O. Oancă

National Research and Development Institute for Welding and Material Testing – ISIM Timisoara, Romania

E-mail: asirbu@isim.ro

Keywords

Thermoplastic composites, ultrasonic bonding, polyplan

1. Introduction

Ultrasonic welding (USW) is not only a well-known industrial process, but it has also been an active research area. Materials ranging from metals to non-metals, e.g. polymers and from virgin materials to non-virgin materials, e.g. composites are easily welded using this welding technique [1].

Ultrasonic welding is a promising joining technique for thermoplastic composites based on low amplitude and high frequency vibrations transversally applied to the surfaces to be welded. Its main features are the high speed of the process (welding times ranging from a fraction of a second to a few seconds) and the fact that no foreign material is needed at the welding interface for either carbon or glass fibre reinforced composites. Several authors investigated the effect of the welding pressure and welding time in the strength of ultrasonic welds concluding that there exists an optimum welding time for each pressure value and an optimum pressure for each welding time [2].

Benatar and Gutowski introduced ultrasonic welding of advanced fibre-reinforced thermoplastic composites. They characterized and modelled ultrasonic welding as a complex process consisting of five distinct, highly coupled sub processes: (i) mechanics and vibration of the parts; (ii) viscoelastic heating of the thermoplastic resin; (iii) heat transfer; (iv) flow and wetting and (v) intermolecular diffusion [3].

Many research works have focused on the influence of process parameters on the quality of the ultrasonic joint of composite polymeric materials [4], [5], [6], [7], [8], [9], [10].

Palardy, et al. [11] has investigated the influence of the thickness of flat energy directors (ED) on the ultrasonic welding (USW) process for carbon fibre/polyetherimide composites. Nikoi et al. [12] experimentally investigated the ultrasonic effect of three process parameters such as welding time, air pressure, vibration amplitude and the amount of glass fiber in the composite (polypropylene composite reinforced with glass fiber, GF) on tensile-shear strength of weld joints. Amplitude, welding time, amount of GF and air pressure are the most significant factors affecting the weld tensile-shear strength.

The literature analysis undertaken did not identify any scientific work performed on polymer composite material “Polyplan”, polyester textile fiber-reinforced polyvinyl chloride (PVC).

The main goal of the research in this paper is to study the process parameters influence on the ultrasonic bonding quality of parts made of the composite material type Polyplan.

2. Materials and methods

2.1. Material selection

The thermoplastic composite used for this research was polyester textile fibre-reinforced PVC (polyvinyl chloride).

Polyplan is a waterproof PVC with polyester textile fiber, mainly used in banners and awnings. Joining this material using conventional processes can be achieved by staples, sewing or bonding by high frequency currents [13].

The material has a specific mass of 500g/m², with a using temperature range $T = -30^{\circ}\text{C} \dots +70^{\circ}\text{C}$.

2.2. Welding process

A 35 kHz HiQ DIALOG 1200 ultrasonic welder with maximum power output of 1200 W was utilised (Figure 1).

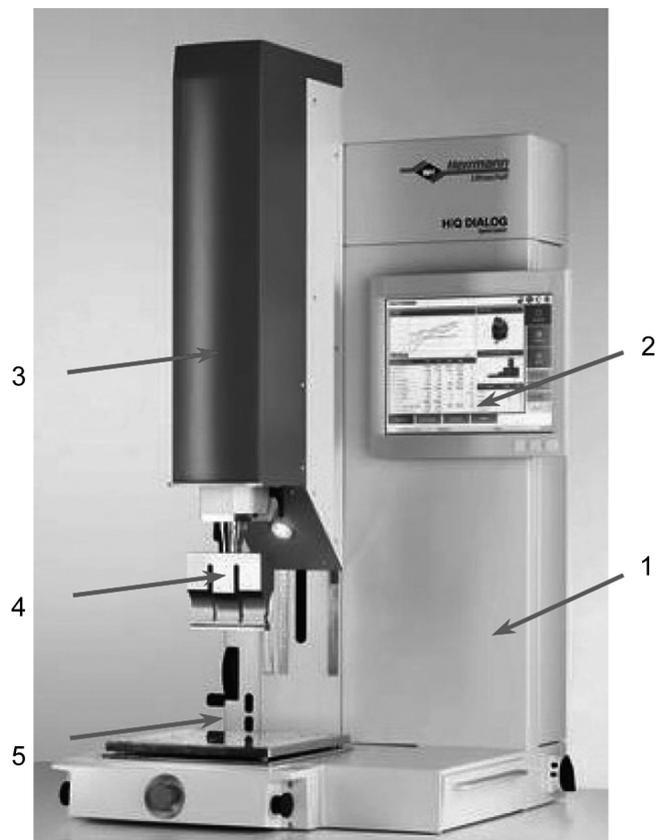


Figure 1. Ultrasonic equipment - 35 kHz, 1200W, HiQ DIALOG: 1 – 35 kHz ultrasonic generator; 2 – 15” control panel; 3 – drive system; 4 – ultrasonic assembly - 35kHz; 5 – anvil.

The technical specification of the ultrasonic welding equipment (UWE) is presented in Table 1.

2.3. Testing method

Experimental tests for the assessment of strength of the welded joints were done in accordance with EN ISO 527-1 (Plastics - Determination of tensile properties - Part 1: General principles), using the equipment Zwick / Roell Z005 - 5 kN, of the mechanical testing laboratory of ISIM Timisoara, shown in Figure 2.

Table 1. Technical specification of the UWE.

HiQ DIALOG	35 kHz
Generator output [W]	1200
Welding force min/max* [lbf] *at 115 psi	2.2-130
Sonotrode stroke [inch]	4
Machine dimensions (w x h* x d) [inch] *at max. height setting	29 / 61 / 28
Throat depth to center of sonotrode [inch]	10
Height adjustment [inch]	17
Control panel - Touchscreen color	15"
Welding modes	6
Number of weld memories	1000
Number of welds stored (Data & Graphs)	300 per Memory
Auxiliary functions (optional)	max. 6



Figure 2. Equipment Zwick/Roell Z005 – 5kN / Detail on the active jaws level.

3. Results and discussion

In order to carry out the experimental tests an ultrasonic assembly was used that provides a working amplitude of 9.8 μm, consisting of a piezoceramic transducer of 35 kHz frequency and 6,5 μm amplitude, the intermediate assembly (booster) with gain factor (the ratio of the booster’s amplitude output to amplitude input) of 1:1.5, respectively a specialized sonotrode made of titanium grade 5, characterized by a gain factor of 1:1 and a rectangular active surface with the area S = 60 mm².

Experimental tests aimed to study the influence of welding time (t_w) on the bond strength, while taking into account the quality (appearance) of the surfaces obtained by the ultrasonic bonding process. The experimental assessments were performed for values of the welding force F = 35 N, welding time (t) between 1÷16 s, hold time t_h = 0.1 s and values of the trigger delay distance (gap) (T_r) of 0.1 mm and 0.2 mm.

Time-based variation of the process parameters by the ultrasonic welding for the 16 technological regimes (t = 1÷16 s)

is shown in the Figure 3 (Figure 3.a – trigger delay distance T_r = 0.1 mm and Figure 3.b – trigger delay distance T_r = 0.2 mm), respectively Table 2 shows the appearance of the surfaces (in contact with the sonotrode, respectively the anvil) after the ultrasonic bonding is done.

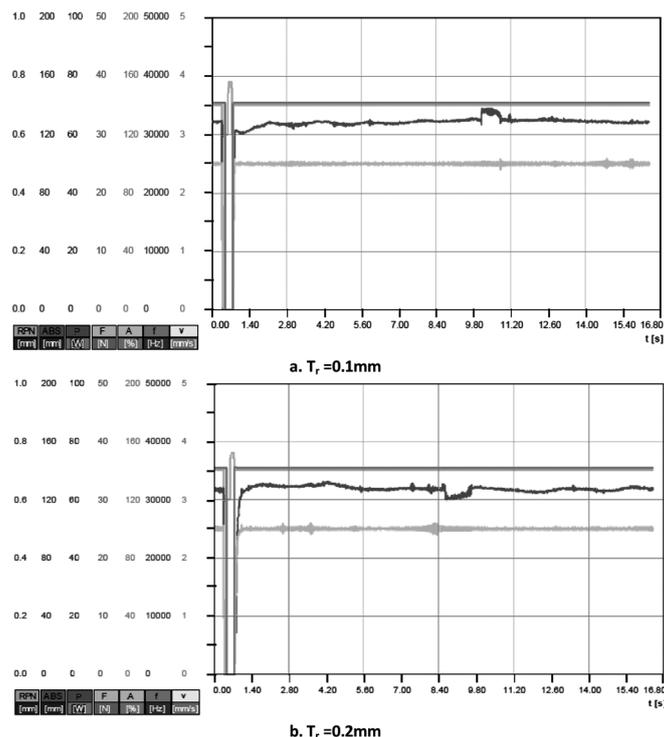


Figure 3. Time-based variation of the process parameters.

In the Figure 4 the curves of tensile strength are presented and the Table 3 presents the values of the process parameters, set and / or measured during the ultrasonic joining process, as well as the tensile test results (ultimate force - F [N], ε_H ultimate elongation (by breaking) [%] and the shear strength at the joint level σ_f = F / LxW, σ_f = F / 15x4 [N / mm²]).

After the completion of the experimental program the following aspects can be highlighted:

- the visual testing of the ultrasonically welded surfaces in terms of their quality, especially of the surface of the welded material, in contact with the anvil (Table 2 - surface B), ie the areas useful in exploiting the final product, revealed that the look of these surfaces remains unchanged after the ultrasonic bonding process.
- analysis of the influence of ultrasonic welding time (t) on the strength of the welded joints showed that the value of the ultimate tensile strength increases with increasing the welding time extent; strong joints, with values of the ultimate tensile strength over 400 N, have been obtained at welding times of 13÷15 seconds for the experiment 1 (T_r = 0.1 mm), respectively t = 11÷16 seconds for the experiment 2 (T_r = 0.2 mm);
- although printing the material surface in contact with the sonotrode (table 2 - surface A) is more pronounced for the value T_r = 0.2 mm compared to T_r = 0.1mm, it was found that the parameter trigger delay distance (T_r) did not significantly affect the extent of the ultimate (breaking) force, as for the experiment 2 (Tr = 0.2 mm) ultimate force values (F) were obtained at most 16 N higher, compared to the experiment 1 (Tr = 0.1 mm);
- Looking forward to replacing the classic joining process for the material Polyplan using high frequency, resulting in the fact

that the joining of a linear meter of material is performed in less than a minute, with the ultrasonic bonding process, given the experimental results obtained, the need emerges to continue the experimental research in order to identify technological regimes that result in higher productivity compared with the productivity of the applied classical process. In order to achieve this goal, activities will also be considered to develop new ultrasonic tools (sonotrodes) - linear sonotrodes with increased active

length (> 80mm) required for sequential splicing, respectively rotary sonotrodes for continue joints, all over the whole surface to merge.

4. Conclusions

As a result of the program of experiments, we conclude that the use of ultrasounds in the process of joining Polyplan material gave very good results, in order to obtain an ultimate

Table 2. Quality of the surfaces after the USW.

Test number/ welding regime	Ultrasonic joining with variable welding time ($t_s = 1\div 16$ s)			
	Trigger delay distance $T_r = 0.1$ mm		Trigger delay distance $T_r = 0.2$ mm	
	Matte surface in contact with the sonotrode (A)	Polished surface in contact with the anvil (B)	Matte surface in contact with the sonotrode (A)	Polished surface in contact with the anvil (B)
1.				
8.				
15.				

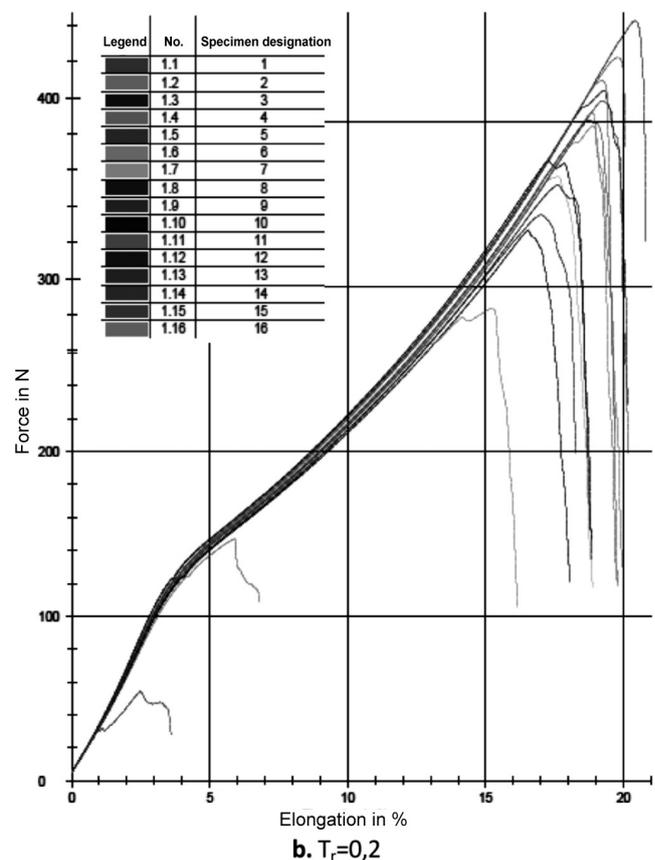
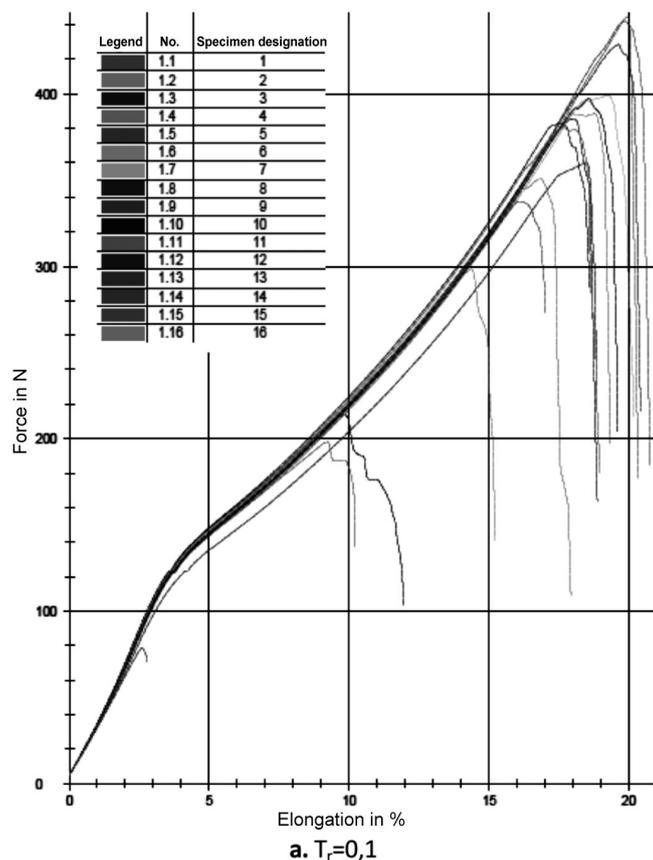


Figure 4. Variation curves of the tensile strength.

Table 3. The numerical values of the process parameters and tensile test results.

Test number	t [s]	E [J]	P _{peak} [W]	P _{end} [W]	f [kHz]	TP [mm]	T _r [mm]	F [N]	ε _H [%]	σ _f [N/mm ²]
1.	1	61	65	65	35.432	95.56	0.1	78.8	2.5	1.3
2.	2	128	67	66	35.475	95.58		198.2	9	3.3
3.	3	190	65	64	35.474	95.57		213.8	10	3.56
4.	4	257	66	65	35.471	95.57		298.4	14.5	4.97
5.	5	324	68	66	35.465	95.57		360	18.5	6
6.	6	385	66	65	35.457	95.57		350.7	17	5.84
7.	7	451	67	65	35.446	95.56		399.1	19	6.65
8.	8	516	67	65	35.435	95.56		381.9	17.5	6.36
9.	9	574	66	64	35.424	95.57		337.6	16	5.62
10.	10	636	65	64	35.416	95.57		397.2	18.5	6.62
11.	11	698	65	65	35.395	95.57		388.4	18	6.47
12.	12	769	66	64	35.381	95.56		385.6	18	6.42
13.	13	821	64	64	35.368	95.57		442.3	20	7.37
14.	14	899	66	64	35.354	95.57		444.8	20	7.41
15.	15	967	68	63	35.343	95.57		428.7	19.5	7.14
16.	16	1025	69	64	35.333	95.56		380.7	17.5	6.34
17.	1	1012	66	63	35.312	95.56	0.2	54	2.5	0.9
18.	2	960	69	64	35.324	95.56		146.9	6	2.44
19.	3	899	68	64	35.342	95.56		334.7	16.5	5.57
20.	4	832	66	65	35.358	95.57		286.8	15	4.78
21.	5	770	66	64	35.374	95.56		343.8	17	5.73
22.	6	706	67	63	35.395	95.58		397.8	19	6.63
23.	7	648	68	65	35.405	95.56		367.2	17.5	6.12
24.	8	571	66	65	35.418	95.57		361.8	17.5	6.03
25.	9	520	67	65	35.430	95.57		413.1	19	6.88
26.	10	453	68	66	35.440	95.57		377.3	17.5	6.28
27.	11	390	68	64	35.451	95.55		405.7	19	6.76
28.	12	329	70	66	35.458	95.59		419.5	19.5	6.99
29.	13	261	71	66	35.464	95.57		401.6	18.5	6.69
30.	14	192	70	69	35.471	95.57		439.3	20	7.32
31.	15	121	65	64	35.472	95.58		461	20.5	7.68

t = weld time; E = energy; P_{peak} = power (peak); P_{end} = power (end); TP = trigger point; f = frequency (end); T_r = trigger delay distance; F = ultimate (breaking) force; ε_H = ultimate elongation (by breaking); σ_f = shear strength

(breaking) force F > 400 N; in order for this technique to be an alternative required for the classical bonding method based on high frequency currents, further research is useful, both from the point of view of identification of new technological regimes allowing higher productivity compared to the classic process, as well as regarding the development of new ultrasonic tools (sonotrodes) - linear sonotrodes with increased active length (> 80 mm) for sequential joints, respectively rotary sonotrodes for continue joints, over the entire surface to be bonded.

Acknowledgement

The paper was developed on the basis of preliminary results achieved in the project PN 16 08 102 entitled “Development of new, innovative and environmentally friendly processes of joining advanced materials using unconventional techniques”, financed under the ”Nucleu” Program (contract 7N/2016-2017) of the ISIM Timisoara, by the National Authority for Scientific Research and Innovation - ANCSI.

References

[1]. Raza, S. F. (2015). Ultrasonic welding of thermoplastics (Doctoral dissertation, University of Sheffield);
 [2]. Villegas, I. F. (2013). In situ monitoring of ultrasonic welding of thermoplastic composites through power and displacement data, Journal of Thermoplastic Composite Materials, 0892705712475015;
 [3]. Fernandez, I., Stavrov, D., & Bersee, H. E. N. Ultrasonic welding of advanced thermoplastic composites: an investigation on energy directing surfaces;
 [4]. Deepak Kumar M, Karthik V, P.G.Venkatakrishnan. (2016). Ultrasonic Plastic Welding Of Glass Fiber Reinforced Plastic, International Journal of Innovative Studies in Sciences and Engineering Technology, Volume: 2 Issue: 5 | May 2016, ISSN 2455-4863 (Online);
 [5]. Broek, C. A. (2015). Optimising Ultrasonic Welding of Carbon Fibre PEKK Composites (Doctoral dissertation, TU Delft, Delft University of Technology);

[6]. Villegas, I. F. (2013). Optimum processing conditions for ultrasonic welding of thermoplastic composites. In Proceedings of the 19th International Conference on Composite Materials, pp. 1-20;

[7]. Villegas, I. F., Grande, B. V., Bersee, H. E. N., & Benedictus, R. (2014). A comparative evaluation between flat and traditional energy directors for ultrasonic welding of thermoplastic composites. In Proceedings of the 16th European Conference on Composite Materials, ECCM16, Sevilla, Spain, June 22 (Vol. 26);

[8]. Villegas, I. F., & Bersee, H. E. (2010). Ultrasonic welding of advanced thermoplastic composites: An investigation on energy-directing surfaces. *Advances in Polymer Technology*, 29(2), pp. 112-121;

[9]. da Costa, A. P., Botelho, E. C., Costa, M. L., Narita, N. E., & Tarpani, J. R. A (2012). A review of welding technologies for thermoplastic composites in aerospace applications,

DOI 10.5028/jatm. 2012.040303912. *Journal of Aerospace Technology and Management*, 4(3), pp. 255-266;

[10]. Roos, L. W. M., & Kalas, V. Welding of thermoplastic composites;

[11]. Palardy, G., & Fernandez Villegas, I. (2015, July). Ultrasonic welding of thermoplastic composites with flat energy directors: Influence of the thickness of the energy director on the welding process. In ICCM 20: 20th International Conference on Composite Materials, Copenhagen, Denmark, 19-24 July 2015. ICCM;

[12]. R. Nikoi, M. M. Sheikhi, N. Bani Mostafa Arab (2015). Experimental Analysis of Effects of Ultrasonic Welding on Weld Strength of Polypropylene Composite Samples. *IJE TRANSACTIONS C: Aspects* Vol. 28, No. 3, (March 2015) pp. 447-453;

[13]. <http://www.e-vasion.ro/Amenajari-interioare-si-exteroare/Poliplan/POLIPLAN/>



Calendar of international and national events

2017			
Febr. 7-9	7 th Conference on Industrial Computed Tomography	Belgium, Leuven	https://www.ict2017.org/
Mar. 1-3	21 th Russian National Science and Technology Conference on NDT	Moscow, Russia	http://www.ronktd.ru/
Mar. 21-22	4 th IEBW International Electron Beam Welding Conference	Aachen, Germany	http://www.dvs-ev.de/iebw2017
Mar. 25-29	SPIE Smart Structures/NDE 2017	Portland, OR, USA	http://spie.org/conferences-and-exhibitions/smart-structures/nde
Apr. 7-8	ASR Conference "WELDING 2017"	Iași, Romania	http://www.asr.ro
May 17-19	ICWAM 2017 - The first IIW international congress on Welding, Additive Manufacturing and Associated Non-destructive Testing	Metz, France	http://www.icwam.com
Jun. 25-30	70 th IIW Annual Assembly and International Conference	Shanghai, China	http://www.iiw2017.com



iCT 2017

7th Conference on Industrial Computed Tomography
Leuven (Belgium), February 7th – 9th, 2017



iCT 2017 is the 7th edition in a series of international scientific meetings on Industrial Computed Tomography. Traditionally organized in Wels, this conference will now for the first time be organized in Leuven, Belgium, hence emphasizing the international character of this major event on industrial CT.

www.ict2017.org

Sudarea și Încercarea Materialelor