Experimental and Theoretical Researches Regarding Ultrasonic Welding Process Optimization of the Polymeric Matrix Composite Materials

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The optimization of the ultrasound welding of composed materials means finding an objective function that comprises all acoustic, mechanical and technological parameters and determining the minimum cost of the process or the maximum productivity in obtaining a superior quality of the welded join.In the paper there are presented the dependency of the quality of composed materials welded joins on acoustic parameters and mechanical and technological parameters.

Key words: ultrasounds, welding, plastic material, technology

Theoretical considerations

The quality of an ultrasound welded join of composed materials is determined by the following three groups of parameters:

- acoustic parameters: the ultrasound oscillation type exercised in the ultra acoustic system, the oscillation amplitude, the ultrasound oscillation frequency, the ultrasound energy intensity, the ultra acoustic energy density, the acoustic anvil reflection and absorption qualities;
- mechanical parameters: the static pressing force, the local static pressure of the joining surfaces, the maintaining pressure, the shape and material of the (sonotrod) and the acoustic anvil, the shape factor of the ultrasound energy concentrator, the welding time, the maintaining time;
- technological parameters: the composed materials nature, the geometrical configuration of the joining surfaces, the welding materials thickness, the joining surfaces state, the welding method, the demanded conditions of the functional role, the number of acoustic energy concentrators.

The optimization of the ultrasound welding of composed materials means finding an objective function that comprises all the parameters and determining the minimum cost of the process or the maximum productivity with the minimum cost or the maximum productivity in obtaining a superior quality of the welded join.

In most cases the quality of welded joins is estimated by determining the shearing-traction force F, needed to break the join of two welded bars.

The statistic analysis of the results presumes the calculation of the following [1, 20]:

-the medium value of the traction break force $\overline{F}$, that is calculated with the relation:

$$\overline{F} = \frac{1}{n}\sum_{i=1}^{n} Fi \qquad (1)$$

-the corrected dispersion $\overline{s}^2$, with:

$$\overline{s}^2 = \frac{1}{n-1}\sum_{i=1}^{n}(Fi - \overline{F})^2 \qquad (2)$$

-the corrected medium square deviation $\overline{s}$, with:

$$\overline{s} = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(Fi - \overline{F})^2} \qquad (3)$$

-the variation coefficient W, with:

$$W = \frac{\overline{s}}{\overline{F}} \cdot 100\% \qquad (4)$$

where: Fi is the tested value ; n- number of measurements

To exclude the result of a reject we use the student criterion:

$$t = \frac{F_j - \overline{F}}{\overline{s}} \qquad (5)$$

where: F_j is the tested value (the highest or the lowest in the n measurements) $\overline{F}$ - the medium value of the traction break force.

To verify the hypothesis that two random medium values $\overline{F}_1$ and $\overline{F}_2$ belong to the same real value, first the „F" test is used:

$$F = \overline{s_1^2} / \overline{s_2^2} \qquad (6)$$

and then the „t" test, under the form :

$$t = \frac{\overline{F}_1 - \overline{F}_2}{\overline{s}}\sqrt{\frac{n_1 \cdot n_2}{n_1 + n_2}} \qquad (7)$$

where: $\overline{F}_1$ and $\overline{F}_2$ are the studied medium values; n_1, n_2 – the number of experiments where $\overline{F}_1, \overline{F}_2$ were determined;

$\overline{s}$ - the corrected medium square deviation, calculated as such:

$$\overline{s} = \sqrt{\frac{f_1 \cdot \overline{s_1^2} + f_2 \cdot \overline{s_2^2}}{f}} \qquad (8)$$

where: $f_1=n_1-1$; $f_2=n_2-1$; $f=f_1+f_2=n_1+n_2-2$ are the degrees of freedom.

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Due to the fact that it is extremely difficult to find an objective function that comprises all the acoustic, mechanical and technological parameters, there were established the dependencies between different parameters, in groups of three, using a 3D statistical analysis programme, and for the graphs canonic functions were used.

The dependency of the quality of composed materials welded joins on acoustic parameters

The quality of welded joins can be determined by the plastic deforming in joining materials' layers and influenced by the welding forming acoustic conditions [3, 4].

Acoustic conditions are produced by the action of welding materials of the different oscillation types (longitudinal, shearing, bending, spinning and combined) which are stimulated at the welding sight by performant ultra acoustic systems.

Experiments proved that by stimulating longitudinal waves in a sonotrod, the joining quality depends on the sonotrod's length, and the pressing static force application sight. In the case of bending oscillations, the welded join quality is lower than in the anterior case, because of the high variation of frequency autoregulation system entrance impedance.

The experimental research made on certain polymeric matrix composed materials have shown that shearing or longitudinal-transversal oscillations insure a good removal of oxide layers from the joining surfaces, a better limitation of oxygen penetration in the welding area, a complex material displacing in the contact area, this way obtaining high quality welded joins [8, 11, 19].

The dependency of welded joins resistance on oscillations amplitude

The ultrasound oscillation welded join forming process depends mostly on the sonotrod's A oscillation's amplitude and on the pressing static force P_s.

The variation of breaking resistance *F*, of the welded join due to the A oscillation's amplitude and the welding time t, are presented in table 1 and figure 1.

We can observe that at lower values of oscillation amplitude we obtain lower resistance welded joins, and at lower than minimum amplitude values, the join can not be possible.

Dosing the acoustic energy in the welding zone is influenced by the acoustic concentrator frontal part oscillation amplitude value, which has to be higher in the first state of the join forming, that is the realization of the intimate contact between the welding surfaces. In the next state it is necessary that the oscillation amplitude to be lowered so that to avoid the breaking of the braces that formed, the entire acoustic energy being used for accelerating the plastifing and melting processes of the material in the welding area.

Temperature rising in the welding area boost the atom's thermic energy, which favorises the transferring process of the material in the existing microspores, in the detriment of the diffusion process.

The A oscillation amplitude's variation, depending on the output power of the transductor $\mathbf{W_t}$ and the oscillation types are presented in table 2 and figure 2.

We observe that in all the cases there is a rise in the concentrators oscillation amplitudes, due to the output power rise.

Experimentally, it was established that the mechanical resistance F, of the welding process is most favorable for a

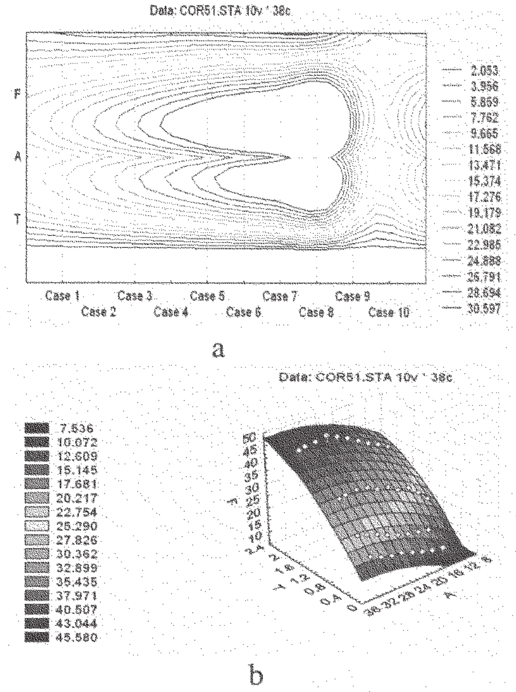


Fig.1. Variation of breaking resistance F, in daN depending on the oscillation amplitude A, in μm and the welding time t, in s: 1-t=0,15s; 2-t=0,5s; 3-t=1,0s; 4-t=2,0s; a– the 3D graphic representation on contour; b – the 3D graph determined with the lowest squares method

certain amplitude and for a certain type of excited oscillation ultra acoustic (table 3 and fig.3).

The surface $\mathbf{S_c}$ between the contact asperities rises with the output power of the transductor $\mathbf{W_t}$ (table 4 and fig. 4), this being explained by the rise of thermic energy by super positioning the acoustic energy. Similarly, there is a rise of the coalescence depth $\mathbf{h_p}$ of the asperities that form the welded join. (table 5 and fig 5).

When welding with ultrasound composed materials, the optimum frequency is determined taking into account the oscillation amplitude, the ultrasound energy intensity, the static contact pressure, the welding materials nature and thickness.

Table 1

DEPENDENCY F=f(A,t)

#	1 T	2 A	3 F	VA
1	.150	15.000	11.000	
2	.150	17.500	11.840	
3	.150	20.000	13.000	
4	.150	22.500	14.610	
5	.150	25.000	16.150	
6	.150	27.500	16.920	
7	.150	30.000	18.000	
8	.150	32.500	20.000	
9	.500	15.000	15.000	
10	.500	17.500	16.000	
11	.500	20.000	17.000	
12	.500	22.500	18.000	
13	.500	25.000	20.000	
14	.500	27.500	22.000	
15	.500	30.000	23.500	
16	.500	32.000	24.500	
17	1.000	10.000	20.000	
18	1.000	12.500	24.000	
19	1.000	15.000	27.500	
20	1.000	17.500	28.500	
21	1.000	20.000	31.000	
22	1.000	22.500	32.000	
23	1.000	25.000	34.000	
24	1.000	27.500	35.000	
25	1.000	30.000	34.500	
26	1.000	31.500	34.000	
27	2.000	10.000	32.500	
28	2.000	12.500	35.000	
29	2.000	15.000	37.000	
30	2.000	17.500	39.500	
31	2.000	20.000	42.000	
32	2.000	22.500	44.000	
33	2.000	25.000	46.000	

Table 2

DEPENDENCY A= f(W_t, OSCILATION TYPES)

#	1 TIP_OSC	2 PUT_W	3 AMPLIT_A
1	1.000	5.000	7.100
2	1.000	50.000	8.860
3	1.000	60.000	10.690
4	1.000	70.000	12.600
5	1.000	80.000	15.000
6	1.000	90.000	16.030
7	1.000	100.000	17.410
8	1.000	110.000	17.500
9	2.000	5.000	5.000
10	2.000	50.000	5.350
11	2.000	60.000	6.030
12	2.000	70.000	7.070
13	2.000	80.000	9.300
14	2.000	90.000	11.400
15	2.000	100.000	15.000
16	2.000	110.000	18.600
17	3.000	5.000	5.000
18	3.000	50.000	3.300
19	3.000	60.000	3.000
20	3.000	70.000	3.150
21	3.000	80.000	4.650
22	3.000	90.000	7.000
23	3.000	100.000	10.000
24	3.000	110.000	11.730
25	4.000	5.000	8.100
26	4.000	50.000	13.300
27	4.000	60.000	15.000
28	4.000	70.000	16.730
29	4.000	80.000	17.800
30	4.000	90.000	18.600
31	4.000	100.000	18.800

Table 3

DEPENDENCY F=f(A, OSCILATION TYPES)

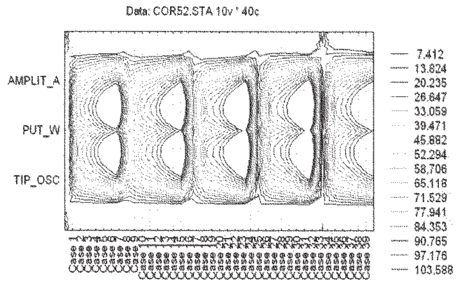
#	1 TIP_OSC	2 AMP_A	3 REZ_F
1	1.000	2.500	5.280
2	1.000	5.000	5.850
3	1.000	7.500	7.000
4	1.000	10.000	8.710
5	1.000	12.500	9.290
6	1.000	15.000	8.710
7	1.000	17.500	7.290
8	1.000	20.000	5.000
9	1.000	22.500	4.430
10	1.000	25.000	3.570
11	1.000	27.500	3.430
12	1.000	30.000	3.430
13	2.000	2.500	3.998
14	2.000	5.000	4.425
15	2.000	7.500	4.860
16	2.000	10.000	5.700
17	2.000	12.500	6.430
18	2.000	15.000	6.860
19	2.000	17.500	7.290
20	2.000	20.000	7.570
21	2.000	22.500	7.290
22	2.000	25.000	6.720
23	2.000	27.500	6.150
24	2.000	30.000	5.860
25	3.000	2.500	0.000
26	3.000	5.000	0.000
27	3.000	7.500	3.000
28	3.000	10.000	3.860
29	3.000	12.500	4.430
30	3.000	15.000	5.290
31	3.000	17.500	6.000
32	3.000	20.000	7.000
33	3.000	22.500	8.140
34	3.000	25.000	8.710

There is an optimum frequency that obtains very high quality welds. Experimentally, it was established that, for a certain output power from the transductor, the higher the ultrasound frequency, the lower is the oscillation amplitude.

Depending on the output power of the transductor and the material nature, the obtained experiment results show that the optimum frequency is between 18...40 Khz (table 6, fig. 6)

The dependency of welded joins resistance on the ultrasound energy intensity

The optimum ultrasound energy intensity is difficult to determine because it depends on many parameters: the transductors output power, the amplitude at the peak of the concentrator, the nature of the oscillation conducted in the ultra acoustic system, the contact surfaces geometry, and the welding materials nature.



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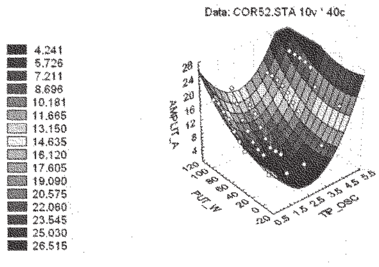

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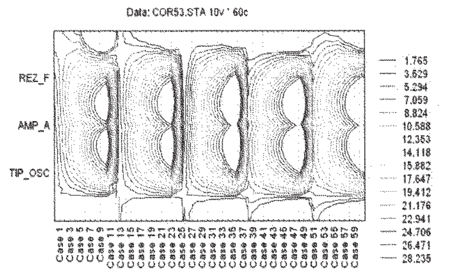
Fig. 2 The scillation amplitude's variation, in μm, depending on the output power of the transductor, W_t, in W and the oscillation types: 1 – longitudinal, 2 – shearing, 3 – bending, 4 – longitudinal-torsional, 5 – torsional. Material : ABS, Frequency 24 Khz; a - the 3D graphic representation on contour; b – the 3D graph determined with the lowest squares method



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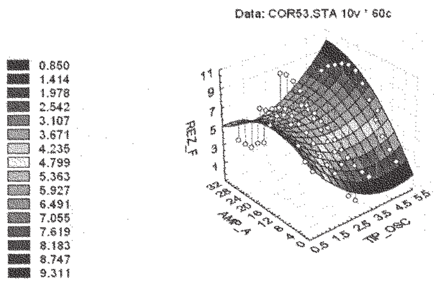

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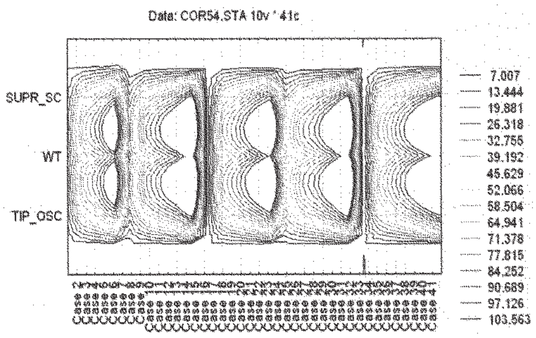
Fig 3. Variation of the resistance F, in daN depending on the oscillation amplitude A, in μm and the oscillation types 1-longitudinal, 2-shearing, 3 - bending, 4 -longitudinal-torsional, 5 - torsional.a - the 3D graphic representation on contour; b – the 3D graph determined with the lowest squares method

The obtained experiment results show that when the acoustic energy density rises to an optimum value, the welded join breaking resistance also rises, with the lowering of the welding time (table 7 and fig. 7).

Over the optimum value of acoustic energy density, the thermic energy rises severely in the welding zone and the material is destroyed. We observe that the optimum acoustic energy is between 4...7 W/cm^2, depending on the material nature, the amplitude and the static pressing force in the welding zone.



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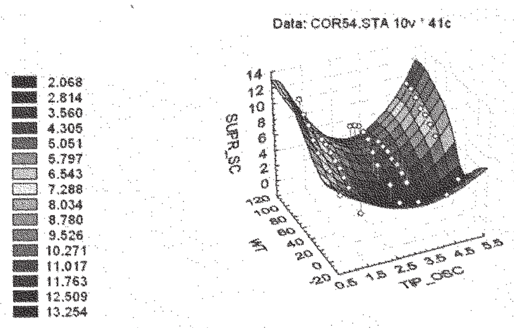

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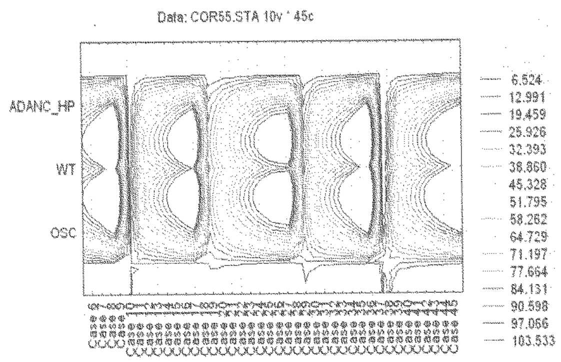
Fig. 4. Variation of contact surface S_c , in 10^{-2}mm^2, depending on the output power of the transductor W_t, in W and the oscillation types: 1 – longitudinal, 2 – shearing, 3 – bending, 4 – longitudinal-torsional, 5 – torsional. Material : ABS, Frequency 24 Khz;a - the 3D graphic representation on contour; b – the 3D graph determined with the lowest squares method



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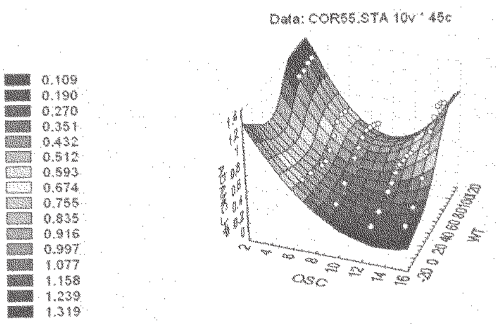

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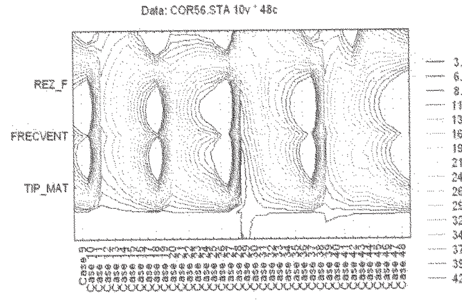
Fig. 5. Variation of interpenetration depth h_p, in mm, depending on the output power of the transductor W, in W and oscillation types: 1 – longitudinal, 2 – shearing, 3 – bending, 4 – longitudinal-torsional, 5 – torsional.Material : ABS, Frequency 24 Khz; a - the 3D graphic representation on contour; b – the 3D graph determined with the lowest squares method



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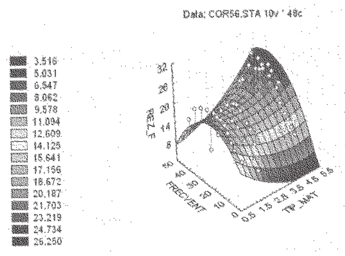

b

Fig. 6. Variation of the join's resistance F, in daN, depending on oscillation frequency (V), in Khz and plastic materials types: 1 – ABS, 2 – polistiren, 3 – polycarbonate, 4 – rough vinyl polichloride, 5 – high density poliethilen. a - the 3D graphic representation on contour; b – the 3D graph determined with the lowest squares method

Table 4
DEPENDENCY
S_c=f(W_t,OSCILATION TYPES)

#	1 TIP_OSC	2 WT	3 SUPR_SC
1	1.000	5.000	5.710
2	1.000	25.000	7.300
3	1.000	50.000	7.900
4	1.000	60.000	8.860
5	1.000	70.000	10.000
6	1.000	80.000	10.720
7	1.000	90.000	12.000
8	2.000	25.000	1.000
9	2.000	50.000	2.570
10	2.000	60.000	3.140
11	2.000	70.000	3.710
12	2.000	80.000	4.000
13	2.000	90.000	4.430
14	2.000	100.000	4.850
15	2.000	110.000	4.860
16	3.000	5.000	2.860
17	3.000	25.000	3.710
18	3.000	50.000	4.570
19	3.000	60.000	5.570
20	3.000	70.000	6.570
21	3.000	80.000	6.860
22	3.000	90.000	7.000
23	3.000	100.000	6.430
24	3.000	110.000	5.710
25	4.000	25.000	.600
26	4.000	50.000	1.430
27	4.000	60.000	2.000
28	4.000	70.000	2.430
29	4.000	80.000	2.570
30	4.000	90.000	2.860
31	4.000	100.000	2.860
32	4.000	110.000	2.860
33	5.000	5.000	4.000
34	5.000	25.000	.570

Table 5
DEPENDENCY
h_p=f(W_t, OSCILATION TYPES)

#	1 OSC	2 WT	3 ADANC_HP
1	3.000	5.000	.686
2	3.000	25.000	.815
3	3.000	50.000	.960
4	3.000	60.000	1.043
5	3.000	70.000	1.115
6	3.000	80.000	1.187
7	3.000	90.000	1.200
8	3.000	100.000	1.230
9	3.000	110.000	1.230
10	6.000	5.000	.486
11	6.000	25.000	.429
12	6.000	50.000	.343
13	6.000	60.000	.330
14	6.000	70.000	.400
15	6.000	80.000	.515
16	6.000	90.000	.629
17	6.000	100.000	.657
18	6.000	110.000	.629
19	9.000	5.000	.257
20	9.000	25.000	.371
21	9.000	50.000	.515
22	9.000	60.000	.571
23	9.000	70.000	.629
24	9.000	80.000	.657
25	9.000	90.000	.629
26	9.000	100.000	.590
27	9.000	110.000	.543
28	12.000	5.000	.057
29	12.000	25.000	.086
30	12.000	50.000	.157
31	12.000	60.000	.200
32	12.000	70.000	.257
33	12.000	80.000	.286
34	12.000	90.000	.271

Table 6
DEPENDENCY F=f(ν, PLASTIC MATERIAL TYPES)

#	1 TIP_MAT	2 FRECVENT	3 REZ_F
1	1.000	5.000	14.200
2	1.000	10.000	16.200
3	1.000	12.500	17.800
4	1.000	15.000	20.000
5	1.000	20.000	22.400
6	1.000	22.500	22.600
7	1.000	25.000	23.000
8	1.000	30.000	22.600
9	1.000	35.000	21.600
10	1.000	40.000	20.000
11	1.000	45.000	15.400
12	2.000	5.000	8.800
13	2.000	10.000	11.200
14	2.000	15.000	15.000
15	2.000	20.000	17.600
16	2.000	24.000	18.400
17	2.000	30.000	15.400
18	2.000	35.000	10.800
19	2.000	41.000	4.000
20	3.000	19.000	10.000
21	3.000	22.500	13.600
22	3.000	25.000	15.000
23	3.000	30.000	17.400
24	3.000	32.500	18.400
25	3.000	35.000	18.000
26	3.000	40.000	16.200
27	3.000	45.000	13.000
28	4.000	9.000	20.000
29	4.000	12.500	22.400
30	4.000	15.000	26.200
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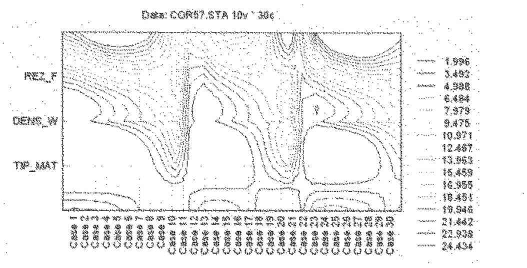
33	4.000	27.500	28.400
34	4.000	30.000	28.000



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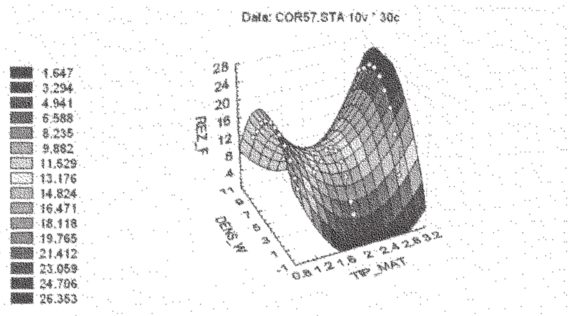
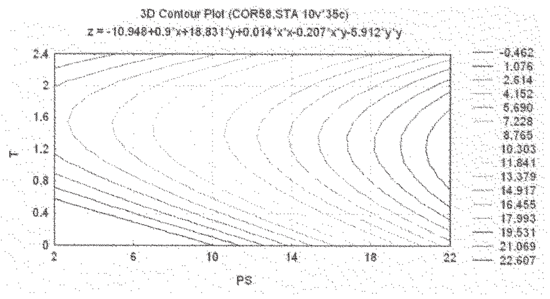


b

Fig. 7. Variation of the join's resistance F, in daN, depending on the acoustic energy density I_s, in W/cm^2, and plastic materials types: 1 – ABS, 2 – high density poliethilen, 3 – policarbonat, P_s=10 daN; D_f=30 mm; A=24μm;
a - the 3D graphic representation on contour;
b – the 3D graph determined with the lowest squares method



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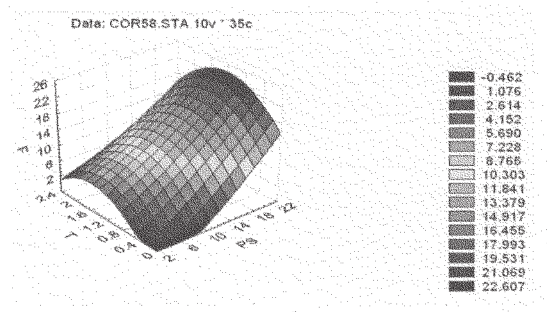
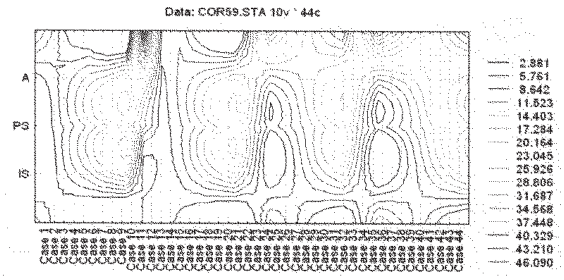


b

Fig.8. Variation of the join's resistance F, in daN, depending on the welding time t, in s and the static pressing force P_s, in daN:
1- P_{sy}=5 daN; 2- P_s=10 daN; 3- P_s=15 daN; 4- P_s=20 daN;
a - 3D graphic representation on contour; b – 3D graph determined with the lowest squares method



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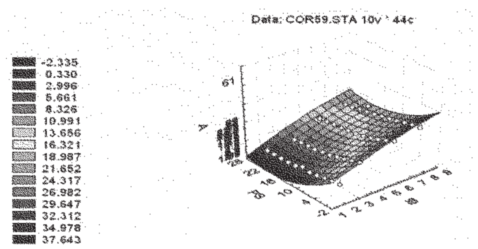


b

Fig.9 . Variation of oscillation amplitude A, in μm, depending on the static pressing force Ps, in daN, and on the acoustic energy density I_s, in W/cm^2: 1- 2W/cm^2; 2- 4W/cm^2; 3- 6W/cm^2; 4- 8 W/cm^2;
a - the 3D graphic representation on contour;
b – the 3D graph determined with the lowest squares method
Material ABS; Frequency: 24 KHz; Amplitude A: 30 μm

The dependency of the welded join's resistance on the static pressing force

Theoretical and experimental research have shown the decisive role of the static pressing force on the ultrasound welded joins medium breaking resistance [21-23].

The results obtained for the ABS welding (table 8 and fig. 8), indicate an optimum value for the static pressing force, which depends on the welding time t, and the concentrator's amplitude A (table 9 and fig. 9).

We can observe that, while the static pressing force rises, the acoustic concentrator's peak amplitude is lowered, and when going over the optimum static pressing force there is a significant drop in the welded join's resistance.

The static pressing force influences the local contact pressure (table 10 and fig. 10). We observe that at different acoustic energy densities, the local contact pressure rises with the rise of the static pressing force.

Depending on the static pressing force, for different material thicknesses, we obtain the optimum values for the welded joins resistance (table 11 and fig.11).

Table 7
DEPENDENCY F=f(I_s, PLASTIC MATERIAL TYPES)

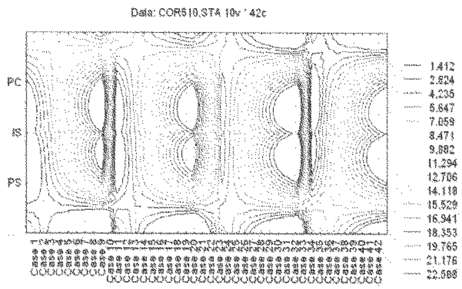
#	1 TIP_MAT	2 DENS_U	3 REZ_F
1	1.000	.500	14.070
2	1.000	1.000	15.620
3	1.000	2.000	18.140
4	1.000	3.000	20.000
5	1.000	4.000	20.930
6	1.000	5.000	21.240
7	1.000	6.000	20.930
8	1.000	7.000	20.000
9	1.000	8.000	18.140
10	1.000	9.000	15.000
11	1.000	10.000	12.520
12	2.000	.500	5.000
13	2.000	1.000	7.170
14	2.000	2.000	11.240
15	2.000	3.000	13.410
16	2.000	4.000	14.380
17	2.000	5.000	13.760
18	2.000	6.000	11.860
19	2.000	7.000	7.800
20	2.000	8.000	4.690
21	2.000	8.500	3.100
22	3.000	2.000	8.450
23	3.000	3.000	16.240
24	3.000	4.000	20.930
25	3.000	5.000	23.450
26	3.000	6.000	25.310
27	3.000	7.000	25.930
28	3.000	8.000	25.310
29	3.000	9.000	23.450

Table 8
DEPENDENCY F=f(t,P_s)

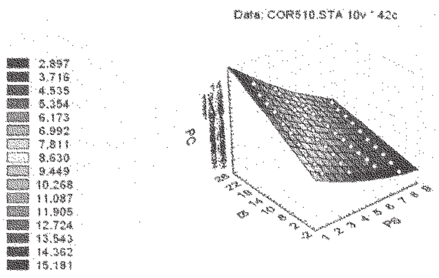
#	1 Ps	2 T	3 F
1	5.000	.250	.800
2	5.000	.500	1.800
3	5.000	.750	3.000
4	5.000	1.000	4.500
5	5.000	1.250	5.500
6	5.000	1.500	7.000
7	5.000	1.750	6.500
8	5.000	2.000	4.500
9	10.000	.150	2.800
10	10.000	.250	3.500
11	10.000	.500	5.000
12	10.000	.750	7.000
13	10.000	1.000	10.000
14	10.000	1.250	12.500
15	10.000	1.500	13.500
16	10.000	1.750	13.000
17	10.000	2.000	12.500
18	15.000	.150	7.500
19	15.000	.250	8.500
20	15.000	.500	9.500
21	15.000	.750	11.500
22	15.000	1.000	16.500
23	15.000	1.250	17.500
24	15.000	1.500	16.500
25	15.000	1.750	13.700
26	15.000	2.000	11.000
27	20.000	.150	12.000
28	20.000	.250	14.500
29	20.000	.400	18.500
30	20.000	.500	22.000
31	20.000	.650	23.500
32	20.000	.750	23.000
33	20.000	.850	21.000
34	20.000	1.000	20.000

Table 9
DEPENDENCY A=f(P_s,I_s)

#	1 IS	2 PS	3 A
1	2.000	0.000	8.000
2	2.000	2.500	7.000
3	2.000	5.000	6.000
4	2.000	7.500	4.800
5	2.000	10.000	3.500
6	2.000	12.500	5.000
7	2.000	15.000	2.300
8	2.000	17.500	1.850
9	2.000	20.000	1.750
10	2.000	22.500	1.750
11	2.000	25.000	1.750
12	4.000	0.000	61.000
13	4.000	2.500	13.700
14	4.000	5.000	11.500
15	4.000	7.500	9.500
16	4.000	10.000	8.000
17	4.000	12.500	6.500
18	4.000	15.000	5.500
19	4.000	17.500	4.500
20	4.000	20.000	4.000
21	4.000	22.500	3.500
22	4.000	25.000	2.800
23	6.000	0.000	26.000
24	6.000	2.500	23.500
25	6.000	5.000	20.800
26	6.000	7.500	19.000
27	6.000	10.000	17.500
28	6.000	12.500	16.000
29	6.000	15.000	15.000



a



b

Fig. 10 Variation of the local contact pressure p_c, in daN/cm^2, depending on the static pressing force P_s, in daN, and on the energy density I_s, in W/cm^2: 1- 2W/cm^2; 2- 4W/cm^2; 3- 6W/cm^2; 4- 8W/cm^2; a - the 3D graphic representation on contour; b – the 3D graph determined with the lowest squares method
Material ABS; Frequency: 24 KHz; Amplitude A: 25 µm

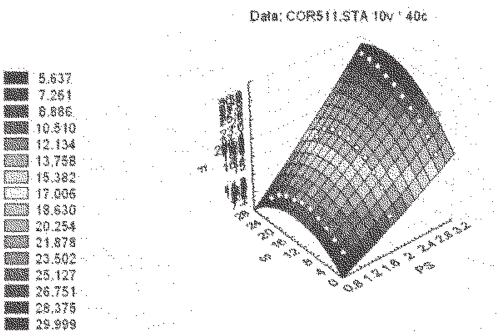


Fig. 11 Variation of the join's resistance F, in daN, depending on the static pressing force P_s, in daN, and on the welding materials' thickness s, in mm: 1- s=1,0+1,0; 2- s=2,0+2,0; 3- s=3,0+3,0
The 3D graph determined with the lowest squares method

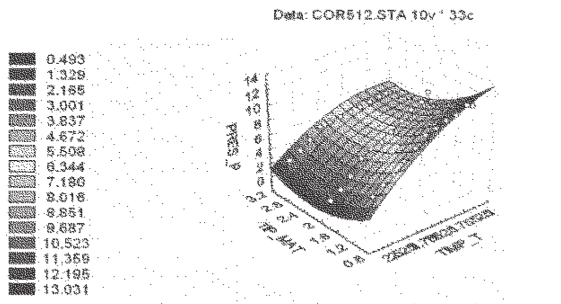
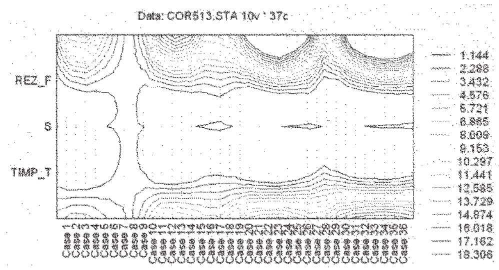


Fig. 12 Variation of the local contact static pressure, p_c, in daN/cm^2, depending on the welding time t, in s and the plastic material types: 1 – ABS, 2 – high density poliethilen, 3 – policarbonat.. The 3D graph determined with the lowest squares method



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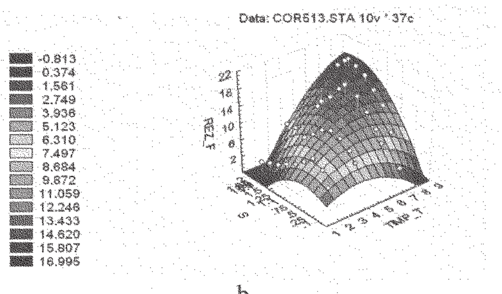


b

Fig.13. Variation of the welding resistance F, in daN depending on the welding time t, in s and the welding parts thickness s, in [mm]: 1- 1,0+1,0; 2- 2,0+2,0; 3- 3,0+3,0; 4- 4,0+4,0;
a- the 3D graphic representation on contour; b– the 3D graph determined with the lowest squares method
Material ABS; Frequency: 24 KHz; Amplitude A: 25 µm

Table 10
DEPENDENCY $p_c=f(P_s, I_s)$

#	1 IS	2 PS	3 PC
10	2.000	22.000	14.000
11	4.000	0.000	5.400
12	4.000	2.500	6.000
13	4.000	5.000	6.600
14	4.000	7.500	7.100
15	4.000	10.000	7.400
16	4.000	12.500	8.300
17	4.000	15.000	9.100
18	4.000	17.500	9.700
19	4.000	20.000	10.300
20	4.000	22.500	10.900
21	4.000	24.000	11.200
22	6.000	0.000	4.600
23	6.000	2.500	4.900
24	6.000	5.000	5.100
25	6.000	7.500	5.400
26	6.000	10.000	5.700
27	6.000	12.500	6.000
28	6.000	15.000	6.400
29	6.000	17.500	6.700
30	6.000	20.000	6.900
31	6.000	22.500	7.000
32	6.000	23.500	7.300
33	8.000	0.000	2.000
34	8.000	2.500	2.600
35	8.000	5.000	3.200
36	8.000	7.500	3.700
37	8.000	10.000	4.000
38	8.000	12.500	4.600
39	8.000	15.000	5.200
40	8.000	17.500	5.700
41	8.000	20.000	6.000
42	8.000	22.000	6.600

Table 11
DEPENDENCY $F=f(P_s,s)$

#	1 PS	2 S	3 F
1	1.000	2.500	7.100
2	1.000	5.000	8.600
3	1.000	7.500	9.800
4	1.000	10.000	10.700
5	1.000	12.500	11.300
6	1.000	15.000	11.400
7	1.000	17.500	10.800
8	1.000	20.000	10.300
9	1.000	22.500	9.300
10	1.000	25.000	7.200
11	2.000	2.500	10.000
12	2.000	5.000	15.000
13	2.000	7.500	17.000
14	2.000	10.000	19.000
15	2.000	12.500	20.000
16	2.000	15.000	20.700
17	2.000	17.500	20.650
18	2.000	20.000	20.300
19	2.000	22.500	19.300
20	2.000	25.000	16.400
21	3.000	2.500	18.600
22	3.000	5.000	21.400
23	3.000	7.500	23.600
24	3.000	10.000	25.000
25	3.000	12.500	26.400
26	3.000	15.000	27.800
27	3.000	17.500	28.600
28	3.000	20.000	29.600
29	3.000	22.500	30.000
30	3.000	25.000	30.200
31	3.000	2.500	27.200
32			

Table 12
DEPENDENCY $p_c=f$(t, PLASTIC MATERIALS TYPES)

#	1 TIP_MAT	2 TIMP_T	3 PRES_P
1	1.000	100	11.200
2	1.000	250	11.600
3	1.000	500	10.800
4	1.000	750	10.600
5	1.000	1.000	10.200
6	1.000	1.250	9.800
7	1.000	1.500	8.600
8	1.000	1.750	7.400
9	1.000	2.000	6.200
10	1.000	2.250	5.400
11	1.000	2.500	4.400
12	2.000	100	10.000
13	2.000	250	9.000
14	2.000	500	8.400
15	2.000	750	7.400
16	2.000	1.000	6.400
17	2.000	1.250	5.600
18	2.000	1.500	5.200
19	2.000	1.750	4.400
20	2.000	2.000	2.400
21	2.000	2.250	1.200
22	2.000	2.500	200
23	3.000	100	6.800
24	3.000	250	6.600
25	3.000	500	6.400
26	3.000	750	6.200
27	3.000	1.000	6.000
28	3.000	1.250	5.800
29	3.000	1.500	5.600
30	3.000	1.750	5.500
31	3.000	2.000	4.200
32	3.000	2.250	3.200
33	3.000	2.500	2.400

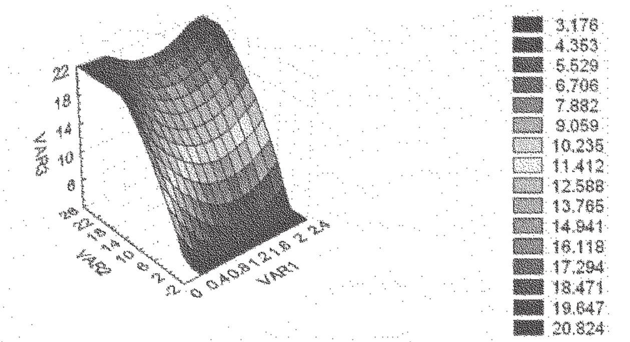


Fig.14. The variation of the welding resistance F, in daN (VAR 3) depending on the welding time t, in s (VAR 1) and the plastic material types (VAR2): 1- high density poliethilen; 2- ABS; 3-policarbonat; 3D graph determined with the lowest squares method Frequency: 24 KHz; Amplitude A: 25 μm

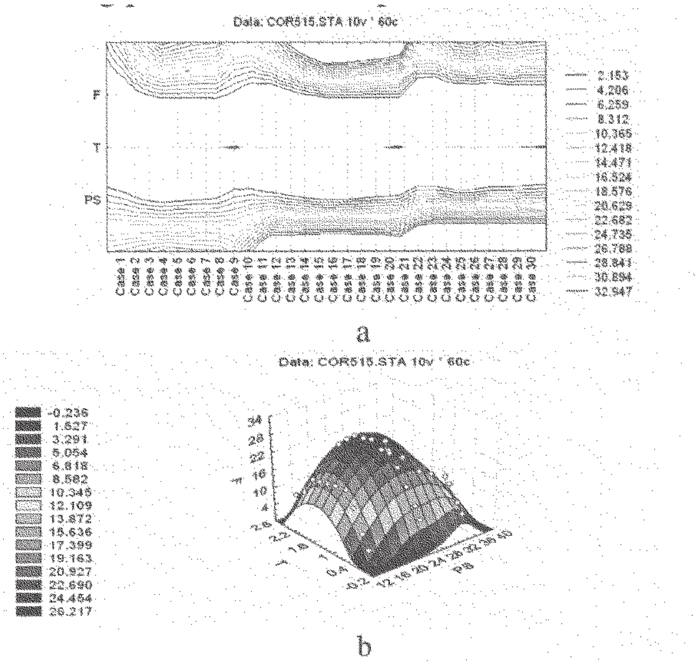


Fig. 15. Variation of the join's resistance F, in daN, depending on the welding time t, in s and the static pressing force P_s, in daN: 1- P_s=15 daN; 2- P_s=25 daN; 3- P_s=35daN; A - the 3D graphic representation on contour; B – the 3D graph determined with the lowest squares method 4. The dependency of composed materials welded joins quality on technological parameters

The dependency of welded joins quality on local contact static pressure

The experimental research made on different materials have shown the dependency of the local contact static pressure on the static pressing force, on the welding time, the welding parts thicknesses, the dimensions and geometrical configurations of the contact area.

We observe that, while the welding time rises, going from the first to the second stage of the welding process, the contact area expands, determining a drop in the local contact static pressure (table 12 and fig.12). There is an optimum value for the local contact static pressure, over which the welding is not possible.

For a high quality welded join, it is necessary to make a certain geometry for the contact area, the so-called acoustic energy concentrators. These obtain not only a rapid acoustic and thermic energy concentration in the local welding areas, but also a high static pressure in these areas, pressure that drops when the concentrators melt, enlarging the contact area .

The number and dimensions of these concentrators depend on the materials' nature, and on the geometrical configuration of the welding parts.

The dependency of the welded joins resistance on the welding time

The welding time, meaning the duration of the ultrasonic energy transmission to the contact area, influences significantly the welded join's resistance.

The experimental research made on different materials, with different thicknesses, have shown that here is an optimum welding time value for each material, depending on their properties, and for each thickness, the maximum resistance moving with the diminishing thicknesses (table 13 and fig. 13, table 14 and fig. 14)

Table 13
DEPENDENCY F=f(t,s)

#	1 TIMP_T	2 S	3 REZ_F
1	2.000	.100	4.170
2	2.000	.250	7.480
3	2.000	.500	8.900
4	2.000	.750	6.930
5	2.000	1.000	5.000
6	2.000	1.250	3.620
7	2.000	1.500	2.200
8	2.000	1.750	1.380
9	2.000	2.000	.280
10	4.000	.100	7.200
11	4.000	.250	9.450
12	4.000	.500	11.100
13	4.000	.750	11.650
14	4.000	1.000	10.550
15	4.000	1.250	8.350
16	4.000	1.500	6.350
17	4.000	1.750	7.520
18	4.000	2.000	7.200
19	6.000	.100	9.450
20	6.000	.250	11.930
21	6.000	.500	14.720
22	6.000	.750	17.200
23	6.000	1.100	18.350
24	6.000	1.250	16.660
25	6.000	1.500	13.620
26	6.000	1.750	11.380
27	6.000	1.850	9.720
28	8.000	.250	0.000
29	8.000	.500	7.500
30	8.000	.750	12.800
31	8.000	1.000	15.280
32	8.000	1.250	17.480
33	8.000	1.500	18.620
34	8.000	1.700	19.450
35	8.000	1.800	18.620
36	8.000	2.000	16.650

Table 14
DEPENDENCY F=f(t, PLASTIC MATERIAL TYPES)

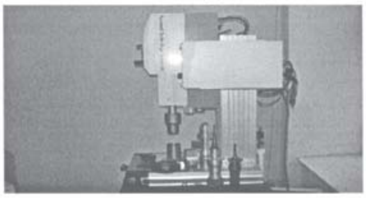
#	1 TIP_MAT	2 TIMP_T	3 REZ_F
1	1.000	.500	3.100
2	1.000	.750	4.690
3	1.000	1.000	6.220
4	1.000	1.250	7.140
5	1.000	1.500	7.480
6	1.000	1.750	7.170
7	1.000	2.000	6.860
8	1.000	2.250	6.240
9	1.000	2.500	5.620
10	2.000	.100	6.240
11	2.000	.500	8.100
12	2.000	.750	11.240
13	2.000	1.000	12.800
14	2.000	1.250	14.070
15	2.000	1.500	15.000
16	2.000	1.750	15.620
17	2.000	2.000	15.500
18	2.000	2.250	15.000
19	2.000	2.500	13.760
20	3.000	.100	13.100
21	3.000	.250	15.620
22	3.000	.500	17.830
23	3.000	.750	20.000
24	3.000	1.000	21.240
25	3.000	1.250	22.500
26	3.000	1.500	22.170
27	3.000	1.750	20.620
28	3.000	2.000	16.550
29	3.000	2.250	12.480
30	3.000	2.500	10.000

Tabel 15
DEPENDENCY F=f(t,P_s)

#	1 PS	2 T	3 F
1	15.000	.300	1.860
2	15.000	.500	6.240
3	15.000	.750	13.760
4	15.000	.940	18.760
5	15.000	1.250	18.140
6	15.000	1.500	17.210
7	15.000	1.750	16.510
8	15.000	1.940	16.240
9	15.000	2.250	10.000
10	15.000	2.500	7.480
11	25.000	.100	8.140
12	25.000	.250	11.860
13	25.000	.500	16.860
14	25.000	.750	21.860
15	25.000	1.000	26.240
16	25.000	1.100	28.760
17	25.000	1.500	27.170
18	25.000	1.750	26.240
19	25.000	2.000	25.620
20	25.000	2.250	23.140
21	25.000	2.500	20.000
22	35.000	.100	4.380
23	35.000	.250	7.480
24	35.000	.500	12.480
25	35.000	.620	14.380
26	35.000	1.000	13.140
27	35.000	1.370	11.860
28	35.000	1.870	13.760
29	35.000	2.250	13.140
30	35.000	2.500	12.830


a


b


c


d


e

Fig.16. The MECASONIC ultrasound welding installation of composed materials used in the experiments: general view; b- frontal view; c- lateral view; d- detail with the used ultraacoustic systems; e- the pneumatic equipment KAESER for triggering the ultraacoustic system

The variation of the breaking resistance F, of the welding join depending on the welding time t and the static pressing force $\mathbf{P_s}$, are presented in table 15 and figure 15. We observe that there is an optimum value for the welding time for each value of the static pressing force, the maximum welded join's resistance being higher or lower depending on $\mathbf{P_s}$ value.

Directly correlated with the welding time is the plastering speed in the welding areas. The short time rise of this speed based on the action of the acoustic energy in the contact area creates favorable conditions for the welding process to develop.

In concordance with the welded parts functional role, the technological parameters directly influence the shape, size and characteristics of the welded joins.

The dependency of welded joins quality on the welding material nature

The obtained experimental results have shown that the weld ability is appreciated by the damping factor β, of the oscillations amplitude in that material [21-23] [1].As the damping factor is higher, the energy will be less leading to the welding materials separation limit and so, the welded join will be more difficult to form, and the parts thicknesses will have to be smaller to obtain a quality weld.

The dependency of welded joins quality on the welding materials' surface micro irregularities

Every surface micro regularity is an acoustic energy concentrator and the first melted areas will appear in the higher microirregularities. The melted material is sent to the lower micro irregularities contributing to the melting intensification in these ones, this process being accelerated by the acoustic energy introduced in the welding area. Experimental results confirmed that, as the contact surface micro irregularities are bigger, so does the welding process prime faster, making a higher quality weld.

The dependency of welded joins quality on the welding method

The welding method influences in a special way the welded joins quality because depending on it the ultrasound energy introduced in the surface micro irregularities is assigned , the ultrasound energy is dosed, and the degree of continuity and mechanization of the welding process is obtained.

By the way the assignment and dosage of the ultrasound energy are made in the welding surfaces, there are „close field" and „far field" welding methods used.

The experiments were made on different composed materials on existing equipment at different enterprises or on existing installations in the T.M.S. department (fig.17).

Conclusions

The making of ultrasound welded composed materials is a complex technology because there must be taken into account several acoustic, mechanical and technological parameters, that have different influences on the welding process.

The main acoustic parameters that must be optimized are: the acoustic conditions and the ultrasonic oscillation type in the ultra acoustic system; the oscillation amplitude, the ultrasound oscillation frequency, the ultrasound energy intensity, the ultra acoustic energy density, the reflexion and absorbsion qualities of the acoustic anvil, etc.

The main mechanical parameters that must be optimized are: the static pressing force, the local static contact pressure of the welding areas, the shape factor of the ultrasound energy concentrator, the shape and material of the sonotrod and of the acoustic anvil, the welding type, the maintaining time, etc.

The main technological parameters that must be optimized are: the welding materials nature, the geometrical configuration of the welding surfaces, the welding materials thickness, the welding surfaces state, the welding method, etc.

The quality of ultrasound welded joins also depend on other parameters that have not been treated in this paper, that is the state and quality of the sonotrod surface and of the acoustic anvil, the cleaning state of the welding surface, the physical state of the limit contact area of the welding materials, the nature of the surroundings in which the welding is made, etc.

The optimization of the ultrasound welding process means finding an objective function that comprises all the parameters, function that can be optimized with a minimum cost of the welding operation or with a maximum productivity. Because it is extremely hard to find such a function, there were established the dependencies between different parameters, in groups of three, using a 3D analysis programme, and for the graphs there were used canonic functions.

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