Ultrasonic Welding With The Application Of Rotating Welding Tool And Roller Support

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***Abstract* – The article shows the results of studies of the formation of continuous lengthy seams with the application of rotating welding tool and roller support. Obtained dependences of the process productivity (the speed of seam formation) on the parameters of ultrasonic action (vibration amplitude are in the range of 20…50 µm), the width of the welding tool is from 2…20 mm, the thickness of the materials is 100 µm to 2 mm, pressing force allow design rotating welding tool and develop specialized high-productive equipment for the generation continuous welding seams.**

***Index Terms* – Ultrasonic rotating welding, continuous lengthy seams, technology.**

I. INTRODUCTION

CONTINUOUS ULTRASONIC welding is the most perspective method of obtaining of qualitative secure continuous welding seam of thermoplastic polymer films and fabrics. It is proved by the possibility of providing durable welding seam (up 80% of the strength of the main material) at the welding speed of 1 m/sec.

In food, pharmaceutical and other branches of industry continuous welding is widely used for the formation of lengthy welding seams (see Fig.1) [1] allowing solve problems of the packaging and production of various articles [2].

Fig. 1. Examples of formed seams and the articles with continuous welding seams.

II. PROBLEM DEFINITION

The main requirement to the systems of the ultrasonic continuous welding is the formation of qualitative lengthy and if necessary hermetic welding seam with maximum productivity.

The implementation of this requirement causes the necessity to fulfill several obligatory conditions.

The main of these conditions is the necessity of providing optimum ultrasonic action (frequency, vibration amplitude) at different conditions of the process realization (joining of the materials with different properties varying in the density and the thickness, at different time or at various speeds of continuous movement and the use of different anvils, on which the seam is formed).

That is why, auxiliary conditions promoting value decrease of energy action and increase of process speed are:

– selection and application of the optimum scheme of the seam formation determining the method of introduction of vibrations (providing of contact and pressing force of the radiating surface of the vibrating system to the surface of the materials to be welded) and movement along formed seam;

– selection and application of the anvil (form and material), on which the seam is formed, it is intended not only for the creation of the conditions (exclude shift, provide necessary movement, etc.) of seam formation, but for providing with maximum productivity of the process due to efficient energy release in the welding zone and exclusion of such energy release outside the welding zone;

– application (if necessary) of additional laying materials, which protect formed article from mechanical damage during the welding process.

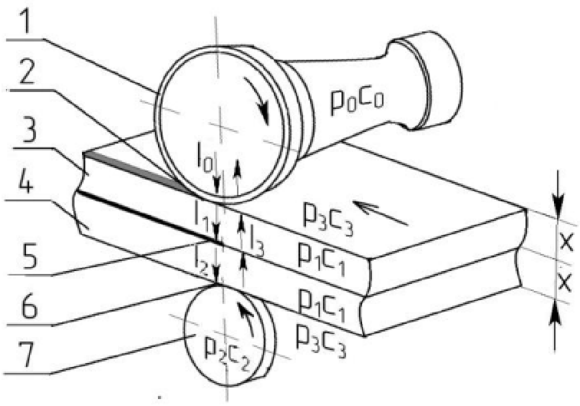
In order to fulfill all mentioned above conditions it is necessary to carry out the analysis of the process of continuous welding to determine the modes of ultrasonic action, which are necessary and sufficient for the generation of seam and they will allow reduce and optimize the parameters of the action.

III. THEORY

At present for the generation of continuous seam with high speed two methods of the process realization are used. At the first method the welding tool remains immovable, on its surface the materials to be welded are drawn, they are pressed by special rotating or traveling support (ultrasonic sewing machine). At the second method rotating working tool travels on the materials placed and fixed on the flat support (table). Each of the methods has both advantages and disadvantages; most of them can be easily eliminated at the welding realization at the simultaneous rotation of the working tool and the support made in the form of rotating roller.

Such scheme of the welding realization [3] – [5] is the most efficient for the formation of continuous welding joint (see Fig.2), but it is not studied well.

The materials to be welded 3 and 4, which are characterized by the acoustic impedance $Z_1 = \rho_1 c_1$ and have thickness X each, are limited with the radiating surface of the welding tool 1 of the ultrasonic vibrating system from the material with the acoustic impedance $Z_0 = \rho_0 c_0$ from one side and with the roller 7 from the material with the acoustic impedance $Z_2 = \rho_2 c_2$, to which the materials are pressed by the welding tool of the ultrasonic vibrating system under pressure P, from the other side. Air is characterized by the acoustic impedance $Z_3 = \rho_3 c_3$. The area 2 in the volume of the materials to be welded, limited by surface area S and thickness of the materials 2x, corresponds to the zone of ultrasonic vibrations absorption, heat release and formation of welding joint. Ultrasonic vibrations generated and amplified by the vibrating system are introduced by the radiating surface into the materials to be welded.



1 – welding tool, 2,6 – interface, 3,4 – materials to be welded, 5 – welding zone, 7 – roller

Fig. 2. Scheme of continuous seam ultrasonic welding of thermoplastics.

Intensity of ultrasonic vibrations generated by the radiating surface of the ultrasonic vibrating system can be expressed as

$$I_0 = 2\pi^2 f^2 A_0^2 \rho_0 c_0 \qquad (1)$$

Taking into account the fact, that at the ultrasonic welding full acoustic contact of the radiating surface of the ultrasonic vibrating system and the materials to be welded is provided, at the interface 2 ultrasonic waves are reflected and only a part of ultrasonic vibrations passes through the interface to the welded material 3. At that reflection coefficient η_1 and transmission coefficient of d wave on the interface are defined by well-known formulae:

$$\eta_1 = \left(\frac{\rho_0 c_0 - \rho_1 c_1}{\rho_0 c_0 + \rho_1 c_1}\right)^2 \qquad (2)$$

$$d = 1 - \eta_1 \qquad (3)$$

Then vibrations with intensity (4) will be introduced into thermoplastic material with the acoustic impedance:

$$I_1 = 2\pi^2 f^2 A_0^2 \rho_0 c_0 \left(1 - \left(\frac{\rho_0 c_0 - \rho_1 c_1}{\rho_0 c_0 + \rho_1 c_1}\right)^2\right) \qquad (4)$$

Energy absorbed by the thermoplastic material 2 with the acoustic impedance $\rho_1 c_1$ at the passing of ultrasonic can be defined as follows [3-5]:

$$W_1 = (I_1 - I_1 e^{-2\alpha x})S, \qquad (5)$$

where α is the amplitude damping coefficient, $I_1 e^{-2\alpha x}$ is the intensity of ultrasonic vibrations on the interface 6, where $2x$ is the way passed by way.

$$W_2 = (I_1 e^{-2\alpha x} - I_1 e^{-4\alpha x})S + (\eta_2 I_1 e^{-4\alpha x} - \eta_2 I_1 e^{-8\alpha x})s + (\eta_3 I_1 e^{-4\alpha x} - \eta_3 I_1 e^{-8\alpha x})(S - s), \qquad (6)$$

where s is the area of the contact zone of welded materials, and S is the area of introduction of ultrasonic vibrations, i.e. area of active zone of ultrasonic action.

Energy dissipation rate of ultrasonic vibrations or instantaneous rate of heat release in welded materials can be expressed in a following way [6]:

$$W = 2\pi^2 f^2 A_0^2 \rho_0 c_0 (1-\eta_1)(S - e^{-2\alpha x} S - e^{-4\alpha x} S + \eta_2 e^{-4\alpha x} s - \eta_2 e^{-8\alpha x} s + \eta_3 e^{-4\alpha x}(S - s) - \eta_3 e^{-8\alpha x}(S - s)), \qquad (7)$$

where the area of the contact zone is calculated from the dependences (8),

$$s = \frac{2\pi \cdot Ri \cdot ArcSin\left(\frac{Ecc}{2 \cdot Ri}\right)}{360}, \qquad (8)$$

where Ecc is the roller coefficient, s is the active contact area for the tool or the roller support, Ri is the radius of the roller.

$$Ecc = \frac{1}{A}\sqrt{-(A+R2+R1+x)(A+R2-R1-x)(A-R2+R1+x)(A-R2-R1-x)} \qquad (9)$$

$$A = R1 + R2 + Z \qquad (10)$$

$$Z = x - \frac{F \cdot x}{E \cdot S_0}, \qquad (11)$$

where A is the distance between the centers of the rotating mechanism, Z is the gap between the roller and the tool, x is the thickness of the materials, F is the pressing force of the welding tool to the materials; E is the elastic modulus of the materials.

The results of the calculations of the gap value between the tool and the roller support depending on applied pressing force to the welding tool are shown in Table I: Based on the obtained values for applied force of the tool on the material the dependences of the rate can be determined for various materials from the expression:

$$V_{np} = \frac{s}{t \cdot b}, \qquad (12)$$

where S is the contact area, b is the width of the contact zone, t is the welding time.

TABLE I

LIMITS OF APPLIED FORCE OF THE TOOL FOR UNDER STUDY MATERIALS

Material	Elastic modulus, kilogauss/m²	Yield point of the polymer, MPa	Maximum force of action on the material, N	Gap between the tool and the roller support, micron
Polyethylene	122.36	20	291	173.6
Polypropylene	170.29	30	439	171.3
Polystyrene	183.54	20	291	182.4
PVC	275.32	30	439	182.3
PEF	1437.7	40	580	195.5

From the expressions (12) taking into account (7) let's define broaching speed:

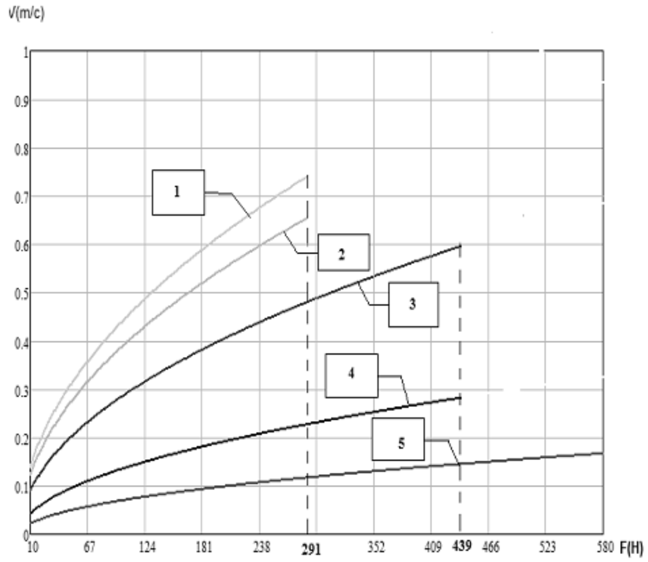
$$V_{np} = \frac{W \cdot S}{b\rho_1 V_1 \int_{T_{нн}}^{T_{пл}} C\,dT + \lambda \rho_1 V_2 + Q_3} \qquad (13)$$

The expression (13) shows the dependence of time of ultrasonic welding on amplitude and frequency of ultrasonic vibrations, thickness of the materials and width of formed welding joint subject to physical, acoustic and thermodynamic properties of the materials (density, speed of sound, etc.).

The value Q_3 takes into consideration heat loss in the welding zone [3] – [5].

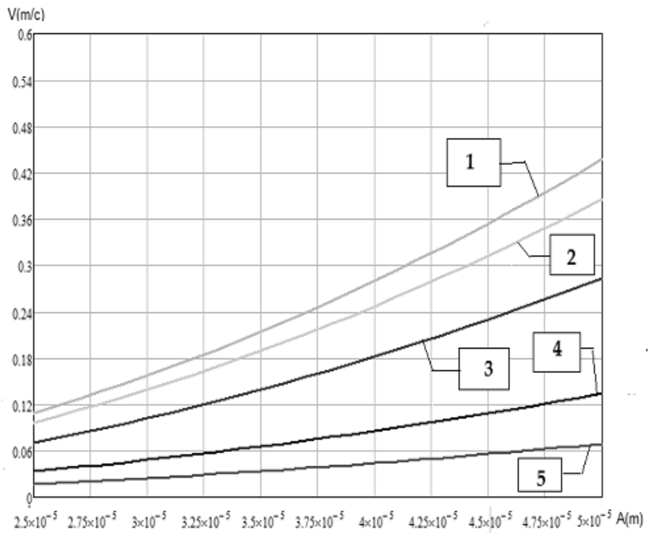
Obtained results allow use the dependences of broaching speed of the materials on the value of applied force (see Fig.3), on vibration amplitude of the radiating surface of the tool (see Fig.4), on the thickness of the materials to be welded (see Fig.5) for solution of practical tasks of welding of materials with various properties.

Besides that obtained dependences let determine productivity of the process (broaching speed) on the width of formed seam (see Fig.6).



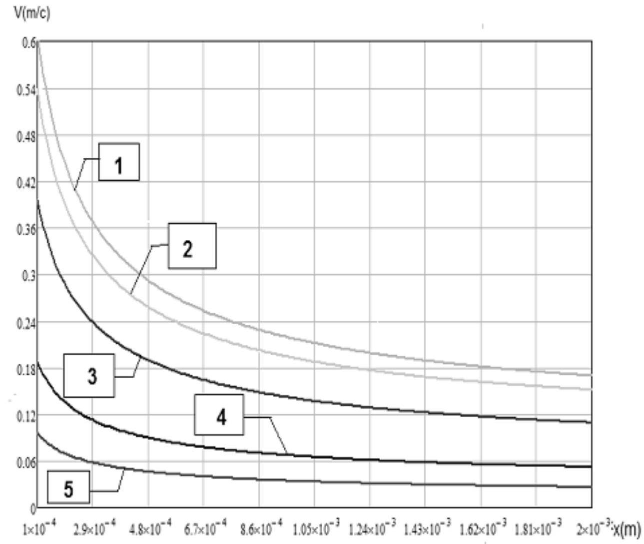
1– polystyrene; 2 – polyethylene; 3 – PVC; 4 – polypropylene; 5 – PEF

Fig. 3. Dependence of the broaching speed of the materials on applied force at the thickness of the material of 200 μm.



1– polystyrene; 2 – polyethylene; 3 – PVC; 4 – polypropylene; 5 – PEF

Fig. 4. Dependence of the broaching speed of the material on amplitude of ultrasonic vibrations of the tool.



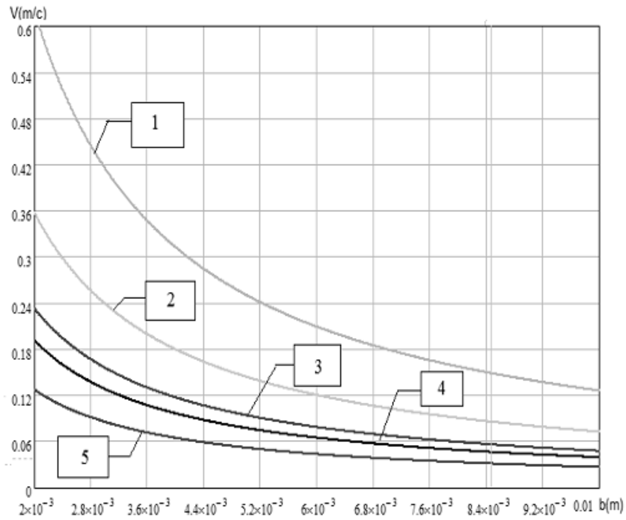
1– polystyrene; 2 – polyethylene; 3 – PVC; 4 – polypropylene; 5 – PEF

Fig. 5. Dependence of the broaching speed of the material on the thickness of the materials to be welded.

IV. Experimental Results

Thus carried out analysis of the formation of continuous welding joint with the application of the rotating tool and the support let determine the dependences of the broaching speed of the materials (productivity of the process) on: vibration amplitude A (μm) in the range of 20…50; width of the welding tool h (mm) in the range of 2…10; the thickness of the material x (mm) in the range of 0.1...2; pressing force of the welding tool F(N) in the range of:

1) 10–580 N for PEF;
2) 10–439 N for polypropylene and PVC;
3) 10–290 N for polystyrene and polyethylene.



1– polystyrene; 2 – polyethylene; 3 – PVC; 4 – polypropylene; 5 – PEF

Fig. 6. Dependence of the broaching speed of the material on the width of the welding tool.

Ultrasonic welding with the application of the rotating tool and the support can be realized by the ultrasonic vibrating system, which is able to provide transformation of longitudinal vibrations of the piezoelectric transducer into the radial vibrations of the rotating welding tool [6,7]. The formation of continuous lengthy welding seam is accomplished by pressing of the radiating surface of the welding tool of the ultrasonic vibrating system to the roller-support. For the realization of the process special welding tools (see Fig.7), being a part of the ultrasonic vibrating system shown in Fig.8, were developed.

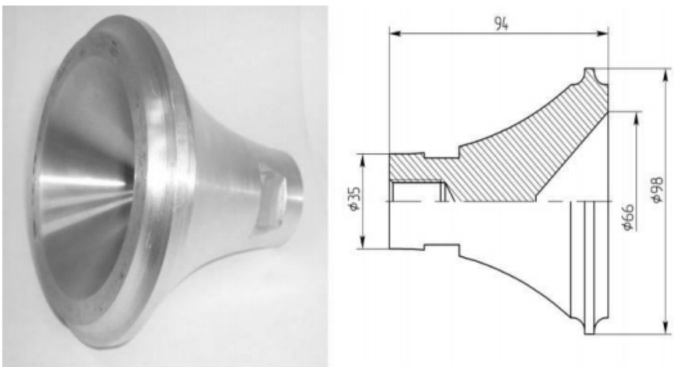


Fig. 7. Welding tool for the formation of lengthy continuous welding seams.

The use of developed ultrasonic vibrating system provides the formation of radial vibrations of the welding tool with the amplitude of up to 35 µm at the deflection along the radiating surface not exceeding 6%.

Fig.9 shows the examples of the welding seams made by developed special-purpose equipment and rotating roller-support with the special rolling on the surface.

Fig. 8. Vibrating system providing the transformation of longitudinal vibrations into radial ones.

Fig. 9. Examples of welding seams made with the application of the ultrasonic equipment.

V. CONCLUSION

As a result of carried out researches we analyzed the process of continuous ultrasonic welding with the use of rotating support, the analysis allowed determine the dependences of process productivity (broaching speed) on the parameters of ultrasonic action (vibration amplitude in the range of 20…50 µm), width of the welding tool in the range of 2…20 mm, thickness of the materials in the range of 100 µm to 2 mm, pressing forces.

Developed specific ultrasonic equipment [8] – [10] is applied at the formation of continuous welding seams in practice at several enterprises and its large-scale production is being prepared now.

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