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EXPERIMENTAL STUDY AND OPTIMISATION OF TECHNOLOGICAL PARAMETERS OF ULTRASONIC WELDING OF SYNTHETIC POLYMERIC MATERIALS

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The paper analyzes the possible ways of joining of polymer-based synthetic fabrics. The technological capabilities of seam ultrasonic welding of synthetic fabrics are considered. Experiments on the weldability of polyester, nylon and polypropylene fabrics are carried out. The main parameters of the mode of seam ultrasonic welding of synthetic fabrics are determined.

***Keywords*: **ultrasonic welding, synthetic fabrics, static welded pressure, the fixed gap, amplitude of fluctuations, a wave guide tool

Nowadays, synthetic fabrics are widely used in industry and various branches of national economy for the manufacture of linen and household products, heavy sea ropes, fishing nets, V-belts and belts, workwear, fire hoses, fabrics for the needs of medicine, as well as in chemical, mining, oil-refining industries and non-ferrous metallurgy [1, 2].

Successful application of synthetic fabrics is due to a complex of properties, such as high physical and mechanical properties, minimal water absorption, resistance to aggressive media and elevated temperatures, izno- sostoyanie, etc., as well as to the use of synthetic fabrics. Due to these properties synthetic fabrics successfully compete with natural fabrics. The most widespread synthetic fabrics are divided into the following groups according to the chemical structure of their fibres: polyamide (capron, anid), polyester (lavsan), polyacrylonitrile (nitron), polychlorovinyl (chlorine) and polypropylene [2, 3]. Until recently, synthetic fabrics were joined with threads on sewing machines. However, this method of joining has significant disadvantages [1, 2]. Thus, when threading synthetic fabrics with high elasticity, the formation of waviness and corrugations is inevitable, which leads to an unsatisfactory appearance of seams. The fabrics wrinkle and deteriorate, especially if the stitching is in the weft. At high speeds, when the thread passes through the eye of the needle at a speed of 0.3 metres per second, the thread and fabric heat up due to frictional heat. The heating can be so great that it causes the thread to melt and break. Attempts to reduce heating by cooling the needle with a cold air jet and using various needle lubricants result in more complicated sewing machine construction, contamination of fabrics or corrosion damage to needles. Often, due to the scarcity of synthetic threads, synthetic fabrics are sewn together with cotton threads, which significantly reduces the strength and performance properties of the fabric joints. When joining a number of technical fabrics impregnated with various compositions to give them special properties, as well as in the manufacture of products that require tightness of the joint (for example, a filter for liquid and gaseous media), the method of sewing with threads becomes generally unacceptable [1, 4, 5]. When sewing garments made of synthetic materials sewing threads should have the same chemical composition as the material, otherwise there is wrinkling of seams in the process of sewing or after washing and cleaning due to different shrinkage of threads and fabrics. These defects are poorly eliminated by subsequent wet and heat treatment [1, 4].

Due to the listed disadvantages of threaded joints, threadless methods of fabric joining are becoming more and more widespread: thermal contact, high-frequency and ultrasonic welding. The most promising of the methods is ultrasonic welding, which allows to eliminate most of the above-mentioned disadvantages while ensuring the required strength of seams. In addition, the refusal to use sewing threads in the process of joining fabrics eliminates such problems as selection of threads by needle diameter, thickness, colour and chemical composition; thread refilling in case of their breakage or termination; thread cutting and fixation of their ends; needle position, etc. [4, 6].

One of the best methods of ultrasonic welding, which makes it possible to produce synthetic fabrics with rectilinear and curvilinear seams of long length, is ultrasonic seam welding [6, 7].

According to the latest classification of ultrasonic welding methods developed by the staff of the Department of Welding Technology and Diagnostics of the Bauman Moscow State Technical University, welding is divided into press and continuous welding. Press welding is performed in one working movement of the waveguide-tool. This method produces spot, rectilinear and closed seams of various contours. Continuous welding is classified according to the following main features: the degree of mechanisation, the method of moving the material to be welded and the method of dosing the input energy [4, 7].

According to the degree of mechanisation, continuous welding is divided into manual and mechanised welding. In manual welding, welds are obtained by moving the welding unit manually, and the product is fixed on the support stationary. In mechanised welding, as a rule, the product to be welded is moved and the welding unit remains stationary. The workpiece is moved by a special mechanism.

Depending on the method of the material to be welded, continuous welding is divided into seam-step and seam welding. Seam-step welding combines press welding with the movement of the material to be welded by a certain step. The step size is selected so that the overlap of the seams is ensured. In "pull-through" welding, the workpiece is pulled between the support and the working end of the waveguide connected to the travelling mechanism. In the "rotating-roller-support" welding scheme, the material to be welded is moved by a special roller, which serves as a support at the same time [6, 8].

Ultrasonic welding is subdivided into fixed gap welding and fixed draft welding according to the method of dosing the input mechanical energy. The scheme with fixed gap can be used both for seam-step welding and for seam welding, and the scheme with fixed draft □ can be used only for seam-step welding.

Of all these methods, fixed gap ultrasonic seam welding is the most commonly used for welding of synthetic fabrics. This welding method is relatively simple, it also allows to regulate the welding speed and to obtain welded joints of any length and configuration (Fig. 1).

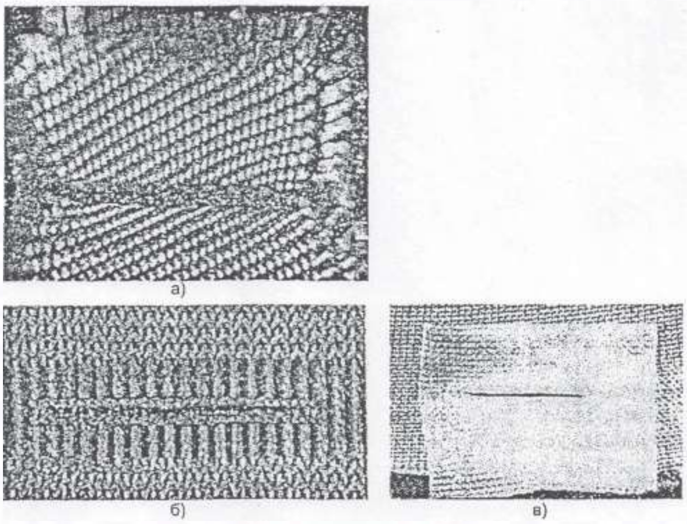

Fig. 1. Welded joints of synthetic fabrics made with ultrasound: a □ welded seam; b □ welding of loops; c □ process of ultrasonic cutting of fabrics.

In this work we studied the weldability of 600 µm thick lavsan, capro- new and polypropylene fabrics. During the research, ultrasonic welding of synthetic fabrics was carried out on a continuous seam welding machine with a fixed gap UPSH-12, developed at the Department of Welding Technology and Diagnostics of Bauman Moscow State Technical University (Fig. 2). The peculiarity of the machine UPSH-12 is that to increase the strength of the welded joint behind the waveguide there is a rolling roller mounted on the bed bracket. Due to the fact that fabrics have a large heat capacity and a small coefficient of heat recoil, the welded seam approaches the roller not yet cooled, so rolling takes place at an increased temperature. As a result of rolling, the strength of the welded joint is increased by 4□7% compared to the strength of the welded joint obtained without rolling. The position of the rolling roller can be adjusted depending on the thickness of the synthetic fabric, which enables the fabric to be rolled with different pressing force during welding. The set screw is used to adjust the gap between the end of the waveguide and the support up to 5 mm. The USP-12 machine is equipped with a piezo-ceramic converter with a power of 0.4 kW, frequency of 22 kHz, operating from a power supply.

22 kHz, operating from ultrasonic generator IL10-0,4, developed by the company "Ultrasonic Technology - INLAB" (St. Petersburg). The generator is manufactured with output power from 100 W to 10 kW on field-effect transistors and with the possibility of operative regulation of all operating parameters. In this work we used IL10-0,4 generator with 400 W power, equipped with smooth adjustment of acoustic power, which is very important when welding synthetic fabrics, digital frequency meter and analogue indicator of acoustic system resonance. The generator has a phase auto-tuning frequency and a polarisation source with an output current of up to 30A. The generator is forced air-cooled, operating frequency is 22 kHz.

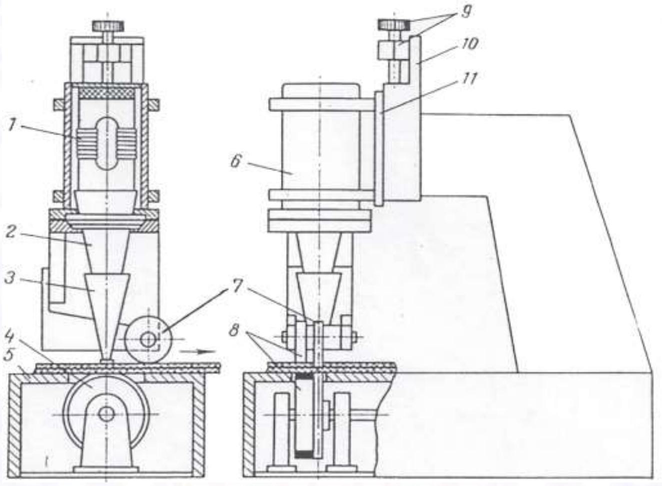

Fig. 2. Welding machine UPSH-12: 1 □ converter; 2 □ trans-former of elastic oscillations; 3 □ waveguide-tool; 4 □ support-role; 5 □ working table; 6 □ converter fence; 7 □ rolling roller; 8 □ pulling rollers; 9 □ setting screw and nut; 10 □ bed; 11 □ moving panel.

The mass of the generator is 6.2 kg. The IL10-0,4 generator allows to choose the operating mode of ultrasonic equipment for welding synthetic fabrics, at which the efficiency of the acoustic unit will be maximal.

The UPSH-12 machine is used for ultrasonic welding of filter jackets made of synthetic fabrics with seam length of 2.5 m at mining and processing plants. It provides up to the required strength. The machine operates without water cooling. The high efficiency of the machine is primarily due to the goodness of the ultrasonic piezoceramic vibrating system and low natural losses. The results of research of high-quietness vibrating systems used for welding of synthetic fabrics allowed to determine the optimal modes of operation.

The optimal parameters of the continuous seam welding mode are: the amplitude of oscillations of the working end of the waveguide A (μm), oscillation frequency f' (kHz), welding speed V (m/s), and static welding pressure Pst (MPa) or the waveguide-to-material force F (N). Such parameters were determined in the process of ultrasonic seam welding of three types of fabrics: capron, lavsan and polypropylene with a thickness of 600 μm. The delamination strength of the joint was chosen as an optimisation parameter. When studying the influence of one of the welding mode parameters on the strength of the welded joint, the values of the other two parameters are kept constant [8]. One value is varied while the other parameters remain unchanged. The limits of variation of the parameters are determined by the values at which the maximum strength of the synthetic fabrics to be welded is detected. The sequence of parameter selection to determine the stability of the best welding mode can be different. The oscillation frequency depends on the generator used and, as a rule, remains unchanged, i.e. of the order of 22 kHz. The constant parameters in each case are selected by the method of successive approximation and are close to the optimum. For example, A = 30□40 μm, and the optimum amplitudes for high-power magnetostrictive transducers are approximately within this range. The amplitude of waveguide oscillations A during welding of synthetic fabrics is different, which can be explained by their different melting temperatures Tpl: for polypropylene fabric Tpl = 165°C, kapron fabric 215°C, lavsan fabric 260°C [2, 8]. The optimum values of static welding pressure Pst for different materials are approximately the same and amount to about 24 MPa. In our system, the welding pressure is created by the gap between the waveguide and the support, which is approximately half of the total thickness of the synthetic fabrics to be welded. The optimum welding speed V is low: it is about 20 m/h for all fabrics, while in high-powered machines the welding speed is up to 50 or even 100 m/h. Increasing the welding speed V is usually achieved by increasing the static welding pressure Pst, but in high-voltage oscillating systems, increasing Pst leads to a sharp decrease in the amplitude of waveguide oscillations. The point is that with increasing welding pressure, the resistance of the acoustic load increases, which, due to the low resistance of the intrinsic losses of such systems, begins to strongly affect the operating mode of welding sets [4, 6]. Thus, in conditions where high productivity of the process is required, powerful power sources (400 W and higher) and metallic magnetostrictive transducers should be used for welding of synthetic fabrics.

The strength of the welded joints of synthetic fabrics also depends on the material of the waveguide and support. The height and shape of the support have virtually no effect on the strength of the welded joints. When selecting a waveguide material for welding synthetic fabrics, two points should also be taken into account. Firstly, if the waveguide is made of a material characterised by high hysteresis losses, e.g. steel, it heats up during prolonged operation and the heat dissipation from the welding zone deteriorates. Since the duration of ultrasound exposure to the material remains constant, the deterioration of heat dissipation leads to excessive melting and squeezing of the weld zone, due to which the strength of the welded joint decreases.

Secondly, when calculating the geometrical dimensions of the waveguide from the resonance condition, energy losses in the waveguide material are not taken into account [4, 7]. In this case, the influence of the waveguide material on the strength of the welded joint is similar to the influence of the vibration amplitude.

Exponential knife waveguides made of steel 45 and aluminium alloy D16T were used to investigate the strength of a welded joint made of welded fabrics. Both waveguides had the same gain and their length corresponded to resonance at the same frequency of 22 kHz. However, the amplitude of oscillation of the D16T alloy waveguide with lower hysteresis loss was 30 µm, while the amplitude of oscillation of the steel waveguide was 45.20 µm. The results of the tear test of the welded joints welded with these waveguides are given in Table 1.

Material	Tensile strength, MPa, at welding duration, s									
	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9	1,0
D16T alloy	1,8	3,5	5,5	6,0	6,5	7,0	7,3	7,5	7,7	8,0
Steel 45	1,0	2,4	3,5	4,5	5,5	6,0	6,2	6,5	6,8	7,0

In the production of round loops with a diameter of 13 mm, a hole was simultaneously punched in the fabric and metal film to form a rim. The use of ultrasonic welding in this case allowed to reduce the loop manufacturing time from 49 to 5 s, i.e. the productivity increased 10 times. Fabrics with thickness from 220 to 500 microns made of polypropylene and capro- new fibres in combination with wool, cotton and artificial silk with synthetic fibre content not less than 50% were used.

Studies of knitted fabric press welding have shown that good results are achieved when welding at a fixed weld thickness. For dense materials that do not change their thickness in the range of static welding pressure of 24 MPa. The weld thickness is equal to the thickness of one layer of material, regardless of the number of layers (24) and the type of weld (butt weld, overlay weld).

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