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HEAT-PULSE WELDING OF WOVEN POLYMERIC SHEET MATERIALS

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The aim of the work is to test the technology of welding filter bags made of polyester ultralight fabric of linen weaving. The tasks are the choice of welding method, creating an experimental installation, adjusting the parameters of the welding process and evaluating the quality of the produced welds. The method of heat-pulse welding with T-shaped welt seams with continuous penetration and simultaneous cutting of the welded material was chosen. An experimental installation with a heating element made of nichrome wire of 0.8 mm diameter was developed. During one cycle of heat-pulse welding, two longitudinal welds, the so-called T-shaped welt seams are formed, the shape and size of which depend on the heating mode of the polymeric material. Welded filter bags were turned before using in such a way that T-shaped seams in the working environment were directed inwards and the load on dangerous areas of welds was reduced. Mechanical tests of welds of filter polyester fabric produced by heat-pulse welding showed a sufficient level of their mechanical strength. To control the quality of the finished filter bags, it is sufficient to visually inspect the welds for leaks or other obvious defects. Results of the work is the technology of manufacturing filter bags from mesh polyester fabric by means of heat-pulse welding of welt seams with continuous penetration and cutting of the welded material is worked out. The welding installation was created. Parameters of a welding mode were established. It was determined that produced welded joints in terms of strength characteristics meet the necessary criteria for the intended use of filter bags made of ultra-thin polymeric fabrics. 9 Ref., 8 Figures.

Keywords: thermoplastics, welded joints, polyester fabric, heat-pulse welding

Polymers are used as construction materials in different fields of production [1–3]. In particular, fabrics made of polyester synthetic fibers are widely used both in the production of consumer goods as well as in different technical products. The most well-known representative of polyesters used for the production of fibers is polyethylene terephthalate (PET). The traditional name for PET in post-Soviet countries is lavsan, other trade names for this polymer are dacron (USA), terylene (Britain), tekadur (Germany), and tetoron (Japan). PET is an aliphatic-aromatic polyester obtained by polycondensation of ethylene glycol with teraphthalic acid. This polymer is a solid rigid thermoplastic, transparent in the amorphous state and white in the crystalline state.

The production of polyester fiber is carried out by the traditional method of extrusion, i.e. by squeezing a melt of polyethylene terephthalate through numerous ultra-thin holes in the die with the following air cooling. For the production of yarn (threads) in the textile industry, so-called staple fibers of a specially determined length, not more than 40–45 mm, are used [4]. The vast majority of all synthetic threads of different types are used for the production of different fabrics.

The principle of fabric production has remained unchanged for many centuries. Technical filter fabrics, depending on the field of application differ in the method and density of weaving. In the modern textile industry, dozens of different types of weaving are used, the simplest of which is linen, when longitudinal threads (warp) and transverse threads (weft) alternately intersect. The geometric density of fabric is determined as a number of threads per unit length [5].

An important area for application of technical polyester fabrics is filter elements for laboratory equipment designed to determine the specific content of cellulose (non-nutritious part) in plant products. Determination of cellulose content by the Weende method consists in the fact that the sample of plant product is first subjected to hydrolysis in a solution of sulfuric acid, and then to alkaline hydrolysis in a solution of sodium hydroxide [6]. Samples of products during laboratory analysis are loaded into special small bags of filter fabric. At the present, such packages are not produced in Ukraine, though they are in a great need. Therefore, the development of domestic technologies and equipment for production of filter bags is an urgent task. For joining fabrics of polymeric thermoplastic fibers, it is possible to use those welding methods which are developed for polymeric films [7, 8].

For production of filter bags, polyester ultralight technical fabric of linen weaving of the Saatifil brand was chosen [9]. The fabric of the article PES 68/38 is

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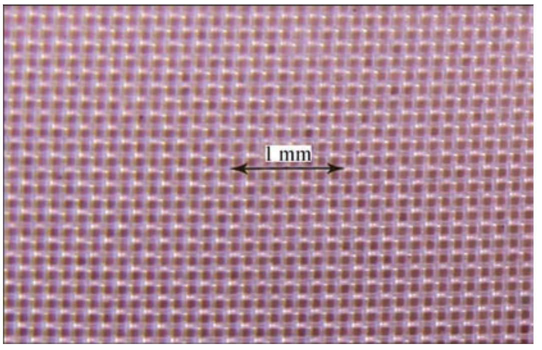

Figure 1. Structure of light polyester (lavsan) filter fabric of linen weaving

resistant to the action of acids and alkalis at elevated temperature, it has a milky color and its specific weight is 32 g/m^2.

Figure 1 shows an enlarged view of the structure of the polyester fabric PES 68/38. Linen weaving of a low-density provides the formation of a mesh structure of the fabric uniform in both directions and well permeable to air and water. The linear density of the fabric amounts to 90 threads per centimeter. The longitudinal and transverse threads of the fabric are absolutely identical, the average diameter of the thread, which consists of several polyester monofibers, is 40 μm. The average size of the square gaps between the threads is 68 μm. Therefore, during the research works the fabric can reliably hold fragments of a refined material with a minimum size of 0.1 mm.

A filter bag of polyester fabric is 120 by 45 mm in size. Its production according to the standard technology of sewing with threads is difficult and low-efficient. There is a technology of welding filter bags by ultrasonic method, according to which by means of the inlet weld, from the band a fabric sleeve is formed, and in the second stage a «bottom» is formed by the transverse T-shaped weld. However, the strength of such welds is not more than 35–40 % from the level of the base material, which leads to their frequent fractures during the analysis. A promising method of joining ultra-thin thermoplastic material in the manufacture of filter bags is heat-pulse welding using a heated tool.

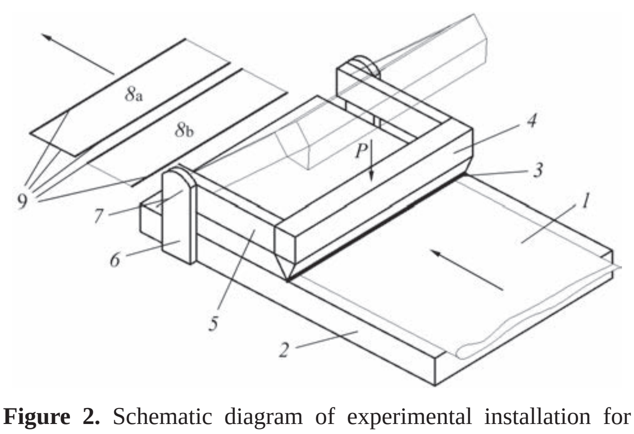

Figure 2. Schematic diagram of experimental installation for heat-pulse welding of filter bags (designation see in the text)

Welding of ultra-thin polymeric materials with a thickness of up to 250 μm, which are very sensitive to excessive heating of material in the joint area, is performed by heat-pulse method using a heating tool of low weight and heat capacity, which is heated for a short time by a powerful electric pulse. In this case, the method of heat-pulse welding by T-shaped welt seams with full penetration and simultaneous cutting of the welded material was chosen.

To optimize the process operation diagram of welding thin polyester fabric, an experimental installation was designed (Figure 2). On a rectangular base *2* all parts of the installation are fixed and welded materials *1* are placed. The wire heating element *3* is fixed in the lower part of the housing of the upper electrode *4*. From the rear side, two brackets *5* are attached to the electrode, connected by their ends to the vertical struts *6* by a horizontal axis *7*. The upper electrode with the brackets can swing relative to the axis *7*, getting into contact with the base plane, its own weight is sufficient to create a working force of pressing *P*. The heating element was made of cylindrical nichrome wire of 0.8 mm diameter and 150 mm length. The heater through the insulating gasket was fixed in the lower part of the movable electrode of the installation with the connection of the power supply wires.

Two process operation diagrams of filter bag formation were compared. In the first variant, two samples of fabric were welded laid on each other and filter bags of type 8a with two side and one lower weld were obtained. In the second variant, the samples of fabric were welded, folded in half in the longitudinal direction, and bags of type 8b were welded with two side welds and a bottom, formed by the fabric fold, were obtained.

When through the heating element electric current of 9–10 A passes, the wire is heated to the saturation temperature at the level of 270–290 °C for about 1 s and then its temperature increases slowly. Therefore, heating of the welding zone was regulated by the duration of the operating current pulse.

The stages of the process of heat-pulse welding of polyester fabric are schematically shown in Figure 3. At the initial stage (Figure 3, *a*) the heating element *1* approaches the place of welded joint of fabric samples *2*, which are laid in two layers on a flat base *3*. After that, the power source is turned on and the working current pulse begins. At the second stage (Figure 3, *b*), the heated wire tool begins to melt a polymeric material of the fabric. Under the action of the pressing force, the heating tool is gradually lowered, melting first the upper layer of the fabric and then the lower one. Such melting is finished at the moment, when the heater touches the surface of the base and both layers of the fabric are cut with a cylindrical wire at the place of joining. On both sides

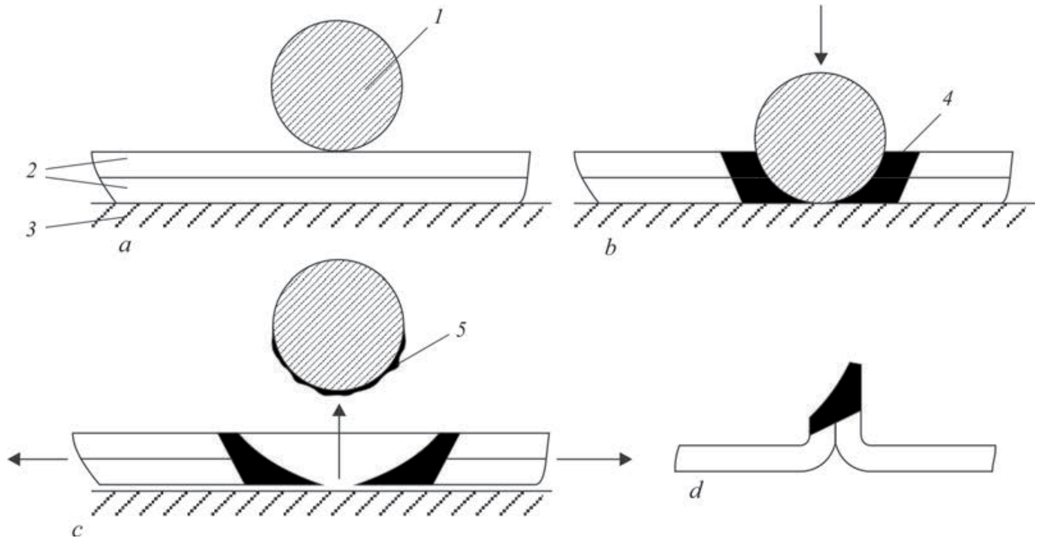

Figure 3. Main stages of technological process of heat-pulse welding with simultaneous thermal cutting (designation see in the text)

of the heater, small volumes of a molten polymer 4 are formed, which subsequently form welds.

Thus, in one cycle of heat-pulse welding, two longitudinal welds are formed on both sides of the cylindrical heating element. After a complete penetration of the fabric, its cut parts are removed from each other (Figure 3, c), the heating element is raised and removed from the welding zone. On the surface of the heater wire, a small amount of molten polymer material 5 remains. If the duration of a working current pulse is extended by 1–2 s, the stickened material completely evaporates and has almost no effect on the quality of the weld to be produce in the next cycle. The developed technology allows producing so-called T-shaped welt seams, the shape and size of which depend on the heating mode of the polymeric material. Usually in a working condition such seams are located perpendicularly to the main plane of fabric (Figure 3, *d*).

Tests of welded bags under the conditions simulating workloads showed that from the point of view of fracturing, the most dangerous are the initial areas of the welds near the neck of the small bag and the final areas of the welds at the corners of a product. Therefore, it was decided to turn out filter bags before using so that the welts of T-shaped seams in the working environment were directed inwards. The load on the dangerous areas of the welds in this case is significantly reduced due to changes in the geometric shape of the fabric (Figure 4).

The T-shaped welt seam of polyester fabric is formed as a result of melting the sewn polymer material of the fabric, which after cooling and hardening forms a solid rigid polymer structure. As a result, a welded joint of a flexible mesh fabric linen is formed, consisting of a fibrous material with a solid hardened polymeric material of the weld (Figure 5). During loading of a T-shaped welt seam, the main stresses are concentrated in a narrow zone along the weld, where the fibrous sewn material of the fabric mates the hardened rigid polymeric material of a weld. Therefore, the size and shape of the weld itself have little effect on the strength of welded joint.

The mesh fibrous polymeric material of the filter fabric melts rather quickly at a temperature of 260–270 °C. Therefore even at a short contact of a heater with a fabric, within 3–5 s, on a fabric the longitudinal band of 1–2 mm width melts. As a result, after hardening of the melt, a solid polyester welt with a width from 1 to 3 mm is formed having a nonuniformly distributed thickness along the weld. Moreover, the welded joint itself at the place of contact between fabric threads and a solid weld has almost the same thickness, which is approximately equal to the thickness of one layer of the filter fabric. This is clearly seen in the enlarged image of the cross-section of the weld (Figure 5).

To evaluate the strength parameters of T-shaped welds of polyester fabric, a series of mechanical tests

Figure 4. Turned out filter bag prepared for use

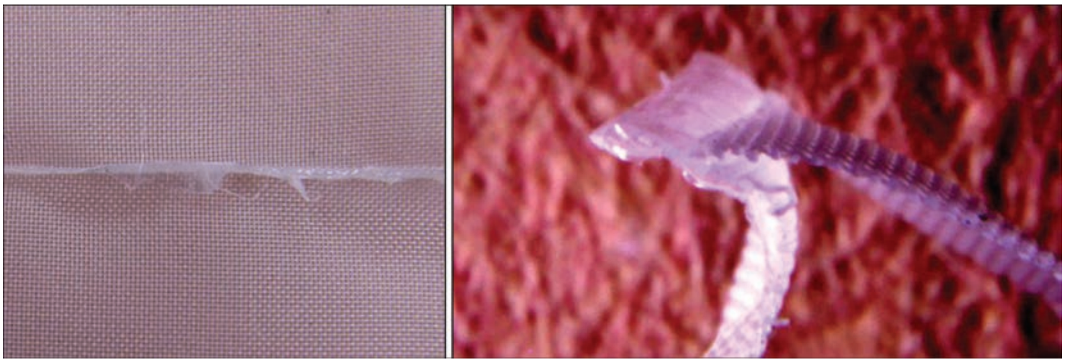

Figure 5. Longitudinal T-shaped weld of polyester filter fabric

were performed. The strength of welded joints of the fabric was determined with the use of a rupture machine during tensile tests of band samples of 50 mm width with a welt seam in the center of the sample. With the excess in the critical load level, the fracture of the weld begins in the weakest places on both sides from a rigid welt formation, and the hardened polymeric material of the weld remains sound. When tearing away the main linen from the weld, the mesh structure of a linen weave of the fabric maintains its regularity and remains almost sound. Thus, the main factors influencing the strength of welded joint of a filter fabric are physical and geometric parameters of the place of joining each transverse thread of the fabric relative to the weld with a rigid polymeric material of a T-shaped welt. Thus, the strength of the entire weld is formed as an integral sum of the strength of attachment of individual threads to the monolithic material.

A linen mesh weaving of fabric with a small density of threads adjacent to each other creates a symmetrical spatial structure of the fabric without significant differences between the shape of longitudinal and transverse threads. All threads of the fabric after weaving acquire a wavy sinusoidal shape. Therefore, in the area of joining the fabric with the weld, there are alternating «upper» and «lower» transverse threads, intertwined relative to the longitudinal thread. Accordingly, flattenings on the threads near the joint are formed alternately either from top, or from bottom, which in the photos of the weld in the plan looks like alternation of such formations through one (Figure 6).

During fracture of the seam of the fabric under the action of tensile load, the rupture occurs along the line of joning, which is formed by a chain of flattened transverse threads, partially joined with remnants of a longitudinal thread, which is not completely melted during welding. Along the fragment of the fabric edge torn from the weld, deformed ends of the upper and lower transverse threads alternately follow one another. At the enlarged image of the torn edge (Figure 7), it is seen that deformation of the ends of the threads represents namely flattening of a fibrous cylindrical material, which becomes flat, expands and reduces its thickness.

The scheme of forming a welded joint of a mesh thread structure, inherent to polyester fabric, is presented in Figure 8. Fragments of the fabric to be joined are formed by interweaving of transverse and longitudinal threads relative to the weld line. In the process of welding, a part of threads, which directly undergo the action of the heating tool, melts and forms a solid array of a polymer melt along the entire weld line. Since the process of heating the weld is short and takes units of seconds, threads that do not have a direct contact with the heater, are almost not subjected to thermal effect and do not change their size and shape. This applies to the threads longitudinal relative to the weld, which in the mesh fabric are separated by free gaps of 65–70 μm. Longitudinal threads directly adjacent to the fusion line are melted only partially and in selected areas depending on their distance to the heater during welding.

On the contrary, all transverse threads inevitably contact with the heating tool during heating of the wo-

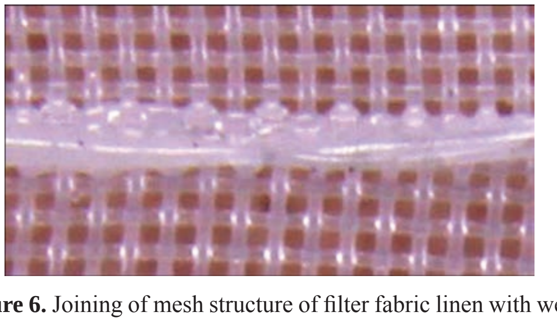

Figure 6. Joining of mesh structure of filter fabric linen with weld material

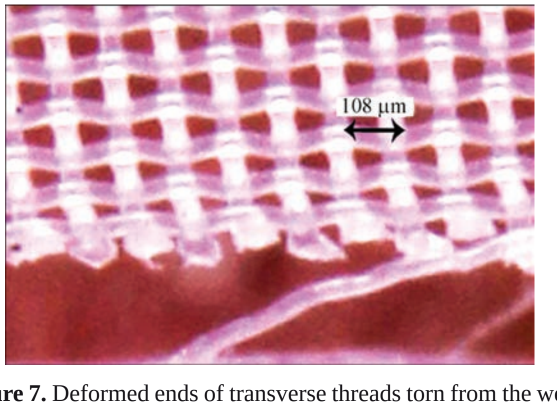

Figure 7. Deformed ends of transverse threads torn from the weld of mesh fabric

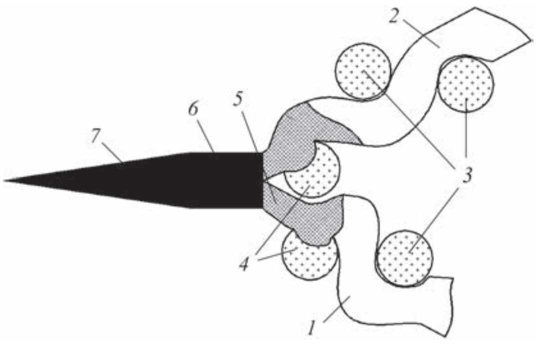

Figure 8. Scheme of formation of cut-out T-shaped weld of mesh filter fabric: *1*, *2* — lower and upper cross threads; *3* — longitudinal undeformed threads; *4* — longitudinal partially melted threads; *5* — shape changes at the places of joining transverse threads; *6* — solid hardened weld; *7* — «tail» of a solidified melt formed during welds disjoining

ven material, the corresponding parts of them melt and participate in the formation of a pool of a homogeneous melt. Through the zone of transition from the polymer melt to the unconverted fibrous polymeric material of the thread, the line of joining of the fabric to be welded is formed. In the scheme, Figure 8 it is shown that the thickness of the threads in these places is significantly reduced as a result of their flattening, as far as the wire of the heating tool with a diameter of 800 μm acts as a punch on the thread with an average diameter of 40 μm.

After completion of heating and removal of the heating tool, the array of a solid polymer melt hardens and forms a hard weld along the entire welding line. Since in this case welding with cutting takes place, two longitudinal welds are simultaneously formed on both sides of the heater string. The volume of a molten material of threads is small, so the transverse dimensions of the hard weld amount to fractions of a millimeter. On the other hand, at the moment of disjoining the parts of the fabric cut by heating, strands from the melt are formed, which after hardening in some places of the weld «tails» in the form of fibers of different shapes and lengths form.

Thus, joining the mesh fabric with the rigid weld occurs through the deformed flattened sections of the transverse threads, the strength of which is certainly reduced as compared to the basic strength of the thread. Each thread of the fabric has a complex inner structure and is woven from several tens of primary staple or continuous polyester fibers. In a welded joint, in the flattened areas these fibers are partially torn, change the angle of inclination and mutual orientation. It is almost impossible to preserve an undamaged fibrous structure of the thread during welded joint formation.

Mechanical tests of welds of a filter polyester fabric produced by heat-pulse welding showed that the maximum level of their mechanical tensile strength does not exceed 60–70 % of the level of the base material. Taken into account the high primary strength of woven polyester material, such strength of welds is quite sufficient for reliable service of filter bags made of it. After turning out, welded filter bags are completely ready for use. Taking into account the small level of mechanical loads on the fabric and welds of the bag during its service as a part of a laboratory installation, in order to test the quality of finished products, it is sufficient to visually inspect the welds to detect lacks of penetrations or other obvious defects.

Conclusions

The studies showed that the most effective method of joining a mesh filter polyester fabric is heat-pulse welding. The technology of manufacturing filter bags from polyester mesh fabric using a modified scheme of heat-pulse welding with welt seams with a full penetration and simultaneous cutting of welded material was developed. A welding installation was created, the studies of morphology and strength characteristics of welded joints produced by means of a modified method of heat-pulse welding were carried out. It was determined that produced welded joints meet the necessary criteria for the intended use of products made of corresponding ultra-thin woven fabrics.

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