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MECHANIZED WELDING OF LAMINATED PVC FABRICS WITH HOT AIR

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Technical laminated fabrics, which are used for the manufacture of awnings and inflatable products for different purposes, are made with double-sided PVC coating. The most widespread practical method of manual and mechanical welding of laminated fabrics with PVC coating is hot air welding. In this work, the features of hot air welding of the overlap welds of laminated PVC fabric were investigated in the manufactured experimental set up. The geometric dimensions and shape of the produced experimental welds from laminated fabric Unisol 950 (specific weight of 950 g/m^2) were established. In the course of the work, the mechanical strength of the welds produced by experimental welding was investigated, as well as tear test of the welds was carried out. The range of welding speed was set, within which welded joints of the laminated fabric are formed with tight penetration. It is shown that a tight penetration along the entire plane of the welded joint is achieved by forming a bead of molten PVC, uniform as to its diameter, under the pressure roller in the welding process. The nature of running of thermal processes in the welding zone was evaluated by the geometric parameters of the melt bead. The optimal parameters of the process of producing the butt welds of laminated fabrics, joined by a tape on both sides, and visual criteria for sound joint formation were determined, and the principles of manual control of the hot air welding process in real time were developed. 4 Ref., 10 Figures.

K e y w o r d s : welded joints, laminated PVC fabric, hot air welding

Laminated fabrics are a separate kind of thermoplastic composite materials (TCM) which are widely applied in different branches of the national economy: for manufacturing a wide range of consumer goods, as well as numerous products for engineering applications, such as awnings, architectural awnings, and inflatable products. They are produced by treatment of fiber base fabrics by different polymer compositions: melts, solutions, dispersions and pastes. Thus, laminated fabrics are textile sheets, the main characteristic of which is the pattern of thread weaving, i.e. a certain order of overlap of longitudinal (warp) threads with transverse (weft) threads. Such fabrics have high anisotropy of mechanical and electric characteristics that creates technological complexities during their welding. One of the main methods to join polymer laminated fabrics is hot air welding.

A large part of laminated fabrics are made using plasticized polyvinylchloride (PVC) as coating. Polyvinyl chloride is a transparent thermoplastic polymer, a product of polymerization of vinyl chloride (ethylene chloride). At present, PVC is the second most consumed polymer with the annual world production volume of more than 25 mln t. Pure polyvinylchloride is a rigid material, which becomes elastic only after heating up to the temperature of 70–75 °C. However, PVC elasticity can be achieved at room temperatures by adding special plasticizers, namely ethers of various alcohols and dicarbonyc acids. Salts of tin, barium, cadmium and calcium (3–5 mass fract.) are used as thermal stabilizers of plasticized PVC. Their main objective is material stabilization due to binding hydrogen chloride (HCl), which forms during thermal oxidative destruction of PVC at higher service temperatures [1].

Technical laminated fabrics, which are used to manufacture awning and inflatable products for different applications, which are made with two-sided PVC coating. Such fabrics have higher elasticity and high strength, their coating is airtight and resistant to the impact of sunlight, atmosphere and water. The majority of technical PVC fabrics are made by SOL-technology (from the English solution). By this technology, calendering of the fabric base by a solution of plasticized PVC in a light organic solvent is performed. In order to improve the adhesion of PVC coating with the sheet, two thin layers of polymer glue-adhesive are applied on the fabric simultaneously with calendering. Thus, the laminated PVC fabric has a five-layer structure (Figure 1). Products from the leading manufacturers are presented in the market, in particular fabrics for inflatable boats: Valmex, Plastel (Czechia), Heytex (Germany), Unisol Boat (South Korea), etc. [2]. Specialized laminated PVC fabrics are not yet produced in Ukraine.

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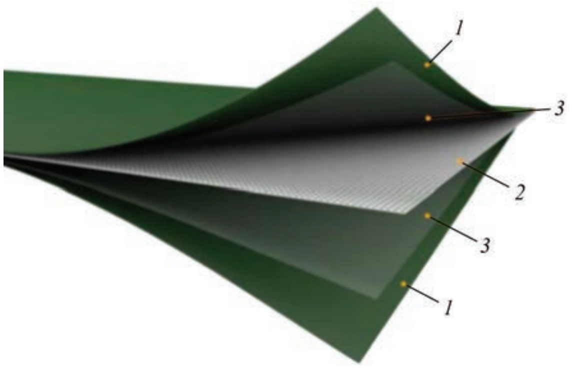

Figure 1. Scheme of design of laminated PVC fabric: *1* — outer and inner PVC layers; *2* — polyester woven base; *3* — layers of polymer adhesive

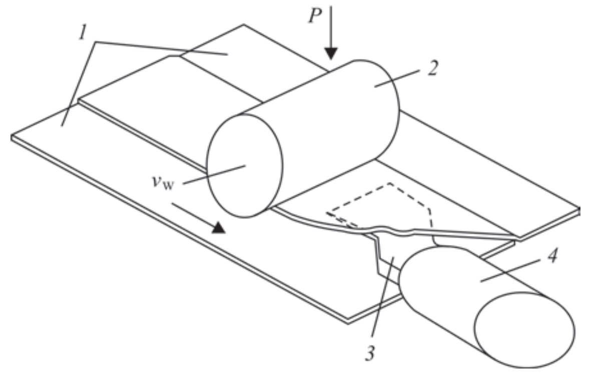

Figure 2. Scheme of overlap welding of fabrics with PVC coating using hot air: *1* — fabrics being welded; *2* — press-down roller; *3* — nozzle for overlap welding; *4* — hot air heater

Fabrics, laminated by plasticized thermoplastic PVC are suitable for welding by a heated tool (wedge) and hot air, as well as high-frequency welding [3]. High-frequency welding requires complex and costly equipment, which is designed for joining small rectilinear or local welds in one cycle. The heated wedge is applied as a rule, for joining thick polymer films and fabrics with thick polymer coating at manufacture of waterproofing compound and large tanks. Hot air welding is the method of welding laminated fabrics with PVC coating, which is the most widely accepted in practice. In this case, heating the parts to be welded is performed by a hot air jet of the temperature of 250–400 °C, and press-down rollers of various designs are used to form the welded joint. Hot air welding can be performed with addition of the filler material and without it, in the manual and mechanized mode. The method of hot air welding is versatile and flexible; it enables welding materials of a broad range of thicknesses, making welds of a complex configuration and located in different positions in space, and does not require complex equipment. The main element of any equipment for hot air welding is a special heater — a dryer fitted with the respective nozzles [4].

The schematic of the process of overlap welding of laminated fabrics in the manual and mechanized modes is shown in Figure 2. In overlap welding, the heater nozzle contacts the fabric surface directly. It leads to fracture and destruction of PVC coating of the fabric, and sticking of the molten polymer to the nozzle surface that does not allow producing sound joints for thin fabrics over the entire area of the overlap weld. Thus, it is rational to use semi-automatic machines for butt welding of fabric elements by a tape, in order to weld fabrics with a thin layer of PVC coating. In this case, there is no contact of the fabric surface with the heater nozzle, and the welding zone is heated exclusively by a hot air jet.

Practical experience proves that in manufacture of awning and inflatable products the required quality is provided by application of butt welds of the laminated fabric, joined by a tape from both sides. Here, the outer tape of the weld provides the main strength of the joint, while the inner tape is additional and ensures normal formation and tightness of the joints. Therefore, the inner tape is not welded separately, but is covered by the glue and is used as the backing for joining the laminated fabric. At heat sealing of the outer tape, the adhesive layer is activated, so that the inner tape is bonded to the butt.

In this work, an experimental set-up was manufactured for hot air welding of butt welds of laminated PVC fabrics. In this unit a modified carriage with an electromechanical drive from Leister semi-automatic machine was used for movement of the dryer and press-down roller along the butt of the fabrics. The scheme of the technological process of welding laminated PVC fabrics by a tape using hot air is shown in Figure 3. The butt of the two parts from laminated fabric *1* was placed on a solid surface together with backing tape *3* from the same material or from PVC film, coated by a thin layer of polyurethane glue. Bonding was performed using tape *2*, cut out of the same laminated fabric, as the parts. The welded joint was formed, using a roller with rubber coating *4* that was pressed to the tape and the parts from laminated fabric with force *P* and was displaced along the welding line at speed v_w. It should be noted that the roller width is by 2–3 mm greater than the width of the tape for welding.

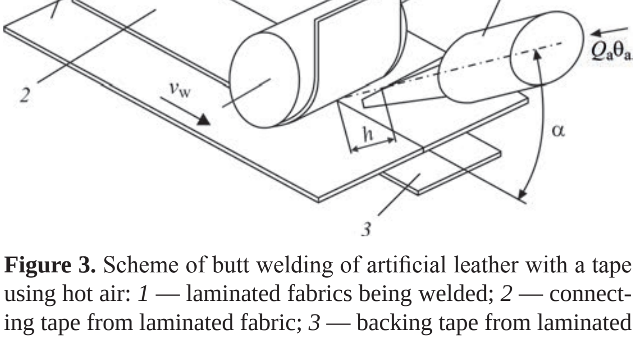

Figure 3. Scheme of butt welding of artificial leather with a tape using hot air: *1* — laminated fabrics being welded; *2* — connecting tape from laminated fabric; *3* — backing tape from laminated fabric; *4* — press-down roller; *5* — hot air heater with nozzle

Heating of the welding zone was performed by hot air that is supplied from the heater — electric heating dryer *5* through a flat nozzle, the width of which was equal to the width of the tape for welding. The main parameters of the heater are as follows: heated air temperature θ_a and air flow rate Q_a. The nature of heating of artificial leather in the welding zone was affected by the angle of positioning of heater nozzle α and distance from the nozzle to fabric h. The nozzle was located parallel to the joint plane, and the nozzle edge was parallel to the roller axis.

The width of the main tape from laminated PVC fabric for welding and backing tape was the same and equal to 38–40 mm. It should be noted that PVC fabrics with a lower specific weight can be also used as backing tape. During heat sealing the backing tape is heated up to the temperature of 70–80 °C. At heating, the adhesion ability of the interlayer of polyurethane glue increases significantly, and the tape sticking to the lower part of the welded joint takes place. It ensures the joint sealing and its additional strength.

In order to study the process of hot air welding of Unisol 950 laminated fabric of 0.8 mm thickness with specific weight of 950 g/m^2 straight experimental welds of 1.0–1.5 m length were produced. Welding was performed on a horizontal table with a longitudinal slot 40 mm wide and 0.8 mm deep for laying the backing tape. Leister Triak-S air heater with a flat nozzle 40 mm wide and press-down roller of 42 mm width and 30 mm diameter with heat-resistant rubber coating were installed on the carriage. Triak-S heater had a stable value of heated air flow of 230 l/min, air temperature was controlled by a regulator on the unit casing. Carriage movement speed was adjusted by its electric drive regulator. The load on the press-down roller was regulated by placing measured loads on the carriage.

It is determined that the optimum distance from the heater nozzle to the welding zone is equal to 7–8 mm. In this case, sufficient visibility of the heated fabric under the roller is ensured, and excess overheating of the fabric near the welded joint takes place. The load on the press-down roller that ensured normal formation of the welded joint, was equal to 5–6 kg (1.25–1.5 kg/cm). Experimental welding of joints of Unisol 950 laminated fabric was also performed with different values of hot air temperature and welding speed.

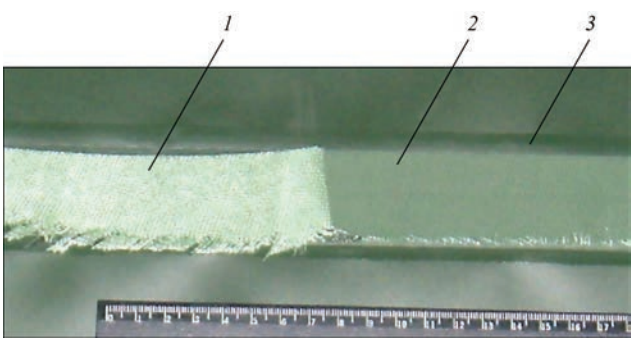

Figure 4. Sound weld of Unisol 950 laminated fabric after testing for tearing off of connecting tape: *1* — torn off tape with exposed cord; *2* — weld; *3* —HAZ near the weld

In order to determine the experimental weld strength, testing for uniaxial tension of laminated fabric strips 50 mm wide, cut out of samples in the transverse direction with the weld located in the strip middle, was conducted. Testing showed that the strength of sound welds is equal to base metal strength and is 290–310 kg that corresponds to the declared strength of Unisol 950 laminated fabric in the transverse direction (weft direction). The laminated fabric strips that were tested by tension, failed mainly in the base material. The main defect that reduced the weld strength, were lacks-of-penetration. Joints with lacks-of-penetration failed in the weld during tensile testing at smaller load values.

The quality of welded joints of laminated fabric can be evaluated also without conducting complex mechanical testing by application of express-method of testing the welds for pulling off the connecting tape. The tape welded from the weld end face is torn off the butt on a short length using a knife and pliers, the weld edge is clamped in a vice, the tape is held in pliers with wide jaws and is torn off the weld on its entire length. In the case of a sound bonding of the tape and the base material the coatings are fused together, and when the tape is torn off the weld, its cord or the cord of the base laminated fabric are bared, and the layer of fused PVC remains on the opposite side.

At pull testing of the weld with complete penetration, tape tearing off with complete exposure of the cord usually occurs (Figure 4). A uniform layer of fused PVC with traces of cord threads remains on the welded joint. Adhesion of the tape cord to PVC layer is so strong that destruction of the cord is observed on the one side of the tape at pulling off. The lower backing tape functionally has an additional role in the welded joint. At tearing off from the base it usually separates from the weld along the adhesive layer without destruction of PVC coating of the laminated fabric.

The main factors influencing the heat processes in the zone of fabric welding, and, thus, the weld quality, are the heated air temperature and welding speed. With rising of the air temperature, the welding speed, and, hence, labour efficiency, increase, but, on the other hand, the probability of overheating of the welding zone becomes higher. At overheating, not just the thin layer of PVC on the fabric coating is melted, but also the entire coating, particularly in the HAZ near the weld. In welding a large amount of PVC melt is removed from under the connecting tape, it sticks to the roller and forms sharp protrusions at solidifi-

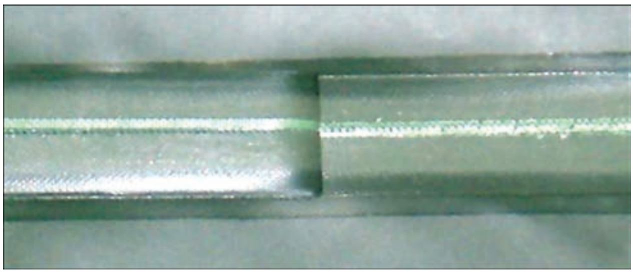

Figure 5. Weld of Unisol 950 laminated fabric made with insufficient heating of the welding zone

cation. In an overheated weld, all the layers of PVC coating on artificial leather are deformed and thinned. Such welds do not satisfy the requirements, either on strength and tightness or on appearance.

At lowering of the hot air temperature the probability of insufficient heating of the welding zone becomes higher. In this case, PVC coating of artificial leather usually melts only in the weld central part. At testing of such a weld for tape tearing off (Figure 5), the cord is bared only in a narrow band near the joint axis, while bands of total lack-of-penetration are observed along the weld edges.

The results of studying the experimental welds, made at different parameters of the mode, were used to determine the ratios of hot air temperature θ_a and welding speed v_w, at which normal welded joint formation is observed from the outside. At welding at hot air temperatures below 400 °C and low welding speeds, formation of regions of insufficient heating of the fabric and of local lacks-of-penetration is possible (Figure 6). Such regions cannot be detected visually, by examining the fabric weld from the outside. In service of a product with local lacks-of-penetration inside the welds, its sudden destruction can occur in extreme loading mode. In order to guarantee sound welds, modes with average values of air temperature on the level of 420–450 °C at heater outlet and corresponding values of welding speed should be selected. Separate factors, influencing formation of penetration in artificial leather joints, are nonuniform heating of the welding zone over the weld width and nonuniform pressure on artificial leather over press-down roller width. In this case, a longitudinal lack-of-penetration forms from one of the weld sides (Figure 7).

The axis of rotation of the press-down roller should be exactly parallel to welded joint plane. At deviation from parallelism, the roller pressure on one edge of the weld increases and the pressure on the opposite edge decreases. Consequently, removal of PVC melt from under the tape and formation of excess flash occur in the higher pressure zone. From the opposite edge of the weld, the pressure value turns out to be insufficient, molten PVC layers do not bond with each other and lack-of-penetration forms. At shifting of the hot air unit nozzle to the side, or deviation of nozzle axis from the axes of symmetry, an insufficiently heated

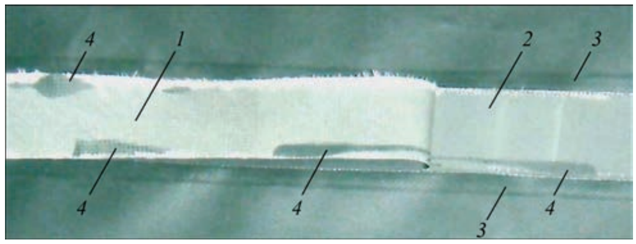

Figure 6. Weld of Unisol 950 laminated fabric with local lacks-of-penetration in the weld after testing for tearing off of the connecting strip: *1* — torn off tape with exposed cord; *2* — weld; *3* — HAZ near the weld; *4* — region of lack-of-penetration on the tape and on the weld

zone appears from one of the sides of the press-down roller and a lack-of-penetration also forms.

The absence of continuous and local lacks-of-penetration in the weld can be a criterion for evaluation of the quality of laminated fabric welded joint. A sound weld should have a 100 % penetration that is revealed as complete tearing off of the connecting tape cord from the weld PVC. Welds made at experimental welding in different modes, were tested for tape tearing off, and then the percentage of unwelded zones per a unit of weld area was determined. Analysis of investigation results showed that there exists a range of welding speeds of 0.07–0.12 m/s, in which welded joints of laminated fabric with complete penetration form, yielding 100 % value of penetration density P (Figure 8). Average values of heated air temperature of 420–450 °C at the outlet from heater nozzle correspond to these speeds.

It should be noted that during welding various process disturbances, shifting of parts from laminated fabric or of welding tools may arise that causes appearance of defective areas of the weld. Another problem also is ensuring normal formation of the joint at the start and end of the weld. That is why, the need arises for development of a special procedure for controlling the welding process and correction of its parameters in real time during welding. It was experimentally established that continuous tight penetration over the entire area of the welded joint is achieved at formation of a molten PVC bead of uniform diameter under the press-down roller in welding (Figure 9).

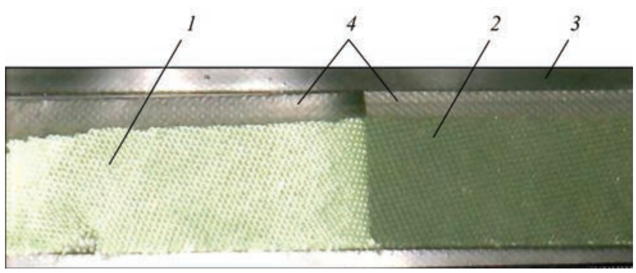

Figure 7. Weld of Unisol 950 laminated fabric with a lack-of-penetration near the weld edge after testing for tearing off of the connecting tape; *1* — torn off strip with exposed cord; *2* — weld; *3* — HAZ near the weld; *4* — zone of lack-of-penetration on the weld and on the tape

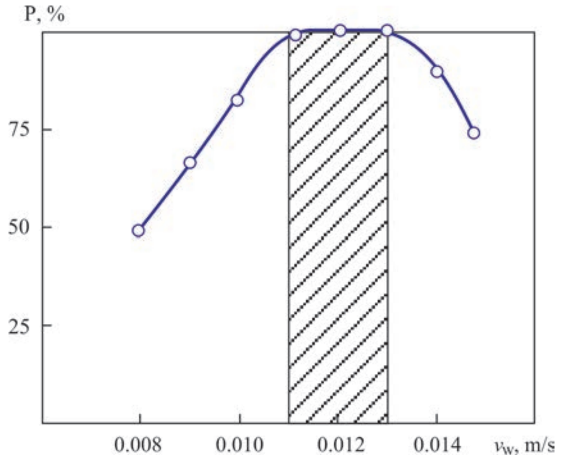

Figure 8. Dependence of tightness of penetration of the laminated fabric welded joint on welding speed

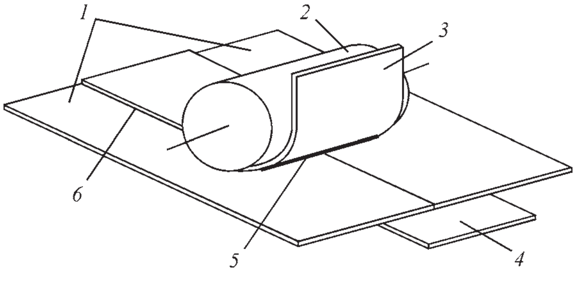

Figure 9. Scheme of optimal process of hot air welding of laminated fabric: *1* — laminated fabrics being welded; *2* — press-down roller; *3* — connecting tape from laminated fabric; *4* — backing tape from laminated fabric; *5* — PVC melt that forms during welding; *6* — PVC flash from welded joint sides

Geometrical parameters of the melt bead are informative values, which make it easy to evaluate the nature of running of thermal processes in the welding zone and adjusting them, if required. At sufficient lighting of the space under the roller, it is possible to visually observe the parameters of the melt bead. Presence of the bead indicates that melting of the laminated fabric PVC coating occurred, bead diameter is proportional to the heating level and amount of molten PVC coating and bead absence in some weld zone is an indication of formation of a lack-of-penetration.

Adjustment of thermal processes in the welding zone can be achieved by changing the heated air temperature, welding speed or changing the heater nozzle orientation. Change of the heated air temperature is a rather sluggish process that lasts tens of seconds. Therefore, air temperature is set before welding and it remains unchanged furtheron. Figure 10 shows the schemes of typical violations that arise in hot air welding of laminated fabric.

In the absence or fragmentary appearance of a melt bead of a small diameter under the roller (Figure 10, *a*, *b*), the temperature in the welding zone is below the required one. Welding speed should be smoothly decreased up to appearance of a uniform bead of the melt over the entire weld width.

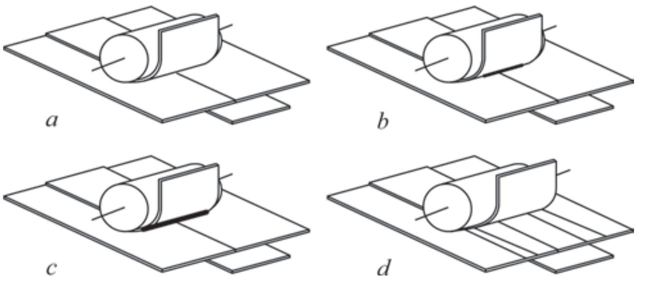

Figure 10. Scheme of possible violations of the optimal process of hot air welding of artificial leather (for description see the text)

At formation of a large diameter bead under the roller and pressing out of part of the melt from under the tape (Figure 10, *a*) the welding zone is overheated, and a too large amount of PVC melt forms. The welding speed should be smoothly lowered, while monitoring the dimensions of the melt bead without allowing it to disappear or lack-of-penetration to form.

Absence of the melt bead from one of the roller sides is indicative of nonuniformity of the welding zone heating by the weld width. In this case, it is necessary to move the heater by a screw mechanism so that the nozzle shifted towards the unheated region. During welding, shifting of the connecting tape from the weld axis to the side (Figure 10, *d*) can occur. It usually points to an incorrect orientation of the axis of roller rotation and its deviation in the horizontal or vertical planes, and the press-down roller position should be adjusted.

It is convenient to perform correction of the mode of heating the fabrics being welded by changing the welding speed, and by adjustment of the electric parameters of the welding unit drive.

An experimental set up was manufactured, in which a carriage with an electromechanical drive is used to move the air heater with the press-down roller along the butt of the fabrics, in order to perform butt welding of laminated fabrics, connected by a tape on both sides. An experimental study of the process of butt heat sealing of laminated PVC fabrics by an outer tape, using heated air, was performed. Optimum parameters of the welding process and visual criteria of sound formation of a laminated fabric joint were determined, and principles of manual real-time adjustment of the process of heat sealing by hot air were developed.

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