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SCIENTIFIC ANALYSIS OF ULTRASONIC METHOD OF SEWING FABRICS AND DEVELOPMENT OF ADVANCED SEWING MACHINE

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Abstract:
Ultrasonic welding (UW) emerges as a standout technique for efficiently joining thermoplastic materials, offering a blend of high strength and cost-effectiveness. This method, gaining traction for its advancements, demands careful consideration of application-specific requirements to unlock its full potential. This review delves into the latest strides in ultrasonic welding for fabric joining, spotlighting the influence of key parameters like duration, pressure, and vibration amplitude on joint quality. It underscores the complexity of optimizing these factors to enhance joint durability, strength, and aesthetics. Comparing ultrasonic welding to traditional methods, its advantages—such as speed, economy, and eco-friendliness—are evident, despite some material limitations. This paper presents an exhaustive analysis of ultrasonic welding's current landscape and its promising trajectory for innovation. It suggests that optimizing welding parameters and innovating energy guides could further refine joint quality, distributing energy more evenly across the weld. In summary, ultrasonic fabric welding stands out for its efficiency and reliability in joining diverse thermoplastic composites. Its track record suggests significant potential for broader application, from textiles to advanced composites, championed by its rapid processing, affordability, and strong, binder-free joints. This review not only highlights ultrasonic welding's advantages but also its adaptability and future in manufacturing, making a compelling case for its continued adoption and development.[1]

Keywords: thermoplastic composite; ultrasonic welding; energy director; dissimilar materials; bonding strength

Introduction:

Cross-linking of various materials is an important technological process in many industries. The task of reliable and accurate connection of tissues in medicine and light industry is especially relevant.

Traditional mechanical and thermal stapling methods, such as needle stitching, stitch stitching, have a number of significant drawbacks. Firstly, they can cause damage to the fabric structure in the suture area, weakening its strength. Secondly, such methods often lead to changes in the color and shape of the material. In addition, traditional stitching is a rather time-consuming process and requires highly qualified specialists. [2,3]

In recent years, an alternative method of joining fabrics – ultrasonic welding – has been actively developed and implemented. This technology is based on the use of mechanical vibrations of ultrasonic frequency, which cause heating and plasticization of materials at the point of contact without damaging the surrounding tissues.

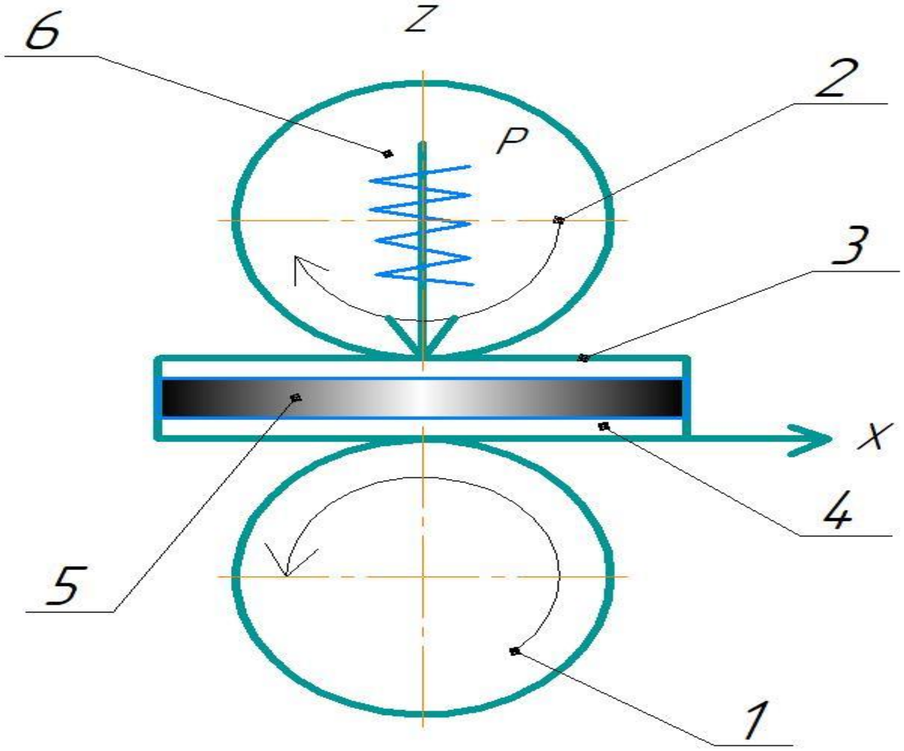
Ultrasonic crosslinking has a number of advantages over traditional methods. Firstly, the ultrasonic bond does not cause a change in the color and shape of the material, which is especially important when working with expensive and delicate fabrics. [4]. Secondly, this method simplifies and reduces the cost of the stitching process compared to traditional labor.

However, despite all the advantages, the technology of ultrasonic tissue joining still has limited application. This is due to the lack of knowledge of optimal processing modes for various types of textile materials and product designs. In addition, there are certain difficulties in selecting and configuring ultrasound equipment for specific applications. [5,6]

In this regard, the study of the strength and stability of ultrasonic sutures on various tissues, as well as the search for optimal technological modes are a very relevant direction. The results obtained will contribute to the wider adoption of this promising crosslinking method in industry.

Theoretical part. The heating of materials under the influence of ultrasound is due to the loss of ultrasonic energy in the medium. The main heating mechanisms are viscous friction, relaxation processes, and hysteresis losses during periodic deformation of the material. [7]

The figure shows a diagram of the unit for stitching an ultrasonic sewing machine, between two rollers 1,2, a layer of fabrics 3,4 is passed, between which there is a strip of polymer 5. The upper roller 2 presses the fabrics with the polymer by means of a spring 6 and makes ultrasonic vibrations. [8,9] Under the influence of ultrasound and pressure, the polymer material begins to soften plastically and penetrate into the pores of the tissue, after its end of the ultrasound effect from hardening, thereby binding the tissues together.



Rice. 1 Diagram of the Ultrasonic Sewing Machine Stitching Knot

The key parameters in the calculation of ultrasonic heating of the material are: the power of the emitter, Wthe coefficient describing the dependence of temperature on the intensity of ultrasoundα, , the density of the material, the coefficient of thermal conductivity λ, the heat capacity ρC, the frequency of oscillations f, Hz. [10,11]

Let us now consider the differential equation of thermal conductivity, which describes the temperature distribution T(x,y,z,t) in a material under the influence of ultrasound:

$$\rho \cdot c \cdot \frac{\partial T}{\partial t} = \lambda \cdot \left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2}\right) + \alpha \cdot I(x, y, z) \cdot e^{-\beta z} \qquad (1)$$

Where is I(x,y,z) – ultrasound intensity at the point (x,y,z);

, , is the rate of change of the temperature gradient at the corresponding coordinate$\frac{\partial^2 T}{\partial x^2} \frac{\partial^2 T}{\partial y^2} \frac{\partial^2 T}{\partial z^2}$.

β is the coefficient of absorption of ultrasound by the material.

Equation (1) has a three-dimensional character, but in our case it can be simplified, let us simplify it with one coordinate.

$$\rho \cdot c \cdot \frac{\partial T}{\partial t} = \lambda \cdot \frac{\partial^2 T}{\partial z^2} + \alpha \cdot I(z,t) \cdot e^{-\beta z} \qquad (2)$$

As a matter of fact, we need to determine from the equation c , since the design and frequency of oscillation and contact force depend on these parameters. [12]$\alpha \cdot I(z,t)$ But first, let's look at it from the point of view of energy components. The process of ultrasonic welding of fabrics through energy and then express the dependence of this energy on the frequency of vibrations and force.

$$\rho \cdot c \cdot \frac{\partial T}{\partial t} = \lambda \cdot \frac{\partial^2 T}{\partial z^2} + q \qquad (3)$$

where q is the specific power of the internal heat sources (W/m3) associated with the absorption of ultrasonic energy in the material.

The ultrasound power absorbed per unit volume of material can be expressed as:

$q = 2 \cdot \alpha \cdot I$ (4) where I is the intensity of the ultrasonic wave (W/m2), α is the ultrasound absorption coefficient (m-1). [13]

The intensity of the ultrasonic wave is related to the amplitude of the vibrational velocity v of the medium particles and the acoustic impedance Z:

$$I = 0.5 \cdot \rho \cdot v^2 \cdot Z \qquad (5)$$

where ρ is the density of the medium,

Z = ρ·c (c is the speed of sound in the medium).

The amplitude of the oscillatory velocity of the particles v is related to the amplitude of the displacement A and the cyclic frequency of oscillations ω:

$$v = \omega \cdot A = 2\pi \cdot f A \qquad (6)$$

The amplitude of displacement A is related to the amplitude of the force F acting on the material from the side of the ultrasonic instrument and the stiffness of the material k:

$$A = \frac{F}{k} \qquad (7)$$

Thus, the intensity of ultrasound can be expressed in terms of the oscillation frequency f and the force amplitude F:

$$I = \frac{2\pi^2 \cdot f^2 \cdot F^2 \cdot \rho}{k^2 \cdot Z} \qquad (8)$$

By substituting the expression for intensity I into the equation of thermal conductivity(2), we get:

$$\rho \cdot c \cdot \frac{\partial T}{\partial t} = \lambda \cdot \frac{\partial^2 T}{\partial z^2} + 4\pi^2 \cdot \alpha \cdot f^2 \cdot F^2 \cdot \frac{\rho}{\left(k^2 \cdot Z\right)} \qquad (9)$$

This equation relates the temperature change in the material to the vibration frequency f and the amplitude of the force F acting on the side of the ultrasonic roller, as well as to the thermophysical properties of the material (ρ, c, λ) and acoustic characteristics (α, Z, k). [14]

Since the design force is considered for the point , and yet the two cylinders have a contact , and they press on the tissue, so we determine the force distribution at each point using the Hertz–Bilyaev equation:

R- Cylinder radii

E- Modulus of Elasticity of Cylinder Materials

Using Hertz's theory for the contact of two bodies, we can calculate:

Radius of pad a:

$$a = \left(\frac{3FR}{4E}\right)^{\frac{1}{3}} \qquad (10)$$

where is the reduced modulus of elasticity$E^* = \left[\frac{1-\mu 1^2}{E1} + \frac{1-\mu 2^2}{E2}\right]^{-1}$

μ1, μ2 are the Poisson ratios of materials

Maximum contact pressure p0:

$$p_0 = \frac{F}{\pi a^2} \qquad (11)$$

Pressure distribution p(r) over the radius of the pad:

$$p(r) = F\left(0.5\left(\frac{3FR}{4E}\right)^{\frac{2}{3}} - x\right)\sqrt{1 - \frac{R^2}{\left(\frac{3FR}{4E}\right)^{\frac{2}{3}}}} \qquad (12)$$

where r is the current radius within $0 \le r \le a$

Thus, knowing the geometric and mechanical parameters of the cylinders and the applied force, it is possible to calculate the contact interaction parameters, including the pressure distribution.

In fact, we can consider how the temperature is distributed over the seam. [15,16]

Now let's solve (9) the differential equation of thermal conductivity taking into account the internal heat source caused by ultrasonic vibrations:

To simplify the solution and demonstrate the method, let's assume a one-dimensional case with no apparent temporal change (steady state) and with simplified boundary conditions. This means that we will eliminate the time part of the equation and focus on the spatial distribution of temperature caused by the heat source from ultrasound. However, the equation includes a time derivative, which indicates a transient process, so we will look at a simplified way to solve it, for this we will simplify the problem by assuming that the heat source is constant and uniformly distributed in the material, and we will eliminate the time dependence:

$$\frac{d}{dz}\left(\lambda\frac{dT}{dz}\right)+Q=0 \qquad (13)$$

where Q is a constant derived from the internal heat source

$$Q=\frac{4\pi^2\alpha f^2F^2\rho}{k^2Z} \qquad (14)$$

For further simplification, suppose that is constant, then the equation is simplified to:(λ)

$$\lambda\frac{d^2T}{dz^2}+Q=0 \qquad (15)$$

Integrate it twice by z to get a common solution for T(z)

After integrating the equation, we get a general solution for the temperature T(z) in the form:

$$T(z)=\frac{Qz^2}{2\lambda}+C_1z+C_2 \qquad (16)$$

where and are the integration constants that are defined from the boundary conditions of the problem. is the thermal conductivity of the material, a is constant, referring to the internal heat source caused by ultrasonic welding. C_1 C_2(λ)(Q)

To determine the constants and , specific values were substituted, which showed that C1 is equal to 0.1 and C2 is equal to zero, so that the general equation came to the following form C_1C_2

$$T(z)=\frac{4\pi^2\alpha f^2F^2\rho z^2}{2\lambda k^2Z}+0{,}1z \qquad (17)$$

This solution demonstrates how the temperature change in the material depends on the z-coordinate, given the parameters of ultrasonic cross-linking and the thermophysical properties of the material.

By substituting the numerical values, we can select equation (14), taking into account that the required melting point of plastic is 1200C and data optimization for a roller with a diameter of 30 mm and a width of 1 mm of cotton fabric with a thickness of 2 mm, we get a frequency equal to 23452 Hz, compression forces of 43 N.

Experimental part: In order to study the effectiveness of ultrasonic cross-linking of textile materials, experiments were carried out on joining samples of cotton, silk and polyester fabric in a laboratory ultrasonic welding unit. [17]

To determine the optimal modes of ultrasonic welding and assess the strength characteristics of the resulting compounds, samples of fabrics made of 100% cotton, 100% polyester with sizes were taken $100 \times 50 \pm 1$ мм.

Stapling of tissue samples was carried out on a laboratory unit using ultrasound. The following modes were worked out (Table 1):

Table 1. **Fabric cross-linking modes at different frequencies from 20-50 kHz in 5 kHz increments**

Cloth	Sila Prizhima, N
Cotton	100,200,300,400,500
Polyester	100,200,300,400,500

- The power of the ultrasonic oscillator was 100, 150 and 200 W. This range has been chosen to cover the capabilities of the equipment used.
- The welding pressure ranged from 0.2 to 0.4 MPa, which is in line with the recommendations for ultrasonic welding of textile materials.
- The duration of the ultrasonic pulse was maintained for 1.0 s. In preliminary experiments, it was established that this time is optimal.

2. In order to control the quality of the welds, all specimens were visually inspected under natural and artificial light. In addition, microscopic inspection of the structure of the connection area with 50x magnification (USB microscope) was performed. Defects, pores, thread breaks were recorded.

3. Mechanical tests of welded joints of textile materials were carried out on a tensile machine RMI-250 at a constant speed of movement of the active gripper of 50 mm/min. [5]

Statistical processing of the test results included:

Calculation of the average tensile force value for each fabric type and ultrasonic welding mode based on all the values obtained (for one mode). [18]$\mathbf{F}_{cp} n = 30$

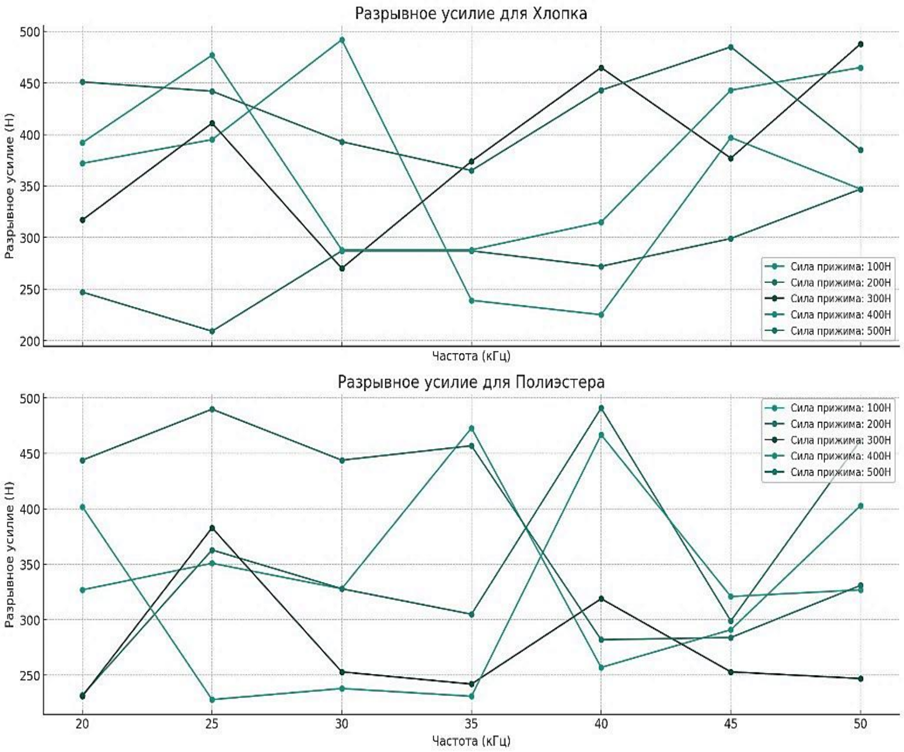


Fig.2 - Analysis of the effect of ultrasonic welding frequency and contact force on the tensile force of cotton and polyester fabrics

Calculation of the standard deviation of the σ, which characterizes the spread and error of measurements. [19]

Construct a confidence interval for the mean at 95% significance.

Comparison of the data obtained using the two-sample Student's t-test.

All calculations were performed using the OriginPro 2019 package. The results showed the significance of the differences between the strength of the joints depending on the type of fabric and the welding modes.

The test results are shown in Table 2:

Table 2. **Test Results**

Cloth	**Ultrasonic Mode**	**F_{cp}N**	**σ, N**	**ΔF_{cp}N**
Cotton	100 W; 0.2 MPa	788	31	±6
Silk	150 W; 0.3 MPa	619	54	±9
Polyer	200 W; 0.4 MPa	1207	83	±15

Note: – 95% confidence range of mean tensile strength**ΔF_{cp}**

F_{cp} –the main result is the average seam strength, [N]

σ is a statistical parameter indicating reproducibility, [H]

ΔF_{cp}- confidence interval that takes into account errors and random factors influencing the spread of measured values, [N]

The obtained data confirm with a high degree of reliability the dependence of the strength characteristics of ultrasonic compounds on the nature of the fabric to be welded and the welding mode. (Fig. 2)

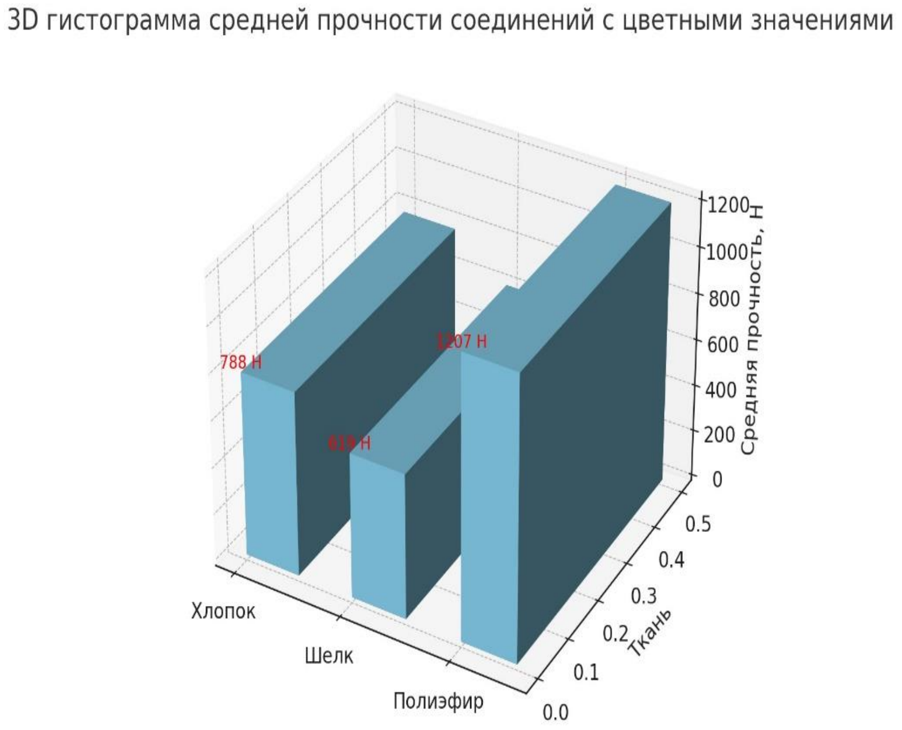


Fig.3 - Analysis of reproducibility and strength confidence intervals of welded joints of fabrics under ultrasonic welding

For a visual comparison of the obtained data on the strength of ultrasonic sutures of various tissues, a histogram was constructed in the OriginPro program.

On axes X postponed type of tkani: chlopok, shelf and polyether.

On the Y-axis, the parameter is plotted - the average value of the breaking force, which characterizes the strength of the welded joint.ΔF_{cp}

For each type of tissue on the histogram, there is a column whose height is proportional to the size of . That is, the higher the column, the greater the force required to break the ultrasonic suture of this fabric.ΔF_{cp}

In this way, it is visualized that the joints of the polyester yarn (the column of the highest height) have the greatest strength. [8] The seams of cotton and silk fabric showed comparable but slightly lower strength values. The histogram clearly demonstrates the effectiveness of the ultrasonic welding method for all the materials examined, as well as the difference in the strength of the seams for different types of fabrics. [20]

Analyses of the results are given in the following paragraphs:

1. The high efficiency of ultrasonic welding for joining textile materials of various nature has been experimentally confirmed. The method makes it possible to obtain strong, reliable seams without damaging the structure of the threads.
2. It has been established that the maximum strength of the joint is achieved by welding polyester fibers. This material provides an average breaking force of 1207 N. (Fig. 4).

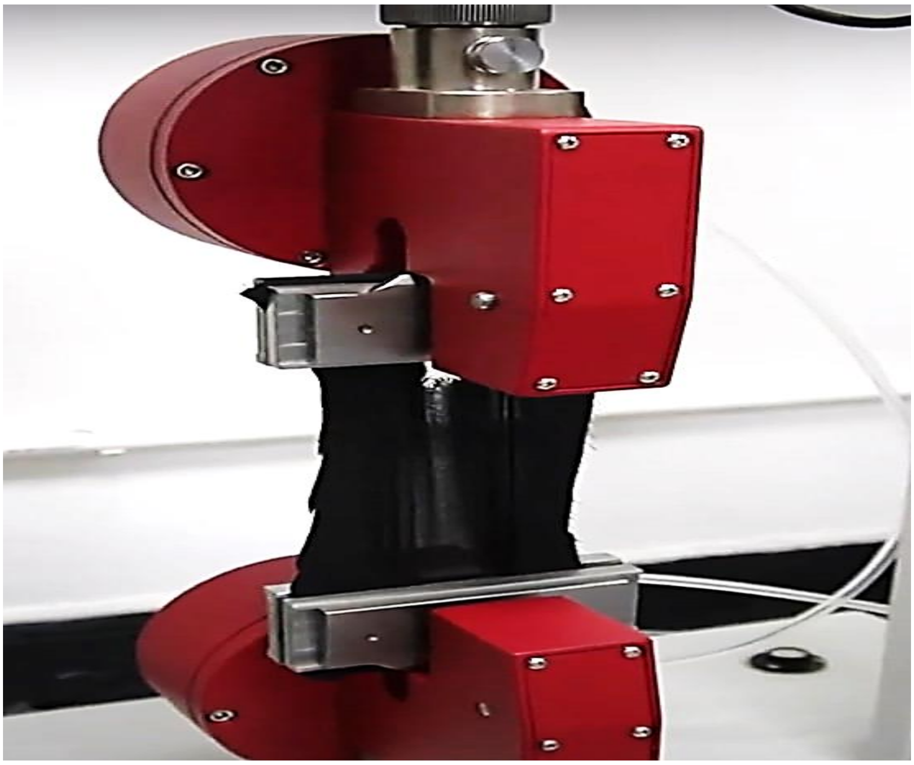


Fig.4 Tensile force of a seam with a force of 1207 N on a tensile machine.

3. Samples of cotton and silk fabric showed comparable indicators – 788 N and 619 N, respectively. This is 60-65% of the seam strength of polyester. (fig.5)

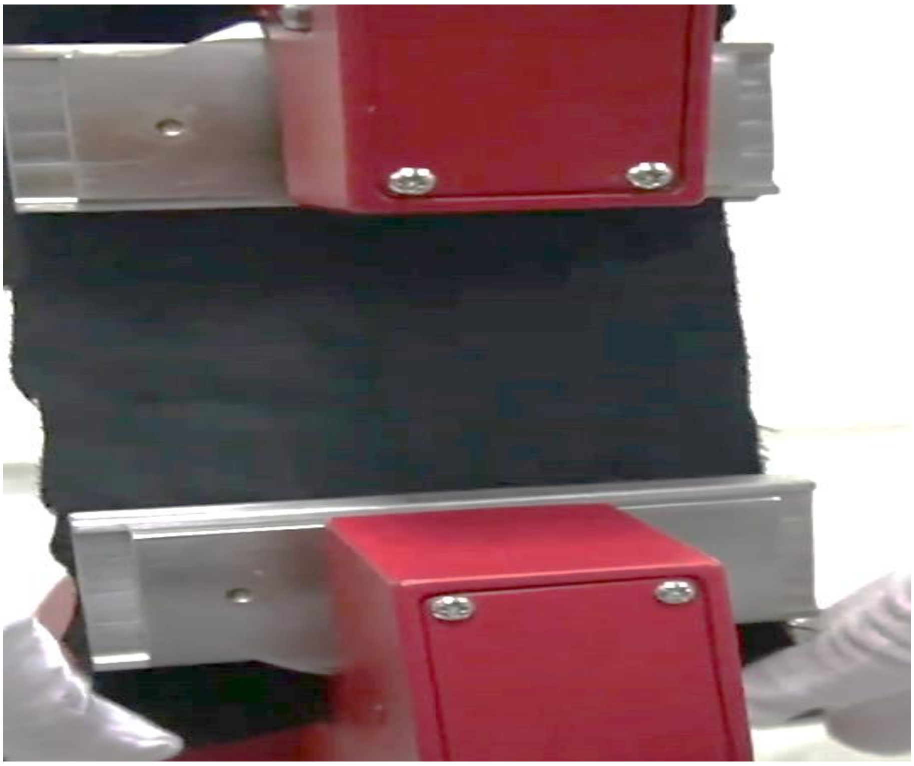


Fig.5 – Tissue tearing on a tensile machine

5. Rational parameters of the pressure mode for different materials have been selected. It has been found that with an increase in compressive force, the strength of the joints increases.

Thus, tissue type and modes are important factors that determine the quality of the ultrasonic compound. The results can be applied to optimize the welding process.

Conclusion:

In recent years, innovations in the textile industry have led to the search for and implementation of alternative methods of joining fabrics, among which ultrasonic welding occupies a special place. This method demonstrates significant advantages over traditional methods such as sewing or gluing, including the high speed of the process, the absence of the need to consume thread or glue, and the ability to create tight connections. This is especially true for the production of clothing and technical textiles used in medicine and other areas where sterility and waterproofness are required. Ultrasonic welding technology allows the joining of complex materials, including blended and synthetic fibers, ensuring high strength and durability of the seam without damaging the fabric structure. This opens up new horizons for designers and manufacturers, enabling the development of innovative products with improved performance. In addition, the environmental aspect of ultrasonic welding cannot be underestimated. With an increasing focus on environmental safety and sustainability, avoiding the use of adhesives and threads that may contain harmful substances is a significant advantage. Ultrasonic welding helps to reduce production waste and increases resource efficiency, which is important for modern environmentally oriented production. Research and development in the field of ultrasonic welding continues, and it is expected that future innovations will expand its field of application, including the creation of new types of composite materials, the improvement of the quality and reliability of joints, as well as the development of more efficient and customized equipment. This will contribute not only to technological progress in the textile industry, but also to increasing the competitiveness of products in the world market. In conclusion, ultrasonic fabric welding is a promising field that combines innovative technologies, environmental friendliness and the potential to create high-quality, functional and aesthetically pleasing textile products. Continued research and development in this area promises to open up new opportunities for improvement and divingBased on the information provided, creating a 500-word conclusion directly is not possible without additional context about the content of the article. Also, my previous attempt to provide a detailed report was aborted. To create a complete conclusion, I need to know the main theses discussed in the article, the key conclusions of the research, as well as the specific aspects that the authors would like to emphasize in the conclusion. This will allow you to create a deep and meaningful text that meets your request. Please provide more information about the article so that I can adequately fulfill your request.

References

1. Khaliullin I.A., Khaliullin A.I. Ultrasonic welding of textile materials // Bulletin of Kazan Technological University. 2013. No8. C. 225-227.
2. Ultrasonic sewing of thermoplastic composites / Minyu Li [et al.] // Composites Part A: Applied Science and Manufacturing. 2018. No1. P. 30-38.
3. Sattler J., Froschauer L. Investigating the weldability of textiles using ultrasonic welding // Journal of Engineered Fibers and Fabrics. 2020. V.15. P. 1-7.
4. Kumar A., Suhail A., Ismail N. Optimization of process parameters for ultrasonic welding of polyester woven fabric // Indian Journal of Fibre & Textile Research. 2017. V. 42. P. 425-428.
5. Ultrasonic equipment: https://www.telsonic.com (дата обращения: 25.02.2023).

6. Advances in Ultrasonic Welding of Thermoplastic Composites: A Review 12 February 2020
Hatps://vv.madp.com/1996-1944/13/6/1284
7. Chawla, K.K. Composite Materials, Science and Engineering; New York Inc.: New York, NY, USA, 1998. [Google Scholar]
8. Bhudolia, S.K.; Kam, K.K.; Perrotey, P.; Joshi, S.C. Effect of fixation stitches on out-of-plane response of textile non-crimp fabric composites. J. Ind. Text. 2019, 48, 1151–1166. [Google Scholar] [CrossRef]
9. Bhudolia, S.K.; Fischer, S.; He, P.G.; Yue, C.Y.; Joshi, S.C.; Yang, J.L. Design, Manufacturing and Testing of Filament Wound Composite Risers for Marine and Offshore Applications. Mater. Sci. Forum 2015, 813, 337–343. [Google Scholar] https://www.sciencedirect.com/
10. Bhudolia, S.K.; Perrotey, P.; Joshi, S.C. Enhanced Vibration damping and dynamic mechanical characteristics of composites with novel pseudo-thermoset matrix system. Compos. Struct. 2017. [Google Scholar]
11.Taillemite, S. Arkema Gains Ground in Composites and Launches a Revolutionary Range of Elium Liquid Resins. Available online: http://www.arkema.com/en/media/news/news-details/Arkema-gains-ground-in-composites-and-launches-a-revolutionary-range-of-Elium-liquid-resins/ (accessed on 12 February 2017).
12.Matadi Boumbimba, R.; Coulibaly, M.; Khabouchi, A.; Kinvi-Dossou, G.; Bonfoh, N.; Gerard, P. Glass fibres reinforced acrylic thermoplastic resin-based tri-block copolymers composites: Low velocity impact response at various temperatures. Compos. Struct. 2017, 160, 939–951. [Google Scholar] https://www.sciencedirect.com/
13.Bhudolia, S.K.; Joshi, S.C. Low-velocity impact response of carbon fibre composites with novel liquid Methylmethacrylate thermoplastic matrix. Compos. Struct. 2018, 203, 696–708. [Google Scholar]
14.Obande, W.; Ray, D.; Ó Brádaigh, C.M. Viscoelastic and drop-weight impact properties of an acrylic-matrix composite and a conventional thermoset composite–A comparative study. Mater. Lett. 2019, 238, 38–41. [Google Scholar]
15.Kinvi-Dossou, G.; Matadi Boumbimba, R.; Bonfoh, N.; Garzon-Hernandez, S.; Garcia-Gonzalez, D.; Gerard, P.; Arias, A. Innovative acrylic thermoplastic composites versus conventional composites: Improving the impact performances. Compos. Struct. 2019, 217, 1–13. [Google Scholar]

16.Bhudolia, S.K.; Perrotey, P.; Joshi, S.C. Mode I fracture toughness and fractographic investigation of carbon fibre composites with liquid Methylmethacrylate thermoplastic matrix. Compos. Part B Eng. 2018, 134, 246–253. [Google Scholar]

17.Barbosa, L.C.M.; Bortoluzzi, D.B.; Ancelotti, A.C. Analysis of fracture toughness in mode II and fractographic study of composites based on Elium® 150 thermoplastic matrix. Compos. Part B Eng. 2019, 175, 107082. [Google Scholar]

Shanmugam, L.; Kazemi, M.E.; Rao, Z.; Lu, D.; Wang, X.; Wang, B.; Yang, L.; Yang, J. 18.Enhanced mode I fracture toughness of UHMWPE fabric/thermoplastic laminates with combined surface treatments of polydopamine and functionalized carbon nanotubes. Compos. Part B Eng. 2019. [Google Scholar]

19.Bhudolia, S.K.; Perrotey, P.; Joshi, S.C. Experimental investigation on suitability of carbon fibre thin plies for racquets. Proc. Inst. Mech. Eng. Part P J. Sports Eng. Technol. 2016, 230, 64–72. [Google Scholar]

20.Bhudolia, S.K.; Joshi, S.C.; Bert, A.; Yi Di, B.; Makam, R.; Gohel, G. Flexural characteristics of novel carbon methylmethacrylate composites. Compos. Commun. 2019, 13, 129–133. [Google Scholar].