Design development of technological complex for friction welding of thin-walled products made of armlen

V Nemtinov¹, V Sergeev² and Yu Nemtinova³.4,*

¹Department of «Computer-integrated systems in mechanical engineering», Tambov State Technical University, 106 Sovetskaya Street, Tambov 392000, Russian Federation
²PLC «ARTI –Plant», 392000, Morshanskoye Sh., 19A, Tambov 392000, Russian Federation
³Department of «Economic security and quality», Tambov State Technical University, 106 Sovetskaya Street, Tambov 392000, Russian Federation
⁴Department of «Management, marketing and advertising», Tambov State University named after G.R. Derzhavin, 33, Internatsionalnaya Street, Tambov 392000, Russian Federation

* jnemtinova@hotmail.com

Abstract. In this paper, we present the results of engineering design of a technological complex for friction welding of thin-walled products from armlen. We have also analyzed welding methods for plastic details. The main technological parameters of friction welding are: relative speed of welded surfaces rotation or linear velocity of the planes relative to each other; melting pressure for creating of a friction force; heating time; sediment pressure; cooling time of the weld. Each of these parameters depends on the material type and the shape of welded surfaces, assuming that absolutely flat surfaces are considered, since flatness does not strongly affect these parameters for thin-wall products. Further, welding technology of thin-walled parts from mineral-filled polypropylene (armlen) is offered, calculations of technological parameters of welding process are carried out and an electronic model of the complex is developed. On the basis of the electronic model and drawings, a prototype of the technological complex was made. Approbation of the complex on the example of gas-proof boxes production showed its high efficiency and prospects of its use for the whole class of thin-walled products from armlen.

1. Introduction
Currently, increasing production of plastic products, as well as their increasing use in consumer goods, leads to creation of a variety of ways of melting them into finished products. Taking into account the number of plastics used, the total volume of technological variations and the number of installations and devices welding takes the leading role among production methods of finished products from plastic [1]. This method of production allows realizing the main advantages of plastics. When welding, the product remains solid and sealed, unlike other methods of connection.

The process of thermoplastics welding is formation of joints due to the contact of surfaces activated by heating [2, 3]. The sequence of operations can be different: welded materials are first brought into close contact and then connected surfaces are activated; connected surfaces are first subjected to
activation and then brought into contact; contact and activation of the connected surfaces are carried out simultaneously. Application of energy required for activation of the connected surfaces and pressure required to achieve contact between them is possible with the same or different tools.

In thermoplastics welding, as well as in metals welding, the following processes occur in the welding zone: conversion of energy that ensures activation of welded surfaces; interaction of activated welded surfaces upon their contact; formation of the material structure in the contact zone. Activation of welded surfaces can occur as a result of their contact with heat carriers - heated tools, gases or filler materials, as well as by absorbing and converting energy of high-frequency electrical vibrations of radiant energy, mechanical friction energy, or energy of high-frequency mechanical vibrations. That is, heating occurs with an increase in internal temperature of the body (energy of macromolecules), while the welding process itself consists of macromolecules convergence of the connected surfaces to a distance of forming intermolecular interaction forces.

In this case, the main conditions under which it is possible to weld plastics are as follows: temperature of the heated surfaces should be higher than the temperature of the viscous state, but below the temperature of plastic destruction; tight contact of heated surfaces; and most importantly, optimal welding time, holding time at pressure and cooling time. It should be noted, that it is possible to weld at the temperature below the viscous state with lower energy costs, but the quality is likely to decrease.

From a variety of welding types (gas coolant with an additive, gas coolant without an additive, contact-heat welding, ultrasound, radiation, etc.) the authors have chosen friction welding of plastics and proposed an original design of the technological welding complex.

Friction welding was chosen for the following reasons: welding method itself is very simple, while it can be automated and welding can be performed in almost any conditions; low power consumption - 5-10 times less than contact welding. In the welding process, mechanical energy in the contact zone is converted into heat due to friction forces, as a result, plastic transforms into viscous state, part of the melt goes to the grate, then the rotation stops, and connection is done by the sediment force. At the same time, there is a small heat loss in the heat-affected zone due to low thermal conductivity of armilen (mineral-filled polypropylene) compared to metals.

Among the distinctive properties of armilen the following should be noted: resistance to water (up to 130 °C), acids, alkalis, except strong oxidants (HNO3, H2SO4, compounds with chromium); thermal conductivity of 0.15 W/(m*K); heat resistance by the Vic device ~ 95-110 °C; frost resistance from -5 to -25 °C; impact resistance, resistance to bending loads; good wear resistance, maximum operating temperature of products ~120-140 °C; melting temperature 160-176 °C; density ~ 0.90-0.92 g/cm³. Thus, the material has excellent chemical resistance, good mechanical properties, excellent elasticity, increased rigidity and strength, resistance to atmospheric factors, which ensure its wide application [4 - 6].

2. Welding process parameters
The main technological parameters of friction welding are: relative rotation speed of the welded surfaces or linear velocity of the planes relative to each other; melting pressure to create friction force; heating time; sediment pressure; cooling time of the weld. Each of these parameters depends on the type of material and the shape of surfaces to be welded, assuming that absolutely flat surfaces are considered, since flatness does not strongly affect these parameters for products with thin walls.

To estimate technological parameters, a formula was derived to calculate the total amount of work produced by friction of hollow round (or solid) parts from any thermoplastics:

\[
A = \frac{4}{3} \pi^2 f P (R_2^3 - R_1^3) \cdot \left( \frac{n}{60} \right) t, \text{ J}
\]

where: \( f \) – coefficient of friction; \( n \) – relative rotation speed, rpm; \( P \) – clamping pressure, N/m²; \( R_2 \) – radius of the outer wall, m; \( R_1 \) – radius of the inner wall, m; \( t \) – heating time (friction time), s.

Of the total number of these values, constants are: friction coefficient \( f \) and rotation speed \( n \) in rpm. Rotation speed should be chosen as follows: at high rotation speeds welding cycle time is reduced, but
its strong increase also leads to intensive destruction, increased vibration of the designed complex, and misalignment of the welded products; at low speeds, in addition to increased welding time there is a simple grinding or even chipping of surfaces. Clamping pressure is a function of linear velocity, i.e. of the outer radius \( R_2 \) and the angular velocity of rotation. It follows that at a lower welding speed the pressure should be proportionally increased, and vice versa. Heating time \( t \) for the required technological mode, can be found by equating \( A (J) \) and the amount of heat \( Q (J) \) required for heating.

As a result of comparative analysis of technological parameters of the welding process, their values for the designed complex were determined:
- spindle rotation 1500 rpm, feed to touch (point 0) of 1000 mm/min, working feed of 8 mm/min at a distance of 0.9 mm;
- spindle stop, feed of 20 mm/min by 3.3 mm from 0, i.e. 2.4 mm from 0.9 mm;
- feeding stop and holding for 5 seconds.

3. Engineering design of a technological complex

Engineering design of a technological complex for friction welding was carried out with design parameters optimal for welding of thin-walled products up to 200 mm long and up to 300 mm in diameter.

The block diagram of the designed technological complex includes the following main components and mechanisms:
- frame - two-module, frame-rack;
- pneumatic cylinders - for implementation of vertical movement, removal and installation of workpieces;
- cam driven by a gear motor – to ensure a complete welding cycle with a predetermined feed rate mm/min;
- asynchronous motor of type AIR 80 - to ensure rotation of the workpiece (1500 min⁻¹);
- rack structure with rails – to create vertical force due to its weight together with the motor weight;
- lower mandrel – for fixing the workpiece due to workpiece’s weight and its axial fixation in the mandrel (the workpiece must be simply put in the mandrel);
- upper mandrel – for fixing the workpiece by means of threads with turns opposite to rotation of the motor (the workpiece is simply screwed on the thread);
- adjustable cams with inductive switches – for electronic control of complete welding cycle.

During engineering design, pneumatic equipment with inexpensive pneumatic automation and a fairly simple scheme of its use was actively used in addition to an electric motor. For fixing and installation of workpieces, mobile and fixed easy-to-change clips were developed with an open workplace, which is convenient for the operator serving the technological complex. The workplace was organized as open, because obtained technological parameters of welding allowed not to construct additional casings or difficult automated stop systems for the whole complex [7 - 8].

A plate with an electric motor was chosen for heating and setting forces, which provided the compact design of the entire complex.

The mechanism that provides the entire welding cycle with all technological parameters is a cam with a roller. Cam’s drive is carried out by a gear motor, to which simultaneously adjustable switches of the command apparatus are fixed on the rear shaft, which, in turn, give commands to actuators through inductive sensors. When changing the product range, it is possible to redesign the cam, to build its profile, to produce and to replace it.

When assembling the technological complex, the following standard units we used: air preparation unit with an SMC safety valve for pneumatic systems; pressure gauges to monitor pneumatic cylinders; pneumo-dumper; electro-pneumatic 5-line distributors; pneumo-chokes; pneumatic cylinders; two-stage worm gear motor 9MCH2-30/40 with gear ratio – 600; asynchronous motor type AIR80; inductive non-contact VBI touch switches.
It is possible to install the “Stop” button of emergency shutdown of drive rotation, as well as the “Start” button to launch the spindle at a speed of ~100 rpm to install the parts into the upper mandrel. Rotation is performed only when the "Start" button is pressed and the cam is in its initial position.

Based on the results of the works [9 - 12] the authors have developed a virtual model of the technological complex. General 3D view of the model is shown in Fig. 1, main units – in fig. 2.

Thus, the design of the complex is made in the most resource-intensive way compared with other welding types. Thus, it was possible to halve welding time twice and to halve the cost of manufacturing by combining many operations of the welding cycle in one unit of the technological complex.

All this reduces assembly costs by about 150 thousand rubles per 1 complex compared to a heat welding complex. But most importantly, the proposed design reduces welding costs in comparison with the contact-heat welding by 5-6 times due to the fact contact-heat welding requires heating element to be constantly heated, and in friction welding heating energy is supplied to the welding zone.

Engineering design was carried out using a three-dimensional modeling system COMPASS-3D and COMPASS–Graph for drawings.

4. Experimental results of the technological complex for friction welding
Approbation of the developed friction welding technological complex was carried out at JSC "ARTI-Zavod" for production of gas boxes FPC GP-7 and GP-7 KB (see Fig. 3). Tensile, bending, toughness and torsion testing of joints made by friction welding showed positive results.

If welding is carried out at technological modes other than optimal, the following defects may appear:
- incomplete fusion of the middle section, if heating was not intense enough or short-term;
- annular incomplete fusion at the periphery.
Figure 2. 3D model of the command apparatus with cams and non-contact inductive sensors of the friction welding complex

In addition, friction welding outweights other welding methods, since the quality of connections is not affected by random external factors (voltage fluctuations, surface condition, air humidity, etc.) with small values of heating precipitate. Quality of welding is more stable within a batch performed without readjusting the complex.

5. Conclusions
In this work, the authors have carried out calculations to determine technological parameters of friction welding of thin-walled parts from armlen, conducted engineering design and manufactured a prototype of the technological complex that implements this process. Approbation of the complex on the example of gas-proof boxes production showed its high efficiency and prospects of use for the whole class of thin-walled products from armlen.

Figure 3. 3D-view of gas-proof boxes: a) FPC GP-7, b) GP-7
References

[1] Nandan R, Roy G G, Debroy T 2006 Metallurgical and Materials Transactions A: Physical Metallurgy and Materials Science 37(4) 1247-1259

[2] Takasu N, Yosetsu Gakkai Shi 2003 Journal of the Japan Welding Society 72(2) 34-37.

[3] Liu X, Wu C, Padhy G K 2015 Scripta Materialia 102(1) 95-98.

[4] Nemtinov V A, Nemtinova Yu V 2005 Journal of Computer and Systems Sciences International 44(3) 389-398.

[5] Mokrozub V G, Nemtinov V A, Mokrozub A V 2017 Chemical and Petroleum Engineering 53(5-6) 326-331.

[6] Mokrozub V G, Nemtinov V A 2015 Chemical and petroleum engineering 51(7-8) 31-35

[7] Nemtinov V A, Bolshakov N A, Nemtinova Yu V 2017 MATEC Web of Conferences 129 ICMTMTE-2017

[8] Wang J M, Zhang L, Liu Y B, Mo X N, Ren G Q 2010 Computer Integrated Manufacturing Systems 16(10) 2017-2023

[9] Mokrozub V G, Manuilov K D, Gorshkov V V, Gorshkova T S 2016 Chemical and Petroleum Engineering 51(9-10) 613- 617

[10] Borisenko A B, Karpushkin S V 2014 Journal of Computer and Systems Sciences International 53(3) 410-419.

[11] Ivannikov A, Kulagin V, Romanov A, Pozdneev B 2016 EWDTS-2016 Proceedings, 14th IEEE EAST-WEST DESIGN & TEST SYMPOSIUM

[12] Malygin E N, Mokrozub V G, Nemtinov V A 2017 MATEC Web of Conferences 129 ICMTMTE-2017