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Technology and Equipment for Friction Welding of Thin-Walled Parts Made of Mineral-Filled Polypropylene

V.A. Nemtinov[1*], V.S. Sergeyev[2], Yu.V. Nemtinova[1], V.G. Mokrozub[1]

[1] *Department of Computer-Integrated Systems in Mechanical Engineering, Tambov State Technical University, 1, Leningradskaya St., Tambov, 392000, Russia*
[2] *PLC «ARTI –Plant, 19A, Morshanskoye Sh., Tambov, 392000, Russia*

[*] Corresponding author: Tel. + 7 (4752) 63-07-06; *E-mail*: nemtinov@mail.gaps.tstu.ru

Abstract

Welding techniques for plastic parts have been analyzed. The technology of welding thin-walled parts made of mineral-filled polypropylene (Armlen) has been proposed and calculations to determine the process parameters of welding have been made. R&D and manufacture of an experimental sample of the technological complex that implements this process have been done. The complex has been tested in the production of respirator canisters taken as an example. The developed technology can be applied to a whole class of thin-walled products made of Armlen.

Keywords

Friction welding; mineral-filled polypropylene; plastics; technological complex; thin-walled Armlen products.

Introduction

Nowadays, the increasing production volume of plastic products as well as their increasing use in consumer goods leads to the development of different ways of their remelting into finished products. In terms of the amount of the used plastics, the number of plants and devices as well as the total volume of process variants, welding is one of the key methods of manufacturing finished products made of plastics [1]. In creating one-piece products it allows realizing the main advantages of plastics to the maximum. When welding, the product remains solid and impermeable, unlike other joining techniques.

The welding process of thermoplastic consists in the formation of joints owing to the contact of the heat-activated surfaces to be joined [2, 3]. The sequence of operations may vary: the materials to be welded are first brought into close contact, and then the activation of the joined surfaces occurs; the surfaces to be joined are first subjected to activation, and then brought into contact; contacting and activation of the joined surfaces is performed simultaneously. Energy required for activating the surfaces to be joined and pressure required to achieve contact between them are provided using the same or different instruments.

In welding thermoplastics, as well as in welding metals, the following processes take place in the welding zone: energy conversion which provides the activation of the welded surfaces; the interaction of activated welded surfaces at their contact; formation of the structure material in the contact zone. Activation of welded surfaces may occur as a result of their contact with coolants – heated tools, gases or filler materials, as well as due to the absorption and transformation of the energy of high-frequency electrical oscillations of radiant energy, mechanical friction energy or energy of high-frequency mechanical vibrations [4–7]. That is, heating occurs with an increase in the internal body temperature (macromolecules energy), and the welding process itself consists in bringing together the macromolecules of the joined surfaces to generate forces of intermolecular interaction.

The main conditions under which welding of plastics could be carried out are as follows: the temperature of the heated surfaces should be higher than the temperature of viscous-flow state, but below the temperature of the plastics destruction; close contact between hot surfaces; and most importantly, the optimum welding time, the holding time at a pressure and cooling time. It must be born in mind that welding can occur at temperatures below viscous-flow state, that is, with less expenditure of energy, however, the weld quality is likely to be reduced.

Rotary friction welding started to be applied to thermoplastic polymers not long ago. The parameters of rotary friction welding such as the welding speed, the rotation speed and inclination angle affect the joint strength. To achieve maximum strength of the joint, these parameters must be properly selected and optimized. Ahmadi et al. [8] proposed to use Taguchi methods to optimize these parameters for 4 mm polypropylene composite sheets with a weight percent of carbon content of 20 %. The analysis of variation and testing for compliance with specifications were also performed.

Another example of application of rotary friction welding is considered in [9]. The rotation speed was varied in the range of 800…1200 rpm, transverse velocity was from 40 to 200 mm per minute, the axial force was from 1 to 5 kN.

Banjare et al. [10] developed a design of the heating tool to obtain a better quality of surface finish, less chip formation and material loss during rotational friction welding, and also to avoid problems with the lack of surface heating that leads to the formation of pores and joint defects. The differences in the measurement of temperature at the initial, middle and end points were established in [11].

The effect of application of multi-walled carbon nanotubes on the mechanical properties of joining dissimilar materials of high density polyethylene, and acrylonitrile butadiene styrene was studied in [12]. It resulted in the reduction of a number of defects, such as pores and cracks, an increase in tensile strength, and relative elongation at rupture, however, the joint strength decreased.

Lambiase et al. [13] developed a model to analyze the effect of rotation speed and time on the mechanical behavior of the joint using spot friction welding to polycarbonate sheets. The following parameters were chosen for analysis: rotation speed, the speed of the tool in-feed movement, warm-up time, hold time, and standby time. On the basis of the results obtained, the directions for improving the mechanical behavior of thermoplastic joints were formulated. Paoletti et al. [14] also studied the effect of various parameters in rotation friction welding. It was found that low values of feed-in velocity have a favorable effect both on the welding process and on the mechanical behavior of the joint.

There exists a variety of welding types (gas-coolant with a filler, gas-coolant without a filler, contact-heat welding, ultrasound, radiation, etc.) described in [15–17]. This paper deals with the study and original design of the technological complex of friction welding of plastics.

Friction welding was chosen for the following reasons [5]: the welding method itself is very simple, moreover, it can be automated and performed almost in "field" conditions; it has low power consumption – 5–10 times less than resistance welding. In the welding process the mechanical energy is converted in the contact zone into the heat energy due to friction forces, as a result plastics transforms into a viscous-flow state, part of the melt enters the flash, then rotation shutdown and joining by upsetting [5]. A small heat loss in the heat-affected zone due to the low thermal conductivity of Armlen (mineral-filled polypropylene) compared with metals should be noted.

The distinctive properties of Armlen are: resistance to water (up to 130 °C), acids, alkalis, except strong oxidants (HNO_3, H_2SO_4, chromium compounds); thermal conductivity of 0.15 W/(m·K); heat resistance on the Vicat apparatus ~95…110 °C; frost resistance from –5 to –25 °C; impact resistance, resistance to bending loads; good wear resistance, the maximum temperature of operation of products ~120…140 °C; melting point of ~160…176 °C; density of ~0,90…0,92 g/cm^3. Thus, the material has excellent chemical resistance, good mechanical properties, excellent elasticity, increased stiffness and strength, resistance to atmospheric effects, which provide its wide application.

Welding Process Parameters

The main process parameters of friction welding are: relative rotation speed of the surfaces to be welded or linear velocity of the plane displacement relative to each other; fusion pressure to create the friction force; heating time; precipitation pressure; the cooling time of the weld. Each of these parameters depends on the type of material and the shape of the surfaces to be welded on the assumption that the perfectly flat surfaces are treated, since nonflatness does not affect these parameters significantly in thin walls [18–20].

To assess the process parameters, there was derived a formula for calculating the total amount of work done by friction of circular hollow (or one-piece) parts made of any thermoplastic

$$A = (4/3)\pi^2 fP\left(R_2^3 - R_1^3\right)(n/60)t, \text{ J};$$

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

Among the total number of these values the constants are: friction coefficient f, the value of the rotation speed n, in rpm. The rotation speed should be selected based on the recommendations given in [5]: on the one hand, at high speeds of rotation the welding cycle time is reduced, on the other hand, a strong increase in rotation speed may result in the intense destruction, an increase in the vibration of the complex to be designed, and misalignment of welded products; at low speeds, in addition to an increase in welding time, there occurs simple grinding, or even surface chipping. The down pressure is a function of the linear velocity, and hence the outer radius R_2 and the angular velocity of rotation. It follows that at a lower welding speed the pressure must be increased in proportion, and vice versa. Heating time t, as a required process parameter can be found by equating work A, J and the amount of heat Q, J required for heating.

As a result of the comparative analysis of the welding process parameters values calculated by the method proposed by M.L. Samorukov [21] and those obtained in our own experiments performed on CNC machines, the values for the designed complex were determined:

– spindle rotation – 1500 rpm, the feed to the touch (point 0) 1000 mm/min, the working feed 8 mm/min at a distance of 0.9 mm;

– spindle stopping, the feed of 20 mm/min at a distance of 3.3 mm from 0, i.e. 2.4 mm from 0.9 mm;

– feed stopping and hold for 5 s.

Technological Complex of Friction Welding of Thin-Walled Products Made of Armlen

The design of the technological complex for friction welding has been carried out with the parameters optimal for welding of thin-walled products with a length of up to 200 mm and a diameter of up to 300 mm.

The block diagram of the designed technological complex includes the following main components and mechanisms:

– a frame – two-module, wireframe-rack mounted;

– pneumatic cylinders – to realize vertical movement, removal and placement of workpieces;

– a cam driven by a gear-motor – to ensure a complete welding cycle with preset feed velocities in mm/min;

– an asynchronous electric motor of AIP 80 type – to provide workpieces rotation (1500 min^{-1});

– a rack-mounted structure with rails – to create a vertical force due to its weight together with the weight of the motor;

– a bottom mandrel – to fix a workpiece due to the weight of the workpiece itself and its axial fixation in the mandrel (a workpiece should be simply placed in the mandrel);

– a top mandrel – to fix a workpiece due to the thread with coils opposite to the rotation of the motor (a workpiece is simply screwed by the thread);

– adjustable cams with inductive switches – for electronic control of the complete welding cycle.

In designing the structure in addition to the electric motor, we actively applied the pneumatic equipment with inexpensive pneumatic automation and relatively simple scheme of its use. To fix and place workpieces there have been designed movable and immovable easily changed clamps (mandrels) with an open workplace which is comfortable for an operator who services the technological complex. The workplace was organized open because the proposed welding process parameters allowed us not to build additional enclosures or complex automated shutdown systems for the whole complex.

To generate forces during heating and upsetting, a panel with an electric motor was chosen, ensuring compact design of the whole complex.

A mechanism which provides the entire welding cycle with all the process parameters is a cam with a roller. A cam is driven by a gear-motor, on the rear shaft of which adjustable switches of the controller are mounted, which, in turn, through inductive sensors send commands to the actuators. When product nomenclature changes, the cam can be redesigned and replaced.

The following standard components were used in the layout of the technological complex: air preparation unit with an SMC safety valve for the pneumatic system; pressure gauges to monitor the efforts of cylinders; air silencers; a two-stage worm gear-motor with a standard size of 9MCH2-30/40, having a gear ratio of 600; an asynchronous electric motor of AIP 80 type; inductive non-contact sensory switches of EPD series.

You can set the “Stop” button of emergency switching off the rotation drive of the parts to be welded, as well as the button “Start” to start the spindle at a speed of about 100 rpm for placing the parts in the top mandrel. The rotation is performed only when the “Start” button is pressed and the cam is in the initial position.

Based on the results presented in [22–24], the authors developed a virtual model of the technological complex. A general 3D view of the model is shown in Fig. 1. Individual basic units are demonstrated in Fig. 2 and Fig. 3.

Thus, the structure of the complex is made the most resource-intensive. In comparison with other types of welding we have managed to reduce the

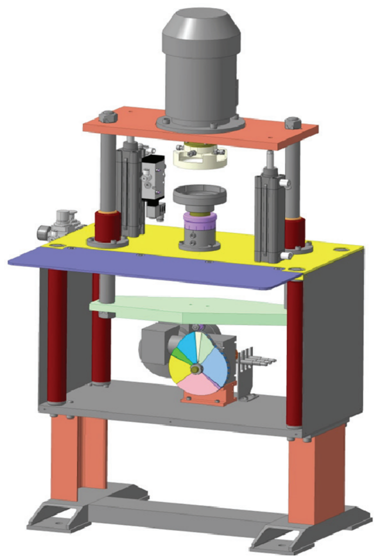

Fig. 1. 3D view of the technological complex model for friction welding

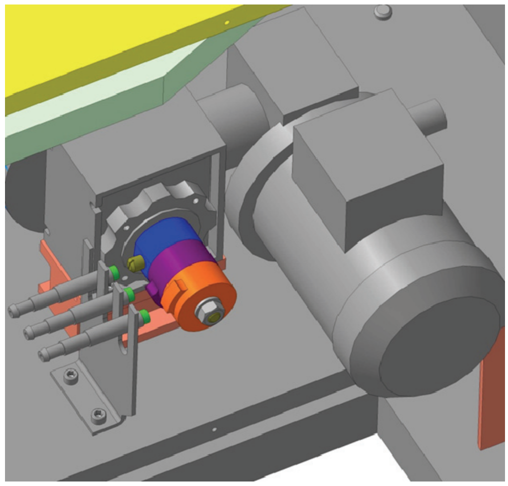

Fig. 2. 3D view of a controller model with cams and inductive non-contact sensors of the technological complex for friction welding

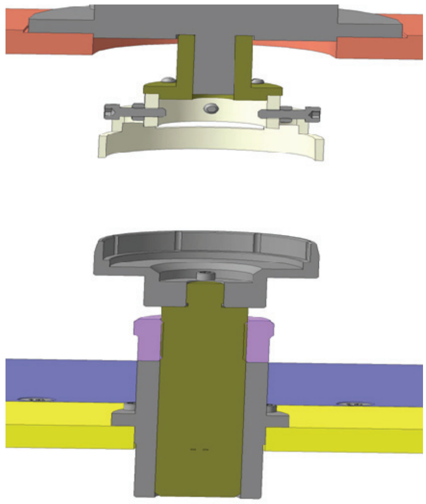

Fig. 3. 3D view of the model of the rotation unit with mandrels for workpieces of the technological complex for friction welding

welding time in half and decrease the costs of production of finished complexes twice by combining many operations of the welding cycle on one element of the technological complex structure.

All this reduces the cost of assembly of finished complexes by about 150 thousand rubles per one copy compared with a similar complex of contact-heat welding. But most importantly, the proposed design reduces the cost of welding operation in comparison with contact-heat welding 5–6 times due to the fact that in contact-heats welding the heating element must be always heated, while in friction welding the heat energy is dose-input into the welding zone.

R&D work was carried out using three-dimensional modeling system KOMPAS-3D, and drawings were made in the KOMPAS-Graphic system.

Test Results of the Technological Complex

Trial operation of the developed technological complex for friction welding was carried out at PLC "ARTI-Plant" in the production of respirator canisters FPK GP-7 and GP-7 KB (see Fig. 4).

a) *b*)

Fig. 4. 3D view of the canister:
a – FPK GP-7; *b* – GP-7

Tensile, bending, impact strength and torsion testing of joints made by friction welding showed good results.

If the welding process is carried out under conditions other than the optimal ones, the following faults may occur:

– lack of fusion in the mid-section, if the heating process was insufficiently intense or short-time;

– circumferential lack of fusion at the periphery.

In addition, friction welding has some advantages over other methods of welding since the quality of joints is not affected by random external factors (voltage fluctuations, the state of the surface, humidity, etc.) at small values of heating upsetting. The quality of welding is notable for greater stability within a batch produced without readjustment of the complex.

Conclusion

In this paper, the authors analyzed methods of welding plastic parts. The technology of welding thin-walled parts made of mineral-filled polypropylene (Armlen) was proposed and calculations to determine the process parameters of welding have been made. R&D and manufacture of an experimental sample of the technological complex that implements this process have been done. Testing the complex in the process of production of respirator canisters taken as an example showed its high efficiency and prospects of its use for the entire class of thin-walled products made of Armlen.

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