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LASER WELDING OF POLYETHYLENE FILMS

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***Summary**. Currently, the scope of application of laser welding is constantly expanding, in particular for the connection of polymer films of different types. This method of welding successfully competes with traditional methods, such as welding with heated tools and ultrasound in the light, medical, food and packaging industries. Advantages of laser welding are the absence of direct contact between the energy source and the heated surfaces and the ability to vary the intensity of heating by adjusting the temperature of the radiator and the distance to it. Currently, the most common laser welding technology is the transmission (permeable) method for overhead joints, which uses the effect of transparency of some polymeric materials for the laser beam.*

The transmission welding of low-power short-focus laser of polyethylene films of different types is carried out in the work. Knee welding was performed using a diode laser with a power of 1 W with a wavelength of 532 nm (green color of the visible light range). The laser on the clamping platform was moved along the connection line by means of a mechanical trolley. During welding, a 0.8–1 mm wide seam was formed and a slight convexity to the outside due to the expansion of the molten polymer material. Experimental studies of the influence of the main parameters of the laser welding process on the morphology of joints of polyethylene films of grades T and H. It is shown that welding laser films in the range of 0.015–0.1 mm does not require expensive laser equipment. A laser with a power of no more than 1 watt is enough to make a good connection.

The quality of the welded joints of the films was evaluated by visual inspection, examination under a microscope and tear tests. Studies of experimental welds have shown their strength at the level of the base material.

***Key words**: welded joints, polyethylene films, transmission laser welding, diode laser.*

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Statement of the problem. At present, the scope of plastics applications is constantly expanding [1, 2]. A large class of plastic products consists of different types of films, for the connection of which several welding technologies have been developed. Laser welding of polymer films is currently successfully competing with such methods as hot-tool welding and ultrasonic welding in various fields, such as light and food industries, medicine, different types of packaging. The use of this welding method is limited by the high cost of laser equipment. Therefore, it is important to develop methods for welding polymer films using low-power cheap lasers.

Analysis of available investigation results. While binding polymer films, the problem of welding process effectiveness is usually the most important. The use of laser radiation in this case makes it possible to achieve high values of power and energy flux density, which makes it fundamentally different from other heat sources. It is believed that almost all thermoplastics and thermoplastic elastomers are suitable for laser welding [3].

Lately, the most common technology of laser welding of polymeric materials is welding of overlap joints by transmission (permeable) method [4]. The essence of this method is that the laser radiation passes through the transparent upper part of the welded joint and is absorbed with heat release on the surface of the lower opaque parts. The typical scheme of the technological process of plastics transmission welding is shown in Fig. 1. The overlapping weld consists of the upper transparent to the laser beam part and the lower opaque (absorbing) polymer part. The laser beam easily passes through the upper part, is absorbed by the surface

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of the lower part and heats it (stage 1). In the general case, the parts are not flat against each other, so a gap is shown between them. The material of the lower part in the irradiation zone increases in volume and melts (stage 2). Over time, the heated material of the lower part comes into contact with the upper part and heat it (stage 3). The material of the upper part also melts (stage 4) and mixes with the melt of the lower part, forming the future weld. All these 4 stages take a short period of time, during which the area of laser radiation moving along the joint with the welding speed passes a specific seam section.

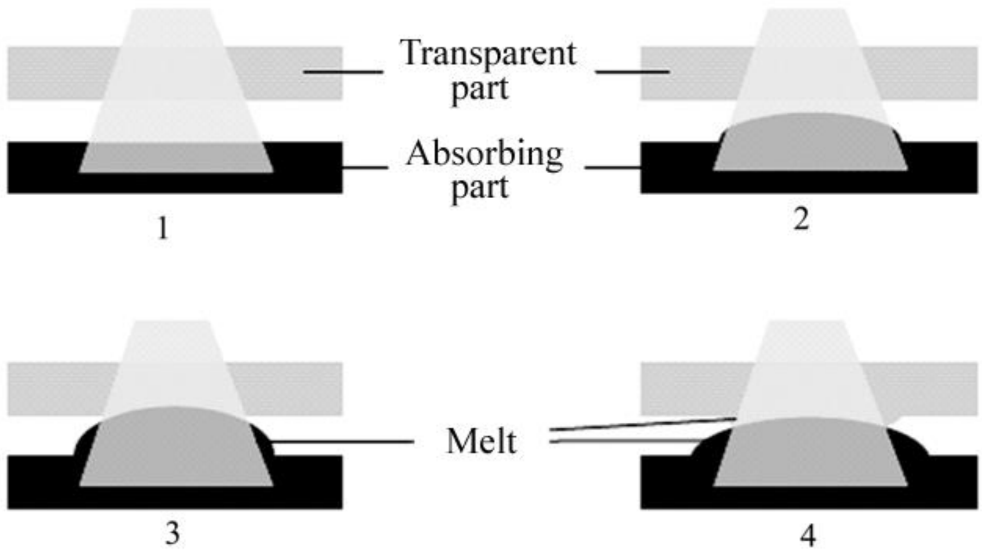

Figure 1. Scheme of laser transmission welding of polymeric materials: 1) the stage of radiation energy conversion into heat; 2) the stage of absorbing part melting; 3) the stage of melt expansion and its contact with the upper part; 4) the stage of heating and melting of the upper part

After termination of radiation, the melts of both parts harden, forming the weld. If the upper part is light, some pressure is applied to it to ensure the quality of the weld. Previously, we showed that for welding of translucent thin PVC films it is possible to use low-power laser with visible radiation [5]. In this work, the classical scheme of transmission welding of polyethylene films, with upper transparent and lower opaque ones, by means of such laser is tested.

The objective of the paper is to develop the method of polyethylene films welding by means of low-power laser, to find out the patterns of the welding process, as well as to investigate the mechanical properties of welds.

Statement of the problem. In this paper, the features of transmission laser welding of thin polyethylene films by low-power laser of optical radiation range and mechanical properties of the obtained welded joints are investigated on the experimental equipment.

Materials and methods. In this work, laser welding of polyethylene films of T and H grades is performed: the lower layer is black material that absorbs light, the upper layer is transparent film of white-gray color. The top polyethylene film of T grade is designed for technical use in construction, repair, packing of technical products. The lower polyethylene film of H brand is designed for production of consumer goods and packing materials of this category. The properties of polyethylene films of T and H grades are specified in the currently invalid interstate standard (GOST) [6].

1 W diode laser with 532 nm radiation wavelength (green colour of the visible light range) is used in this work for polyethylene films welding. It should be noted that diode

(semiconductor) lasers belong to the solid class [7]. The generation of radiation in them occurs under the action of the forced photons formation during the transitions of electrons between the semiconductor zones under conditions of their high concentration in the conduction area. The active media of such lasers are semiconductors based on gallium (for example, gallium arsenide GaAs) and indium (indium phosphide InP). In this case, the laser optical system is made in the short-focus version.

Investigation results. The general view of the experimental installation for transmission laser welding of polymer films is shown in Fig. 2. Special slides are used to mount the laser and apply pressure to the surface of the film to be welded. A fluoroplastic plate is fixed on the lower surface of the slides to ease sliding along the film surface. The slides are attached to the cart with two hinged levers, which allow them to track freely the profile of the surface on which the cart moves. The diode laser case mounted on the slides is able to rotate relatively to the horizontal axis in order to adjust the location of the laser beam spot on the welded surface. The laser beam is constantly focused on the spot with 0.8–1.0 mm diameter at 45 mm distance from the front plane of its case. The laser power during welding remains constant, the amount of penetration is adjusted by changing the welding speed. The laser is moved along the joint line with the welding speed, as in the previous work [3], by means of mechanical cart from Leister apparatus. The cart speed is regulated by electronic device within the range 0.1–5 m/min.

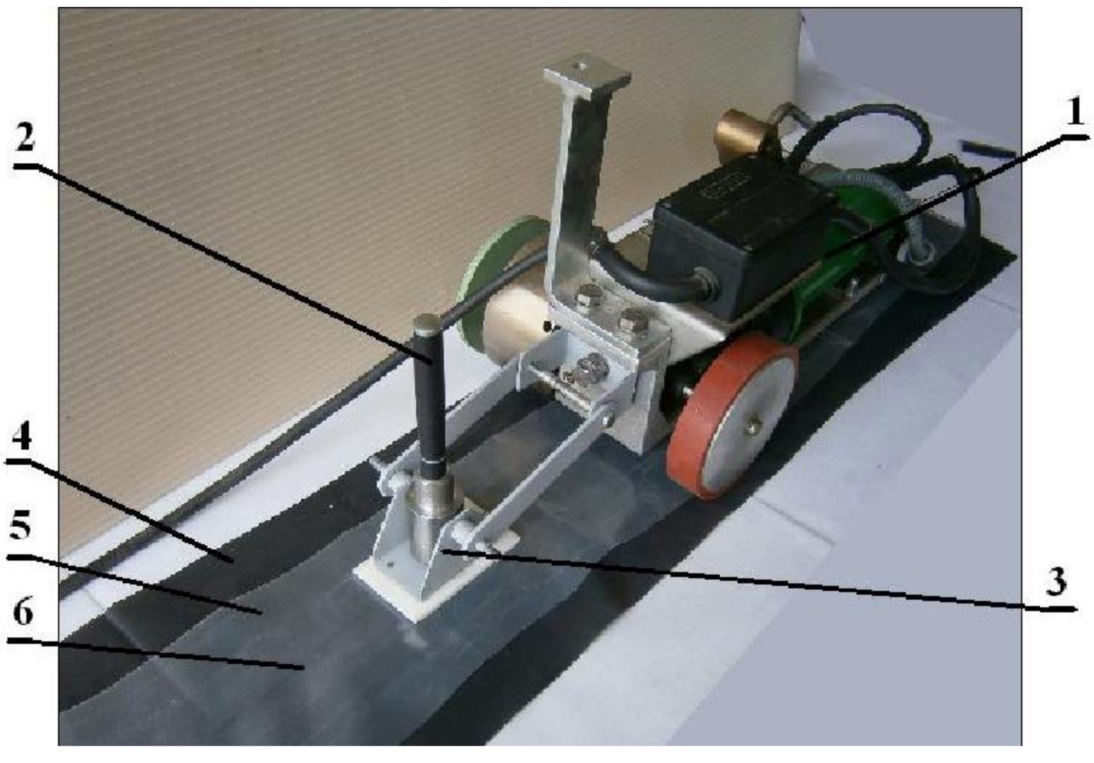

Figure 2. Experimental installation for transmission laser welding of polymer film with short-focus laser. 1) – welding cart; 2) – diode laser; 3) – slider-clamp for laser mounting; 4) – lower polyethylene film of black colour; 5 – upper transparent polyethylene film; 6 – weld

The quality of welded joints was assessed by visual inspection, microscopic examination and tear tests. During laser welding of polyethylene film, the seam with 0.8–1 mm width is formed. It has a slight excess weld outside due to the expansion of the molten material. Enlarged image of the weld of polyethylene films with 0.1 mm thickness (upper) and 0.05 (lower) is shown in Fig. 3, and its cross section – in Fig.4. The formation of pores and shells on the surface of the weld is possible (Fig. 3). This is caused by intense heating of the wel material by laser beam and evaporation of various impurities and contaminants on the surface and in the welded material. Investigations of welds shows that a small number of pores on the weld surface does not affect its strength and tightness.

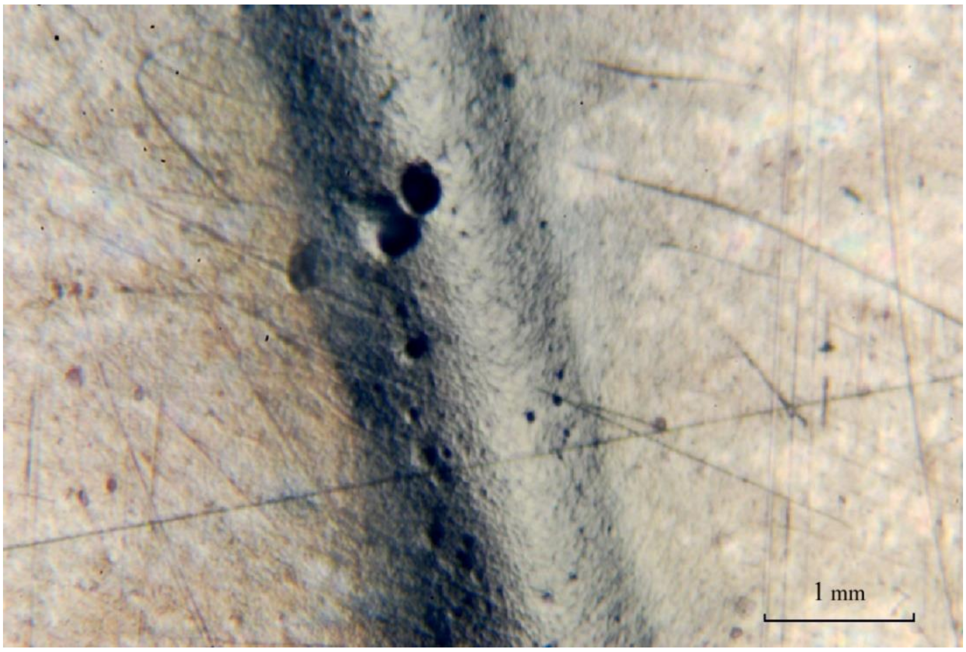

Figure 3. External view of the polyethylene film weld performed by transmission laser welding

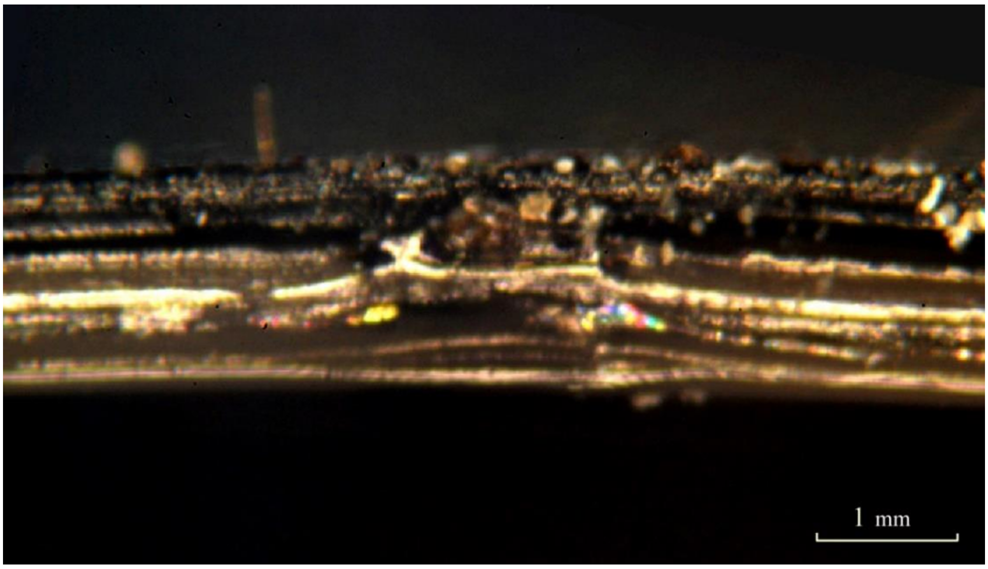

Figure 4. Cross-section of two polyethylene films joint performed by transmission laser welding

The cross section of the weld (Fig. 4) shows that mainly the material of the lower film melts, increasing in volume and due to heat transfer heats the thin layer of material of the upper film. After that, the weld is formed. Its quality depends on the amount of specific energy supplied to the welding area. Insufficient heating of the welding area does not fuse the upper and lower films, excessive heating creates numerous pores and gaps, which reduces the mechanical properties of the welded joint.

Conclusions. The experimental installation for transmission laser welding of polyethylene films with short-focus laser is developed and manufactured. Experimental investigations of the influence of laser welding process main parameters on the morphology of the joints of polyethylene films of T and H grades are carried out. It is determined that for welding of films with 0.05–0.1 mm thickness range, laser with 1 W power is generally sufficient to form high-quality joint. The disadvantage of the proposed technological scheme is the use of slides, which prevent accurately direction of laser beam to the joint line and monitor the welding progress directly.

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ЛАЗЕРНЕ ЗВАРЮВАННЯ ПОЛІЕТИЛЕНОВИХ ПЛІВОК

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Резюме. *В даний час постійно розширюються сфери застосування лазерного зварювання, зокрема для з’єднання полімерних плівок різних типів. Цей спосіб зварювання успішно конкурує з традиційними* *способами, такими, як зварювання нагрітим інструментом та ультразвуком при проведенні робіт у легкій, медичній, харчовій промисловості, пакуванні. Переваги лазерного зварювання – відсутність безпосереднього контакту між джерелом енергії та поверхнями, що нагріваються, та можливість у широких межах змінювати інтенсивність нагрівання регулюючи температуру випромінювача та відстань до нього. Найпоширенішою в даний час технологією лазерного зварювання є трансмісійний (проникний) метод для напускних з'єднань, що використовує ефект прозорості деяких полімерних матеріалів для лазерного променя.*

У роботі проведено трансмісійне зварювання малопотужним короткофокусним лазером поліетиленових плівок різних типів. Зварювання внапуск проведено за допомогою діодного лазера потужністю 1 Вт з довжиною хвилі випромінювання 532 нм (зелений колір світлового видимого діапазону). Лазер на притискній платформі переміщали вздовж лінії з'єднання за допомогою механічного візка. Під час зварування відбувалося формування шва шириною 0,8–1 мм та невеликою опуклістю назовні за рахунок розширення розплавленого полімерного матеріалу. Проведено експериментальні дослідження впливу основних параметрів процесу лазерного зварювання внапуск на морфологію з'єднань поліетиленових плівок марок Т та Н. Показано, що для зварювання плівок у діапазоні товщин 0,015–0,1 мм не потрібне вартісне лазерне обладнання, а для утворення якісного з'єднання достатньо лазера потужністю не більше 1 Вт.

Якість напускних зварних з'єднань плівок оцінювали візуальним оглядом, вивченням під мікроскопом та випробовуваннями на відрив. Проведені дослідження експериментальних зварних швів показали їх міцність на рівні основного матеріалу.

Ключові слова: *зварні з'єднання, поліетиленові плівки, трансмісійне лазерне зварювання, діодні лазери.*

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