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WELDING OF POLYMERS BY INFRARED LASER RADIATION

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***Summary**. A number of polymeric materials are translucent for infrared radiation. The use of low-power infrared lasers makes it possible to weld polymer sheets due to the penetration of radiation into the material depth. The possibilities of transmission welding of polybutene sheets, as well as several layers of polyethylene film are investigated. Epilog Fiber Mark 20 installation equipped with 20-W fiber infrared laser with 1.062 μm radiation wavelength is used. According to the investigation results, the maximum penetration depth of polybutene sheets at thea given radiation power is determined. The ability of welding up to eight layers of colored polyethylene film of PVD-108 and PVD-158 grade is shown.*

***Key words:** welded joints, polymer sheet materials, transmission laser welding, infrared lasers.*

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Statement of the problem. The technological possibilities of laser welding of plastics have been significantly extended by the development and mass industrial production of solid fiber lasers with resonators made of optical fiber alloyed with rare earth elements [1]. Lasers of this type usually emit electromagnetic waves of the near-infrared range, which have considerably higher penetration capacity for polymer materials and make it possible to heat evenly both the surface and the thickness of material in the irradiation zone.

Analysis of available investigation results. Lasers among other sources provide the highest concentration of energy in the heating area, and are widely used for cutting and welding of various materials, particularly plastics [2]. Almost all thermoplastic composite polymer materials, as well as polymer reactive plastics, are transparent for near-infrared radiation [3].

In the past years, powerful CO_2 lasers were used mainly for welding both metals and polymer materials, which provide almost instant material melting from the surface into great depth. In the heating area, there is a powerful splash of material to the outside as a result of the melt extrusion by steam-gas channel and thermal material expansion [4]. While welding plastics, this effect of excessive extrusion of the polymer material significantly complicates the weld formation.

In our previous papers [5] it is shown that for welding polymer films within 0.015–0.1 mm thickness range it is possible to use lasers with the power up to 10 Watts and radiation within the visible spectrum range. More powerful source of energy is required to weld thicker material. Therefore, the industrial fiber laser emitting in the near-infrared range is tested in this investigation. This radiation is not perceived by eyes, but most polymer materials are translucent to it, even with the presence of additional impurities and dyes in the material.

The objective of the paper is to investigate the peculiarities of welding optically opaque polymer materials using the laser with infrared radiation.

Statement of the problem. In this paper, experiments of transmission welding of polybutene sheets and several layers of polyethylene films by infrared laser are carried out on industrial laser equipment, and the properties of the resulting welded joints are investigated.

Materials and methods. The experiments are performed using Epilog Fiber Mark 20 laser unit [6]. The installation is equipped with solid laser based on optical fiber alloyed with ytterbium chemical element. The maximum power of the laser is 20 Watts at 1.062 μm radiation wavelength.

In order to determine the required irradiation modes, experiments of welding the polybutene sheet with 1 mm thickness at power within the range of 50–100% and 1–3 m/min welding speeds are carried out. Polybutene is often used in experimental investigations due to its expressed macrostructure, which contributes to the investigation of the morphology of welds without the use of additional macrosection processing measures. The possibility of welding several layers of colored polyethylene film is investigated as well. Polyethylene film of the first grade (grades H and T) is made of primary high-pressure polyethylene (PVD-108, PVD-158) by the method of extrusion in the form of a sleeve [7].

The results of the investigations. While welding the thin polymer films in one or more layers, it is important to ensure the heating mode by laser beam, which ensures the required amount of penetration. While welding the polymer sheets, it is also necessary to ensure the full depth material melting. At the same time, too much radiation energy results in the formation of burnings, as well as the destruction of the material being welded.

It should be noted that the polybutene sheet is translucent for visible and IR radiation. Under the influence of laser radiation and movement of the laser at a certain welding speed, the material thickness melting occurs, its depth increases in proportion to the amount of specific energy (the energy of laser radiation invested in the unit of weld length per unit of time). The amount of melting reached at the maximum power of specific energy is 0.5 mm. At the same time, rather uneven outer roll of the grating is formed, its width is 0.2–0.3 mm. In the depth of the material, a sharp wedge-shaped melting is formed, which is characteristic of welding with powerful concentrated energy sources (Fig. 1). As the specific energy of the laser beam decreases, the sharpness of the melting wedge decreases, its shape becomes more rounded, which is important in cases of welding thin polymer films. According to the results of experimental investigations, the dependence of the melting depth on the laser radiation power and welding speed is determined.

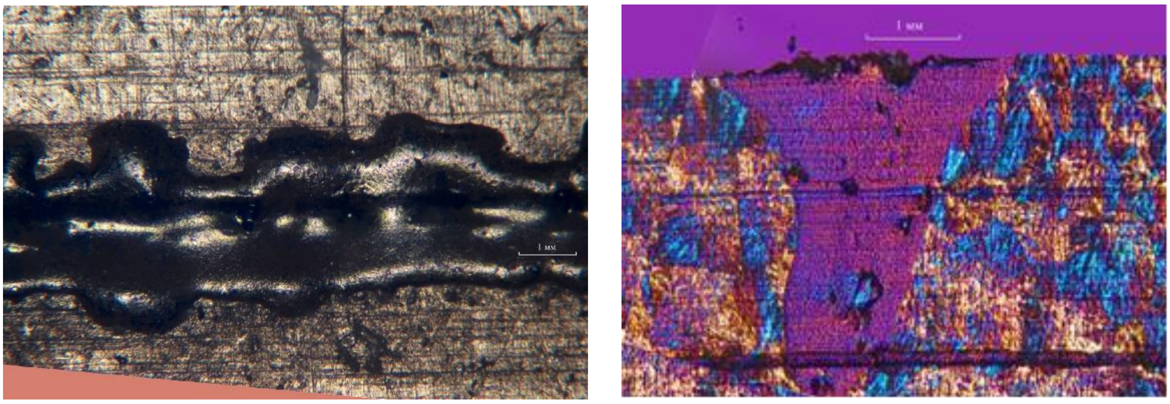

Figure 1. General view and cross section of polybutene sheet melting at maximum specific heating energy

The film for technical purposes is made with the thickness from 0.03 to 0.2 mm with the sleeve having 3 or 6 meters perimeter. Welding of thin film in several layers is quite widely used in packaging industry, since the multilayered film structure usually has greater strength and elastic characteristics than a single-layer film of the same final thickness. The material of polymer films usually contains various impurities and dyes that provide the film with the required physical and chemical properties. Films painted in light colors of unsaturated tones (yellow, blue, green) become translucent, including for both radiation of visible and infrared range, so they can be welded by laser welding in two or more layers.

Experimental welding of 0.05 mm blue polyethylene film is carried out. With 10–20 W laser power and selection of appropriate value of displacement speed, from two to eight layers of polyethylene film are welded well. In order to reduce the concentration of energy during thin film welding, the beam is defocused to the diameter of 1.5–2.0 mm on the material surface. As the result, relatively uniform weld with nice appearance (Fig. 2) is obtained, which in terms of its external and strength parameters is not inferior to similar welds made by heated tool welding.

Figure 2. Appearance of multilayer welded joint of the blue polyethylene film

While welding up to four layers of film, the weld turns out to be heated rather evenly, since laser radiation penetrates into the deep layers of the material and is absorbed there. With the increase in the number of layers of the film being welded, uneven heating of the upper and deep layers becomes apparent. While welding eight layers of polyethylene film (Fig. 3), the two upper layers are partially deformed due to the greater thermal effect of the laser beam.

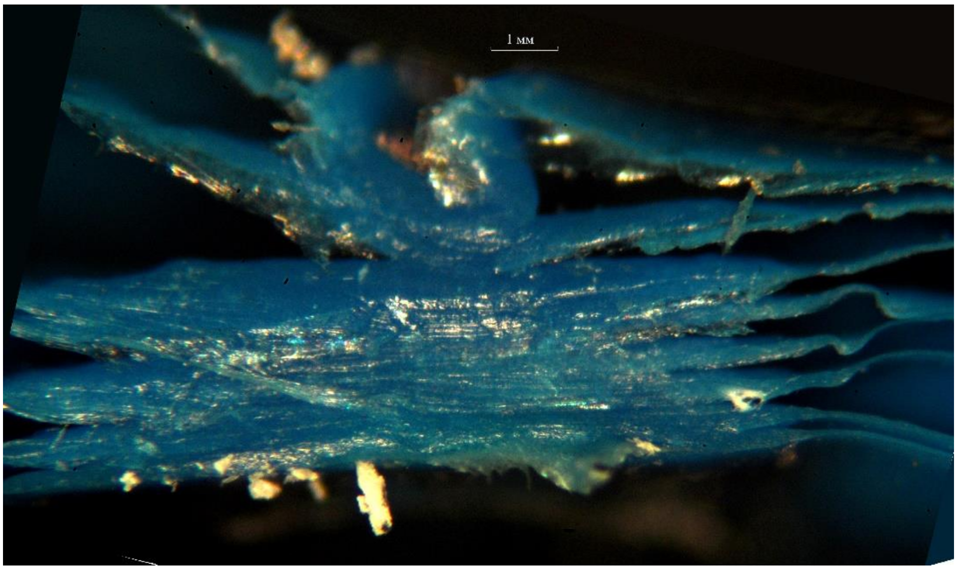

Figure 3. Welded joint of eight layers of the blue polyethylene film

However, it is possible to prevent film deformation due to special clamps-fixers. Obviously, while welding at least two layers of polymer films, it is possible to use less powerful optical range laser, making it possible to control the process of interaction of the laser beam with the substance visually.

Conclusions. Experimental investigations of the influence of the main parameters of the laser infrared irradiation process on the amount of polymer films and sheets melting are carried out. The possibility of laser welding up to eight layers of polyethylene films with small thickness which can serve as an alternative to their joining by means of heated tool is shown.

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ЗВАРЮВАННЯ ПОЛІМЕРІВ ІНФРАЧЕРВОНИМ ЛАЗЕРНИМ ВИПРОМІНЮВАННЯМ

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Резюме. *Трансмісійне лазерне зварювання пластмас зазвичай використовують для з'єднання верхньої прозорої деталі та нижньої непрозорої полімерної деталі, яка розігрівається за рахунок поглинання енергії променя оптичного діапазону. Однак значна кількість полімерних матеріалів є напівпрозорими для інфрачервоного випромінювання, що дозволяє зварювати оптично непрозорі деталі за* *рахунок проникнення випромінювання вглиб матеріалу. Технологічні можливості трансмісійного лазерного зварювання пластмас значно розширили розроблення та масовий промисловий випуск твердотільних інфрачервоних волоконних лазерів, резонатори яких виготовлені з оптичного волокна, легованого рідкоземельними елементами. В роботі досліджено можливості трансмісійного зварювання полімерних листів та плівок малопотужним (20 Вт) інфрачервоним лазером із довжиною хвилі випромінювання 1,062 мкм. Для визначання необхідних режимів опромінення проводили експерименти з проплавлення оптично непрозорого листа полібутену товщиною 1 мм. Показано, що в глибині матеріалу формується проплавлення гострої клинової форми, характерне для зварювання концентрованими джерелами енергії. Залежно від питомої енергії лазерного променя змінюється гострота клину проплавлення та ширина шва. За даної потужності випромінювання для листів полібутену досягнуто максимальну глибину проплавлення 0,5 мм. Також здійснено експериментальні зварювання непрозорої поліетиленової плівки блакитного кольору товщиною 0,05 мм промислових марок ПВД-108 та ПВД-158. Показано, що лазером даної потужності при підборі відповідної швидкості зварювання можливе з'єднання від двох до восьми шарів поліетиленової плівки. Для запобігання перегрівання тонкої плівки зменшували концентрацію енергії лазеру, промінь розфокусовували до діаметра 1,5–2,0 мм на поверхні матеріалу. В результаті отримано досить рівномірний зварний шов з гарним зовнішнім виглядом. Отже, трансмісійне лазерне зварювання може слугувати альтернативою традиційному з'єднанню поліетиленових плівок за допомогою нагрітого інструменту.*

Ключові слова: *зварні з'єднання, листові полімерні матеріали, трансмісійне лазерне зварювання, інфрачервоні лазери.*

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