Вісник Тернопільського національного технічного університету
https://doi.org/10.33108/visnyk_tntu
Scientific Journal of the Ternopil National Technical University
2020, № 1 (97) https://doi.org/10.33108/visnyk_tntu2020.01
ISSN 2522-4433. Web: ***visnyk.tntu.edu.ua***

UDC: 621.384.3:621.791:615.462-035

TECHNOLOGICAL FEATURES OF WELDING OF PLASTICS BASED ON POLYHYDROXYBUTYRATE

Victoriya Talanyuk[1]; Andriy Shadrin[1]; Maksym Iurzhenko[1]; Mykola Korab[1]; Andriy Agapov[2]

[1]E. O. Paton Electric Welding Institute of the NAS of Ukraine, Kyiv, Ukraine
[2]Technical Center of the NAS of Ukraine, Kyiv, Ukraine

Summary*. In particular polymers and biopolymers are increasingly used in various sectors of the economy and more recently biopolymers have been replacing traditional polymers in many applications. The problem of recycling polymeric materials can also be solved by designing products that will facilitate their further processing. In fact, biodegradation is the consistent breaking of chemical bonds of a polymer molecular chain under the action of microorganisms. Destroying a polymer, bacteria, fungi or algae uses the remnants of its molecules as a source of vital organic compounds as well as energy. Usually biodegradation occurs in an aqueous or humid environment during the process of composting. Bioplastics` wastes, like fallen leaves or other organic wastes, are stacked on soil and gradually converted into environmentally friendly material. The ability of a polymer to biodegrade mainly depends on the chemical composition of its molecule. One of the urgent tasks of research and implementation of biopolymers is the connection, in particular welding. Traditionally, plastic welding is widely used in the chemical, food, and other industries, for film packaging and packaging.*

Key words: *biodegradable, polyoxyalkonoates, thermoplastic polymer, bioplastic, polyhydroxybutyrate.*

https://doi.org/10.33108/visnyk_tntu2020.01.065 *Reseived 04.02.2020*

Problem statement. Development of modern industry of Ukraine provides use of polymer composite materials. Promising compositions are contained on thermoplastic polymers. Simple oversized parts are formed and can be joined in long articles using welding techniques. The use of mechanisms and machines containing these products after the end of their useful life poses the problem of their disposal outside how their processing can be problematic. The natural term of decomposition of such materials in the earth reaches several centuries. One alternative solution to this problem is to replace conventional polymers with biodegradable polymers having a shorter decay period, so that there is less environmental damage. But in order to replace conventional polymers with biopolymers on an industrial scale, there is a need to create new welding technologies.

Analysis of known research results. Natural polymers, or biopolymers, were first developed as early as the 1940 s. Henry Ford used these biopolymers in car construction. But with the discovery of petrochemical polymers, their low cost replaced natural materials [1].

The study of biopolymers is not limited to the use of product packaging. These polymers can be used in other industries. Biopolymers should be expected to be used in packaging, medicine, construction, almost every industry in the same way as synthetic plastics at the moment [2–3].

The polymer-based petrochemical industry has created many advantages for their use. The most important factors determining the rapid growth of plastics use in the packaging industry are convenience, safety, low price and sufficient ergonomic properties. But these polymers are derived from fossil resources, consumed and waste disposed of into the environment. The increase in non-recoverable waste significantly pollutes the

Corresponding author: Victoriya Talanyuk; e-mail: vika-toritalanuk@ukr.net

environment [4]. Environmentalists do not have a clear answer to the question of what to do with these *non biodegradable* wastes.

Burning such waste produces large amounts of carbon dioxide that will contribute to global warming. These environmental problems have created an urgent need to develop biopolymer materials, which are not related to the use of toxic and harmful components in their production and can decompose in nature [5]. For these reasons, today in the world, the development of biodegradable materials with controlled properties is the subject of a great research task for scientists and engineers.

Biopolymer, which occupies a significant place in industrial production – polyhydroxybutyrate (PHB) – biopolymer, which in physical properties is close to polystyrene. PHB is rapidly destroyed by soil microorganisms [6, 7].

Possible applications of PHB include the manufacture of biodegradable packaging materials and formed products, disposable wipes, personal care products, films and fibers, a water repellent coating for paper and paperboard. The first industrial production of PHB-PHV copolymers was organized in 1980 by the English company «ICA» under the trademark «Biopol». This polymer has relative thermal stability, passes oxygen, is resistant to aggressive chemicals and has strength compared to polypropylene [8].

One of the relevant tasks of research and introduction of biopolymers is connection, in particular welding [9–11]. Traditionally, plastic welding has been widely used in chemical, food and other industries for the manufacture of film containers and packaging. Welded plastic products are manufactured not only from semi-finished products, but also, increasingly, from packed moulded parts. With the expansion of the use of polymer materials, and subsequently their replacement with biodegradables, there is a need to solve a complex problem common to two types of materials, which is related to the connection of heterogeneous plastics. Even for polymer materials that have the same chemical composition and structure but have rheological properties, new welding technologies need to be developed.

Heated tool welding is the dominant method of welding plastics. It has the largest number of varieties and has been extensively studied in theoretical and applied planes in recent years [12].

Work purpose. To develop a method of forming welds in biopolymers of polyhydroxybutyrate type, to find out technological regularities of their weldability, as well as to study their mechanical properties.

Problem definition. This paper examines the weldability and mechanical properties of the welded compounds to polyhydroxybutyrate. Studies were carried out on plate samples, made by thermal pressing from polymer raw materials of powder form. The similarity of this material in its physical and chemical properties to polystyrene makes it possible to introduce the same welding methods as for conventional polymers.

Materials and methods. In a round metal mould heated to 140^0C, a measured amount of PHB powder was filled and heated for 2 minutes in a free state and for 1.5 minutes under a pressure of 50 MPa. The powder mold was then heated to 180 C and the article was kept at 50 MPa for a minute.

Results of a research. It was experimentally found that as mold temperature increased, residual stresses occurred in the pressed samples which resulted in the formation of cracks. At reduced mold temperatures, the powder did not melt completely, accordingly, a non-homogenous weakened microstructure was formed in the samples during pressing.

After cooling the sample in the mold, a 3–4 mm round-shaped polyhydroxybutyrate (PHB) disk was obtained from which rectangular samples having a width of 15–20 mm were cut. The melting point of the PHB powder was within the range of 180–185^0C. PHB compression experiments have shown that this polymer does not react well to overheating to temperatures above 220^0C. Therefore, during welding, the heater temperature was set to 200 to

210^0C, and the working deposition force was set to 0.1 MPa. The warm-up time was changed between 40 and 90 seconds to determine optimal weld formation conditions.

After cleaning, facing and checking the flat-parallel ends, the samples were butt welded on an experimental welding machine with a heated tool (Figure 1).

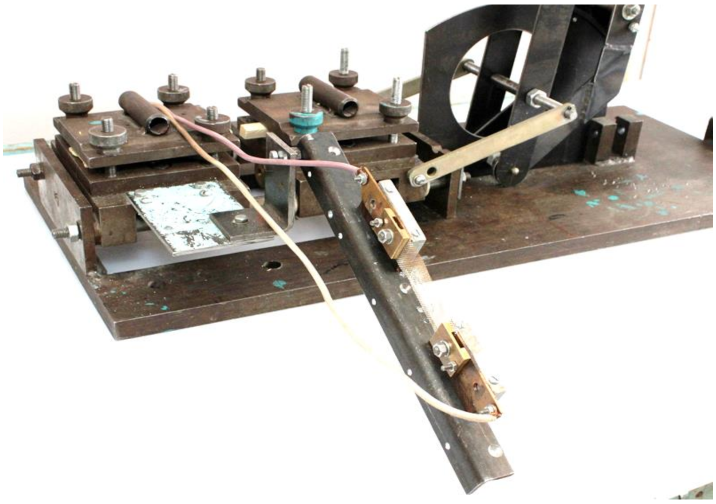

Figure 1. Experimental installation for butt welding with a heated tool of flat samples

During welding, ends were heated to 180^0C temperature. The warm-up time of the ends was varied between 20 and 30 seconds. Further melting was at 210^0C temperature. Sediment under pressure of 0.08 MPa, as well as cooling in the clamps of the plant to 45^0C temperature. The test samples were fixed in clamps and uniformly heated with a heating tool. The heating tool was a thin stainless steel plate or mesh, heated by electric current transmission at 220 V and 22A current. The PHB polymer material has low elastic properties with sufficient solution viscosity to form. When the samples are welded, a narrow elongated grid of complex geometric shape is formed. As the warm-up time of the samples increases, the size of the grata rolls also increases.

The PHB biopolymer proved to be a brittle material with high melt flow when heated. In butt welds, grate rolls were typically formed with melt flow over a portion of the base material of the samples (Figure 2). The grata rollers had a small height, almost the same on both sides of the welded joint.

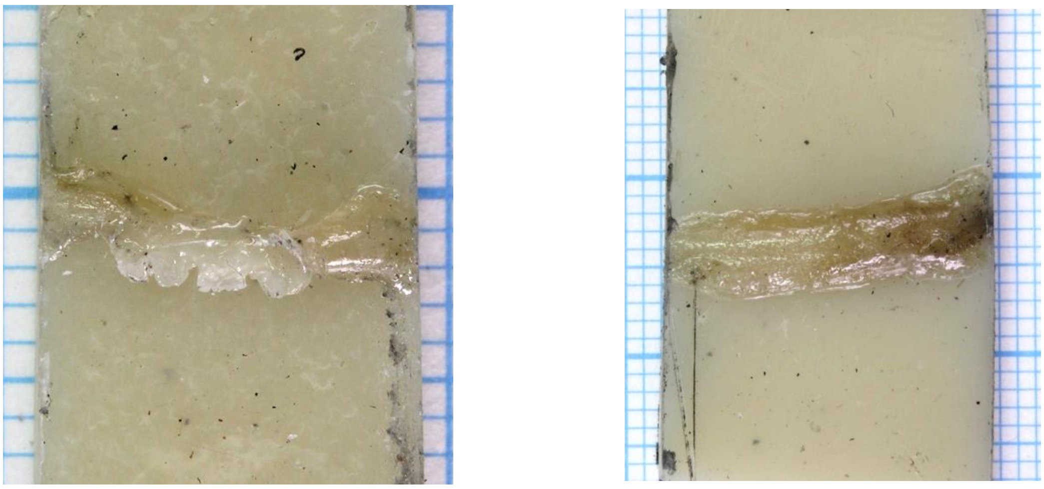

Figure 2. Butt welds of the PHB samples

During the welding process, during the heating of the samples for 40–50 seconds, fragments of underheating of the material were observed on the grille (Figure 2, left), non-melting zones were formed in the weld in certain places (Figure 3), which reduced the strength of the weld joint.

Figure 3. Weld of the PHB specimens with partial non-welded zones

With increasing warm-up time of samples up to 80–90 seconds, optimal formation of butt welded joints with formation of uniform roll of round grate took place. The longitudinal section of the samples (Figure 4) shows the weld of almost the same size in the vertical plane, which indicates uniform heating of the polymer material. The seam consists of a fairly uniform material of altered dark-coloured structure compared to the base polymer material.

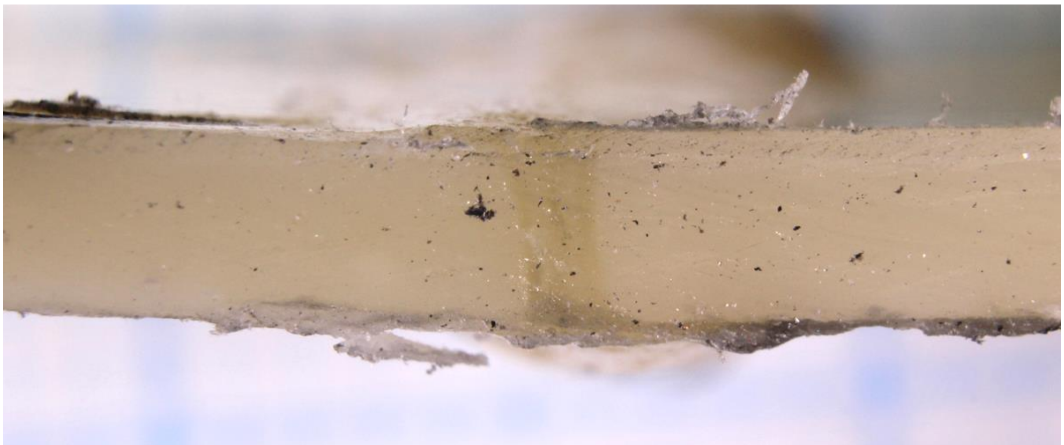

Figure 4. Weld of the PHB samples with the strength equal to the strength of the basic material

During the tensile test, the optimal welds were broken down along the base material near the thermal impact zone (Figure 5). Brittle character of material destruction is found on surfaces. Separation of individual fragments and layers of sample material was observed.

Thus, the PHB polymer material, although having low elastic properties, is well welded by a heated tool.

Figure 5. Destruction of the weld of the PHB samples during tensile tests

Organoleptic studies of the weld joints showed that the weld rolls were symmetrically and evenly distributed around the perimeter of the welded samples, and were not the same color as the base material, had no cracks, pores and foreign inclusions.

During the test on the fracturing machine FP-10 at a speed of 50 mm/min, the seams were broken down along the base material near the thermal impact zone. Mechanical studies of welded joints showed the following mechanical characteristics of welded seams of PHB samples:

- ✓ durability at monoaxial stretching – 42 MPas;
- ✓ relative lengthening at a gap – 10%.

Conclusions. Research of technological processes of welding of articles from polyhydroxybutyrate proves their effectiveness for formation of long structures, including packaging containers. It has been proved that the strength of the seams at the 210^0C forming temperature using the metal element reaches 42 MPa at an elongation of 10%. Equipment designed for other thermoplastic polymeric materials may be used to weld the material. The temperature for other biopolymers should be selected experimentally. In subsequent studies, it is planned to study the effect of the structure on the physical and mechanical characteristics of the weld material. Studies will also be carried out on the term of biodegradation of this polymer in the natural environment.

References

1. Ramsay J. A., Berger E., Voyer R., Chavarie C., Ramsay B. A. Extraction of poly-3-hydroxybutyrate using chlorinated solvents. Biotechnology Techniques. 1994. 8. P. 589–594. DOI: 10.1007/BF00152152. https://doi.org/10.1007/BF00152152
2. Jacquel N., Lo C.-W. Isolation and purification of bacterial poly (3-hydroxy alkanoates) Biochemical Engineering Journal. 2008. 39 (1). P. 15–27. DOI: 10.1016/j.bej.2007.11.029. https://doi.org/10.1016/j.bej.2007.11.029
3. Al-Majed A. A., Abd-Allah A. R., Al-Rikabi A. C., Al-Shabanah O. A. & Mostafa A. M. Effect of oral administration of Arabic gum on cisplatin-induced nephrotoxicity in rats. Journal of Biochemical and Molecular Toxicology. 2013. Vol. 17. No. 3. P. 146–153. ISSN: 1099-0461. https://doi.org/10.1002/jbt.10072
4. Jiang X., Ramsay J. A., Ramsay B. A.: Acetone extrac- tion of mcl-PHA from Pseudomonas putida KT2440. Journal of Microbiological Methods. 2006. 67. P. 212–219. DOI: 10.1016/j.mimet.2006.03.015. https://doi.org/10.1016/j.mimet.2006.03.015
5. Yu J., Chen L. X. L. Cost-effective recovery and purification of polyhydroxyalkanoates by selective dissolution of cell mass. Biotechnology Progress. 2006. 22. P. 547–553. DOI: 10.1021/bp050362g. https://doi.org/10.1021/bp050362g
6. Amanat N., James N. L., McKenzie D. R. Welding methods for joining thermoplastic polymers for the hermetic enclosure of medical devices. Medical Enjineering and physics. 2010. Vol. 32. P. 600–699. DOI: 10.1021/ie9707432. https://doi.org/10.1021/ie9707432
7. Rydz J., Wolna-Stypka K., Adamus G., Janeczek H., Musioł M., Sobota M., Marcinkowski A., Krzan A., Kowalczuk M. Forensic engineering of advanced polymeric materials. Part 1 – degradation studies of polylactide blends with atactic poly [(R, S)-3-hydroxybutyrate] in paraffin. Chem Biochem Eng Quart 29: 247–259. https://doi.org/10.15255/CABEQ.2014.2258
8. Kataev R. F. Welding of plastics. Textbook. Ekaterinburg: UPI Publishing House, 2008. 138 p.

9. Maximilian Brosda, Phong Nguyen, Alexander Olowinsky, Arnold Gillner Laserwelding of biopolymers. Procedia CIRP. Volume 74. 2018. P. 548–552. URL: https://doi.org/10.1016/j.procir.2018.08.116.
10. Karla Enid Lebron, Iowa State University. Interfacial healing and transport phenomena modeling of biopolymers. 2017.
11. Hanuma Reddy Tiyyagura, Tamilse lvan Mohan, Snehashis Pal, Mantravadi Krishna Mohan. 9 – Surface modification of Magnesium and its alloy as orthopedic biomaterials with biopolymers. Fundamental Biomaterials. Metals Woodhead Publishing Series in Biomaterials. 2018. P. 197–210. URL: https://doi.org/10.1016/B978-0-08-102205-4.00009-X.
12. Iurzhenko M., Shestopal A., Gokhfeid V., Korab M., Vasilijev Yu., Shadrin A., Demchenko V., Gusakova K. Dictionary-handbook on welding and glueing of plastics. 2018. P. 368.

Список використаної літератури

1. Ramsay J. A., Berger E., Voyer R., Chavarie C., Ramsay B. A. Extraction of poly-3-hydroxybutyrate using chlorinated solvents. Biotechnology Techniques. 1994. 8. P. 589–594. DOI: 10.1007/BF00152152. https://doi.org/10.1007/BF00152152
2. Jacquel N., Lo C.-W. Isolation and purification of bacterial poly (3-hydroxy alkanoates) Biochemical Engineering Journal. 2008. 39 (1). P. 15–27. DOI: 10.1016/j.bej.2007.11.029. https://doi.org/10.1016/j.bej.2007.11.029
3. Al-Majed A. A., Abd-Allah A. R., Al-Rikabi A. C., Al-Shabanah O. A. & Mostafa A. M. Effect of oral administration of Arabic gum on cisplatin-induced nephrotoxicity in rats. Journal of Biochemical and Molecular Toxicology. 2013. Vol. 17. No. 3. P. 146–153. ISSN: 1099-0461. https://doi.org/10.1002/jbt.10072
4. Jiang X., Ramsay J. A., Ramsay B. A.: Acetone extrac- tion of mcl-PHA from Pseudomonas putida KT2440. Journal of Microbiological Methods. 2006. 67. P. 212–219. DOI: 10.1016/j.mimet.2006.03.015. https://doi.org/10.1016/j.mimet.2006.03.015
5. Yu J., Chen L. X. L. Cost-effective recovery and purification of polyhydroxyalkanoates by selective dissolution of cell mass. Biotechnology Progress. 2006. 22. P. 547–553. DOI: 10.1021/bp050362g. https://doi.org/10.1021/bp050362g
6. Amanat N., James N. L., McKenzie D. R. Welding methods for joining thermoplastic polymers for the hermetic enclosure of medical devices. Medical Enjineering and physics. 2010. Vol. 32. P. 600–699. DOI: 10.1021/ie9707432. https://doi.org/10.1021/ie9707432
7. Rydz J., Wolna-Stypka K., Adamus G., Janeczek H., Musioł M., Sobota M., Marcinkowski A., Krzan A., Kowalczuk M. Forensic engineering of advanced polymeric materials. Part 1 – degradation studies of polylactide blends with atactic poly [(R, S)-3-hydroxybutyrate] in paraffin. Chem Biochem Eng Quart 29: 247–259. https://doi.org/10.15255/CABEQ.2014.2258
8. Катаев Р. Ф. Сварка пластмасс: учебное пособие. Екатеринбург: Изд-во УПИ, 2008. 138 с.
9. Maximilian Brosda, Phong Nguyen, Alexander Olowinsky, Arnold Gillner Laserwelding of biopolymers. Procedia CIRP. Volume 74. 2018. P. 548–552. URL: https://doi.org/10.1016/j.procir.2018.08.116.
10. Karla Enid Lebron, Iowa State University. Interfacial healing and transport phenomena modeling of biopolymers. 2017.
11. Hanuma Reddy Tiyyagura, Tamilse lvan Mohan, Snehashis Pal, Mantravadi Krishna Mohan. 9 – Surface modification of Magnesium and its alloy as orthopedic biomaterials with biopolymers. Fundamental Biomaterials. Metals Woodhead Publishing Series in Biomaterials. 2018. P. 197–210. URL: https://doi.org/10.1016/B978-0-08-102205-4.00009-X.
12. Юрженко М. В., Шестопал А. М., Гохфельд В. Л., Кораб М. Г., Васильєв Ю. С., Шадрін А. О., Демченко В. Л., Гусакова К. Г. Словник-довідник зі зварювання та склеювання пластмас. 2018. 368 с.

УДК: 621.384.3:621.791:615.462-035

ТЕХНОЛОГІЧНІ ОСОБЛИВОСТІ ЗВАРЮВАННЯ ПЛАСТИКІВ НА ОСНОВІ ПОЛІГІДРОКСИБУТИРАТУ

Вікторія Таланюк[1]; Андрій Шадрін[1]; Максим Юрженко[1]; Микола Кораб[1]; Андрій Агапов[2]

[1]Інститут електрозварювання імені Є. О. Патона НАН України, Київ, Україна
[2]Технічний центр НАН України, Київ, Україна

Резюме. *Природні полімери або біополімери, були вперше розроблені ще в 1940-х роках. Генрі Форд використовував ці біополімери у будівництві автомобілів. Але з відкриттям нафтохімічних* *полімерів їх низька вартість замінила натуральні матеріали. Основним недоліком використання пластмас ще й досі лишається екологічний фактор. Дослідження біополімерів не обмежується використанням пакування продуктів. Дані полімери можуть використовуватися в інших областях промисловості. Слід очікувати використання біополімерів у пакуванні, медицині, будівництві, майже в кожній галузі промисловості так само, як синтетичні пластмаси в даний момент. Нафтохімічна промисловість, на основі полімерних технологій, створила багато переваг для їх використання. Найважливішими факторами, що визначають швидке зростання використання пластмас у пакувальній промисловості є зручність, безпека, низька ціна і достатні ергономічні властивості. Але ці полімери отримали з викопних ресурсів, їх споживали і відходи утилізували в навколишнє середовище. Збільшення нерозкладних відходів значно забруднює навколишнє середовище. Біополімер, що займає значне місце у промисловому виробництві – полігідроксибутират (ПГБ) – біополімер, який за фізичними властивостями подібний полістиролу. ПГБ швидко руйнується грунтовими мікроорганізмами. Можливі області застосування ПГБ – це виготовлення біорозкладаних пакувальних матеріалів та формованих товарів, одноразових серветок, предметів особистої гігієни, плівок і волокон, водовідштовхуючого покриття для паперу й картону. Перше промислове виробництво кополімерів PHB-PHV організувала в 1980 році англійська компанія «ICA» під торговою маркою «Biopol». Цей полімер характеризується відносною термостабільністю, пропуском кисню, стійкістю до агресивних хімікатів і має міцність порівнянно з поліпропіленом. Біополімер, що займає значне місце у промисловому виробництві – полігідроксибутират (ПГБ) – біополімер, який за фізичними властивостями, подібний полістиролу. ПГБ швидко руйнується ґрунтовими мікроорганізмами. Зварюваність та властивості зварних з'єднань полігідроксібутирату досліджували на пластинчастих зразках, що виготовляли тепловим пресуванням із полімерної сировини порошкоподібної форми. Експериментально встановлено, що при збільшенні температури форми у пресованих зразках виникали залишкові напруження, які призводили до утворення тріщин. При понижених температурах форми порошок не розплавлявся повністю, відповідно, при пресуванні у зразках формувалася негомогенна ослаблена мікроструктура. При випробуванні на розтяг оптимальні зварні шви руйнуються по основному матеріалу поблизу зони термічного впливу. На поверхнях виявлено крихкий характер руйнування матеріалу. Спостерігали відокремлення окремих фрагментів та шарів матеріалу зразків. Таким чином, полімерний матеріал ПГБ, хоча і має низькі пружні властивості, добре зварюється за допомогою нагрітого інструменту. Під час випробування на розривній машині FP-10 зі швидкістю 50 мм/хв шви руйнувалися по основному матеріалу поблизу зони термічного впливу. Механічні дослідження зварних з'єднань показали наступні механічні характеристики зварних швів зразків ПГБ:*

- ✓ *міцність при одновісному розтягу – 42 МПа;*
- ✓ *відносне подовження при розриві – 10%.*

Ключові слова: *природні полімери, полігідроксибутират, грунтові мікроорганізми, водовідштовхуючі покриття, пластичні маси, стикове зварювання.*

https://doi.org/10.33108/visnyk_tntu2020.01.065 *Отримано 04.02.2020*