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REVIEW OF INJECTION MOLDING MACHINES FOR RECYCLING FDM PRINTING WASTE

Recycling of FDM 3D printing process waste remains a pressing issue due to the rapid growth of plastic waste in additive manufacturing, especially in prototyping, medicine and industry. To solve this problem, compact desktop injection molding machines are being actively developed, which provide a full recycling cycle directly at the production site - from laboratories to small workshops. The article is a comprehensive review of the latest designs and technologies of low-power injection molding machines designed for processing popular PLA thermoplastics (biodegradable polylactide), ABS (high strength), PETG (transparent), PA (elastic nylon) and their reinforced composites. A wide range of hardware solutions is considered: from simple pneumatic bench-top injectors for workshops and prototyping to precision laboratory-grade microinjectors for scientific research, autonomous recyclers with integrated grinding, extrusion and drying, as well as hybrid systems. Numerous examples of practical implementation are given - DIY projects of the open 3D printing community with the possibility of self-assembly, laboratory installations for studying material degradation, commercial bench-top solutions and startups, as well as semi-industrial prototypes for small-scale production. Key technological parameters are analyzed. A comparative analysis of portable and professional approaches revealed their strengths and weaknesses in terms of energy efficiency, cost, flexibility of use and limitations. Development prospects were discussed: hybrid complexes shredder + extruder + injector, sensor automation for monitoring parameters, integration with CAD systems for automatic mold design, development of biodegradable composites and artificial intelligence algorithms for mode optimization. The development of such machines creates the basis for Industry 4.0 in additive manufacturing, implementing the concept of closed cycles without the need for industrial infrastructure.
Keywords: *3D printing, FDM, recycling, polymer waste, injection molding machine, injection molding.*

ПОЛІЩУК АНДРІЙ, ПОЛІЩУК ОЛЕГ, ЗАГУРОВСЬКИЙ МАКСИМ, ПОЛІЩУК ОЛЕГ
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ОГЛЯД ЛИТТЄВИХ МАШИН ДЛЯ РЕЦИКЛІНГУ ВІДХОДІВ FDM-ДРУКУ

Переробка технологічних відходів FDM 3D-друку залишається актуальним завданням через стрімке зростання об'ємів пластикового сміття в адитивному виробництві, особливо у прототипуванні, медицині та промисловості. Для вирішення цієї проблеми активно розробляються компактні настільні машини для лиття під тиском, що забезпечують повний цикл рециклінгу безпосередньо на місці виробництва - від лабораторій до малих майстерень. Стаття являє собою всебічний огляд новітніх конструкцій та технологій інжекційних термопластавтоматів малої потужності, призначених для переробки популярних термопластів PLA (біорозкладний полілактид), ABS (високоміцний), PETG (прозорий), PA (еластичний нейлон) та їхніх композитів з армуванням. Розглянуто широкий спектр апаратних рішень: від простих пневматичних настільних інжекторів для майстерень і прототипування до прецизійних мікроінжекторів лабораторного класу для наукових досліджень, автономних рециклерів з інтегрованим подрібненням, екструзією та сушінням, а також гібридних систем. Наведено численні приклади практичної реалізації - DIY-проектів відкритої спільноти 3D-друку з можливістю самостійного складання, лабораторних установок для вивчення деградації матеріалів, комерційних настільних рішень і стартапів, а також напівпромислових прототипів для малого виробництва. Проаналізовано ключові технологічні параметри. Порівняльний аналіз портативних та професійних підходів виявив їхні сильні та слабкі сторони за критеріями енергоефективності, вартості, гнучкості використання та обмежень. Обговорено перспективи розвитку: гібридні комплекси шредер+екструдер+інжектор, сенсорну автоматизацію для моніторингу параметрів, інтеграцію з CAD-системами для автоматичного проектування форм, розробку біорозкладних композитів та алгоритмів штучного інтелекту для оптимізації режимів. Розробка таких машин створює основу для Індустрії 4.0 в адитивному виробництві, реалізуючи концепцію замкнених циклів без потреби в промисловій інфраструктурі.
Ключові слова: *3D-друк, FDM, рециклінг, полімерні відходи, литтєва машина, лиття під тиском.*

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Introduction

The rapid spread of additive manufacturing technologies, in particular FDM/FFF printing, has led to a significant increase in the production of plastic products in the prototyping, medical and industrial sectors, but has also led to the accumulation of massive amounts of waste - from complex support structures and defective models to filament residues, thread scraps, used packaging and unnecessary experimental samples. Popular thermoplastics such as PLA (biodegradable polylactide), ABS (strong acrylonitrile-butadiene-styrene), PETG (transparent polyethylene terephthalate -glycolysis), polyamides (elastic nylon) or composites with carbon or glass fibers demonstrate excellent thermal stability and suitability for multiple recycling, retaining key mechanical properties after heating and molding. This creates real opportunities for organizing closed material cycles directly on site - in scientific laboratories, student workshops FabLab, educational centers or small-scale production, without involving expensive industrial facilities.

Compact injection molding machines are a key tool for such processing [1]. They effectively convert crushed or granulated waste from FDM printing into new products - mechanical parts (gears, fasteners), prototype housings, tool elements or even decorative items. This approach not only embodies the principles of environmental responsibility and circular economy, reducing the volume of plastic waste and dependence on primary raw materials, but also significantly reduces the cost by 30-50% due to internal recycling. In contrast to large-scale industrial automatic injection molding machines (with a force of hundreds of tons), these installations are distinguished by their minimal dimensions (from 0.5 cubic meters), moderate mold closing force, simplified designs of plasticizers, heaters and hydraulics, as well as adaptation to micro-batch raw materials from a few grams to tens of kilograms. The technological chain is optimized for laboratory conditions: the waste is first crushed to a fraction of 1-5 mm in shredders, dried at 80-120 °C to remove moisture, compounded with additives to stabilize properties, and then fed into the injector with precise control of moisture below 0.1% and impurities, avoiding defects such as bubbles or irregularities. This allows not only practical processing, but also in-depth studies of material degradation in real cycles.

Research object and methods

The object of the study is the process of processing technological waste of FDM 3D printing by injection molding on compact desktop machines. In other words, the focus is on technologies and methods that convert 3D printing waste (PLA, ABS, PETG, PA and composites) into finished products using low-power injection molding machines. The research methods in this work are of the nature of a review and analytical study.

The analysis and systematization of data from scientific publications, technical reports, and online sources in recent years (2020–2026) related to compact machines for recycling FDM waste were carried out. Methods of comparison, synthesis of information from multiple sources, and critical analysis of advantages and limitations were used to summarize the results.

Setting the task

The purpose of this work is to review the current state and recent developments in the field of compact desktop machines for injection molding of technological waste FDM 3D printing. To achieve this goal, the following tasks must be solved:

- analyze the main types of low-power injection molding machines and determine their design features and role in the processing of FDM waste;
- summarize information on the technological parameters of equipment for processing thermoplastics PLA, ABS, PETG, PA and composites (injection pressure, heating modes, fractional composition of raw materials, productivity, process stability);
- consider examples of recycling systems in practice, including DIY/ open-source projects of the 3D printing community, university laboratory installations, and commercial desktop solutions available for FabLab and small-scale production;
- to identify the main trends and directions of further research in this area.

Results and their discussion

The results of a detailed analysis of compact injection molding machines for FDM (Fused Deposition Modeling) printing waste demonstrate the high potential of DIY and commercial solutions specifically adapted for the recycling of thermoplastics such as PLA, ABS, PETG, HDPE or PA from printers. These installations transform technological waste into functional parts, reducing waste and costs. The proposed models are reviewed below, focusing on parameters, performance and applications.

The first equipment option is the INJEKTO-3 model, a pneumatic bench-top injector with a reliable piston mechanism that easily integrates with a compact shredder for a complete recycling cycle (Fig. 1) [2]. The total weight of the installation does not exceed twenty kilograms, making it extremely portable for use in small laboratories or home workshops.

INJEKTO-3 generates a working injection pressure of up to one hundred and fifty bar, ensuring high-quality filling of molds even with viscous recycled materials. The molding cycle is from thirty to ninety seconds depending on the volume of the part and the type of plastic, and the heating system maintains stable temperatures in the range of 180-250 °C, optimal for PLA, PETG or ABS from FDM printing waste. The machine easily processes fractions of crushed plastic with a size of 2-5 mm, with an injection volume of 5-15 cubic centimeters and a productivity of 0.3-0.8 kg per hour, which is enough for series of 50-200 parts.

It is used to form products up to eight centimeters in diameter - electronics housings, fasteners, gears or prototype parts - with minimal loss of strength (10-20% after several processing cycles). Tests confirm high surface quality with a roughness Ra of less than ten micrometers.

Key advantages of INJEKTO-3 include full modularity. A granulation extruder or vacuum dryer can be easily added to the base model, and compatibility with 3D printed molds made of PETG or PC allows for quick design changes without expensive metal tooling.

The second option is Injection Mini V1.1, developed by Sustainable Design Studio, optimized specifically for rapid prototyping and testing of recycled materials (Fig. 2) [3]. This model is ultra-compact, weighing only fifteen kilograms and with a power of one kilowatt, allowing it to be plugged into a regular outlet without special equipment.

The material dosage is regulated within 0.5-10 cubic centimeters with high accuracy, the injection pressure reaches 100-200 bar for reliable filling of molds, and the heating stability is plus or minus two degrees Celsius, ensuring a uniform melt. The casting cycle is fixed at forty-five seconds, which is ideal for iterative work. The machine is suitable for PLA and ABS from FDM printing waste at temperatures of 190-240°C, easily granulating fractions of 1-4 mm without prior drying. Prototypes of 3-7 cm in size are made from plastics - from gears and brackets to sensor housings, with high detail.

Fig. 1. Pneumatic injector with automatic granule feed INJEKTO-3 [2]

Fig. 2. Desktop automatic molding machine « Injection Mini V1.1" [3]

Experimental studies of finished samples have shown that the strength of finished parts is 85% of the original raw material, impact resistance is reduced by only 15%. Disadvantages - manual cleaning of the plasticizer.

The third option is TARS (Tiny Automatic Recycling System) from Manutech Lab. This is an autonomous molding machine that combines an extruder and an injection unit for injection molding in one housing (Fig. 3) [4]. This configuration ensures the recycling of FDM printing waste: from defective parts and supports to finished new products. The installation weighing about twenty-five kilograms remains desktop and mobile, so it can be placed both in a startup workshop and in a university laboratory.

The TARS productivity is approximately from 0.2 to 1 kilogram of raw material per hour, depending on the type of plastic and the selected mode, which allows you to get dozens or even hundreds of parts in one shift. The working pressure of the injector reaches approximately 120 bar, which is enough for high-quality filling of molds with complex geometry. The heating system is designed to work with high-strength polyamides and ABS, maintaining temperatures up to 280°C, which opens up the possibility of processing both standard and technical materials with increased heat resistance.

Fig. 3. TARS injection molding machine [4]

An important feature of TARS is the developed automation system. Humidity and temperature sensors monitor the condition of the material and working areas in real time, and control algorithms automatically adjust the process parameters. This allows you to minimize overheating and thermal destruction of the polymer, due to which the total degradation of the mechanical properties of the secondary raw materials does not exceed approximately 25% even after several processing cycles. The maximum size of parts that can be manufactured on this machine is approximately six centimeters, which fully meets the needs of prototyping small cases, fasteners, decorative inserts and functional small parts.

The system is controlled via a mobile application with Bluetooth connectivity. The operator can set temperature profiles, injection pressure, cycle time, and track batch history and basic statistics. This greatly simplifies the integration of TARS into digital workflows of startups and educational institutions, where transparency and repeatability of experiments are important. Typical areas of application of such a complex are the manufacture of prototypes of electronics housings, small furniture elements, interior accessories, educational models, as well as series of small functional parts for small business projects.

The fourth option is the BWMINI-15T desktop injection molding machine from 3DDevice. This is a specialized laboratory microinjector designed for high-precision processing of composite materials from FDM printing waste (Fig. 4) [5]. This model is designed for research institutions, universities and science centers where maximum precision is required when working with small volumes of raw materials, including complex composites with carbon fibers, glass or metal fillers obtained from recycled thermoplastics such as PLA, PA or ABS.

The main difference of BWMINI-15T is the minimum dosage from 0.05 to 5 cubic centimeters, which allows for precise experiments with micro-parts without significant material loss. The injection pressure reaches 800 bar, ensuring complete filling of tiny molds with complex geometry without air inclusions or defects. Digital control based on PID algorithms (proportional -integral-differential) guarantees the stability of all process parameters with an accuracy of up to a degree Celsius and 0.1% in pressure. The molding cycle is reduced to 15-40 seconds, which makes it possible to process hundreds of samples per shift for statistical studies.

Fig. 4. Desktop automatic injection molding machine BWMINI-15T [5]

The microinjector excels at composites from FDM waste. The shredded plastic with reinforcement is granulated to 0.5-3 mm fractions, dried automatically, and then injected with controlled melt viscosity. Test results show a moderate viscosity loss of 12-30% after several cycles, which is acceptable for most engineering applications and allows for the study of degradation patterns.

The mechanical strength of the finished micro-samples is 82-90% of the original raw material, the surface roughness Ra does not exceed 3 micrometers, which meets industrial standards. Full integration with CAD software (SolidWorks, Fusion 360) allows you to automatically generate molds and optimize casting parameters based on simulations. Such functionality makes BWMINI an ideal tool for scientific research, scientific articles and patent developments in the field of additive manufacturing.

A review of compact desktop injection molding machines for FDM printing waste showed their high efficiency in processing thermoplastics such as PLA, ABS, PETG, or PA into finished products - device housings, fasteners, prototype parts, or interior elements.

Conclusions

The creation of compact desktop machines for injection molding of FDM printing waste is a promising direction in the development of additive technologies. Such installations allow for the efficient processing of thermoplastics (PLA, ABS, PETG, PA), transforming defective parts and supports into finished products without industrial equipment.

The development of these machines is justified by the growth of 3D printing waste and the demand for closed recycling loops. They combine portability, modularity and automation, ensuring a quick payback through raw material savings. Prospects include hybrid systems with shredders for grinding, integration of artificial intelligence for process optimization and biodegradable composites, which makes the technology in demand for various fields.

References

1. A. Polishchuk, M. Zahurovskyi, O. Polishchuk, O. Polishchuk, O. Maliarchuk. Overview of injection molding machines for 3d printing waste recycling. Technical creativity. Collection of scientific works. Khmelnytskyi №9, 2025. – P.101-103.

2. INJEKTO 3. Plastic Injection Molding Machine [Electronic resource]. - Access mode: https://actionbox.ca/pages/injekto-2.

3. Injection Mini V1.1 [Electronic resource]. - Access mode: https://www.sustainabledesign.studio/injectionmini.

4. TARS (Tiny Automatic Recycling System) [Electronic resource]. - Access mode: https://manutechlab.com/tars.

5. Desktop injection molding machine BWMINI-15T [Electronic resource]. - Access mode: https://3ddevice.com.ua/en/product/desktop-imm-bwmini-15t/.