https://doi.org/10.31891/2307-5732-2026-365-15
УДК 621.791.92:678.027

DEMCHUK BOHDAN
Khmelnytskyi National University
https://orcid.org/0009-0006-2995-4328
e-mail: demchukbv@khmnu.edu.ua
DRACH ILONA
Khmelnytskyi National University
https://orcid.org/0000-0003-0590-9814
e-mail: drachil@khmnu.edu.ua

POST-PROCESSING PROCESSES OF POLYMER PARTS MANUFACTURED BY FDM METHOD: A REVIEW OF CURRENT RESEARCH

Fused Deposition Modeling (FDM) has become a key technology in additive manufacturing for rapid production of complex geometry polymer parts without expensive molds. However, anisotropy of mechanical properties, insufficient interlayer adhesion, and geometric dimensional deviations significantly limit the application scope of such products in critical structures. In response to these challenges, post-processing technologies are actively developing, allowing to increase density, strength, and accuracy of FDM parts after printing. The article presents a comparative analysis of thermal, thermomechanical, and chemical post-processing methods, as well as complex combined approaches for improving properties of polymer products. Structural changes in the polymer matrix during treatment and material behavior at different processing stages have been analyzed.

Special attention is paid to temperature, annealing duration, and mechanical loading during heating. The influence of these factors on strength, elastic modulus, interlayer adhesion, surface roughness, and dimensional stability of finished parts is discussed using data from recent studies. Optimal selection of processing modes ensures substantial growth of mechanical characteristics and achievement of required dimensional tolerances for products. The analysis highlights the importance of glass transition temperature thresholds and cooling rates in preventing unwanted thermal shrinkage and warpage. The presented recommendations enable well-grounded selection of post-processing parameters for specific polymer materials like PLA, ABS, and PETG, considering their unique operating conditions. This review helps engineers move from prototypes to real industrial parts and provides practical guidance for selecting appropriate treatment methods.

***Keywords**: additive technologies, polymers, interlayer properties, post-processing, surface roughness, mechanical strength*

ДЕМЧУК БОГДАН, ДРАЧ ІЛОНА
Хмельницький національний університет

ПРОЦЕСИ ПОСТОБРОБЛЕННЯ ПОЛІМЕРНИХ ДЕТАЛЕЙ, ВИГОТОВЛЕНИХ МЕТОДОМ FDM: ОГЛЯД СУЧАСНИХ ДОСЛІДЖЕНЬ

Метод пошарового наплавлення (FDM) став ключовою технологією адитивного виробництва для оперативного виготовлення полімерних деталей складної геометрії без дорогих прес-форм. Проте анізотропія механічних характеристик, недостатня адгезія між шарами та відхилення геометричних розмірів істотно звужують сферу застосування таких виробів у відповідальних конструкціях. У відповідь на ці виклики активно розвиваються технології постоброблення, що дозволяють підвищити щільність, міцність і точність FDM-деталей після друку. У статті здійснено порівняльний аналіз термічних, хімічних, термомеханічних методів постоброблення, а також комбінованих підходів для покращення властивостей полімерних виробів. Особливу увагу приділено технологічним параметрам процесів – температурі, тривалості відпалу та величині механічного навантаження при нагріванні. Встановлено, як зазначені фактори впливають на міцність, модуль пружності, міжшарову адгезію, шорсткість поверхні та стабільність розмірів готових деталей. З'ясовано, що оптимальний підбір режимів термомеханічної обробки забезпечує істотне зростання механічних характеристик і досягнення необхідних допусків на розміри виробів. Викладені рекомендації дають змогу обґрунтовано підбирати параметри постоброблення для конкретних полімерних матеріалів та умов їхньої експлуатації.

***Ключові слова**: адитивні технології, полімери, міжшарові властивості, постоброблення, шорсткість поверхні, механічна міцність.*

Стаття надійшла до редакції / Received 11.02.2026
Прийнята до друку / Accepted 11.03.2026
Опубліковано / Published 28.05.2026

1. Introduction

Additive manufacturing of polymers has transformed from a prototyping tool into a full-scale technology for producing functional parts. It is the FDM (Fused Deposition Modeling) method that leads here – not due to the perfection of the process, but because of its accessibility: relatively inexpensive equipment, a wide range of materials, and the ability to print geometries that traditional processing methods would only master at significant cost. In medicine, aviation, and mechanical engineering, FDM is already competing with injection molding.

However, the stepped nature of melt layering leaves its mark. There are micropores between the layers, adhesion is often weaker than the internal strength of the material, and surface roughness forces engineers to additionally process parts before assembly. For prototypes this is tolerable, for critical components it is vital. Here post-processing ceases to be an option and becomes a necessity.

Literature offers various solutions to these problems: from thermal annealing to chemical polishing and mechanical densification. Recently, combined approaches have emerged that combine heating with controlled deformation. The results are impressive – strength increase of 30-50%, roughness reduction by an order of magnitude. However, there is a gap between laboratory samples and industrial recommendations. Researchers often contradict each other: temperature regimes for PLA differ by tens of degrees in different works, and mechanical methods effective for ABS destroy PETG parts.

This very inconsistency became the reason for this review. Systematized here is not just a list of methods, but the patterns of their action: which parameters are critical for specific polymers, where the boundaries lie between structure improvement and product deformation, how to combine operations to achieve a synergistic effect. A significant role in the analysis is played by the impact of post-processing on geometric accuracy – a parameter that often falls out of the field of view of researchers focused exclusively on mechanics.

2. Review of post-processing methods

2.1 Thermal post-processing

Thermal post-processing is among the effective and, at the same time, technologically simple ways to improve the mechanical properties of parts printed using additive manufacturing methods. It reduces interlayer porosity, relaxes residual stresses, and increases polymer crystallinity – all of which directly impact the strength, stiffness, and dimensional stability of the finished products. However, conventional annealing is often time-consuming and carries a risk of deformation, so engineers are actively seeking accelerated and hybrid solutions.

ABS with a PC core (polycarbonate APEC 1795) reduces annealing time from 72 to 8 hours [1]. The heat-resistant core stabilizes the geometry of the part when heated to 155 °C, providing an 83% increase in impact strength without critical deformations. The effect only manifests at an infill density of at least 94% – below this threshold, the PC core cannot handle the load. PLA/ABS composites with 9% carbon fiber give different results: at 150 °C, tensile strength increased to 257.4 MPa (+155%), and porosity decreased to 8% [2]. A rectangular grid (infill structure in FDM printing) showed 33% higher tensile strength compared to concentric circles. The best performance was achieved by the PLACF-ABSCF-PLACF structure due to improved interlayer adhesion. PLA with 30% fibrillated lyocell fibers requires pre-modification with maleic anhydride [3]. Combination of fibrillation and annealing (105 °C, 2 hrs) increases tensile strength by 30% (85 MPa), Young's modulus reaches 7.2 GPa (+108%), crystallinity 31%, and at 80 °C the dynamic elastic modulus increases approximately 200 times. For ABS with recycled carbon fiber (rCF, 10-20%) in [4], annealing at 175 °C for 0.5 hr was applied – flexural strength increased by 42%, elastic modulus by 71% due to reduced porosity. The composites showed better dimensional stability compared to pure ABS: shrinkage decreases from 27% to 14% with increasing rCF content. PEEK composites behave differently: at 250 °C/6 hr, tensile strength increased by 15%, shear strength increased by 16% for short fibers (PEEK/SCF) and by 85% for continuous ones (PEEK/CCF) [5]. Continuous composites result in larger dimensional changes due to the thermal expansion of the polyamide. Results for materials with additives are shown in Figure 1. Fillers provide a significant increase in strength, but the heat treatment regime must be selected individually – the maximum effect requires long-term annealing, while accelerated cycles give a compromise result.

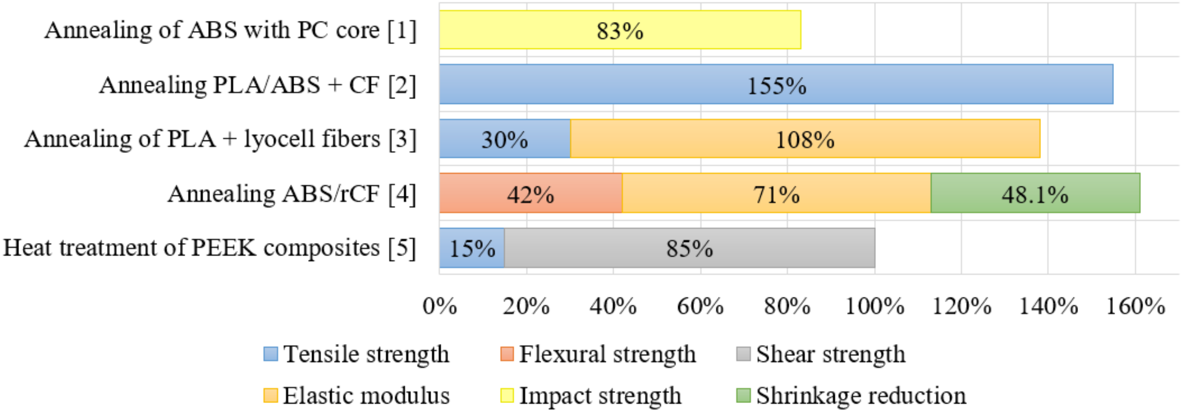

Fig. 1. Relative change in properties of FDM parts with additives after thermal post-processing

Surface stability is no less critical. CO2 laser polishing of ABS at a speed of 229 mm/s and hatch spacing of 0.14 mm reduces roughness by 18.9% (to 6,5 µm) and increases tensile strength by 8.1%, processing time was 0.14 min [6]. This confirms the possibility of simultaneous improvement of mechanical and surface properties with minimal processing time. For PETG in [7], the CO2 laser polishing parameters are different – 321 mm/s, 5.4 W: roughness decreased by 58% (to 2.81 µm), and tensile strength increased by 8.9% (to 49.1 MPa), processing time – 0.22 min, although flexural strength dropped by 5% due to porosity. A heat gun (400 °C, 55 s) allows sealing polypropylene parts for vacuum equipment (0.4 mTorr at 98% fill overlap) [8]. The limitation is obvious – the operating temperature range of such products is low due to the risk of seal destruction.

Heating directly during printing provides an advantage over post-annealing. “Lazy annealing” of PLA in [9] increased tensile strength by 14% for honeycomb structure, whereas for Grid and Triangles the improvement of mechanical properties was insignificant. The process took place directly on the printer in an insulating enclosure at 100 °C, time – 2.5 hr, and required sample alignment with steel plates to minimize deformation during heating. Annealing of PLA parts (80 °C hot air) directly during printing [10] increased tensile strength by 44% at a 0.8 mm nozzle, reduced surface roughness by 63%. However, the Martens hardness decreased by 8.6% and Shore D by 1.4% due to the relaxation of internal stresses. Auxiliary heating (120 °C) directly during the printing of PLA [11] proved to be even more effective. This allowed for an increase in tensile strength from 38.4 MPa to 63.6 MPa (+66%), a reduction in anisotropy from 0.51 to 0.22, and a decrease in warping from 10.6 mm to 0.4 mm. The effect is explained by the reduction of the temperature differential between layers and improved fusion of the material filaments, which give better result than traditional post-annealing (51.4 MPa).

Annealing of PLA, PETG, and PVA polymers at 110 °C for 6400 s gives mixed results [12]. For PLA, heat treatment increased crystallinity from 2.6% to 34%, raised flexural strength by 9% (to 90 MPa) and Young's modulus by 11% (to 3287 MPa), but caused significant geometric changes (a 6.7% reduction in length and a 13% increase in thickness). For amorphous PETG, annealing decreased mechanical properties, while for crystalline PVA, the effect was positive. The x-z orientation at a nozzle temperature of 190 °C and a layer height of 0.3 mm reduces the brittleness of PLA and enhances flexural strength [13]. Additional annealing at 75 °C increases the ultimate load, and hot deformation followed by shape recovery practically does not degrade the mechanics. Annealing of PEEK parts printed by the FDM method requires high temperatures [14]. At 360 °C/6 hr, tensile strength increased by 7.3% (to 90 MPa), roughness decreased by 58%, and at 330 °C/6 hr, flexural strength reached 146 MPa (+10.6%). Atomic force microscopy analysis confirmed an increase in the size of crystalline grains and material stiffness.

Thermal post-processing modifies the microstructure of FDM parts unevenly. For materials with additives (Figure 1), the highest increase in tensile strength (+155%) was achieved for PLA/ABS composites with carbon fiber [2]. ABS with a PC core allows for reducing the 72-hour annealing to 8 hours while maintaining 83% of the impact strength [1]. Pure polymers and integrated methods (Figure 2) give smaller but more stable results: laser polishing of ABS and PETG provides a plus 8-9% in tensile strength [6,7], and heating during printing outperforms post-annealing (63.6 MPa versus 51.4 MPa for PLA) while simultaneously reducing warping [11]. Geometric stability remains a key limitation for both approaches – even with fillers, dimensional changes reach 6-14% [12].

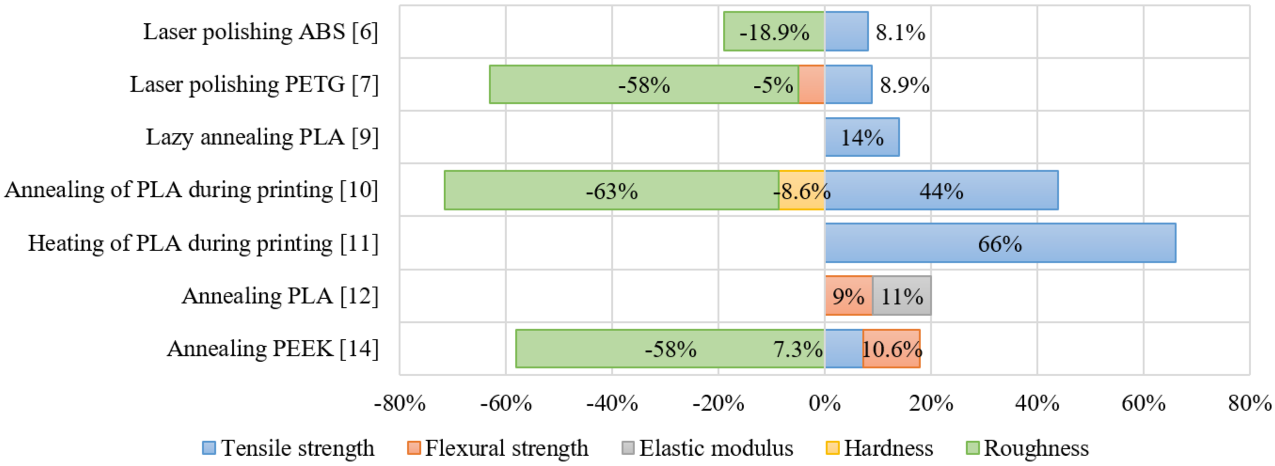

Fig.2. Relative change in properties of FDM parts after thermal post-processing

2.2 Chemical post-processing

Among various approaches, chemical methods hold a special place, allowing effective modification of polymer component properties without mechanical processing. One of the most common approaches to chemical post-processing is immersing parts in liquid solvent. In particular, [15] proposed a method of chemical polishing of ABS parts by short-term immersion in acetone – 5 seconds at 20-second intervals. This allowed reducing surface roughness by 69%, from 185.4 to 57.6 µm, and decreasing water absorption. However, a negative effect was also identified – tensile strength decreased by 10.6%, from 29.37 to 26.25 MPa due to acetone penetration into surface layers and material softening. An alternative to immersion is vapor treatment, which avoids direct contact between the part and the liquid. For instance, in [16], ethyl acetate vapors were used to treat PLA parts produced by the FFF method. The optimal regime is 180-360 seconds with a minimal amount of solvent in a container of boiling water. The roughness Ra decreased from 15-30 µm to 1-2 µm on the top surface and from 25-40 µm to 3-5 µm on the side faces. The method is distinguished by the low toxicity and cost of ethyl acetate. Further improvement of vapor treatment involves using heated vapors to accelerate the process kinetics, as presented in [17], where hot acetone treatment of ABS parts was investigated. An exposure of 35 seconds reduced the roughness Ra by 89.3% – from 5.3 to 0.57 µm and increased the gloss. Bulk mechanical properties were preserved, but surface hardness decreased by 45.6%, from 156.1 to 84.9 MPa. The kinetics of the process follows a power law, which ensures high industrial scalability. Another direction of post-processing is the automation of the process through the creation of specialized units [18], a device for cold acetone vapor treatment of ABS parts with precise control of temperature, time, and solvent volume. Optimal parameters – 65 °C for 30-50 minutes with 70 ml of acetone – provided an increase in tensile strength by 32% (up to 20.35 MPa) and a reduction in surface roughness. At the same time, there was an increase in the mass of the samples by 5.73% and changes in geometric dimensions due to solvent absorption and softening of the polymer.

The analyzed studies indicate a gradual evolution of chemical post-processing – from simple immersion to controlled vapor processes (Figure 3). The general trend is toward minimizing deterioration of mechanical properties while maximizing surface quality improvement. In particular, cold vapor treatment increases tensile strength by 32%, whereas immersion reduces it by 10.6%. This indicates the necessity of selecting the treatment regime depending on the priority requirements for the product – maximum surface smoothness or preservation of the part's load-bearing capacity.

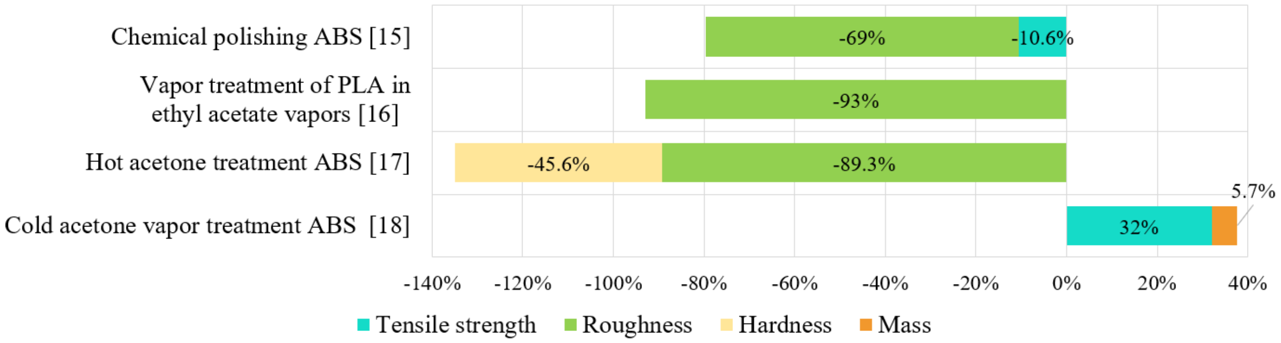

Fig.3. Relative change in properties of FDM parts after chemical post-processing.

2.3 Thermomechanical post-processing

Thermomechanical post-processing combines heating of the polymer with mechanical action, which allows for the modification of its microstructure and the improvement of the characteristics of finished parts. Let's consider the main approaches – from simple annealing to complex systems with multiple components.

Isothermal annealing with an additional load improves the properties of parts through thermal diffusion. The tensile strength of FFF ABS parts was increased by 89% after annealing at 180°C [19]. Static axial loading in this case did not have a significant impact. At the optimal temperature, pore fusion and increased interlayer bonding occur, whereas at 180°C, strength drops due to loss of ductility. For high-temperature polymers, different approaches to preserving geometry are required. In [20], low-temperature annealing of ULTEM™ 9085 was investigated at 170-180°C for 24-96 hours using supports printed along with the part. This gave a tensile strength increase of 1.4%, a geometry changes of less than 5%, and an increase in ductility up to 27% due to the relaxation of internal stresses.

Better results are achieved by combining heating with isostatic pressure – this maintains the part's shape and accelerates the diffusion of polymer chains. A reduction in ABS shrinkage by 83% (from 12% to 2%) at 240 °C by wrapping parts in layers of ceramic powder (150 μm) under a pressure of 12 g/cm² with annealing was achieved in [21]. For PLA, the reduction in shrinkage was 62% due to the lower shrinkage of the semi-crystalline polymer. The flexural strength remained unchanged. The same post-processing principle was used in [22], where the shrinkage of ABS parts during annealing (135 °C, 120 min) was reduced by 80-90% by wrapping them in layers of ceramic powder under a pressure of 12 g/cm². This works best when the layer direction coincides with the main axis of the part – with a perpendicular orientation, deformations are already minimal. In [23], a method was developed for remelting FDM parts in SiO_2 powder by heating above the melting point. For PLA at 220 °C for 60 min, tensile strength increased by 170% and ductility by 260%; for PEEK at 450 °C for 40 min, the increases were 500% and 180% respectively. Remelting forms a solid isotropic structure without layering while preserving the geometry of the part. Soluble powders [24] solve the problem of material residues on the surface. The strength of PETG parts was increased by remelting in NaCl powder as a support medium at 220 °C for 5-15 min with a compression of 1.5 kg. Vertically oriented samples showed a 143% increase in tensile strength (up to 37.4 MPa) and a 50% increase in compression. SEM analysis confirmed the filling of interlayer pores and improved polymer diffusion, which reduces anisotropy and deformation of the products.

Isostatic pressing in vacuum packaging eliminates interlayer porosity even in reinforced composites. Interlayer strength of CF/PA12 composites was increased by warm isostatic pressing (170 °C, 50 bar, 30 min) in vacuum packaging [25]. Tensile strength of samples with a raster angle of 90° (loading direction perpendicular to layers) increased by 238.7%, compression by 19%, flexure by 266%, anisotropy decreased from 77.3% to 42.1% with complete elimination of pores between layers. In [26], the effect of warm isostatic pressing (WIP) parameters on ABS parts was investigated. Optimal – 120 °C, 90 bar, 1 hour in vacuum: elongation and impact toughness grow linearly, pores disappear. At temperatures above 130 °C, the polymer degrades. Fiber surface modification with thermal pressing [27] allows substantial improvement of mechanical properties of parts. PPS composites with carbon fiber (CCF) were modified with dopamine and silica nanoparticles and subjected to hot pressing in a salt bath. Treatment increased interlayer shear strength by 172% and flexural strength by 27% with porosity reduction from 10.2% to 3.4% and preservation of complex structure geometry.

The conducted analysis demonstrates the transformation of approaches to thermomechanical post-processing from simple annealing to complex technologies. As shown in Figure 4, the efficiency of methods varies from 1.4% for conservative annealing to 500% for PEEK remelting. The best results are achieved by hot isostatic pressing of composites, which eliminates defects and reduces anisotropy. The development of adaptive regimes that account for part geometry and its microstructure for quality optimization at minimum costs is promising.

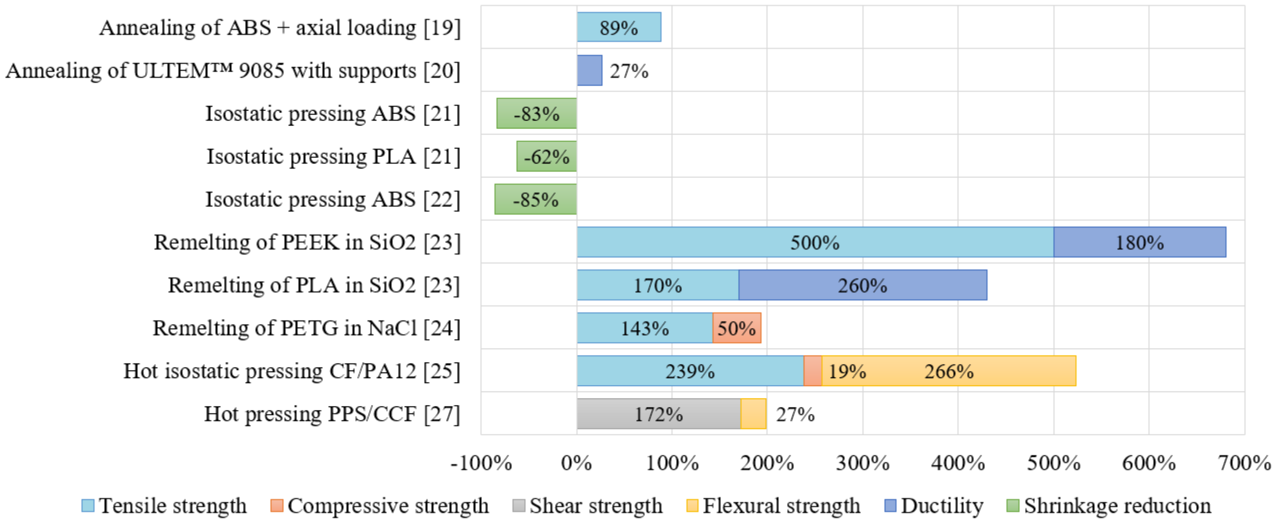

Fig.4. Relative change in properties of FDM parts after thermomechanical post-processing

2.4 Combined post-processing methods

Combining different post-processing methods often allows for the compensation of their individual drawbacks and achieving a balanced improvement in the properties of the parts. In particular, in [28], the effect of acetone treatment and CuO coating on the properties of FDM parts made of ABS was studied. CuO coating for 2 hours increased the tensile strength by 17%, while acetone treatment reduced it by 20%. The combination of both methods showed a tensile strength at the level of untreated samples and increased the flexural strength by 46.5%. Both methods reduce the friction coefficient by 15-16%. In [29], a combined post-processing method for FDM parts made of PLA was proposed, combining thermal annealing with the application of an MDF powder coating at 120 °C. The optimal treatment duration is 11 minutes, which ensures an increase in flexural strength from 250 N to 470 N (by 88%) and the formation of a glossy surface. Continuing the treatment beyond 11 minutes does not give an increase in strength but leads to deformations. Thus, combined processing opens up opportunities for the simultaneous improvement of surface quality and mechanical properties (Figure 5), although it requires careful selection of regimes to avoid deformations.

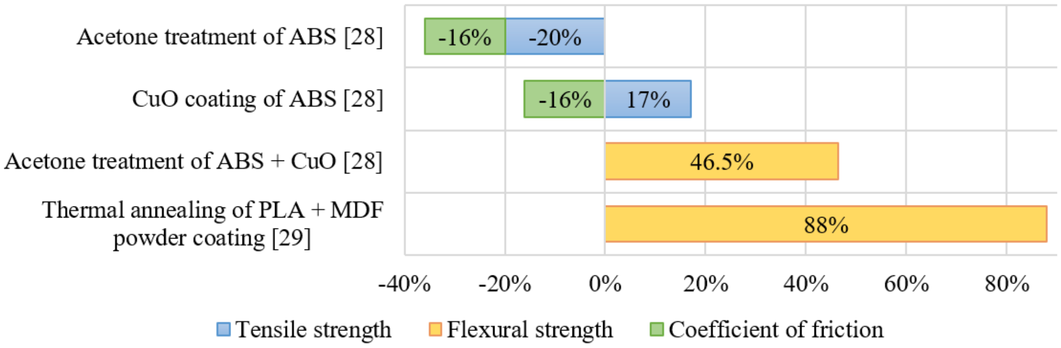

Fig.5. Relative change in properties of FDM parts after combined post-processing methods

2.5 Multi-method post-processing

Production practice shows that the choice of post-processing technology depends not only on the part material but also on priority requirements for final properties – surface smoothness, dimensional accuracy, or adhesion. Comparative studies evaluating several approaches simultaneously allow avoiding erroneous decisions at the production preparation stage.

For the polymer Ultem 9085, which is used in the aviation industry, the most aggressive chemical smoothing with chloroform for 180 min reduced the roughness by 90-95%, but was accompanied by solvent absorption [30]. Thermal annealing at 210-240 °C produced a smaller effect – only a 15% reduction in roughness on the upper surface, while the samples expanded along the printing direction and contracted in the transverse direction due to the relaxation of internal stresses. Ball burnishing (400 N, 10 passes) showed a compromise result – a 70% reduction in roughness without critical changes in geometry. Abrasive shot blasting with glass and corundum showed a reduction in roughness by 10-25%, but significantly changed the microrelief to improve coating adhesion. Therefore, for Ultem 9085 maximum roughness reduction requires the use of a chemical method, preservation of dimensions – a mechanical method, and preparation for coating – an abrasive method (Figure 6).

When gluing PLA parts, traditional acetone smoothing gives a negative effect – the pull-off strength drops by 37% (to 3.5 MPa) despite a 54% reduction in roughness [31]. Instead, treatment with isopropyl alcohol increased the pull-off strength by 52% (over 8.5 MPa), roughness increased by 8%. Mechanical sanding showed an intermediate result – a 7% increase in pull-off strength (6 MPa) with a 46% reduction in roughness. The improvement in adhesion here is caused not by roughness, but by surface cleaning and an optimal microrelief. For adhesive joints of PLA, the balance between cleaning and preserving surface morphology proves to be critical (Figure 7).

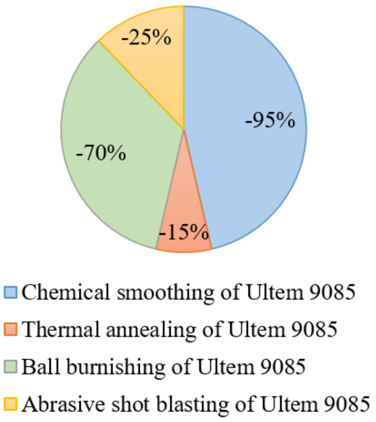

Fig.6. Change in roughness of Ultem 9085 during multi-method post-processing [30].

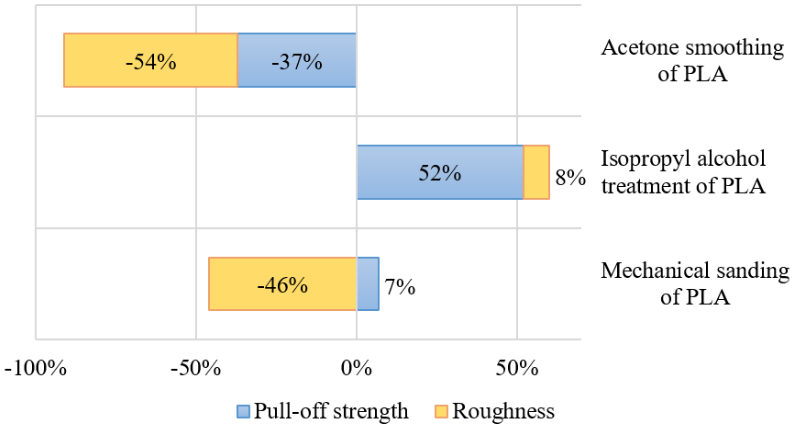

Fig.7. Change in properties of PLA during multi-method post-processing [31]

Cyclic freezing destroys the interlayer adhesion of rPET-G, which is relevant for parts operated in winter. After 60 freeze/thaw cycles with salt spray, thermal annealing at 85 °C increased tensile strength by 15% (up to 45 MPa), flexural strength increased by 16% (up to 64 MPa), impact strength increased by 14% (up to 88.5 kJ/m²), and ductility increased by 24%, while simultaneously reducing moisture absorption [32]. Chemical smoothing with dichloromethane improved flexural strength by 7% and impact strength by 9%, but worsened ductility by 17% (down to 5.2 mm). Epoxy resin and synthetic coating minimized moisture absorption but proved to be brittle, while the water-soluble coating peeled off prematurely. For winter conditions, a combination of thermal annealing and coating is optimal (Figure 8).

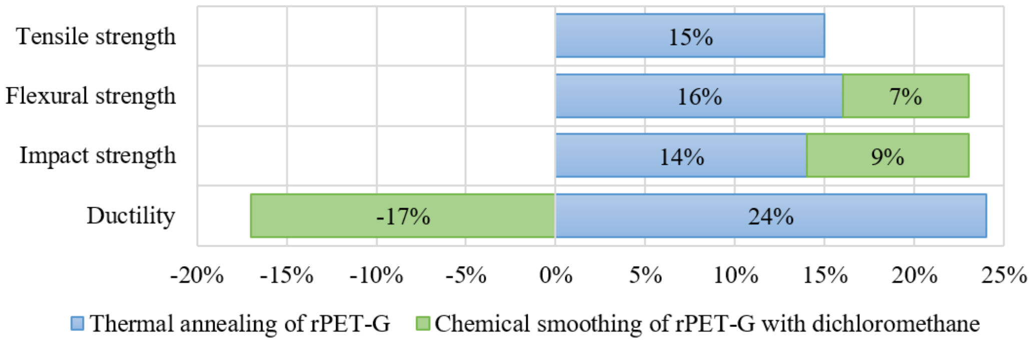

Fig.8. Change in properties of rPET-G during multi-method post-processing [32].

3. Conclusions and prospects for further research

The conducted analysis of FDM parts post-processing methods shows that each approach has a distinct scope of application. Thermal post-processing is the simplest way to increase strength and reduce porosity, but it requires a long time and carries a risk of deformation. Chemical methods provide the best surface smoothness but often degrade mechanical properties due to solvent penetration. Thermomechanical approaches, especially isostatic pressing, demonstrate the highest efficiency: a 200-500% increase in strength while maintaining geometry, although they require specialized equipment. Combined methods allow for the compensation of individual technology drawbacks, and multi-method comparison enables the selection of the optimal variant for specific requirements – strength, accuracy, or adhesion.

The main part of current research is focused on ABS and PLA. This is explained by their popularity in industry and laboratories, but both materials have a limited range of operating temperatures and mechanical strength insufficient for critical structures. PETG, meanwhile, combines good impact strength, chemical resistance, and ease of printing. It crystallizes more slowly than PLA, which provides a larger window for controlling the microstructure using thermomechanical methods. There are significantly fewer studies on the post-processing of PETG than for ABS/PLA, therefore optimizing the parameters of thermomechanical treatment specifically for this material is a logical step.

Further work is planned to be aimed at determining the optimal temperatures, pressures and durations of thermomechanical treatment for PETG parts. The balance between increasing strength and maintaining geometric accuracy, as well as reducing the anisotropy of properties, remains critical. The results will allow for the formulation of practical recommendations for the production of functional parts with enhanced performance characteristics.

References

1. Pugatch M., Teece M., Lee J., Patil N., Dunn R., Hart K., Wetzel E., Park J.H. Accelerated annealing of fused filament fabricated (FFF) thermoplastics via an improved core-shell filament. Scientific Reports 2023, 13, 13538. https://doi.org/10.1038/s41598-023-40855-6
2. Nassar A., Younis M., Elzareef M., Nassar E. Effects of Heat-Treatment on Tensile Behavior and Dimension Stability of 3D Printed Carbon Fiber Reinforced Composites. Polymers 2021, 13(24), 4305. https://doi.org/10.3390/polym13244305
3. Gauss C., Pickering K. L., Graupner N., Müssig J. 3D-printed polylactide composites reinforced with short lyocell fibres – Enhanced mechanical properties based on bio-inspired fibre fibrillation and post-print annealing. Additive Manufacturing 2023, **77**, 103806. https://doi.org/10.1016/j.addma.2023.103806
4. Seok W., Jeon E., Kim Y. Effects of Annealing for Strength Enhancement of FDM 3D-Printed ABS Reinforced with Recycled Carbon Fiber. Polymers 2023, 15 (14), 3110. https://doi.org/10.3390/polym15143110
5. Wang P., Zou B. Improvement of Heat Treatment Process on Mechanical Properties of FDM 3D-Printed Short- and Continuous-Fiber-Reinforced PEEK Composites. Coatings 2022, 12(6), 827. https://doi.org/10.3390/coatings12060827
6. Mushtaq R.T., Wang Y., Bao C., Chen X., Anwar S., Sharma S., Khan A.M., Sharma K., Bisht Y.S., Abbas M., Kozak D., Tropša V. Multi-objective optimization of laser polishing parameters for enhanced mechanical properties, sustainability, and surface finish of 3D-Printed industrial ABS polymers using response surface methodology (RSM). Journal of Materials Research and Technology 2024, 29, 3168–3184. https://doi.org/10.1016/j.jmrt.2024.02.023
7. Mushtaq R.T., Iqbal A., Wang Y., Mashood Khan A., Abu Bakar M.S. Parametric optimization of 3D printing process hybridized with laser-polished PETG polymer. Polymer Testing 2023, 125, 108129. https://doi.org/10.1016/j.polymertesting.2023.108129
8. Mayville P.J., Petsiuk A.L., Pearce J.M. Thermal Post-Processing of 3D Printed Polypropylene Parts for Vacuum Systems. Journal of Manufacturing and Materials Processing 2022, 6(5), 98. https://doi.org/10.3390/jmmp6050098
9. Birosz M.T., Gál A., Hegedűs-Kuti J., Andó M. Lazy thermal annealing of material extrusion-based 3D-printed PLA specimens. Progress in Additive Manufacturing 2025, 10, 1691–1697. https://doi.org/10.1007/s40964-024-00732-8
10. Tamașag I., Beșliu-Băncescu I., Severin T.-L., Dulucheanu C., Cerlincă D.-A. Experimental Study of In-Process Heat Treatment on the Mechanical Properties of 3D Printed Thermoplastic Polymer PLA. Polymers 2023, 15(10), 2367. https://doi.org/10.3390/polym15102367
11. Yu N., Sun X., Wang Z., Zhang D., Li J. Effects of auxiliary heat on the interlayer bonds and mechanical performance of polylactide manufactured through fused deposition modeling. Polymer Testing 2021, 104, 107390. https://doi.org/10.1016/j.polymertesting.2021.107390
12. Yu W., Wang X., Yin X., Ferraris E., Zhang J. The effects of thermal annealing on the performance of material extrusion 3D printed polymer parts. Materials & Design 2023, 226, 111687. https://doi.org/10.1016/j.matdes.2023.111687
13. Chalgham A., Ehrmann A., Wickenkamp I. Mechanical Properties of FDM Printed PLA Parts before and after Thermal Treatment. Polymers 2021, 13(8), 1239. https://doi.org/10.3390/polym13081239
14. Adamson M., Eslami B. Post-Processing PEEK 3D-Printed Parts: Experimental Investigation of Annealing on Microscale and Macroscale Properties. Polymers 2025, 17(6), 744. https://doi.org/10.3390/polym17060744
15. Khosravani M.R., Schüürmann J., Berto F., Reinicke T. On the Post-Processing of 3D-Printed ABS Parts. Polymers 2021, 13(10), 1559. https://doi.org/10.3390/polym13101559
16. Lavecchia F., Guerra M.G., Galantucci L.M. Chemical vapor treatment to improve surface finish of 3D printed polylactic acid (PLA) parts realized by fused filament fabrication. Progress in Additive Manufacturing 2022, 7, 65-75. https://doi.org/10.1007/s40964-021-00213-2
17. Janostik V., Cvek M., Pata V., Senkerik V., Ovsik M. Design and surface enhancement of ABS parts manufactured by Arburg plastic freeforming (APF) using chemical vapor treatment. Materials & Design 2025, 253, 113940. https://doi.org/10.1016/j.matdes.2025.113940
18. Demircali A.A., Yilmaz D., Yilmaz A., Keskin O., Keshavarz M., Uvet H. Enhancing mechanical properties and surface quality of FDM-printed ABS: A comprehensive study on cold acetone vapor treatment. The International Journal of Advanced Manufacturing Technology 2024, 130, 4027-4039. https://doi.org/10.1007/s00170-023-12929-2
19. Rane R., Kulkarni A., Prajapati H., Taylor R., Jain A., Chen V. Post-Process Effects of Isothermal Annealing and Initially Applied Static Uniaxial Loading on the Ultimate Tensile Strength of Fused Filament Fabrication Parts. Materials 2020, 13(2), 352. https://doi.org/10.3390/ma13020352
20. Zhang Y., Moon S. Ki. The Effect of Annealing on Additive Manufactured ULTEM™ 9085 Mechanical Properties. Materials 2021, 14(11), 2907. https://doi.org/10.3390/ma14112907
21. Lluch-Cerezo J., Meseguer M.D., García-Manrique J.A., Benavente R. Influence of Thermal Annealing Temperatures on Powder Mould Effectiveness to Avoid Deformations in ABS and PLA 3D-Printed Parts. Polymers 2022, 14(13), 2607. https://doi.org/10.3390/polym14132607

22. Lluch-Cerezo J., Benavente R., Meseguer M.D., García-Manrique J.A. Effect of a Powder Mould in the Post-Process Thermal Treatment of ABS Parts Manufactured with FDM Technology. Polymers 2021, 13(15), 2422. https://doi.org/10.3390/polym13152422

23. Lee C.-C., Chang T.-F., Chen P.-T., Wu A. Y.-J., Wu A., Chiou K. Additive Manufactured Thermoplastic Parts Strengthen by Remelting Assisted by Inert Powder Mold. ACS Applied Polymer Materials 2024, 6(20), 12550-12558. https://doi.org/10.1021/acsapm.4c02083

24. Amza C.G., Zapciu A., Constantin G., Baciu F., Vasile M.I. Enhancing Mechanical Properties of Polymer 3D Printed Parts. Polymers 2021, 13(4), 562. https://doi.org/10.3390/polym13040562

25. Park S.J., Kim D.H., Ju H.G., Park S.J., Hong S., Son Y., Ahn I.H. Increased interlayer bonding strength of short carbon fiber composite fabricated by material extrusion via warm isostatic pressing (WIP) process. Journal of Materials Research and Technology 2023, 25, 3610-3623. https://doi.org/10.1016/j.jmrt.2023.06.130

26. Park S.J., Park S.J., Son Y., Ahn I.H. Influence of warm isostatic press (WIP) process parameters on mechanical properties of additively manufactured acrylonitrile butadiene styrene (ABS) parts. The International Journal of Advanced Manufacturing Technology 2022, 122, 3311-3322. https://doi.org/10.1007/s00170-022-10094-6

27. Lyu Y., Li A., Wu J., Koutsos V., Wang C., Ó. Brádaigh C.M., Yang D. Enhanced mechanical performance of 3D printed continuous carbon fibre reinforced polyphenylene sulphide composites through dopamine treatment and post-processing compression. Composites Part A: Applied Science and Manufacturing 2025, 190, 108627. https://doi.org/10.1016/j.compositesa.2024.108627

28. Akhil V. M., Mangalore S. J., Chinmay M. C., Shankar K. V., Tawk C. Effect of acetone treatment and copper oxide coating on the mechanical and wear properties of 3D-printed acrylonitrile butadiene styrene structures. Virtual and Physical Prototyping 2024, 19(1), e2345774. https://doi.org/10.1080/17452759.2024.2345774

29. Jovanović J., Đukanović M., Radunović L., Rogić Vuković S., Jovanović M. Enhanced Mechanical Properties and Surface Finish of PLA 3D Prints via Combined Heat Annealing and Powder Coating. Applied Sciences 2025, 15(17), 9338. https://doi.org/10.3390/app15179338

30. Chueca de Bruijn A., Gómez-Gras G., Pérez M. A. A Comparative Analysis of Chemical, Thermal, and Mechanical Post-Process of Fused Filament Fabricated Polyetherimide Parts for Surface Quality Enhancement. Materials 2021, 14(19), 5880. https://doi.org/10.3390/ma14195880

31. Parodo G., Moffa G., Silvestri A., Sorrentino L., Testa G., Turchetta S. Influence of Surface Treatments on the Pull-Off Performance of Adhesively Bonded Polylactic Acid (PLA) Specimens Manufactured by Fused Deposition Modeling (FDM). Materials 2025, 18(17), 3965. https://doi.org/10.3390/ma18173965

32. Lozrt J., Votava J., Henzl R., Kumbár V., Dostál P., Čupera J. Analysis of the Changes in the Mechanical Properties of the 3D Printed Polymer rPET-G with Different Types of Post-Processing Treatments. Applied Sciences 2023, 13(16), 9234. https://doi.org/10.3390/app13169234