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SOFTWARE FOR SELECTIVE LASER MELTING METHOD FOR ADDITIVE TECHNOLOGIES

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The article is devoted to the study of additive manufacturing technologies, which have become increasingly important in recent years in modern mechanical engineering, aerospace engineering, medicine, and other high-tech industries. Of particular interest is the software for selective laser melting (SLM) technology. Modern algorithms allow for high dimensional accuracy, the ability to produce parts with specified properties, and a shorter production cycle compared to traditional manufacturing methods.

In this study, the focus is on the automated control system for printing parts and assemblies using selective laser melting. The obtained data can be further used in the development of algorithms for automated selection of powder compositions and SLM modes.

The purpose of this work is to automate the technology of selecting the composition of the powder material for selective laser melting. To achieve this goal, the work involves studying the SLM technology and the features of obtaining powders from technogenic waste, developing an algorithm for automating the selection of powder composition, and creating a software module that provides automatic selection of the optimal powder composition and printing parameters.

The scientific novelty and significance of the work lie in the creation of a software and hardware complex for the rapid selection of powder composition and parameters of the selective laser melting process. The implementation of the proposed approach makes it possible to produce practical parts in a short time without compromising the quality and performance of the material, and it also forms the basis for further development of automated additive manufacturing control systems.

Keywords: additive manufacturing, software, algorithm, software and hardware complex, selective laser melting (SLM), automation.

АДДИТИВТІ ТЕХНОЛОГИЯЛАРҒА АРНАЛҒАН СЕЛЕКТИВТІ ЛАЗЕРЛІК БАЛҚЫТУ ӘДІСІНІҢ БАҒДАРЛАМАЛЫҚ ЖАСАҚТАМАСЫ

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Мақала соңғы жылдары заманауи машина жасауда, аэроғарыштық техникада, медицинада және басқа да жоғары технологиялық салаларда маңызды рөл атқарған аддитивті өндіріс технологияларын зерттеуге арналған. Селективті лазерлік балқыту (SLM) технологиясының бағдарламалық жасақтамасы ерекше қызығушылық тудырады. Заманауи Алгоритмдер өлшемдердің жоғары дәлдігін, берілген қасиеттері бар бөлшектерді жасау мүмкіндігін және дәстүрлі өндіріс әдістерімен салыстырғанда өндіріс циклін қысқартуға мүмкіндік береді.

Осы зерттеу шеңберінде талдау объектісі ретінде селективті лазерлік балқыту әдісімен бөлшектер мен тораптарды басып шығару процесін басқарудың автоматтандырылған жүйесі қарастырылады. Алынған мәліметтер болашақта ұнтақтардың құрамын және SLM режимдерін автоматтандырылған таңдау алгоритмдерін жасау кезінде қолданыла алады.

Бұл жұмыстың мақсаты селективті лазерлік балқыту үшін ұнтақ материалының құрамын таңдау технологиясын автоматтандыру болып табылады. Жұмыста қойылған мақсатқа жету үшін SLM технологиясын және техногендік қалдықтардан ұнтақтарды алу ерекшеліктерін зерделеу, ұнтақ құрамын таңдауды автоматтандыру алгоритмін әзірлеу, сондай-ақ ұнтақтың оңтайлы құрамы мен басып шығару параметрлерін автоматты түрде таңдауды қамтамасыз ететін бағдарламалық модуль құру көзделеді.

Жұмыстың ғылыми жаңалығы мен маңыздылығы ұнтақтың құрамын және селективті лазерлік балқу процесінің параметрлерін жедел таңдау үшін бағдарламалық-техникалық кешен құру болып табылады. Ұсынылған тәсілді іске асыру материалдың сапасы мен пайдалану қасиеттерін жоғалтпай қысқа мерзімде практикалық бөлшектерді дайындау мүмкіндігін қамтамасыз етеді, сондай-ақ қосымша өндірісті басқарудың автоматтандырылған жүйелерін одан әрі дамыту үшін негіз қалыптастырады.

Түйін сөздер: аддитивті өндіріс, бағдарламалық қамтамасыз ету, алгоритм, бағдарламалық-техникалық кешен, селективті лазерлік балқыту (SLM), автоматтандыру.

ПРОГРАММНОЕ ОБЕСПЕЧЕНИЕ МЕТОДА СЕЛЕКТИВНОГО ЛАЗЕРНОГО ПЛАВЛЕНИЯ ДЛЯ АДДИТИВНЫХ ТЕХНОЛОГИЙ

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Статья посвящена исследованию аддитивных технологий производства, которые в последние годы приобрели значительную важность в современном машиностроении, аэрокосмической технике, медицине и других высокотехнологичных отраслях промышленности. Особый интерес представляет программное обеспечение технологии селективного лазерного плавление (SLM). Современные алгоритмы позволяют обеспечить высокую точность размеров, возможность изготовления деталей с заданными свойствами и сокращение производственного цикла по сравнению с традиционными методами производства.

В рамках данного исследования в качестве объекта анализа рассматривается автоматизированная система управления процессом печати деталей и узлов методом селективного лазерного плавления. Полученные данные могут быть использованы в дальнейшем при разработке алгоритмов автоматизированного подбора состава порошков и режимов SLM.

Целью данной работы является автоматизация технологии подбора состава порошкового материала для селективного лазерного плавления. Для достижения поставленной цели в работе предполагается изучение технологии SLM и особенностей получения порошков из техногенных отходов, разработка алгоритма автоматизации подбора состава порошка, а также создание программного модуля, обеспечивающего автоматический выбор оптимального состава порошка и параметров печати.

Научная новизна и значимость работы заключается в создании программно-технического комплекса для оперативного подбора состава порошка и параметров процесса селективного лазерного плавления. Реализация предлагаемого подхода обеспечивает возможность изготовления практических деталей в сжатые сроки без потери качества и эксплуатационных свойств материала, а также формирует основу для дальнейшего развития автоматизированных систем управления аддитивным производством.

Ключевые слова: аддитивное производство, программное обеспечение, алгоритм, программно-технический комплекс, селективная лазерная плавка (SLM), автоматизация.

Introduction. Current trends in the development of additive manufacturing technologies are closely associated with the implementation of automation and intelligent control of technological processes. The automation of powder composition selection and selective laser melting parameters reduces process preparation time, minimizes the influence of the human factor, and ensures high reproducibility of manufacturing results.

In this study, a gear manufactured by selective laser melting is analyzed as an example of a functional component operating under mechanical loads. To evaluate the quality of the formed material, optical microscopy is employed to investigate the microstructure, the characteristics of layer-by-layer formation, and the presence of defects associated with the laser melting process. The obtained data can be further used to develop algorithms for the automated selection of powder compositions and SLM processing parameters.

The aim of this work is to automate the technology for selecting the composition of powder materials for selective laser melting. To achieve this aim, the study addresses the following objectives: investigation of SLM technology and the features of powder production from industrial waste; development of an algorithm for automating the selection of powder composition; and creation of a software module that enables the automatic determination of optimal powder compositions and SLM processing parameters.

The scientific novelty of this research lies in the fact that, in the Republic of Kazakhstan, studies focused on the development of composite powder materials for additive manufacturing technologies, particularly for selective laser melting, have been extremely limited. Within the framework of this work, powder materials derived from locally available industrial waste are obtained and analyzed for the first time, followed by an assessment of the quality of manufactured parts based on microstructural analysis [1].

The scientific significance of the study consists in the development of a domestically grounded methodology that enables the rapid selection of powder compositions and selective laser melting parameters under various technological conditions. The implementation of the proposed approach makes it possible to manufacture functional parts within a short timeframe without compromising material quality or performance characteristics, and also establishes a foundation for the further development of automated control systems in additive manufacturing.

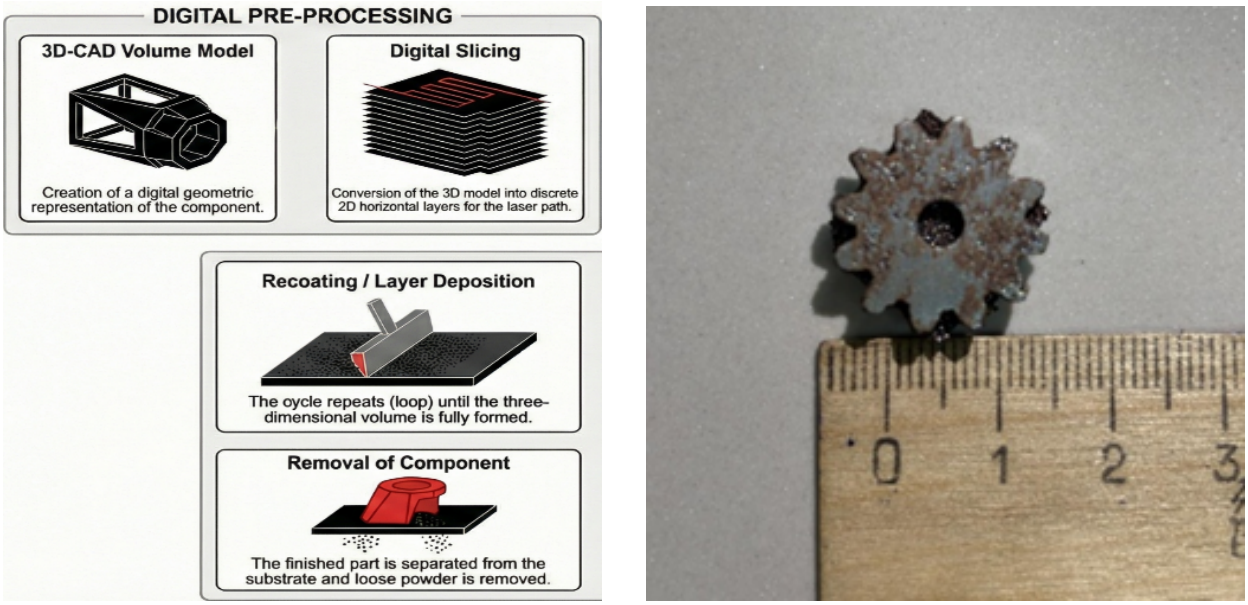
Materials and methods. The object of research in this work is a metal gear made by selective laser melting (Selective Laser Melting, SLM) from powder material. The choice of a gear as an object of research is due to the fact that this part belongs to the class of functional elements of machines and mechanisms operating under conditions of cyclic mechanical loads and increased requirements for geometric accuracy and surface quality [2].

Gears produced using the SLM process are of practical interest for mechanical engineering and precision instrument manufacturing, as additive technologies enable the fabrication of components with complex geometries without the use of conventional machining operations. At the same time, the quality of such products is largely determined by the characteristics of microstructure formation during the layer-by-layer laser melting of the powder material (fig.1a).

In this study, the gear is considered as a model component that allows the assessment of the influence of additive manufacturing process parameters on the structure of the formed material. Microstructural analysis of the product makes it possible to identify characteristic features of SLM technology, including the layered structure, structural heterogeneity, and the presence of potential defects associated with laser processing conditions and the properties of the initial powder material (fig.1b).

For the microscopic examination of the gear structure, a MAGUS Metal 630 metallographic microscope equipped with a trinocular head was used. The microscope is designed for the investigation of opaque metallic samples in reflected light mode [3]. The optical system provides an effective magnification range of approximately 50× to 500×, enabling the

acquisition of both overview images of the surface and detailed images of local microstructural features. (fig.2)



a **b**

Fig.1 - Infographics of SLM technology(a). The resulting sample(b)

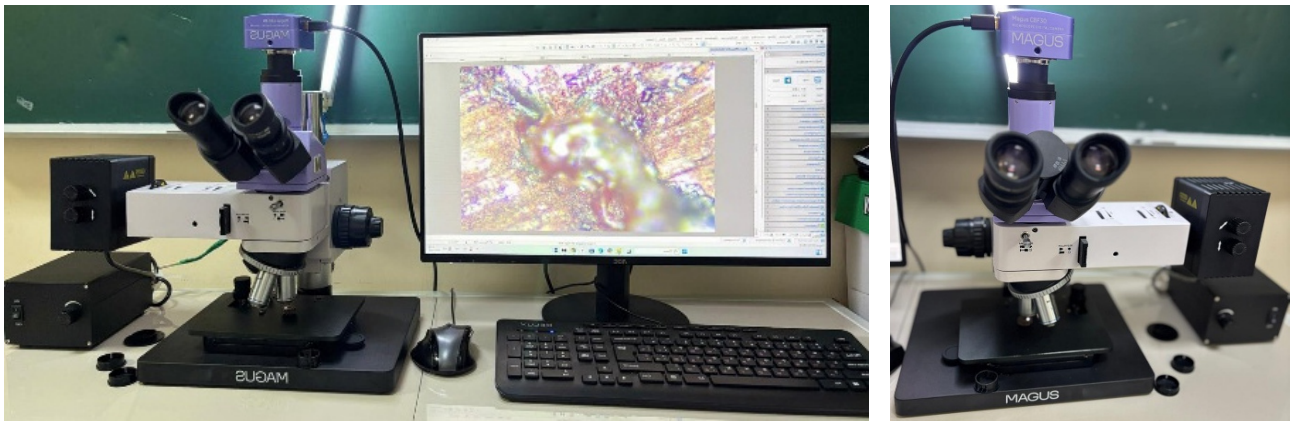


Fig.2 - Magus 630 Microscope

Microscopic observations were carried out in reflected light at various magnifications, which made it possible to obtain a general view of the gear surface as well as high-resolution images of selected areas characterizing the microstructural features of the material [4].

The microscope specifications are presented in Table 1.

The surface of the sample under investigation was subjected to visual analysis without complex metallographic preparation, which is consistent with the objectives of the work and the conditions of practical quality control of additive manufacturing products. This approach allows us to evaluate the possibility of using optical microscopy as an element of operational and potentially automated control of products obtained by the SLM method. (tab.2)

Table 1 - MAGUS Metal 630 microscope specifications

Parameter	Value
Microscope type	Metallographic optical
Purpose	Reflected light microscopy for metals and alloys
Image capture method	Digital camera (MAGUS CBF30)
Magnification (total)	50–500× (basic configuration)
Eyepieces	10×/22 mm (10 mm interpupillary distance) (other eyepiece options available)
Objectives (included)	PL L5×/0,12; PL L10×/0,25; PL L20×/0,40; PL L50×/0,70

Table 2 -Main materials and methods of additive manufacturing of metals

Category	Material / Method	Ultimate tensile strength, MPa	Yield strength, MPa	Application area	Key advantages
Aluminum alloys	AlSi10Mg	460 ± 20	270 ± 10	Aerospace, automotive, defense industries	High strength, corrosion resistance, relatively low cost
	AlSi12	409 ± 20	211 ± 20	Lattice and lightweight structures	High bending strength, good castability
	AlSi9Cu3	415 ± 15	236 ± 8	Aerospace and automotive components	Improved mechanical properties compared to casting
	AlCuMgZr	451 ± 4	446 ± 4	High-load aerospace components	Near-full density, high fatigue strength
Magnesium alloys	WE43 (Mg–Nd–Zn–Zr)	-	-	Biomedical implants	Biocompatibility, biodegradability, porous structure supporting bone ingrowth
Titanium alloys	Ti-6Al-4V / Ti-45Nb	-	-	Implants, aerospace industry	High specific strength, reduced Young's modulus (Ti-45Nb)

During the study, microphotographs of the gear surface were taken, reflecting the nature of the layer-by-layer formation of the material, the presence of porosity, inhomogeneities, and other structural features [5-6]. The images obtained were used for subsequent analysis and interpretation of the microstructure of the product, as well as for comparing the observed features with data presented in scientific publications on selective laser melting (fig.3).

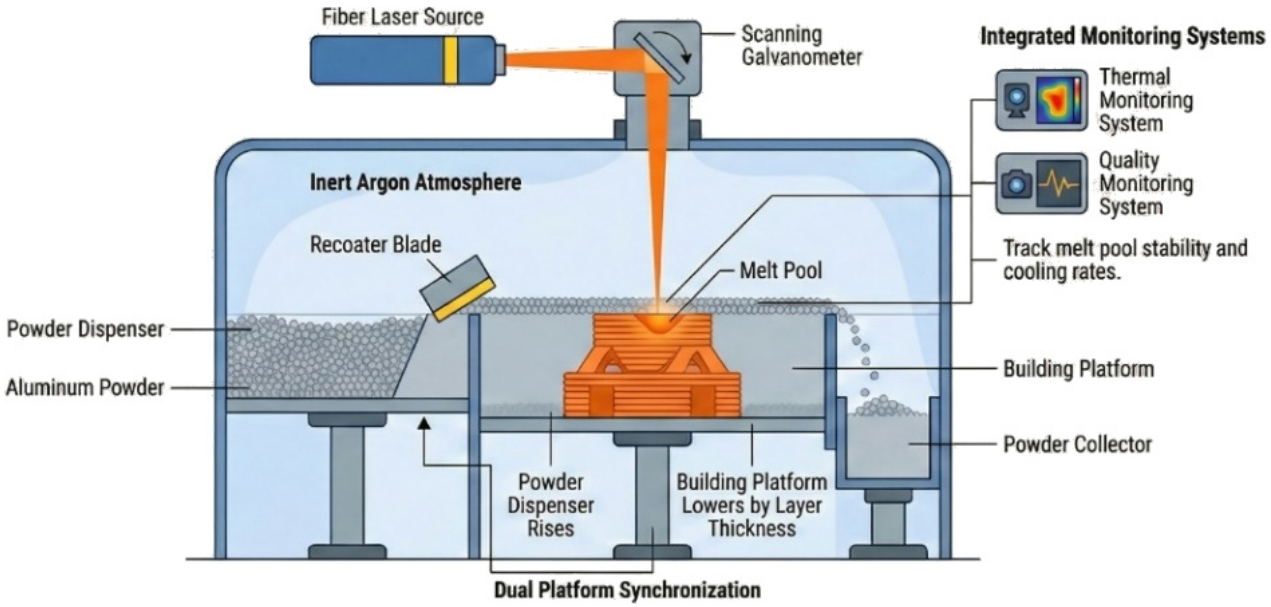


Fig.3 - LPBF Operational Principles and Schematic

Figure 4 illustrates the schematic representation of the selective laser melting (SLM) process used for the fabrication of metal components from powder materials. The process is based on the layer-by-layer melting of a thin powder layer by a high-energy laser beam, followed by solidification and bonding with the previously formed layer.

During the manufacturing process, a powder dispenser supplies a controlled amount of metal powder onto the build platform. A recoater blade spreads the powder into a uniform layer with a predefined thickness. The build chamber is filled with an inert argon atmosphere to prevent oxidation of the molten material and to ensure stable melting conditions [7-9].

A fiber laser source generates a focused laser beam, which is directed onto the powder bed by a scanning galvanometer system. The laser selectively melts the powder according to the predefined scan strategy, forming a localized molten pool. After laser exposure, the molten material rapidly solidifies, resulting in the formation of a dense solid layer.

Results and Discussions. As a result of microscopic analysis of the surface of a gear manufactured using selective laser melting, micrographs were obtained that reflect the peculiarities of material structure formation during the additive manufacturing process. The investigation was conducted at various magnifications, which made it possible to evaluate both the overall surface morphology of the product and local structural features (fig.4).

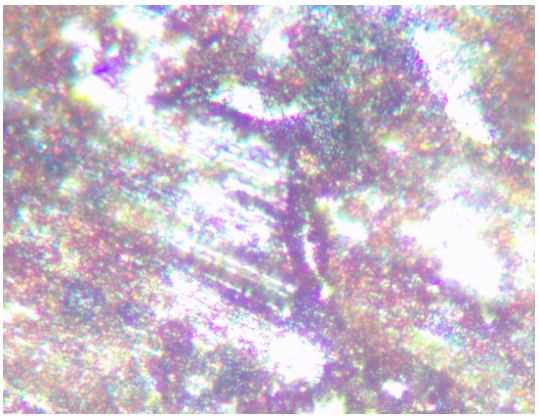


Fig.4 - Photograph of a gear with 40x magnification

At a magnification of 40× (fig.5), a heterogeneous surface structure formed as a result of the layer-by-layer laser melting of the powder material can be clearly observed [10]. The surface morphology is characterized by alternating regions with different degrees of fusion, which is a typical feature of components produced using the SLM process.

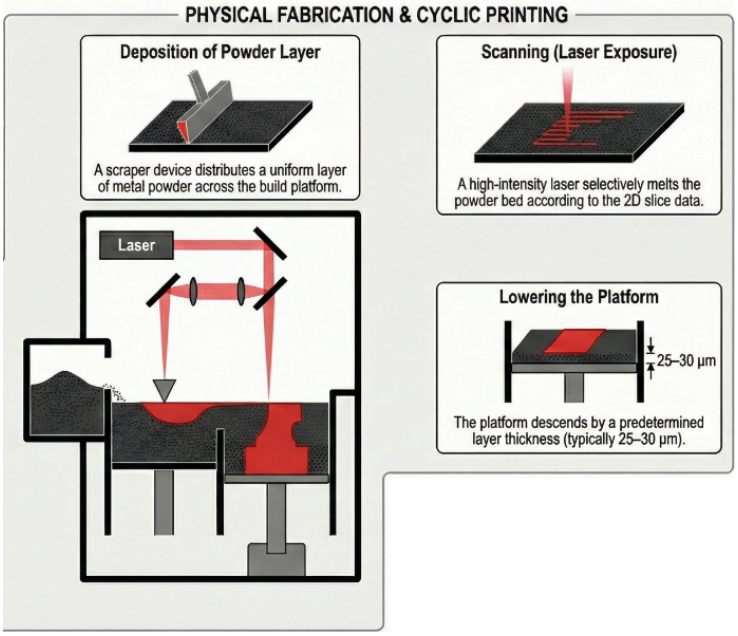
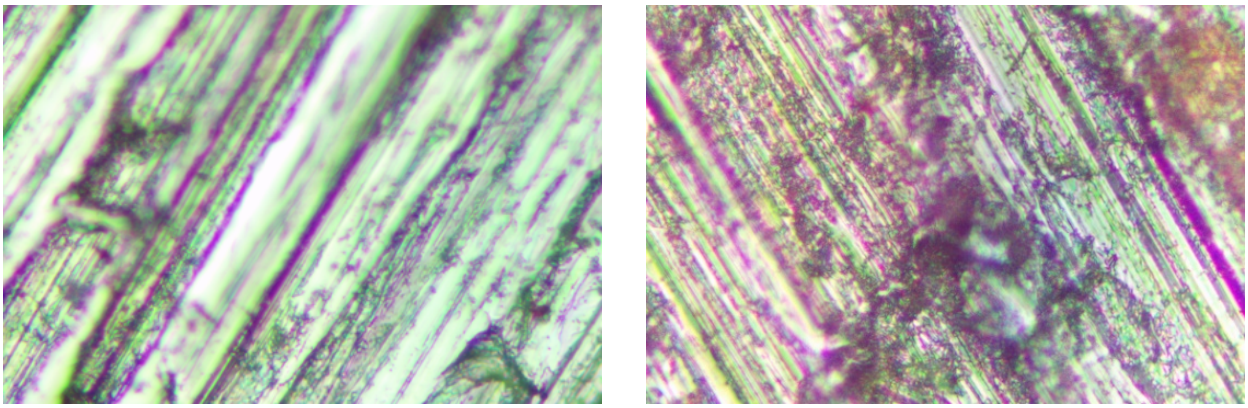


Fig.5 - Powder Bed Fusion Physical Manufacturing Cycle

The arrangement of structural features indicates a pronounced directionality of the material formation process, determined by the laser scanning strategy and the sequence of layer deposition. Similar structural characteristics are widely reported in scientific studies devoted to the selective laser melting of metallic powders and confirm the validity of the selected technological approach. (fig.6a). At a magnification of 50× (fig.6b), a more detailed analysis of the surface structure becomes possible. The micrographs reveal characteristic boundaries between individual layers formed during the successive melting of the powder material. The presence of pronounced layering is a consequence of the discrete nature of the additive manufacturing process and is determined by the applied layer thickness and laser processing parameters.



a **b**

Fig.6 - Photo of the gear from the reverse side 50×

In certain areas of the surface, areas with increased roughness and local structural in homogeneities were identified. These features may be associated with the uneven distribution of heat

flows in the laser exposure zone, as well as with variations in the properties of the powder material, including particle size and shape [11].

It should be noted that no pronounced macrodefects, such as large cracks or regions of incomplete fusion, were detected in the investigated sample. This indicates sufficient stability of the selective laser melting process and appropriately selected baseline printing parameters for the fabrication of a functional component.

Individual micrographs (fig.7) show the presence of small pores distributed unevenly across the surface of the product. Porosity is one of the most common defects in additive manufacturing using the SLM method and can result from insufficient laser energy density, the presence of gas inclusions in the powder, or incomplete fusion of particles.

The size and morphology of the observed pores indicate microporosity, which generally has a less pronounced effect on the operational properties of the component compared to larger defects. Nevertheless, the presence of even fine porosity should be taken into account in the further selection of powder material composition and optimization of selective laser melting process parameters.

The obtained results confirm the feasibility of using microscopic analysis as a tool for the primary quality assessment of components manufactured by selective laser melting, particularly at the stages of powder composition development and process parameter optimization.

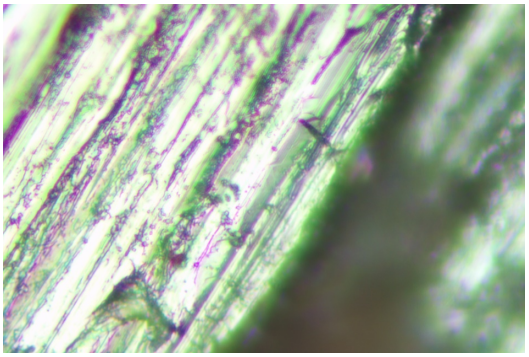


Fig.7 - Morphology of gear wear particles revealed by optical microscopy

The obtained data confirm the feasibility of using microscopic analysis as a tool for the preliminary quality assessment of components manufactured by selective laser melting, particularly at the stages of powder composition development and optimization of technological process parameters.

Figure 8 presents optical micrographs of the surface of the gear manufactured by selective laser melting at different magnifications. At a magnification of 40×, a heterogeneous surface structure associated with the layer-by-layer nature of material formation is clearly observed. At a magnification of 500×, local structural inhomogeneities and individual pores characteristic of SLM-fabricated components are revealed.

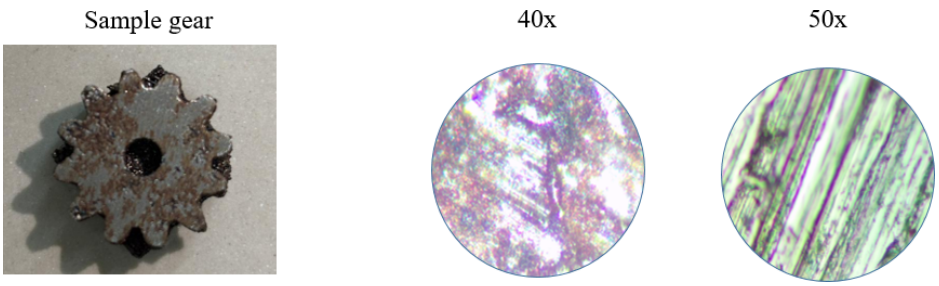


Fig.8 - Photograph of sample images of a gear

Conclusion. During the study, the microstructural features of a gear manufactured by selective laser melting were evaluated using optical microscopy. The obtained micrographs revealed characteristic features of the additive manufacturing process, including layer-by-layer material formation, microstructural heterogeneity, and the presence of microporosity.

The microstructural analysis showed that the

investigated sample exhibits structural features typical of SLM-produced components, while no significant macrodefects, such as cracks or regions of incomplete fusion, were detected. This indicates sufficient stability of the selective laser melting process and an acceptable level of material quality for functional applications.

The results of the study confirm that optical microscopy is an effective and accessible method for the preliminary quality assessment of parts manufactured using selective laser melting. This method enables the rapid identification of key microstructural features and potential defects, which is particularly important during the stages of powder material selection and optimization of SLM processing parameters.

The obtained results can be used as a basis for the further development of automated algorithms for selecting powder compositions and selective laser melting parameters, as well as for the creation of quality control systems in additive manufacturing aimed at improving the reproducibility and reliability of manufactured components.

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