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АНАЛИЗ ПОТЕНЦИАЛА ЭЛЕКТРОИМПУЛЬСНОГО ВОЗДЕЙСТВИЯ КАК МЕТОДА ПОСТОБРАБОТКИ ДЛЯ СПЛАВОВ, ИЗГОТОВЛЕННЫХ АДДИТИВНЫМ СПОСОБОМ

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Аннотация. В настоящей обзорной статье авторами проанализирован потенциал электроимпульсной обработки как метода постобработки для сплавов, изготовленных методом аддитивного производства. Аддитивное производство произвело революцию в современных производственных парадигмах, позволив послойное изготовление сложных геометрий непосредственно из цифровых моделей. Металлические детали, изготовленные методом аддитивного производства, содержат неравновесные микроструктуры, которые часто нежелательны для критического применения. Было доказано, что процесс электроимпульсной обработки является эффективным методом быстрого нагрева для постобработки деталей аддитивного производства. В отличие от обычных видов термообработки, электроимпульсная обработка не только нагревает сплав, но и оказывает полезные эффекты в ходе процесса, включая снижение термодинамических барьеров для фазовых превращений, ускоренную атомную диффузию, улучшенную рекристаллизацию и снижение остаточных напряжений. Настоящее исследование продемонстрировало следующее: электроимпульсная обработка может значительно изменять микротвердость сплавов путем применения подходящих электроимпульсных напряжений; электроимпульсная обработка может изменять и улучшать микроструктуру сплавов путем снижения термодинамических барьеров для фазового превращения $\alpha \rightarrow \beta$; электроимпульсная обработка, используемая при постобработке стального сплава, продемонстрировала повышение пластичности и интенсивную гомогенизацию и др. Из представленного обзора очевидно, что электроимпульсная обработка является потенциальным методом обработки для адаптации микроструктуры и механических свойств сплава, поскольку электроимпульсная обработка занимает гораздо меньше времени, чем термическая обработка с точки зрения получения микроструктурных изменений.

Ключевые слова: электроимпульсная обработка, металлы и сплавы, аддитивное производство, ток высокой плотности, микротвердость, пластичность, механические свойства

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ANALYSIS THE POTENTIAL OF ELECTROPULSING TREATMENT AS A POST-PROCESSING METHOD FOR ADDITIVELY MANUFACTURED ALLOYS

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Abstract. In this review article, we will analyze the potential of electropulsing treatment as a post-processing method for additively manufactured alloys. Additive manufacturing, has revolutionized modern production paradigms by enabling the layer-by-layer fabrication of complex geometries directly from digital models. Additively manufactured metal parts often contain non-equilibrium microstructures, which often undesirable for critical application. It has been proven that the electropulsing treatment process is an effective fast-heating method for post-processing additive manufacturing details. Unlike conventional heat treatments, electropulsing not only heats the alloy but also exerts beneficial effects during the process, including reduced thermodynamic barriers for phase transformations, accelerated atomic diffusion, enhanced recrystallization and reducing the residual stresses. The present study demonstrated what: electropulsing can significantly change the microhardness in alloys through applying suitable electropulsing voltages; electropulsing can modify and refine the microstructure of alloys through the reduction of thermodynamic barriers for $\alpha \rightarrow \beta$ phase transformation; electropulsing used in post-processing of steel alloy demonstrated the increase in ductility and severe homogenization et al. From the presented review it is obvious that the electropulsing is a potential processing method for tailoring the microstructure and mechanical properties of the alloy, because the electropulsing is much less time consuming than the heat treatment in terms of the production of the microstructural changes.

Keywords: electropulsing treatment, metals and alloys, additive manufacturing, high density current, microhardness, ductility, mechanical properties.

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Introduction

Additive manufacturing (AM), has revolutionized modern production paradigms by enabling the layer-by-layer fabrication of complex geometries directly from digital models [1-4]. Since its inception in the 1980s with Chuck Hull's development of stereolithography (SLA), AM has evolved from a rapid prototyping tool into a cornerstone of in-

dustrial manufacturing [5]. By 2025, the global AM market is projected to exceed \$25 billion, driven by its adoption in aerospace [6, 7], healthcare [8, 9], automotive [10, 11], and energy sectors [12, 13]. This growth reflects AM's unique advantages, including design freedom, material efficiency, and the ability to produce customized, lightweight components with reduced waste.

Additively manufactured metal parts often contain non-equilibrium microstructures, including chemical segregations, residual stresses, and dislocation networks [14, 15]. While these microstructures can enhance some properties, they are often undesirable for critical application. Conventional methods like heat treatment can address these issues, but they significantly slow production and may potentially cause part defects and distortions [16, 17].

The electropulsing treatment (EPT) process on the other hand is an effective fast-heating method for post-processing AM details, and its positive effect on microstructure and mechanical properties has attracted attention from various researchers throughout the years [18-24]. It has been revealed in different studies that the electropulsing treatment can be used to improve the ductility in cold-drawing technologies [25, 26], improve the fatigue properties [27] and heal fatigue microcracks [16, 28-30]. It can be also used in refining the microstructure in solid state in deformed materials, as it has been done in [31] by Yang et al. on the deformed ZrTiAlV alloy.

Unlike conventional heat treatments, electropulsing not only heats the alloy but also exerts beneficial effects during the process, including reduced thermodynamic barriers for phase transformations, accelerated atomic diffusion, enhanced recrystallization and reducing the residual stresses [19, 32, 33]. Electropulsing treatment with high-density current ($1.5\text{--}2\text{ kA/mm}^2$) causes thermal effects, because passing through defects or through a large number of particles with high current resistance causes localized heating in these areas (Joule heating). Joule heating provides directional energy transfer that preferentially activates diffusion pathways along current flow lines, enabling anisotropic microstructural control [34-37]. Another effect (athermal) induced by this treatment is the

electron wind, which, at high current densities, allows the flow of electrons to exert a force on atoms and promote their subsequent movement [38-40].

The combination of thermal and non-thermal effects during electropulsing enables unique microstructural modifications that can simultaneously improve strength and ductility in AM materials. In this review article, we will analyze the potential of electropulsing treatment (EPT) as a post-processing method for additively manufactured (AM) alloys.

AM titanium alloys' EPT post-processing

Selective laser melting (SLM), is one of the typical laser-based AM method, has been used in manufacturing of titanium [41] and aluminum alloys [42] due to the great advantage in manufacturing complex details while having a high material utilization rate. Ti6Al4V is extensively used in various advanced manufacturing fields, such as biomedical engineering, aerospace and aviation due to the outstanding corrosion resistance and high strength-weight ratio [43, 44]. As-fabricated SLM-Ti6Al4V has usual drawbacks for AM material such as low ductility and residual stresses. Heat treatment that is widely used in post-processing of such alloys can lead to high expenses and problems with microstructure homogeneity, especially in complex geometries [45]. To solve this problem, Gao et al. [46] employed EPT to enhance the microstructure and mechanical properties for further applications.

They cut the annealed SLM-Ti6Al-4V cylinder into plate-like samples with a dimension of $50 \times 6.5 \times 2.5\text{ mm}^3$ for EPT experiment (Fig. 1a). They have carried out the experiment at ambient temperature using a self-made device equipped with a capacitor bank discharge circuit (Fig. 1b), and the clamping device (Fig. 1c).

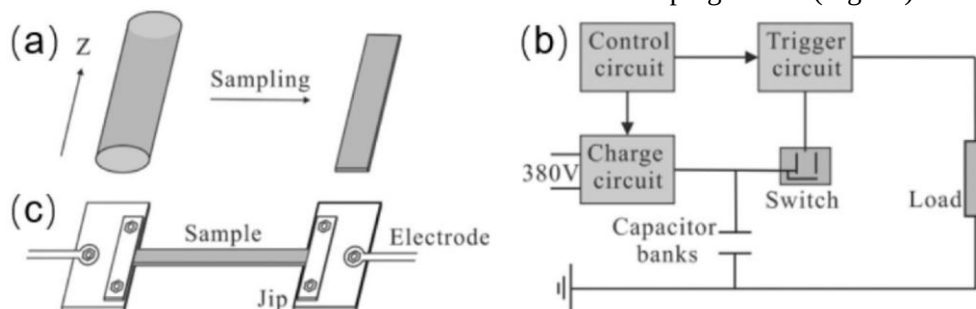


Рис. 1. Иллюстрационная схема экспериментального процесса и оборудования ЭПТ (взято из [46]).

Fig. 1. Illustration diagram of experimental process and EPT equipment (taken from [46]).

They chose EPT voltages from 6 kV to 8.5 kV as experimental parameters, these parameters based on the previous similar experiments [47]. The pulse duration was around 400 ns. The samples treated at 6 kV were referred to as EPT-6 sample and so forth. The EPT-less sample was marked as EPT-0 by authors.

The experiment showed that the microhardness of the SLM-Ti6Al4V can be changed by applying different EPT voltages, as lower voltages can result in a slight decline of microhardness and high voltages can lead to the increase of microhardness (seen in Figure 2).

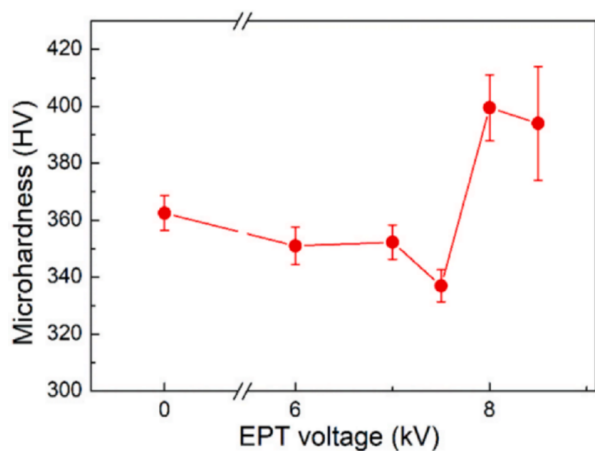


Рис. 2. Микротвердость различных образцов, обработанных различными напряжениями ЭПТ (взято из [46]).

Fig. 2. Microhardness of different samples treated with various EPT voltages (taken from [46]).

The untreated sample was found to consist of the original β -columnar grain with straight boundaries and the lamellar structures, as illustrated in Figure 3a. Following EPT treatment, the specimen softens and its microhardness decreases. The straight β columnar grain boundaries (GB) transform into zigzag ones, and the α lamellar structure significantly coarsens, as demonstrated in Figure 3b. Following exposure to EPT with high voltage, the specimen undergoes a process of hardening, resulting in a decline in microhardness. The authors speculated that the sample could potentially transform to the β columnar GB structure, resulting in equiaxed grains and thinner α lamellas (Fig. 3c). It is evident from Figure 3d that the application of an increased voltage did not result in a change in microhardness. However, it was observed that β equiaxed grains and α lamellas exhibited an increase in size (Fig. 3d).

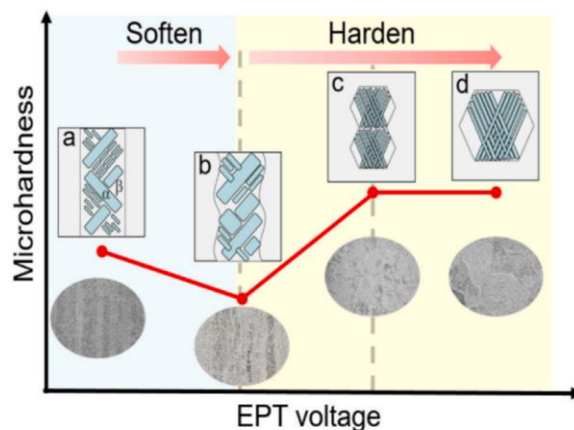


Рис. 3. Микроструктурная эволюция изменения микротвердости, вызванного ЭПТ (взято из [46]).

Fig. 3. Microstructural evolution of EPT-induced change in microhardness (taken from [46]).

AM aluminum alloys and steels' EPT post-processing

EPT can also be used for post-processing aluminum alloys and steels. Noell et al. [48] have investigated the effects of EPT on SLM 316 SS steel and AlSi10Mg aluminum alloys. Authors employed tensile dogbones as a geometry [49, 50] for their steel and aluminum alloy specimens (Fig. 4).

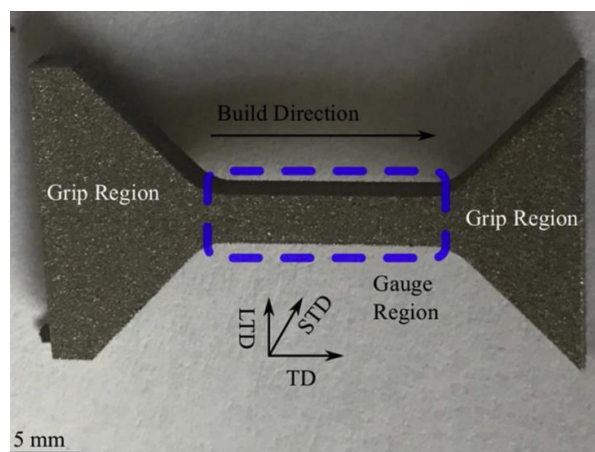


Рис. 4. Оптическое изображение сплава 316 SS, использованного в исследовании с областями (взято из [48]).

Fig. 4. An optical image of a 316 SS alloy used in the study with regions (taken from [48]).

The specimens had a uniform thickness of 2.5 mm. The gauge width was around 2.5 mm and its length around 10 mm, with a 45 degrees' fillet between the grip and gauge regions. Authors have prepared three steel specimens for EPT. They were

electropulsed 5, 10 and 100 times respectively. Significant chemical homogenization occurred in the two 316 SS samples that were pulsed 10 and

100 times as shown in Fig. 5. Remnants of the cellular structure are still visible.

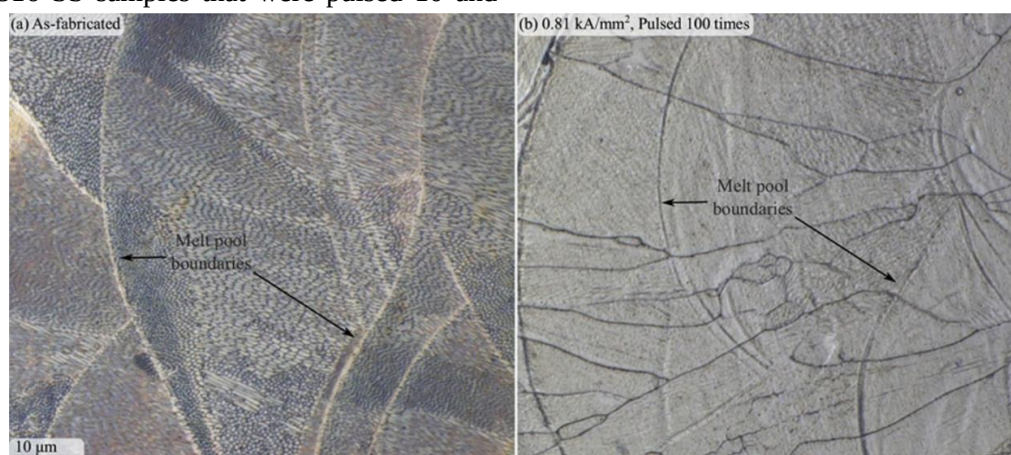


Рис. 5. Оптические изображения образцов 316 SS с большим увеличением: (а) состояние в исходном состоянии, (б) сталь после 100 импульсов с плотностью тока 0,81 кА/мм² (взято из [48]).

Fig. 5. High-magnification optical images of 316 SS specimens: (a) the as-fabricated condition, (b) steel after 100 pulses with a current density of 0.81 kA/mm² (taken from [48]).

Long pulsations (200 ms) have achieved the removal of the microsegregation in the alloy. Electropulsing also didn't affect the dislocation or grain structures in the material. Authors also discovered that EPT did not significantly change the Vickers hardness: the as-fabricated material had 230 HV and electropulsed material had 229 HV.

As for the AlSi10Mg specimens, EPT increased ductility and decreased hardness and strength. The ECCI images showed some spheroidization of the α -silicon phase that occurred in samples 04, 05 and 06 (Fig. 6).

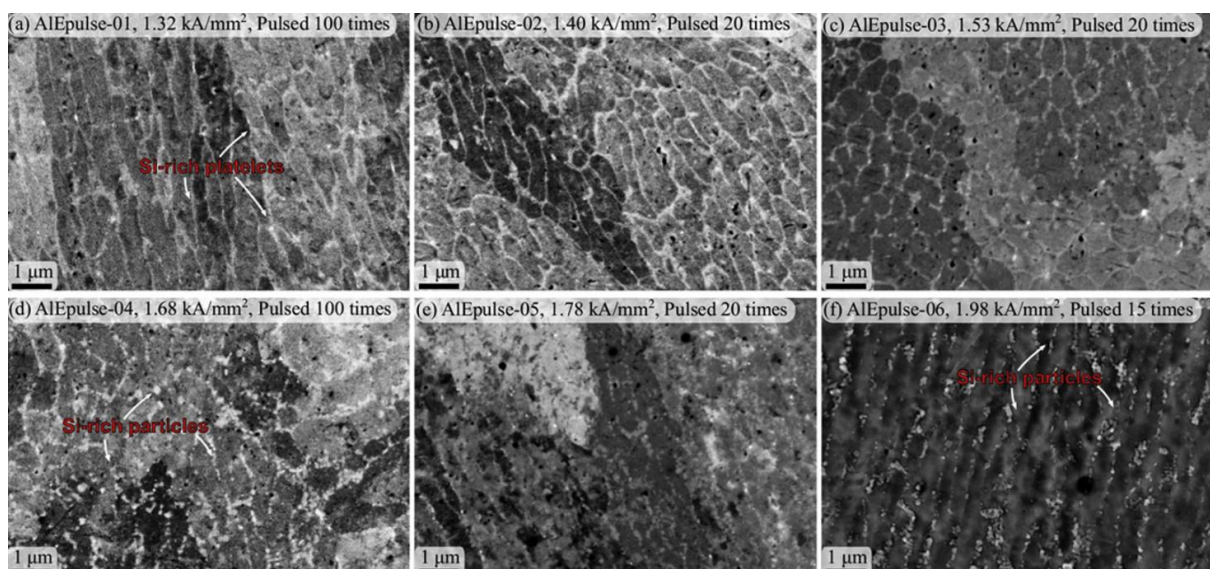


Рис. 6. Контрастные изображения с электронным каналированием шести образцов, которые были подвергнуты электроимпульсной обработке. Образцы (а)-(е) находятся в состоянии после полировки. Образец (f) был протравлен с использованием реагента Келлера после полировки (взято из [48]).

Fig. 6. Electron channelling contrast imaging of the six specimens that were electropulsed are provided. The specimens in (a) to (e) are in the as-polished condition. The specimen in (f) was etched using Keller's reagent after polishing (taken from [48]).

However, none of the AlSi10Mg samples reached the same ductility as the heat treated sample. This demonstrates that below some thresholds of current density and the number of pulses, EPT has no significance on the microstructure.

Conclusions

The present study demonstrated how EPT can be used for post-processing in different AM alloys, and through the study of the recent works on the subject it was concluded that:

1. Electropulsing can significantly change the microhardness in SLM-Ti6Al-4V through applying suitable EPT voltages. As the relatively low voltage resulted in the decline of microhardness, subsequent increase in voltage resulted in the significant increase in microhardness.

2. EPT can modify and refine the microstructure of SLM-Ti6Al-4V through the reduction of thermodynamic barriers for $\alpha \rightarrow \beta$ phase transformation.

3. EPT used in post-processing of 316SS steel alloy demonstrated the increase in ductility and severe homogenization, but it also didn't change the dislocation and grain structure, therefore, the hardness remained the same.

4. In AlSi10Mg however, EPT showed the decline in ductility, compared to the heat-treated sample. It also showed the change in the microstructure, as the spheroidization occurred in some EPT samples.

In conclusion, it is evident that the EPT is a potential processing method for tailoring the microstructure and mechanical properties of the alloy. But it should be noted, as EPT can hold no significance if it's under certain thresholds. However, the EPT is much less time consuming than the heat treatment in terms of the production of the microstructural changes. Further work is necessary to understand the mechanisms and its effects on other AM materials.

Список литературы

1. Bai Y., Li Y., Wang Y., Zhang K., Jiang Q., Liu Z., Hu Z., Wei B. Wavy Interface Enables Extra Strengthening in an Additively Manufactured High-Entropy Alloy with Mortise-Tenon Architecture // *International Journal of Plasticity*, vol. 170, no. 103777 (2023). DOI: 10.1016/j.ijplas.2023.103777.
2. Enikeev N.A., Abramova M.M., Kapustin A.V., Polyakova V.V., Ryzhkin A.A., Kudryasho-

va E.S., Anisimova N.Yu., Kiselevskiy M.V. Design and mechanical performance of additively manufactured porous structures to develop bioactive titanium scaffolds // *Letters on Materials*, vol. 14, is. 1, pp. 3-8 (2024). DOI: 10.48612/letters/2024-1-3-8.

3. Han C., Babicheva R., Chua J.D.Q., Ramamurthy U., Tor S.B., Sun C.-N., Zhou K. Microstructure and Mechanical Properties of (TiB+TiC)/Ti Composites Fabricated in Situ via Selective Laser Melting of Ti and B4C Powders // *Additive Manufacturing*, vol. 36, no. 101466 (2020). DOI: 10.1016/j.addma.2020.101466.

4. Heidarzadeh A., Neikter M., Enikeev N., Cui L., Forouzan F., Mousavian R.T. Post-Treatment of Additively Manufactured Fe-Cr-Ni Stainless Steels by High Pressure Torsion: TRIP Effect // *Materials Science and Engineering: A*, vol. 811, no. 141086 (2021). DOI: 10.1016/j.msea.2021.141086.

5. Cozmei C., Caloian F. Additive Manufacturing Flickering at the Beginning of Existence // *Procedia Economics and Finance*, vol. 3, pp. 457-462 (2012). DOI: 10.1016/S2212-5671(12)00180-3.

6. Liu G., Zhao Q., Jia W., Zhang Y., Song S., Mao C., Zhou W., Zhang S., Zhao Y. Damage Tolerance Performance of High Strength and Toughness Titanium Alloys Formed by Additive Manufacturing in Aerospace: A Review // *Review of Materials Research*, vol. 1, no. 100003 (2025). DOI: 10.1016/j.revmat.2025.100003.

7. Srivastava M., Jayakumar V., Udayan Y., Sathishkumar M., Muthu S.M., Gautam P., Nag A. Additive Manufacturing of Titanium Alloy for Aerospace Applications: Insights into the Process, Microstructure, and Mechanical Properties // *Applied Materials Today*, vol. 41, no. 102481 (2024). DOI: 10.1016/j.apmt.2024.102481.

8. Camargo J.R., Crapnell R.D., Bernalte E., Cunliffe A.J., Redfern J., Janegitz B.C., Banks C.E. Conductive Recycled PETg Additive Manufacturing Filament for Sterilisable Electroanalytical Healthcare Sensors // *Applied Materials Today*, vol. 39, no. 102285 (2024). DOI: 10.1016/j.apmt.2024.102285.

9. Priyadarshini J., Singh R.K., Mishra R., Dora M. Application of Additive Manufacturing for a Sustainable Healthcare Sector: Mapping Current Research and Establishing Future Research Agenda // *Technological Forecasting and Social Change*, vol. 194, no. 122686 (2023). DOI: 10.1016/j.techfore.2023.122686.

10. Bade A., Lasch R., Schneider N. Additive Manufacturing Scenario for Automotive Spare Parts Supply: A Case Study Approach // *International Journal of Production Economics*, vol. 282, no. 109552 (2025). DOI: 10.1016/j.ijpe.2025.109552.
11. Chauhan D., Singh A.P., Chauhan A., Aro-ra R. Sustainable Supply Chain: An Optimization and Resource Efficiency in Additive Manufacturing for Automotive Spare Part // *Sustainable Futures*, vol. 9, no. 100563 (2025). DOI: 10.1016/j.sftr.2025.100563.
12. Chen N., He C., Pang S. Additive Manufacturing of Energetic Materials: Tailoring Energetic Performance via Printing // *Journal of Materials Science & Technology*, vol. 127, pp. 29-47 (2022). DOI: 10.1016/j.jmst.2022.02.047.
13. Šakalys R., O'Hara C., Kariminejad M., Weinert A., Kadivar M., Zluhan B., Costello K., McAfee M., McGranaghan G., Raghavendra R., Tormey D. Additively Manufactured Injection Mould Tooling Incorporating Gradient Density Lattice Structures for Mass and Energy Reduction // *International Journal of Lightweight Materials and Manufacture*, vol. 8, is. 4, pp. 522-536 (2025). DOI: 10.1016/j.ijlmm.2025.03.007.
14. Biffi C.A., Lemke J.N., Bassani P., Fiocchi J., Bregoli C., Tuissi A. Characterization and Postprocessing of Additively Manufactured Shape Memory Alloys // In book: *Additive Manufacturing of Shape Memory Materials*, pp. 315-360 (2025). ISBN: 978-0-443-29594-2.
15. Kumar A., Kumar P., Mittal R.K., Singh H. Preprocessing and Postprocessing in Additive Manufacturing. In *Advances in Additive Manufacturing Artificial Intelligence* // In book: *Nature-Inspired, and Biomanufacturing*, pp. 141-165 (2023). ISBN: 978-0-323-91834-3.
16. Bryzgalov V.A., Morkina A.Y., Abdullina D.U., Semenov A.S., Tatarinov P.S., Yakushev I.A., Bebikhov Y.V., Kukudzhonov K.V., Korznikova E.A., Dmitriev S.V. High-density pulsed current: a review of its role in healing macrocracks in metals // *Materials. Technologies. Design*, vol. 6, is. 2, pp. 38-58, (2024). DOI: 10.54708/26587572_2024_621738.
17. Bedmar J., García-Rodríguez S., Roldán M., Torres B., Rams J. Effects of the Heat Treatment on the Microstructure and Corrosion Behavior of 316 L Stainless Steel Manufactured by Laser Powder Bed Fusion // *Corrosion Science*, vol. 209, no. 110777 (2022). DOI: 10.1016/j.corsci.2022.110777.
18. Ao D., Chu X., Yang Y., Lin S., Gao J. Effect of Electropulsing on Springback during V-Bending of Ti-6Al-4V Titanium Alloy Sheet // *International Journal of Advanced Manufacturing Technology*, vol. 96, pp. 3197-3207 (2018). DOI: 10.1007/s00170-018-1654-1.
19. Ao D.-W., Chu X.-R., Lin S.-X., Yang Y., Gao J. Hot Tensile Behaviors and Microstructure Evolution of Ti-6Al-4V Titanium Alloy Under Electropulsing // *Acta Metallurgica Sinica (English Letters)*, vol. 31, pp. 1287-1296 (2018). DOI: 10.1007/s40195-018-0735-3.
20. Cai Q., Zhou M., Bagherpour E., Hosseini S., Mendis C., Chang I., Assadi H. New Insight Into Crack-Healing Mechanism via Electropulsing Treatment // *Metallurgical and Materials Transactions A*, vol. 54, pp. 2960-2974 (2023). DOI: 10.1007/s11661-023-07073-1.
21. Fu X., Xu X., Zhao Y., Chen D., Wu Z., Yan X., Zhou Y., Yu Y. Retain the Austenite via Diffusion Control under Electropulsing to Improve the Mechanical Properties of the AISI 420 Stainless Steel // *Journal of Materials Research and Technology*, vol. 29, pp. 1665-1674 (2024). DOI: 10.1016/j.jmrt.2024.01.177.
22. Kim M., Song J., Huh H. Effect of Pre-Strain on Tensile Properties of Al5052-H32 under an Electropulsing Condition // *Procedia Engineering*, vol. 207, pp. 371-376 (2017). DOI: 10.1016/j.proeng.2017.10.790.
23. Ding S., Yan L., Cheng X., Zhang X. Improving the Intergranular Corrosion Resistance of Aged 316L Stainless Steel Heat Affected Zone by Electropulsing Beneath the Critical Temperature // *JOM*, vol. 73, pp. 3928-3940 (2021). DOI: 10.1007/s11837-021-04941-2.
24. Kumar R.P., Srinivas N.C.S., Pandey R.K., Manna R. Electropulsing of Low-Density Duplex Steel for Strengthening and Ductilization by Microstructural Refinement // *Journal of Materials Processing Technology*, vol. 329, no. 118423 (2024). DOI: 10.1016/j.jmatprotec.2024.118423.
25. Tang G., Zhang J., Yan Y., Zhou H., Fang W. The Engineering Application of the Electroplastic Effect in the Cold-Drawing of Stainless Steel Wire // *Journal of Materials Processing Technology*, vol. 137, pp. 96-99 (2003). DOI: 10.1016/S0924-0136(02)01091-9.
26. Zimniak Z., Radkiewicz G. The Electroplastic Effect in the Cold-Drawing of Copper Wires for the Automotive Industry // *Archives of Civil and Mechanical Engineering*, vol. 8, pp. 173-

- 179 (2008). DOI: 10.1016/S1644-9665(12)60204-0.
27. Xiao S.H., Guo J.D., Wu S.D., He G.H., Li S.X. Recrystallization in Fatigued Copper Single Crystals under Electropulsing // *Scripta Materialia*, vol. 46, pp. 1-6 (2002). DOI: 10.1016/S1359-6462(01)01186-1.
28. Rusinov P., Pashkov A., Tyurina S., Zhang C., Merkulov A., Dalskaya G., Guminskaya Z., Gusevskaya D., Kurapov G., Sereda P. Development and Research of Electric Pulse Force Intensification Technology to Improve the Reliability and Cyclic Durability of Materials // *Journal of Manufacturing and Materials Processing*, vol. 10, is. 7, no. 227 (2026). DOI: 10.3390/jmmp10070227.
29. Kumar A., Paul S.K. Healing of Fatigue Crack in Steel with the Application of Pulsed Electric Current // *Materialia*, vol. 14, no. 100906 (2020). DOI: 10.1016/j.mtla.2020.100906.
30. Wei D., Han J., Jiang Z.Y., Lu C., Tieu A.K. A Study on Crack Healing in 1045 Steel // *Journal of Materials Processing Technology*, vol. 177, pp. 233-237 (2006). DOI: 10.1016/j.jmatprotec.2006.04.067.
31. Yang Z.N., Jiang F., Wang X.B., Qu L., Li Y.G., Chai L.J., Zhang F.C. Effect of Electropulsing Treatment on Microstructure and Mechanical Properties of a Deformed ZrTiAlV Alloy // *Materials*, vol. 12, no. 3560 (2019). DOI: 10.3390/ma12213560.
32. Yu T., Deng D., Wang G., Zhang H. Crack Healing in SUS304 Stainless Steel by Electropulsing Treatment // *Journal of Cleaner Production*, vol. 113, pp. 989-994 (2016). DOI: 10.1016/j.jclepro.2015.12.060.
33. Wang X., Zhou B., Huang H., Niu J., Guan S., Yuan G. Extraordinary Ductility Enhancement of Mg-Nd-Zn-Zr Alloy Achieved by Electropulsing Treatment // *Journal of Magnesium and Alloys*, vol. 12, pp. 4481-4492 (2024). DOI: 10.1016/j.jma.2022.07.007.
34. Ma K., Li S., Xu C., Gao Z., Yang L., Lu B. Study on the Process Characteristics Based on Joule Heat of Sliding-Pressure Additive Manufacturing // *Materials*, vol. 16, no. 2017 (2023). DOI: 10.3390/ma16052017.
35. Ruskiewicz B.J., Mears L., Roth J.T. Investigation of Heterogeneous Joule Heating as the Explanation for the Transient Electroplastic Stress Drop in Pulsed Tension of 7075-T6 Aluminum // *Journal of Manufacturing Science and Engineering*, vol. 140, no. 091014 (2018). DOI: 10.1115/1.4040349.
36. Yizhou Z., You Z., Guanhu H., Benlian Z. The Healing of Quenched Crack in 1045 Steel under Electropulsing // *Journal of Materials Research*, vol. 16, pp. 17-19 (2001). DOI: 10.1557/jmr.2001.0005.
37. Yu T., Deng D., Wang G., Zhang H. Crack Healing in SUS304 Stainless Steel by Electropulsing Treatment // *Journal of Cleaner Production*, vol. 113, pp. 989-994 (2016). DOI: 10.1016/j.jclepro.2015.12.060.
38. Gupta R.P. The Electron Wind Force in Electromigration // *Journal of Physics and Chemistry of Solids*, vol. 47, pp. 1057-1066 (1986). DOI: 10.1016/0022-3697(86)90072-7.
39. Li X., Zhu Q., Hong Y., Zheng H., Wang J., Wang J., Zhang Z. Revealing the Pulse-Induced Electroplasticity by Decoupling Electron Wind Force // *Nature Communications*, vol. 13, no. 6503 (2022). DOI: 10.1038/s41467-022-34333-2.
40. Krishnaswamy H., Tiwari J., Amirthalingam M. Revisiting Electron-Wind Effect for Electroplasticity: A Critical Interpretation // *Vacuum*, vol. 221, no. 112937 (2024). DOI: 10.1016/j.vacuum.2023.112937.
41. Zafari A., Barati M.R., Xia K. Controlling Martensitic Decomposition during Selective Laser Melting to Achieve Best Ductility in High Strength Ti-6Al-4V // *Materials Science and Engineering: A*, vol. 744, pp. 445-455 (2019). DOI: 10.1016/j.msea.2018.12.047.
42. Ben D.D., Ma Y.R., Yang H.J., Meng L.X., Shao X.H., Liu H.Q., Wang S.G., Duan Q.Q., Zhang Z.F. Heterogeneous Microstructure and Voids Dependence of Tensile Deformation in a Selective Laser Melted AlSi10Mg Alloy // *Materials Science and Engineering: A*, vol. 798, no. 140109 (2020). DOI: 10.1016/j.msea.2020.140109.
43. Shi Y., Gong S., Xu H., Wang Z., Yang G., Qi B. Alloying Strategies for Additive Manufacturing of Ti6Al4V Based Alloys, Composites and Functionally Graded Materials: Microstructure and Phase Evolution of Intra and Inter-Layer // *Journal of Materials Research and Technology*, vol. 27, pp. 6225-6263 (2023). DOI: 10.1016/j.jmrt.2023.11.060.
44. Guo N., Chen Y., Yan C., Meng X., Li Y. Machinability of CFRP/Ti6Al4V Stacks with Low-Frequency-Vibration Assisted Drilling under Different Cooling Strategies // *Journal of Manufacturing Processes*, vol. 108, pp. 852-862 (2023). DOI: 10.1016/j.jmapro.2023.11.044.
45. Liu S., Shin Y.C. Additive Manufacturing of Ti6Al4V Alloy: A Review // *Materials & De-*

sign, vol. 164, no. 107552 (2019). DOI: 10.1016/j.matdes.2018.107552.

46. Gao J.B., Ben D.D., Yang H.J., Meng L.X., Ji H.B., Lian D.L., Chen J., Yi J.L., Wang L., Li P., Zhang Z.F. Effects of Electropulsing on the Microstructure and Microhardness of a Selective Laser Melted Ti6Al4V Alloy // Journal of Alloys and Compounds, vol. 875, no. 160044 (2021). DOI: 10.1016/j.jallcom.2021.160044.

47. Ben D.D., Yang H.J., Ma Y.R., Shao X.H., Pang J.C., Zhang Z.F. Rapid Hardening of AISI 4340 Steel Induced by Electropulsing Treatment // Materials Science and Engineering: A, vol. 725, pp. 28-32 (2018). DOI: 10.1016/j.msea.2018.04.013.

48. Noell P.J., Rodelas J.M., Ghanbari Z.N., Laursen C.M. Microstructural Modification of Additively Manufactured Metals by Electropulsing // Additive Manufacturing, vol. 33, no. 101128 (2020). DOI: 10.1016/j.addma.2020.101128.

49. Hajy Akbary F., Santofimia M.J., Sietsma J. Elastic Strain Measurement of Miniature Tensile Specimens // Experimental Mechanics, vol. 54, pp. 165-173 (2014). DOI: 10.1007/s11340-013-9785-7.

50. Hibbert K., Warner G., Brown C., Ajide O., Owolabi G., Azimi A. The Effects of Build Parameters and Strain Rate on the Mechanical Properties of FDM 3D-Printed Acrylonitrile Butadiene Styrene // Open Journal of Organic Polymer Materials, vol. 9, is. 1, pp. 1-27 (2019). DOI: 10.4236/ojopm.2019.91001.

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References

1. Bai Y., Li Y., Wang Y., Zhang K., Jiang Q., Liu Z., Hu Z., Wei B. Wavy Interface Enables Extra Strengthening in an Additively Manufactured High-Entropy Alloy with Mortise-Tenon Architecture // International Journal of Plasticity, vol. 170, no. 103777 (2023). DOI: 10.1016/j.ijplas.2023.103777.

2. Enikeev N.A., Abramova M.M., Kapustin A.V., Polyakova V.V., Ryzhkin A.A., Kudryashova E.S., Anisimova N.Yu., Kiselevskiy M.V. Design and mechanical performance of additively manufactured porous structures to develop bioactive titanium scaffolds // Letters on Materials, vol. 14, is. 1, pp. 3-8 (2024). DOI: 10.48612/letters/2024-1-3-8.

3. Han C., Babicheva R., Chua J.D.Q., Ramamurthy U., Tor S.B., Sun C.-N., Zhou K. Microstructure and Mechanical Properties of (TiB+TiC)/Ti Composites Fabricated in Situ via Selective Laser Melting of Ti and B4C Powders // Additive Manufacturing, vol. 36, no. 101466 (2020). DOI: 10.1016/j.addma.2020.101466.

4. Heidarzadeh A., Neikter M., Enikeev N., Cui L., Forouzan F., Mousavian R.T. Post-Treatment of Additively Manufactured Fe–Cr–Ni Stainless Steels by High Pressure Torsion: TRIP Effect // Materials Science and Engineering: A, vol. 811, no. 141086 (2021). DOI: 10.1016/j.msea.2021.141086.

5. Cozmei C., Caloian F. Additive Manufacturing Flickering at the Beginning of Existence // Procedia Economics and Finance, vol. 3, pp. 457-462 (2012). DOI: 10.1016/S2212-5671(12)00180-3.

6. Liu G., Zhao Q., Jia W., Zhang Y., Song S., Mao C., Zhou W., Zhang S., Zhao Y. Damage Tolerance Performance of High Strength and Toughness Titanium Alloys Formed by Additive Manufacturing in Aerospace: A Review // *Review of Materials Research*, vol. 1, no. 100003 (2025). DOI: 10.1016/j.revmat.2025.100003.
7. Srivastava M., Jayakumar V., Udayan Y., Sathishkumar M., Muthu S.M., Gautam P., Nag A. Additive Manufacturing of Titanium Alloy for Aerospace Applications: Insights into the Process, Microstructure, and Mechanical Properties // *Applied Materials Today*, vol. 41, no. 102481 (2024). DOI: 10.1016/j.apmt.2024.102481.
8. Camargo J.R., Crapnell R.D., Bernalte E., Cunliffe A.J., Redfern J., Janegitz B.C., Banks C.E. Conductive Recycled PETg Additive Manufacturing Filament for Sterilisable Electroanalytical Healthcare Sensors // *Applied Materials Today*, vol. 39, no. 102285 (2024). DOI: 10.1016/j.apmt.2024.102285.
9. Priyadarshini J., Singh R.K., Mishra R., Dora M. Application of Additive Manufacturing for a Sustainable Healthcare Sector: Mapping Current Research and Establishing Future Research Agenda // *Technological Forecasting and Social Change*, vol. 194, no. 122686 (2023). DOI: 10.1016/j.techfore.2023.122686.
10. Bade A., Lasch R., Schneider N. Additive Manufacturing Scenario for Automotive Spare Parts Supply: A Case Study Approach // *International Journal of Production Economics*, vol. 282, no. 109552 (2025). DOI: 10.1016/j.ijpe.2025.109552.
11. Chauhan D., Singh A.P., Chauhan A., Arora R. Sustainable Supply Chain: An Optimization and Resource Efficiency in Additive Manufacturing for Automotive Spare Part // *Sustainable Futures*, vol. 9, no. 100563 (2025). DOI: 10.1016/j.sfr.2025.100563.
12. Chen N., He C., Pang S. Additive Manufacturing of Energetic Materials: Tailoring Energetic Performance via Printing // *Journal of Materials Science & Technology*, vol. 127, pp. 29-47 (2022). DOI: 10.1016/j.jmst.2022.02.047.
13. Šakalys R., O'Hara C., Kariminejad M., Weinert A., Kadivar M., Zluhan B., Costello K., McAfee M., McGranaghan G., Raghavendra R., Tormey D. Additively Manufactured Injection Mould Tooling Incorporating Gradient Density Lattice Structures for Mass and Energy Reduction // *International Journal of Lightweight Materials and Manufacture*, vol. 8, is. 4, pp. 522-536 (2025). DOI: 10.1016/j.ijlmm.2025.03.007.
14. Biffi C.A., Lemke J.N., Bassani P., Fiocchi J., Bregoli C., Tuissi A. Characterization and Postprocessing of Additively Manufactured Shape Memory Alloys // In book: *Additive Manufacturing of Shape Memory Materials*, pp. 315-360 (2025). ISBN: 978-0-443-29594-2.
15. Kumar A., Kumar P., Mittal R.K., Singh H. Preprocessing and Postprocessing in Additive Manufacturing. In *Advances in Additive Manufacturing Artificial Intelligence* // In book: *Nature-Inspired, and Biomanufacturing*, pp. 141-165 (2023). ISBN: 978-0-323-91834-3.
16. Bryzgalov V.A., Morkina A.Y., Abdullina D.U., Semenov A.S., Tatarinov P.S., Yakushev I.A., Bebikhov Y.V., Kukudzhinov K.V., Korznikova E.A., Dmitriev S.V. High-density pulsed current: a review of its role in healing macrocracks in metals // *Materials. Technologies. Design*, vol. 6, is. 2, pp. 38-58, (2024). DOI: 10.54708/26587572_2024_621738.
17. Bedmar J., García-Rodríguez S., Roldán M., Torres B., Rams J. Effects of the Heat Treatment on the Microstructure and Corrosion Behavior of 316 L Stainless Steel Manufactured by Laser Powder Bed Fusion // *Corrosion Science*, vol. 209, no. 110777 (2022). DOI: 10.1016/j.corsci.2022.110777.
18. Ao D., Chu X., Yang Y., Lin S., Gao J. Effect of Electropulsing on Springback during V-Bending of Ti-6Al-4V Titanium Alloy Sheet // *International Journal of Advanced Manufacturing Technology*, vol. 96, pp. 3197-3207 (2018). DOI: 10.1007/s00170-018-1654-1.
19. Ao D.-W., Chu X.-R., Lin S.-X., Yang Y., Gao J. Hot Tensile Behaviors and Microstructure Evolution of Ti-6Al-4V Titanium Alloy Under Electropulsing // *Acta Metallurgica Sinica (English Letters)*, vol. 31, pp. 1287-1296 (2018). DOI: 10.1007/s40195-018-0735-3.
20. Cai Q., Zhou M., Bagherpour E., Hosseini S., Mendis C., Chang I., Assadi H. New Insight Into Crack-Healing Mechanism via Electropulsing Treatment // *Metallurgical and Materials Transactions A*, vol. 54, pp. 2960-2974 (2023). DOI: 10.1007/s11661-023-07073-1.
21. Fu X., Xu X., Zhao Y., Chen D., Wu Z., Yan X., Zhou Y., Yu Y. Retain the Austenite via Diffusion Control under Electropulsing to Improve the Mechanical Properties of the AISI 420 Stainless Steel // *Journal of Materials Research and Technology*, vol. 29, pp. 1665-1674 (2024). DOI: 10.1016/j.jmrt.2024.01.177.
22. Kim M., Song J., Huh H. Effect of Pre-Strain on Tensile Properties of Al5052-H32 under an Electropulsing Condition // *Procedia Engineering*, vol. 207, pp. 371-376 (2017). DOI: 10.1016/j.proeng.2017.10.790.

23. Ding S., Yan L., Cheng X., Zhang X. Improving the Intergranular Corrosion Resistance of Aged 316L Stainless Steel Heat Affected Zone by Electropulsing Beneath the Critical Temperature // *JOM*, vol. 73, pp. 3928-3940 (2021). DOI: 10.1007/s11837-021-04941-2.
24. Kumar R.P., Srinivas N.C.S., Pandey R.K., Manna R. Electropulsing of Low-Density Duplex Steel for Strengthening and Ductilization by Microstructural Refinement // *Journal of Materials Processing Technology*, vol. 329, no. 118423 (2024). DOI: 10.1016/j.jmatprotec.2024.118423.
25. Tang G., Zhang J., Yan Y., Zhou H., Fang W. The Engineering Application of the Electroplastic Effect in the Cold-Drawing of Stainless Steel Wire // *Journal of Materials Processing Technology*, vol. 137, pp. 96-99 (2003). DOI: 10.1016/S0924-0136(02)01091-9.
26. Zimniak Z., Radkiewicz G. The Electroplastic Effect in the Cold-Drawing of Copper Wires for the Automotive Industry // *Archives of Civil and Mechanical Engineering*, vol. 8, pp. 173-179 (2008). DOI: 10.1016/S1644-9665(12)60204-0.
27. Xiao S.H., Guo J.D., Wu S.D., He G.H., Li S.X. Recrystallization in Fatigued Copper Single Crystals under Electropulsing // *Scripta Materialia*, vol. 46, pp. 1-6 (2002). DOI: 10.1016/S1359-6462(01)01186-1.
28. Rusinov P., Pashkov A., Tyurina S., Zhang C., Merkulov A., Dalskaya G., Guminskaya Z., Gusevskaya D., Kurapov G., Sereda P. Development and Research of Electric Pulse Force Intensification Technology to Improve the Reliability and Cyclic Durability of Materials // *Journal of Manufacturing and Materials Processing*, vol. 10, is. 7, no. 227 (2026). DOI: 10.3390/jmmp10070227.
29. Kumar A., Paul S.K. Healing of Fatigue Crack in Steel with the Application of Pulsed Electric Current // *Materialia*, vol. 14, no. 100906 (2020). DOI: 10.1016/j.mtla.2020.100906.
30. Wei D., Han J., Jiang Z.Y., Lu C., Tieu A.K. A Study on Crack Healing in 1045 Steel // *Journal of Materials Processing Technology*, vol. 177, pp. 233-237 (2006). DOI: 10.1016/j.jmatprotec.2006.04.067.
31. Yang Z.N., Jiang F., Wang X.B., Qu L., Li Y.G., Chai L.J., Zhang F.C. Effect of Electropulsing Treatment on Microstructure and Mechanical Properties of a Deformed ZrTiAlV Alloy // *Materials*, vol. 12, no. 3560 (2019). DOI: 10.3390/ma12213560.
32. Yu T., Deng D., Wang G., Zhang H. Crack Healing in SUS304 Stainless Steel by Electropulsing Treatment // *Journal of Cleaner Production*, vol. 113, pp. 989-994 (2016). DOI: 10.1016/j.jclepro.2015.12.060.
33. Wang X., Zhou B., Huang H., Niu J., Guan S., Yuan G. Extraordinary Ductility Enhancement of Mg-Nd-Zn-Zr Alloy Achieved by Electropulsing Treatment // *Journal of Magnesium and Alloys*, vol. 12, pp. 4481-4492 (2024). DOI: 10.1016/j.jma.2022.07.007.
34. Ma K., Li S., Xu C., Gao Z., Yang L., Lu B. Study on the Process Characteristics Based on Joule Heat of Sliding-Pressure Additive Manufacturing // *Materials*, vol. 16, no. 2017 (2023). DOI: 10.3390/ma16052017.
35. Ruszkiewicz B.J., Mears L., Roth J.T. Investigation of Heterogeneous Joule Heating as the Explanation for the Transient Electroplastic Stress Drop in Pulsed Tension of 7075-T6 Aluminum // *Journal of Manufacturing Science and Engineering*, vol. 140, no. 091014 (2018). DOI: 10.1115/1.4040349.
36. Yizhou Z., You Z., Guanhu H., Benlian Z. The Healing of Quenched Crack in 1045 Steel under Electropulsing // *Journal of Materials Research*, vol. 16, pp. 17-19 (2001). DOI: 10.1557/jmr.2001.0005.
37. Yu T., Deng D., Wang G., Zhang H. Crack Healing in SUS304 Stainless Steel by Electropulsing Treatment // *Journal of Cleaner Production*, vol. 113, pp. 989-994 (2016). DOI: 10.1016/j.jclepro.2015.12.060.
38. Gupta R.P. The Electron Wind Force in Electromigration // *Journal of Physics and Chemistry of Solids*, vol. 47, pp. 1057-1066 (1986). DOI: 10.1016/0022-3697(86)90072-7.
39. Li X., Zhu Q., Hong Y., Zheng H., Wang J., Wang J., Zhang Z. Revealing the Pulse-Induced Electroplasticity by Decoupling Electron Wind Force // *Nature Communications*, vol. 13, no. 6503 (2022). DOI: 10.1038/s41467-022-34333-2.
40. Krishnaswamy H., Tiwari J., Amirthalingam M. Revisiting Electron-Wind Effect for Electroplasticity: A Critical Interpretation // *Vacuum*, vol. 221, no. 112937 (2024). DOI: 10.1016/j.vacuum.2023.112937.
41. Zafari A., Barati M.R., Xia K. Controlling Martensitic Decomposition during Selective Laser Melting to Achieve Best Ductility in High Strength Ti-6Al-4V // *Materials Science and Engineering: A*, vol. 744, pp. 445-455 (2019). DOI: 10.1016/j.msea.2018.12.047.
42. Ben D.D., Ma Y.R., Yang H.J., Meng L.X., Shao X.H., Liu H.Q., Wang S.G., Duan Q.Q., Zhang Z.F. Heterogeneous Microstructure and Voids Dependence of Tensile Deformation in a Selective Laser Melted AlSi10Mg Alloy // *Mate-*

rials Science and Engineering: A, vol. 798, no. 140109 (2020). DOI: 10.1016/j.msea.2020.140109.

43. Shi Y., Gong S., Xu H., Wang Z., Yang G., Qi B. Alloying Strategies for Additive Manufacturing of Ti6Al4V Based Alloys, Composites and Functionally Graded Materials: Microstructure and Phase Evolution of Intra and Inter-Layer // Journal of Materials Research and Technology, vol. 27, pp. 6225-6263 (2023). DOI: 10.1016/j.jmrt.2023.11.060.

44. Guo N., Chen Y., Yan C., Meng X., Li Y. Machinability of CFRP/Ti6Al4V Stacks with Low-Frequency-Vibration Assisted Drilling under Different Cooling Strategies // Journal of Manufacturing Processes, vol. 108, pp. 852-862 (2023). DOI: 10.1016/j.jmapro.2023.11.044.

45. Liu S., Shin Y.C. Additive Manufacturing of Ti6Al4V Alloy: A Review // Materials & Design, vol. 164, no. 107552 (2019). DOI: 10.1016/j.matdes.2018.107552.

46. Gao J.B., Ben D.D., Yang H.J., Meng L.X., Ji H.B., Lian D.L., Chen J., Yi J.L., Wang L., Li P., Zhang Z.F. Effects of Electropulsing on the Microstructure and Microhardness of a Selective Laser Melted Ti6Al4V Alloy // Journal of Alloys and Compounds, vol. 875, no. 160044 (2021). DOI: 10.1016/j.jallcom.2021.160044.

47. Ben D.D., Yang H.J., Ma Y.R., Shao X.H., Pang J.C., Zhang Z.F. Rapid Hardening of AISI 4340 Steel Induced by Electropulsing Treatment // Materials Science and Engineering: A, vol. 725, pp. 28-32 (2018). DOI: 10.1016/j.msea.2018.04.013.

48. Noell P.J., Rodelas J.M., Ghanbari Z.N., Laursen C.M. Microstructural Modification of Additively Manufactured Metals by Electropulsing // Additive Manufacturing, vol. 33, no. 101128 (2020). DOI: 10.1016/j.addma.2020.101128.

49. Hajy Akbary F., Santofimia M.J., Sietsma J. Elastic Strain Measurement of Miniature Tensile Specimens // Experimental Mechanics, vol. 54, pp. 165-173 (2014). DOI: 10.1007/s11340-013-9785-7.

50. Hibbert K., Warner G., Brown C., Ajide O., Owolabi G., Azimi A. The Effects of Build Parameters and Strain Rate on the Mechanical Properties of FDM 3D-Printed Acrylonitrile Butadiene Styrene // Open Journal of Organic Polymer Materials, vol. 9, is. 1, pp. 1-27 (2019). DOI: 10.4236/ojopm.2019.91001.

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