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ENHANCING THE PHYSICAL AND MECHANICAL PROPERTIES OF MATERIALS THROUGH ANNEALING IN THE RECOVERY RANGE.

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The level of mechanical engineering development in the 21st century is characterized by the increased intensity of machine and mechanism operating modes. The growing complexity of operating conditions for components and assemblies requires constant improvement of materials and their manufacturing technologies while ensuring sufficient reliability and durability. The performance characteristics of parts and devices, as well as their service life, are primarily determined by the physical and mechanical properties of their working surfaces.

Modern high-tech production demands new materials with unique properties. Their application in structures is determined by the balance between strength and ductility. Metallic materials possess the most attractive ratio from the standpoint of practical expediency. In recent years, the increase in strength properties has been achieved mainly through the purposeful formation of refined micro- and nanocrystalline structures.

Refinement of the grain (subgrain) structure to a nanocrystalline (NC) state is primarily carried out using the most common methods of severe plastic deformation (SPD). Research results on the strength and ductility of metals and alloys after SPD indicate the possibilities for their enhancement and control during the transition to the NC state. As a result of SPD, a highly misoriented fragmented structure (substructure) is formed due to high strain levels. Systematic studies show that the process of grain refinement (fragmentation) during cold plastic deformation begins in metals at true strain levels of $e \geq 0.2–0.3$, and at $e = 3–4$, the content of such fragments exceeds that of larger regions. Investigations have established that obtaining the nanocrystalline state of α-iron during SPD by friction requires the simultaneous fulfillment of several conditions and achieving a high degree of true strain, specifically $e \geq 10$.

SPD methods include high-pressure torsion (HPT) and equal-channel angular pressing (ECAP), which is the most widely used and has several variations, as well as friction deformation and the multi-directional forging (pressing) method. In multi-directional isothermal forging is presented as one of the primary and effective methods for nanostructuring massive products (up to 50 kg). This method consists of intercritical deformation of the billet with a change in the loading axis at each step, involving 40–60% deformation per single upsetting operation.

Nanostructuring is an effective way to improve the physical and mechanical properties of materials. To address this task, a method of deformation and thermal treatment of metals and alloys has been developed, which includes preliminary deformation of the metal or alloy followed by thermal treatment, termed pre-recrystallization annealing.

Pre-recrystallization thermal treatment of sprayed coatings leads to the refinement of the polygonized substructure with a corresponding increase in hardness. The maximum efficiency of this thermal treatment is observed in electric arc coatings, where nanoscale average subgrain sizes have been recorded.

From a practical standpoint, the main drawback of pre-recrystallization thermal treatment is the short holding time of only a few minutes. Therefore, it is relevant to investigate the possibility of stabilizing the refined polygonized substructure of the sprayed coating during longer holding times in the thermal treatment process through subsequent deformation.

Electric arc coatings made of Sv-08G2S wire were selected for the study, as they are characterized by the smallest coherent scattering region (CSR) values and the highest hardness enhancement effect after pre-recrystallization thermal treatment (Fig. 1). To hinder the movement of dislocation subboundaries during the recovery (coalescence) process that occurs during heating (long holding times), additional deformation of the coating was performed in two ways: by hydraulic pressing at a load of 10 tons (30% strain degree) and by surface plastic deformation (SPD) with steel balls 0.1–0.3 mm in diameter for 2 minutes. The heating temperature of the deformed samples was reduced to 400 °C, considering that the recrystallization temperature threshold decreases as the degree of deformation increases.

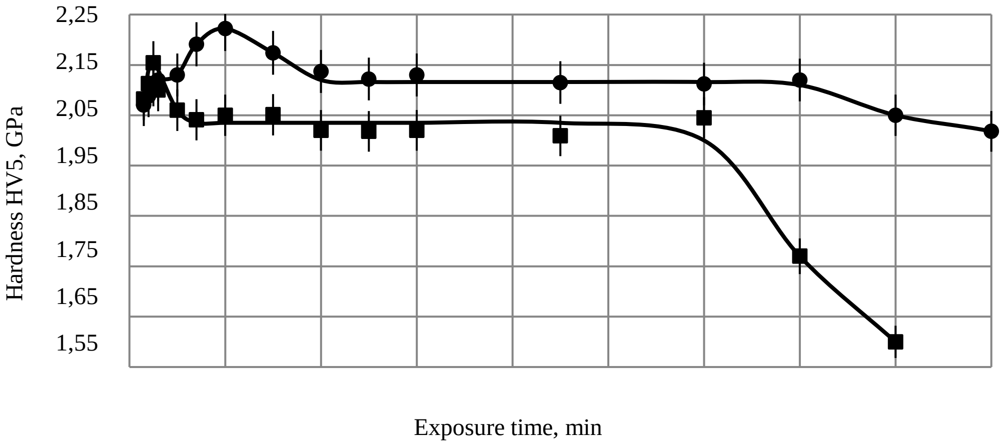

Figure 1 – Dependence of hardness on holding time during pre-recrystallization heat treatment of deformed samples (experiment 1):
● - *technically pure iron;* ■ - *technically pure nickel*

Analysis of the presented data shows that the use of subsequent deformation ensures a smaller reduction in hardness as the holding time during pre-recrystallization thermal treatment increases to 15 minutes. This trend is observed for both types of coating deformation. For instance, the hardness of the coating without subsequent deformation decreases from 2.7 GPa to 2 GPa (–35%) when the holding time increases from 2 to 15 minutes, whereas with subsequent deformation, it decreases from 3 GPa to 2.8 GPa (–7%) for SPD and from 3.1 GPa to 3 GPa (– 3%) for pressing. Generally, sufficiently high hardness values are observed for holding times up to 40 minutes for SPD, and even longer for pressing. This is explained by the fact that during repeated deformation, dislocation interaction results in the emergence of 50% to 75% of dislocation barriers (Hirth and Lomer–Cottrell locks), while the remainder participates in the formation of dislocation tangles. These dislocation barriers, which arise along the direction perpendicular to the deformation axis, hinder dislocation motion and, consequently, reduce the mobility of polygonized subboundaries. Thus, by slowing down the rate of polygonization processes, a stabilizing effect is achieved.

References:

1. Karpechenko A., Bobrov M., Lymar O. Electric Arc Coatings with a Complex of Improved Properties for Repairing And Hardening of Mining Machine Parts // Геоінженерія. 2022. Вип. 7. С. 62-73. DOI: 10.20535/2707-2096.7.2022.267607.
2. Vignesh, S., & Ramya Devi, G. (2023). Performance analysis of novel TiN coated and uncoated carbide tool in CNC wet turning of Super Duplex Stainless steel. Materials Today: Proceedings, 79(Part 1), 155–158. https://doi.org/10.1016/j.matpr.2022.11.420.
3. Callegari, F., Filice, L., & Umbrello, D. (2017). Tool life and wear mechanism analysis of carbide tools used in the machining of martensitic and supermartensitic stainless steels. Tribology International, 105, 102–117. https://doi.org/10.1016/j.triboint.2016.09.035.
4. Ropyak, L., Schuliar, I., Bohachenko, O. (2016). Influence of technological parameters of centrifugal reinforcement upon quality indicators of parts. Eastern-European Journal of Enterprise Technologies, 1 (5 (79)), 53–62. doi: https://doi.org/10.15587/1729-4061.2016.59850.
5. Zawada-Michałowska, M., Pieśko, P., & Józwik, J. (2019). Tribological aspects of cutting tool wear during the turning of stainless steels. Materials, 13(1), 123 (PMCID: PMC6981806). https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6981806/.

6. Marchenko D. D., Lymar O. O., Grigorenko A. O. Ways to improve the reliability of grain harvesting machines to ensure the country's food independence. Продовольча безпека України в умовах післявоєнного відновлення: глобальні та національні виміри. Міжнародний форум : доповіді учасників міжнародної науково-практичної конференції (м. Миколаїв, 28-30 травня 2025 р.) / Міністерство освіти і науки України ; Миколаївський національний аграрний університет. Миколаїв : МНАУ, 2025. С. 356-358. DOI: https://doi.org/10.31521/978-617-7149-86-5-119.

7. Marchenko, D., Matvyeyeva, K., Lymar, O., & Kurepin, V. (2025). Enhancing the reliability and wear resistance of high-speed cutting tools through the use of ionized air-oil lubrication media in machine part restoration. Problems of Tribology, 30(4/118), 72–78. https://doi.org/10.31891/2079-1372-2025-118-4-72-78.

8. Карпеченко А. А., Бобров М. М., Лимар О. О. Формування алюмінієвих композиційних електродугових покриттів з додаванням червоного шламу // Вісник Львівського торговельно-економічного університету. Технічні науки. 2022. № 30. С. 14-21. https://doi.org/10.36477/2522-1221-2022-30-02.

9. Mema, O., Jojic, E., Laze, P., Khramov, M., & Lymar, O. (2024). Application of analytical hierarchical process in assessing the suitability of land for growing grain crops. Scientific Horizons, 27(12), 79–89. https://doi.org/10.48077/scihor12.2024.76.

10. Kairov, A. S., Iskanderov, R. A., Lymar, O. O., Oshovskyi, V. Y., Kapura, I. A., & Bakhshiyev, I. I. (2024). Effect of composite nanocoatings on wear-resistance and productivity of socket mills. International Journal on Technical and Physical Problems of Engineering, 16(4), 77–84.

11. Effect of Prerecovery Annealing on Microstructure and Mechanical Properties of AA8021 Aluminum Alloy used for Aluminum Plastic Films / T. Wang et al. *Advanced Engineering Materials*. 2025. Vol. 27, no. 7. DOI: 10.1002/adem.202500195.

12. Effect of Annealing Treatment on Mechanical Properties of Nanocrystalline Materials / X. Huang et al. *Scientific Reports*. 2015. Vol. 5, art. 8421. DOI: 10.1038/srep08421.

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ТЕХНОЛОГІЧНІ ОСОБЛИВОСТІ ПРОЦЕСУ ФОРМУВАННЯ МАКРОРЕЛЬЄФУ ПРИ ВИКОРИСТАННІ САМООБЕРТАЛЬНОГО ДЕФОРМУЮЧО-РІЗАЛЬНОГО ІНСТРУМЕНТУ

TECHNOLOGICAL FEATURES OF THE MACRORELIEF FORMATION PROCESS USING A SELF-ROTATING DEFORMING-CUTTING TOOL

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Метод грунтується на самообертанні робочих елементів протяжки, призначених для отримання контурних канавок. На рис. 1 показано секцію комбінованої протяжки, за допомогою якої на поверхнях отворів деталей формують рельєфи.

Круглий чорновий деформуючий елемент 1, право та ліво-західний деформуюче-різальний елемент-блок, що самообертається 2-3, в різні сторони з кутовою швидкістю ω при русі протяжки з лінійною швидкістю *V* та трьох упорних шарикопідшипників 4. Елемент 2-3 має деформуючу та ріжучу частини, профіль яких в нормальному перерізі відповідає профілю контурних канавок, а кут нахилу до осі отвору η відповідає кутові підйому канавок. Установлено, що значення кута η повинні знаходитись в межах 8° … 80°.