Chemical Ni–Co–P Deposition and Low-Temperature Heat Treatment of Joint Parts for Hand Rehabilitation Exoskeletons

Volodymyr Shevchuk[1], Andrew Stetsko[2]

1. Department of Technical Mechanics and Engineering Graphics, Lviv Polytechnic National University, UKRAINE, Lviv, S. Bandery Street 12, E-mail: vov4ik.bratik@gmail.com

2. Department of Technical Mechanics and Engineering Graphics, Lviv Polytechnic National University, UKRAINE, Lviv, S. Bandery Street 12, E-mail: andrii.y.stetsko@lpnu.ua

Abstract – This paper considers surface strengthening of kinematic-pair parts of hand rehabilitation exoskeletons within the functionally oriented technological process framework of Applied Mechanics (G9). Chemical (electroless) deposition of a Ni–Co–P coating is proposed in two variants: as-deposited, and with subsequent heat treatment at 400 °C for 1 h, which precipitates the Ni_3P phase and raises coating microhardness. Process temperatures do not exceed 400 °C, so slender parts keep their dimensions without distortion. Criteria for assigning each variant to exoskeleton elements and a process route for joint pins are formulated.

Keywords – hand rehabilitation exoskeleton, functionally oriented technology, electroless Ni–Co–P deposition, heat treatment, Ni_3P, microhardness, applied mechanics.

I. Introduction

Hand rehabilitation exoskeletons move the fingers through repeated flexion–extension cycles during therapy sessions. Many designs use linkage mechanisms, such as four-bar and remote-centre linkages, to drive several finger joints from one actuator (du Plessis et al., 2021). The loads in such linkages pass through small-diameter steel pins, axles and bushings that work under cyclic sliding friction. Their wear increases clearance, adds backlash and reduces the accuracy of the prescribed finger trajectory, while sweat near the skin adds corrosion to wear.

In the functionally oriented approach to process design, the sequence of manufacturing operations is chosen by the operational properties each surface must have, not by geometric accuracy alone (Stupnytskyy, 2013). For exoskeleton joints this means a hard, corrosion-resistant working surface on a tough core, achieved without increasing part mass or distorting slender parts. Chemical deposition of Ni–Co–P coatings, developed at the Department of Technical Mechanics and Engineering Graphics (Stetsko & Stetsko, 2020; Stetsko & Korendiy, 2024), forms such a surface at temperatures below 100 °C.

The aim of this work is to substantiate chemical Ni–Co–P deposition, as-deposited and with heat treatment at 400 °C for 1 h, for the joint parts of a hand rehabilitation exoskeleton and to formulate a functionally oriented process route for their manufacture.

II. Chemical Ni–Co–P Deposition and Heat Treatment

The coating is deposited on the steel part from an aqueous solution containing cobalt sulphate 10–20 g/L, nickel sulphate 25–35 g/L, sodium acetate 80–100 g/L, sodium hypophosphite 25–35 g/L, ammonium chloride 40–50 g/L and ammonia 40–60 mL/L, at 90–95 °C for 60 min (Stetsko, 2025). Hypophosphite reduces nickel and cobalt ions autocatalytically on the part surface and co-deposits phosphorus. Because no external current is needed, pins, holes and grooves of complex shape receive a coating of uniform thickness (Sudagar et al., 2013).

In the as-deposited state, a high-phosphorus coating is amorphous; such coatings are known for their corrosion resistance (Buchtík et al., 2019). Heat treatment at 400 °C for 1 h crystallizes the coating into Ni and the hard Ni_3P phase (Buchtík et al., 2019). For electroless Ni–Co–P, annealing at 400 °C raised

microhardness from 701 to 1155 HV owing to Ni_3P precipitation (De et al., 2022). Table 1 compares the two variants.

Table 1

Variants of the Chemical Ni–Co–P Coating

Parameter	**Variant 1: as-deposited**	**Variant 2: heat-treated**
Process	Deposition at 90–95 °C, 60 min	Deposition + 400 °C, 1 h
Coating structure	Amorphous Ni–Co–P (high P)	Crystalline Ni + Ni_3P
Microhardness, HV	≈ 700	≈ 1150
Main advantage	Corrosion resistance; no heating of the part	Higher hardness and wear resistance
To be verified	Wear under cyclic loading	Corrosion behaviour after crystallization
Source	Buchtík et al. (2019); De et al. (2022)	Buchtík et al. (2019); De et al. (2022)

Both variants keep process temperatures at or below 400 °C, so slender pins are not distorted and their dimensions change only by the coating thickness. For hardened pins, the prior tempering temperature should not be lower than 400 °C, so that the coating heat treatment does not soften the core.

III. Application to Exoskeleton Elements

Functionally oriented zoning divides exoskeleton elements into groups by function and required surface properties (Table 2). The chemical Ni–Co–P coating is assigned only to steel kinematic-pair parts, and the variant is chosen by the dominant loading of each part.

Table 2

Functional Zoning of Hand Exoskeleton Elements

Group	**Typical elements**	**Required surface property**	**Treatment**
Skin-contact	Finger rings, cuffs, straps	Biocompatibility, comfort	Polymer or textile; no Ni-containing coatings
Load-bearing	Links, frame, base plate	Stiffness at low mass	3D-printed polymer or aluminium alloy; uncoated
Kinematic pairs, low load	Cable pulleys, guide axles	Corrosion resistance, low friction	Variant 1: as-deposited Ni–Co–P
Kinematic pairs, high load	Joint pins, bushings, small gears	Wear resistance	Variant 2: Ni–Co–P + 400 °C, 1 h

Variant 1 suits parts exposed to sweat and moderate contact loads, where corrosion resistance matters more than hardness. Variant 2 suits the most loaded joint pins and gears, where wear determines backlash growth. Since only the heat-treatment step differs, both variants are produced on the same deposition line.

Nickel is a common contact allergen, and EU rules restrict nickel release from articles in prolonged skin contact (European Parliament & Council of the European Union, 2006). Coated parts are therefore placed inside the joint, away from the skin. The next step is to measure coating thickness, microhardness, wear and corrosion in artificial sweat on steel 45 pins for both variants.

IV. Functionally Oriented Process Route for Joint Pins

For steel 45 joint pins of the exoskeleton, chemical deposition is built into an eight-stage route in which each stage prepares the surface state required by the next:

1. Turning and grinding of the pins to final size minus the coating thickness;
2. Surface preparation: alkaline degreasing, acid etching and rinsing;
3. Chemical deposition of the Ni–Co–P coating (90–95 °C, 60 min);
4. Rinsing and drying;
5. Heat treatment at 400 °C for 1 h (Variant 2 only);
6. Polishing of the journals where a lower roughness is required;
7. Measurement of coating thickness and microhardness on witness samples;
8. Dimensional inspection and assembly with links and bushings.

Choosing the variant and the deposition time is a multi-criteria task: microhardness and wear resistance are maximized, while corrosion rate, cycle time and energy consumption are minimized. Formalizing these criteria for exoskeleton parts is the subject of further optimization in the dissertation research.

V. Conclusion

1. Kinematic-pair parts are the hand exoskeleton elements that require chemical surface strengthening; skin-contact and load-bearing elements remain without Ni-containing coatings.

2. Chemical Ni–Co–P deposition at 90–95 °C forms a coating of uniform thickness on complex-shaped pins without distortion and without chemical-thermal treatment.

3. Heat treatment at 400 °C for 1 h precipitates Ni_3P and raises coating microhardness from about 700 to 1150 HV (De et al., 2022); it is assigned to the most loaded joint pins, while the as-deposited coating is assigned to corrosion-exposed, lightly loaded parts.

4. Formalizing variant selection as a multi-criteria optimization problem and experimental verification on exoskeleton pins are the next stages of the dissertation research.

References

[1] Buchtík, M., Krystýnová, M., Másilko, J., & Wasserbauer, J. (2019). The effect of heat treatment on properties of Ni–P coatings deposited on a AZ91 magnesium alloy. *Coatings*, 9(7), 461. https://doi.org/10.3390/coatings9070461

[2] De, J., Sarkar, S., Roy, P., Sen, R. S., Majumdar, G., & Oraon, B. (2022). Synthesis and characterization of electroless Ni-Co-P coating. *Sādhanā*, 47, 163. https://doi.org/10.1007/s12046-022-01933-z

[3] du Plessis, T., Djouani, K., & Oosthuizen, C. (2021). A review of active hand exoskeletons for rehabilitation and assistance. *Robotics*, 10(1), 40. https://doi.org/10.3390/robotics10010040

[4] European Parliament & Council of the European Union. (2006). Regulation (EC) No 1907/2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), Annex XVII, entry 27. *Official Journal of the European Union*, L 396, 1–849.

[5] Stetsko, A. E. (2025). *Sposib kompleksnoho boruvannia detalei* [Method of complex boriding of parts] (Ukraine Patent No. UA 129143 C2). Ukrainian National Office for Intellectual Property and Innovations.

[6] Stetsko, A. E., & Korendiy, V. M. (2024). Complex method of Ni-Co-P chemical deposition and chemical-thermal treatment of boron and titanium. In O. Fesenko & L. Yatsenko (Eds.), *Nanomaterials and Nanocomposites, Nanostructures, and Their Applications*. Springer Proceedings in Physics (pp. 275–285). Cham: Springer. https://doi.org/10.1007/978-3-031-67519-5_19

[7] Stetsko, A. E., & Stetsko, Y. T. (2020). Formation of composite reinforced coating by chemical deposition and chemical-thermal treatment of boron and carbon. In A. Pogrebnjak & O. Bondar (Eds.), *Microstructure and Properties of Micro- and Nanoscale Materials, Films, and Coatings (NAP 2019)*. Springer Proceedings in Physics (Vol. 240). Singapore: Springer. https://doi.org/10.1007/978-981-15-1742-6_24

[8] Stupnytskyy, V. V. (2013). Principles of functional-oriented technology manufacturing products engineering production [in Ukrainian]. *Visnyk Natsionalnoho universytetu "Lvivska politekhnika"*, 760, 26–34.

[9] Sudagar, J., Lian, J., & Sha, W. (2013). Electroless nickel, alloy, composite and nano coatings – A critical review. *Journal of Alloys and Compounds*, 571, 183–204. https://doi.org/10.1016/j.jallcom.2013.03.107