Forming the structure and properties of hybrid coatings on reversible rotating extrusion dies

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Abstract

Purpose: *The purpose of this monograph was to develop the methodology of formation, classification of properties and analysis of the structure of the surface layers, particularly the zone connecting the core and the coating and between the single layers created on the working surfaces of dies for the plastic formation on non-ferrous metals, with particular consideration to the specific nature of the extrusion process with reversibly rotating die (the KOBO method).*

Design/methodology/approach: *The solution of the issue required the development, with the use of computer method, of 3D spatial models of residual stress distributions and dislocations of the layers examined as well as tools correlated with the operating parameters. Nanocrystalline structure layers production technology was developed, which included nanocomposite and low-friction layers with desired usable properties ensuring increased durability, abrasive and adhesion wear strength. The production process of dual-layer coatings, such as hard nitride layer – low friction DLC layer, was carried out in the continuous mode, on a device furnished with technologies of lateral, rotating cathodes and central rotating cathode, within one technological process. The developed coatings were tested under the working conditions for the elements coated with them (tools – dies), in order to establish the anticipated responses and properties during their use. Artificial neural networks were also applied for modeling the dependencies between the parameters of the KOBO extrusion process and the finished product properties: the yield strength, tensile strength and elongation. The presented test results concern the synergic characteristics of component layers' cooperation during the process of their use, as well as their effect on the coatings' structure and properties.*

Findings: *The numerous interdisciplinary tests and analyses carried out in the scope of material science, production technology and computer techniques as well as the results obtained provided foundation for the formation of structure and tribological properties of the*

dies by controlled process conditions. The required final quality and durability of the tools for plastic metal formation in the extrusion process was obtained, which has been proven under operating conditions. Both the physical interpretation of the phenomena accompanying the creation and use of the surface layers, the tests on the structure, properties and nature of the interlayer joint between the layers developed and the core of the tool coated, and the results obtained on the trial extrusions represent a significant contribution to the knowledge on the tool materials with highly wear-resistant layers built on their surface and the plastic formation process of non-ferrous metals.

Research limitations/implications: *Despite the fact that this monograph presents a vast, interdisciplinary research area, the results presented apply to a selected and extreme plastic processing section.*

Practical implications: *Under the strong competition on the non-ferrous metals market, the way of conducting technological processes so as to enable offering products and semi-finished products of stable and high quality with optimally low costs, becomes vitally important. Economically efficient process improvement, increased production efficiency and quality and products reliability through increased durability and unfailing operation time of tools for plastic formation of non-ferrous metals and improved usable properties shall guarantee measurable economic effects to the manufacturers and users of the products. Moreover, it will enhance their competitiveness both on the domestic and overseas markets.*

Originality/value: *The Author's original approach was the development of a dual-layer coating within one process. Such coatings consists of the internal hard PVD layer providing the appropriate hardness, strength, low thermal conductivity and restricting the impact of external factors on the wear process of the dies used for non-ferrous metals extrusion and the external low-friction layer providing good tribological properties, which, in combination with the appropriate formation of the transition zone between the base material and coating, and between the single layers in the coating, providing adhesion sufficiently high, enabled increased operating durability of the dies, and this has been proved in this paper.*

Keywords: *PVD and CVD surface layers; Extrusion with reversibly rotating die; Computational materials science; Microstructure; Mechanical properties; Functional properties*

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Wykaz skrótów użytych w pracy

a-C – ang. *amorphous carbon* (amorficzny węgiel)

a-C:H – ang. *hydrogenated amorphous carbon* (amorficzny uwodorniony węgiel)

a-C:H:X – ang. *modified hydrogenated amorphous carbon* (amorficzny uwodorniony węgiel modyfikowany metalami lub niemetalami)

ADF – ang. *technique of annular dark-field scanning transmission electron microscopy* (technika niskokątowego pierścieniowego detektora pola ciemnego w transmisyjnym trybie skaningowym)

AES – ang. *Auger electron soectroscopy* (spektroskopia elektronów Augera)

AFM – ang. *atomic force microscopy* (mikroskop sił atomowych)

ARB – ang. *accumulative roll-bonding* (kumulacyjne walcowanie z łączeniem)

CAE – ang. *cathodic arc evaporation* (katodowe odparowanie łukowe)

CEC – ang. *cyclic extrusion-compression* (cykliczne wyciskanie spęczające)

CERC – ang. *central rotating cathode* (centralna obrotowa katoda)

CPF – eksperymentalne figury biegunowe

CVD – ang. *chemical vapour deposition* (chemiczne osadzanie z fazy gazowej)

DLC – ang. *diamond-like carbon* (diamentopodobne powłoki węglowe)

ECAE – ang. *equal channel angular extrusion* (wielokrotne wyciskanie przez kanał kątowy)

EDS – ang. *energy dispersive spectroscopy/spectrometer* (spektroskopia/spektroskop energii promieniowania rentgenowskiego)

EELS – ang. *electron energy-loss spectroscopy* (spektroskopia strat energii elektronów)

EFTEM – ang. e*nergy filtered transmission electron microscopy* (transmisyjna mikroskopia elektronowa z filtracją energii kinetycznej elektronów)

FRO – funkcja rozkładu orientacji

GDOS – ang. *glow discharge optical spectroscopy/spectrometer* (spektroskopia/spektroskop optycznego wyładowania jarzeniowego)

HAADF – ang. *high-angle annular dark-field scanning transmission electron microscopy* (wysokorozdzielczy szerokokątowy pierścieniowy detektor pola ciemnego w transmisyjnym trybie skaningowym)

HE – hydrostatyczne wyciskania

HPT – skręcanie pod wysokim ciśnieniem

HRTEM – ang. *high-resolution transmission electron microscopy* (transmisyjny mikroskop elektronowy wysokiej rozdzielczości)

KOBO – odkształcenie z rewersyjnym, cyklicznie zmiennym oddziaływaniem narzędzia kształtującego

LARC – ang. *lateral rotating cathodes* (technologia bocznych obracających się katod)

PACVD/PECVD – ang. *plasma assisted/enhanced chemical vapour deposition* (plazmo-chemiczne osadzanie powłok z fazy gazowej)

PCM – ang. *projective covering method* (zmodyfikowana metodę rzutowego pokrycia)

PLC – ang. *Portevein-Le Chatelier effect* (zjawisko Portevein-Le Chatelier)

PSP – funkcja potencjału postsynaptycznego

PVD – ang. *physical vapour deposition* (fizyczne osadzanie z fazy gazowej)

RCS – ang. *repetitive corrugation and straightening* (powtarzalne fałdowanie z prostowaniem)

RPF – ang. kompletne figury biegunowe obliczone z FRO

SEM – ang. *scanning electron microscope/microscopy* (skaningow(y)/-a mikroskop/mikroskopia elektronowy)

SKP – stały kąt padania

SPD – ang. *severe plastic deformation* (intensywne odkształcenie plastyczne)

S/TEM – ang. *scanning transmission electron microscope* (skaningowo-transmisyjny mikroskop elektronowy)

ta-C – ang. *tetrahedral amorphous carbon* (tetraedryczny amorficzny węgiel)

ta-C:H – ang. *hydrogenated tetrahedral amorphous carbon* (tetraedryczny uwodorniony amorficzny węgiel)

ta-C:X – ang. *modified tetrahedral amorphous carbon* (tetraedryczny węgiel modyfikowany metalami lub niemetalami)

TEM – ang. *transmission electron microscope/microscopy* (transmisyjn(y)/-a mikroskop/mikroskopia elektronowa)

XPS – ang. *X-ray photoelectron spectroscopy* (spektroskopia fotoelektronów wzbudzanych promieniowaniem rentgenowskim)