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EDITORIAL

SPECIAL SECTION

Structure and properties of modern engineering materials

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1. INTRODUCTION

The dynamic development of the world industry is closely related to modern engineering materials, the properties of which are constantly being improved. The products obtained must meet the increasingly stringent requirements of many standards. Changes in the parameters of the production processes of these materials may facilitate the improvement of their properties during the production process itself. A significant factor is the influence of manufacturing and processing technology on the evolution of the microstructure and properties of metal alloys. Contemporary trends in materials engineering are related to applying distinct types of alloys, polymers, composites, and nanomaterials. These materials include but are not limited to nanomaterials, amorphous alloys, special-purpose polymers, and geopolymers.

This Special Section of the *Bulletin of the Polish Academy of Sciences Technical Sciences* will be devoted to the selected papers presented in the special session "Structure and properties of modern engineering materials" at the International Conference **"**Material Technologies in Silesia MTS'2022**"** organized in 2022 by the Silesian University of Technology. The conference was attended by over one hundred and fifty participants from research centres located in Poland, Slovakia, the Czech Republic, Ukraine and Turkey, as well as representatives of one of the largest research networks in Europe – the Łukasiewicz Research Network – the Institute of Ferrous Metallurgy, the Institute of Non-Ferrous Metals, the Institute of Welding, the Krakow Institute of Technology, the Institute of Ceramics and Building Materials. The broad topics of the conference included: new alloys, modern metallic materials, nanomaterials, polymers, geopolymer materials, and obtaining and characterizing new functional materials.

2. STRUCTURE AND PROPERTIES OF MODERN ENGINEERING MATERIALS

The presented collection of selected articles summarizes the latest knowledge in the field of modern engineering materials. They concern steel and other ferrous alloys, non-ferrous metals and their alloys and special, functional, and non-metallic materials, as well as thin ceramic layers and nanomaterials.

Appropriate selection of materials and manufacturing technology goes hand in hand with developing various areas of life and is an inseparable element of civilization progress. The multitude of currently available materials makes it necessary to select them correctly for structural or functional elements, tools, and other products. The current criteria for the selection of a material depend primarily on the material density and the cost of its production. Of course, we should additionally consider the expected mechanical properties, crack resistance or fatigue strength, and thermal properties, which we choose depending on the potential application and possible subsequent implementation. These are thermal conductivity, diffusivity, heat capacity, melting point, glass transition temperature, coefficient of thermal expansion, and creep resistance. Another criterion is corrosion resistance, which is essential, among others, for composite material applications, particularly for the aerospace industry.

Progress in the field of materials is based on modifying the existing ones to improve their functional properties, with reduced consumption of raw materials and reduced energy consumption of industrial manufacturing technologies. In addition to changing the existing materials, we attempt to design and manufacture new ones, especially advanced ones, with specific physical and thermal properties. Meeting these assumptions requires continuous collection of operating experience from individual industry branches and ongoing scientific research.

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The development of technology is forcing the demand for increasingly functionally and technologically perfect surface layers. One of the many methods of increasing the reliability and service life of machinery and equipment parts, both new and reconditioned, is the application of coatings by thermal spraying technology, which involves the production of metal, carbide, ceramic and composite coatings with almost any chemical and phase composition on a suitably prepared substrate.

In the presented study, the following parts can be distinguished, including works in the field of shaping the structure and properties of composites, metal materials, as well as thin ceramic layers and nanostructures:

- thermoplastic hardened Cu-Ni-Si-Ag alloy,
- AlSi21CuNiMg cast alloy using colour and deep etching,
- selected properties of $Al_{88}Y_7Fe_5$ and $Al_{88}Y_6Fe_6$ alloys,
- mechanical properties of Super 304H steel,
- retained austenite characteristics in 3-5% Mn multiphase steels,
- WC-based coatings produced on AZ31 magnesium alloy sprayed by HVOF,
- CrN/TiO_2 coatings obtained in a hybrid technology combining PVD and ALD methods on an Al-Si-Cu alloy substrate,
- microstructure and mechanical properties of TP347HFG austenitic stainless steel,
- synthesis of electrospun one-dimensional niobium oxide nanofibers,
- the use of DSC curves and the Kronmüller theory to study the level of structural defects of Fe-based bulk amorphous alloys.

In the paper [B. Krupińska, R. Chulist, M. Kondracki, and K. Labisz, "Thermoplastic hardened Cu-Ni-Si-Ag alloy"], the influence of Ag mass concentration on the Cu-Ni alloys properties is investigated. The applied thermo-derivative analysis allowed us to determine: the range of the temperature values of the beginning and the end of crystallization, its phases and eutectics, and the effects of the modification on the solid fraction of the solidified alloy. In addition to the crystallization kinetics, the microstructure morphology, mechanical properties under real operating conditions, and electrical conductivity are also investigated.

Research shows that even a tiny amount in the Cu alloy causes significant changes without considerably raising the temperature in the liquid state, which is essential for the economy and overheating of the alloy. Silver reduces recrystallization after cold deformation. Copper alloys with a modified chemical composition show increased mechanical properties due to forming strengthening phases (often dispersion, incoherent).

The research [E. Tillová, M. Chalupová, L. Kuchariková, M. Bonek, M. Uhríčik, L. Pastierovičová, "Study of Si morphology in AlSi21CuNiMg cast alloy using colour and deep etching"] focuses on modifying Si-phases as a required way of improving the mechanical response of the hypereutectic cast alloy. An effect of the primary Si-phases and the eutectic Si is emphasized as a significant source of degradation of mechanical properties; therefore, the subject of the performed analysis is of the utmost importance.

Contrary to the common ways to suppress an unacceptable morphology, a novel refining process combining P and Cu is proposed and verified. Quantitative evaluation was achieved with a minimalized scatter of results via metallography. Then, a deep etching was performed, which facilitated a detailed 3D description of the obtained effect on the Si-phases morphology. A successful procedure was achieved, and the specific morphology was revealed via dissolving the Al-matrix without damaging the Si particles. The induced effects are discussed based on a detailed crystallographic interpretation of the kinetics of Si-phases creation.

The paper [R. Babilas, M. Spilka, W. Łoński, A. Radoń, M. Kądziołka-Gaweł, P. Gębara, "Influence of annealing conditions on changes of the structure and selected properties of Al88Y7Fe5 and Al88Y6Fe6 alloys"] presents the investigation results of two aluminium-based alloys differing in iron and yttrium content. The melt-spinning method casts the alloys, and the as-cast ribbons exhibit an amorphous structure. The changes in selected properties of $Al_{88}Y_7Fe_5$ and $Al_{88}Y_6Fe_6$ alloys after annealing for 30 minutes are presented. A diversified influence of heat treatment on the corrosion resistance of these alloys, depending on the chemical composition, was shown, as well as a noticeable impact of heat treatment on improving magnetic properties. The research provides information on changes in the essential functional properties of these alloys as a function of the annealing temperature, which determines the potential application of these materials in technology.

Alloys with an austenitic structure were also evaluated. Compared to the ferritic or martensitic steels used so far in the power industry, they are characterized by different mechanical and physical properties. The paper [A. Zieliński, M. Sroka, H. Purzyńska, F. Novy, "Mechanical properties of Super 304H steel after long-term ageing at 650 and 700°C"] shows the degradation process of the austenitic Super 304H steel, which was subjected to long-term aging for up to 50 000 h. The Super 304H steel has a structure characteristic of austenitic steels with visible annealing twins and single primary NbX precipitates. Precipitation processes lead to a decrease in plastic properties and impact energy as well as alloy over aging. Yield and tensile strength values after 50 000 h of aging were similar to those delivered. The yield and tensile strength value strongly depend on the applied aging temperature.

The study [M. Opiela, A. Grajcar, W. Pakieła, "Effect of hot deformation and isothermal holding temperature on retained austenite characteristics in 3–5% Mn multiphase steels"] provides new insights into the phase transformation behaviour of novel plastically deformed medium-Mn steels with increased aluminium additions. The manuscript addresses relationships between hot deformation conditions and parameters of isothermal holding conditions in the bainitic transformation range in three model steel of different manganese content. The different multiphase microstructures were generated in the advanced automotive steels. The experiments were done in the thermomechanical Gleeble simulator applying three isothermal holding temperatures. The optimal conditions for maximizing the proportion of retained austenite were obtained at the temperature of 400°C.

The paper [E. Jonda, L. Łatka, A. Maciej, M. Godzierz, K. Gołombek, A. Radziszewski, "Effect of spray distance on the microstructure and corrosion resistance of WC-based coatings sprayed by HVOF"] presents the results of testing coatings produced on AZ31 magnesium alloy substrate using commercial tungsten carbide-based powders for thermal spraying. WC-based powders (WC-Co and WC-Co-Cr) were sprayed with High-Velocity Oxy Fuel (HVOF) onto AZ31 magnesium alloy with different spray distances.

Comprehensive studies of morphology and microstructure, phase composition and electrochemical corrosion resistance were conducted. Results revealed that higher spray distance results in greater porosity and lower microhardness values. The corrosion resistance estimated in potentiodynamic polarization measurements was the best for WC-Co-Cr coating deposited from the shorter spray distance. The same influence of spray distance was also observed in the porosity case, and the lower porosity value was connected with better corrosion resistance. Results revealed that higher spray distance results in greater porosity. The corrosion resistance estimated in potentiodynamic polarization measurements was the best for WC-Co-Cr coating deposited from the shorter spray distance.

The paper [M. Staszuk, "Investigations of CrN/TiO_2 coatings obtained in a hybrid PVD/ALD method on Al-Si-Cu alloy"] presents the research results on hybrid coatings obtained by combining PVD and ALD technologies. In particular, the influence of the deposition conditions of TiO_2 titanium oxide layers obtained by atomic layer deposition on CrN chromium nitride coatings deposited by PVD was determined. Electrochemical, physicochemical, and mechanical properties were assessed to select the optimal deposition conditions for the tested coatings. The number of cycles was assumed as the variable ALD parameter. Other deposition conditions, such as temperature and precursor dosing times, were kept constant. The variant with the lowest number of cycles was the most advantageous because, in these conditions, the obtained layer of titanium oxide is amorphous. The dependence of the structure on the deposition conditions was determined using microscopic and spectroscopic methods.

The microstructure and mechanical properties of long-aged austenitic steel TP347HFG were also studied [G. Golański, H. Purzyńska, "Influence of ageing on microstructure and mechanical properties of TP347HFG austenitic stainless steel"]. Long-term aging leads to the preferential precipitation of second-phase particles on the boundaries of grains and twins and inside the grains. On the boundaries of grains and twins, the $M_{23}C_6$ carbides were noticed. After aging (> 5000 hours) at the temperature of 650°C, on the grain boundaries, apart from the $M_{23}C_6$ carbides, the sigma phase precipitates were observed. At the aging temperature of 600°C, this phase was not identified even after 30 000 hours. Inside the grains and twins, similarly, as in the as-received state, the large and dispersive precipitates of the MX type were visible.

The article [M. Zaborowska, W. Smok, T. Tański, "Electrospun niobium oxide 1D nanostructures and their applications in textile industry wastewater treatment"] presents a facile synthesis of electrospun one-dimensional niobium oxide nanofibers with an orthorhombic crystal structure. The nano-photocatalyst morphology, structure, chemical bonds, and optical properties were examined. One-dimensional Nb_2O_5 nanostructures with diameters ranging from 125 to 300 nm of high porosity were tested for the specific surface area using the molecular nitrogen adsorption-desorption isotherms. The photocatalytic activity was established based on the photodegradation of aqueous solutions of methylene blue and rhodamine B. The investigated one-dimensional nanostructures exhibit a high surface-to-volume ratio and a quantum confinement effect, making them ideal candidates for nano-photocatalyst materials.

In the article [B. Jeż, M. Nabiałek, "The use of DSC curves and Kronmüller theory to study the level of structural defects of Fe-based bulk amorphous alloys"] the results of tests conducted on rapid quenched Fe-based alloys were presented. The alloys were made using an injection-casting method. The actual structure of the alloys was also studied using an indirect method, based on H. Kronmüller's theorem. Based on the analysis of the primary magnetization curves, in accordance with the aforementioned theory, it was found that Mo causes a change in internal regions associated with changes in the direction of the magnetization vector. The evolution of the thermal properties with an increasing volume of Mo has been confirmed by the DSC curves.

Based on the research, it is demonstrated that, within the volume of each sample, defects are present in the amorphous structure, the character of which depends on the chemical composition of the alloy. A gradual change in the chemical composition of the alloys leads to the collective re-distribution of the free atoms; this results in the linking of the free volumes into larger, though less thermodynamically stable, two-dimensional defects, in the form of quasi-dislocation dipoles. In Kaul and Corb, it is stated that, in the relaxed amorphous structure, each magnetic atom possesses 12 neighbours, and in stressed regions, 9 to 10 neighbours. This means that a decrease in the value of the parameter D_{spf} could be related to the decreased number of nearest magnetic atoms, which leads to an improvement in the short-range chemical order. This agrees with the results obtained within these studies.

The authors of the paper stated that the DSC curves can be used to indirectly describe the structure of amorphous alloys similar to the theory of the approach to ferromagnetic saturation. This approach is new and can be used by many researchers in this field.

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