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Advanced Aluminium Composites and Alloys

Edited by Leszek A. Dobrzański

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Contributors
Jorge Salguero, Moises Batista, Irene Del Sol, Alvaro Gomez-Parra, Uyime Donatus, Mariana Milagre, João Araujo, Caruline Machado, Isolda Costa, Michael Bodunrin, Ayotunde Olayinka, Olamilekan Oloyode, Sunday Aribo, Zygmunt Mikno, Francisco Mata, Issam Hanafi, Halil Ibrahim Kurt, Engin Ergul, Murat Oduncuoglu, Necip Fazil Yilmaz, Xiaoguang Sun, Xiaogang Li, Chaofang Dong, Maria Richert, Rafał Hubicki, Fawzy H. Samuel, Mohamed H. Abdelaziz, Jacobo Hernandez-Sandoval, Agnes Marie Samuel, Herbert Doty, Leszek A. Dobrzański

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Meet the editor

Prof. Leszek Adam Dobrzański, DSc, Ph.D., MSc, Eng, Hon Prof, M Dr HC is a full professor and the director of the Science Centre ASKLEPIOS of the Medical and Dental Engineering Centre for Research, Design and Production ASKLEPIOS Ltd., Gliwice, Poland. He is president of World Academy WAMME, vice president of the Academy of Engineers in Poland, and a foreign fellow of engineering academies in Ukraine and Slovakia. He is also editor in chief of JAMME and AMSE journals. He was awarded the title of Professor in 1995 by the President of the Republic of Poland and granted abroad a title of Honorary Professor in Lviv, Ukraine. He was also awarded the title of Doctor Honoris Causa in Ruse, Bulgaria; Khmelnytskyi, Ukraine; and Miskolc, Hungary. He is also a recipient of the Commander's Crosses of Rebirth of Poland by the President of Poland, Merite de L'Innvention by King of Belgium, and many other awards. From 1971 to 2017, Dr. Dobrzański was a full professor, director, dean of faculty, and vice-rector at Silesian University of Technology, Gliwice, Poland. He was also vice-rector of the Academy in Bielsko-Biała, Poland, and vice-director of the Institute in Kraków, Poland. He was a visiting professor at more than 100 universities worldwide and an invited lecturer at more than 100 global scientific conferences. Dr. Dobrzański has supervised sixty-two Ph.D. thesis and promoted around 1000 MSc and BSc theses. He is the author or co-author of sixty books and fifty book chapters, sixty patents, and around 3000 publications. He is a scientific editor for many international scientific journals and conferences. He has been cited ca. 15,500 times in scientific journals.

Contents

Preface

Several essential elements characterize the turn of 2020 and 2021. Although the COVID-19 disease pandemic related to the transmission of the SARS-CoV-2 coronavirus has dominated all global activities, the directions of all undertakings are generally determined by the sustainable development goals set by the United Nations [1]. It is about providing people around the world with permanent access to products and consumer goods that directly affect the level and quality of life, the quality and potential of health protection, protection of the climate and natural goods, dissemination and improvement of the level of education, information exchange and other aspects. An important role in this respect is played by the scientific and engineering communities, serving to activate the development of societies. Undoubtedly, an important determinant of the present and future prosperity and high quality of life is the continuous development of engineering materials, closely related to the development of nanotechnology and surface engineering [2].

Industrial production is an important determinant of achieving the goals mentioned above, emphasizing ecological conditions, climate protection, and human health and life. The achieved stage of the scientific and technical revolution Industry 4.0 includes smart factories manufacturing smart products for which raw materials are supplied by smart suppliers and [3]. Physical production processes are monitored by production systems and make smart decisions. It is possible to do experiments with the use of "digital twins" in virtual reality by simulating the actual conditions of production, operation and maintenance of products. To achieve these goals, cyber-physical systems (CPS), Internet of Things (IoT) and cloud computing are used, with the use of large data sets while ensuring cybersecurity. Automation, robotization and digitization are the current essences of industrial activities. The concept of the developed information society Society 5.0 [4] corresponds to this.

However, it turned out that this model is one-sided and requires a correction and a significant extension. The simplified approach in the classic Industry 4.0 model gives the erroneous impression that progress is only about monitoring, controlling, coordinating and integrating information and communication technologies that make up cyber-physical systems, without the need to make real progress in the field of technological machines, manufacturing technologies and the engineering materials necessary for the manufacturing of any product. A far-reaching simplification is also reducing technological issues only to additive production, which is not competitive to many other manufacturing technologies absolutely necessary in overall manufacturing processes. Therefore, a holistic, extended and supplemented model of industry 4.0 was developed [5–9]. Only such a model of Industry 4.0 is adequate to the actual situation in the developing industry.

The general development of material culture and human civilization in general and the associated level and quality of life of societies largely depend on the development of technical materials, mainly engineering [10]. For thousands of years, materials have been implemented from which all products useful for life were made. The selection of materials for these goals was made by trial and error. Nowadays, the possibilities of using cyber-physical systems and large data sets and advanced methods of artificial intelligence and machine learning are the essence of the systematically implemented Materials 4.0 approach [5–10]. It is accompanied by the use of materials on-demand with properties designed and required by designers when still two decades ago, it was only possible to choose from the materials offered by manufacturers. Achieving the material engineering paradigm according to the six expectations rule (6xE) [2, 11] is fully ensured because the operational functions of the product are ensured by designing the expected material, processed using the expected technology, to give the expected geometric features and shape of the product, enabling the expected structure to be obtained order to get a set of expected properties, ensuring the expected utility functions of the designed product.

Beginning in 10,000 years BC, humankind successively mastered the sourcing from nature and manufacturing of gold, copper, bronze, and finally iron and the manufacturing of products expected from these metals to meet the everyday needs of contemporary people [11]. It is also how the successive epochs of civilization development are defined. This progress was slow but systematic. In ancient Egypt, thousands of years BC, an engineering composite material, because artificially manufactured, was invented where reinforcement was made of straw fibres surrounded by a clay matrix, dried in the sun [1]. An important stage in this development was the invention of steel, which probably already took place around the 3rd century BC in ancient India. Still, it is believed that Sir Henry Bessemer, in 1856, was the first to devise a method that is considered the first step in the modern development of steelmaking and starting to steel mass production.

In 1825, Hans Christian Oersted discovered aluminium, and in 1856, thanks to the efforts of Henri Étienne Sainte-Claire Deville, industrial production of aluminium began, which in 1884 reached 3 tons in the world. Over time, numerous aluminium alloys have been developed, currently classified into eight series, differentiated by the alloying additives used, affecting significant but differentiated properties improvements.

Since the 1980s, AMC Aluminum Matrix Composites have become known, mainly due to their applications in the automotive industry. Due to the proliferation of carbon composites, AMC initially did not gain popularity. Breakthrough progress in this area dates back to the last 30 years. It was due to the attractive properties of AMC, including their density and functionality, as well as stiffness, strength, thermal and electrical properties.

The increase in aluminium production, its alloys and composites with aluminium matrix were compared with steel world production. Despite the 30 times lower production of aluminium [12] than steel, aluminium alloys and composites with the aluminium matrix are significant due to their lower density than that of steel. The challenges posed by the development in the Industry 4.0 phase, especially the expectations of the automotive and aviation industries, force constant progress in the development of new materials with the participation of aluminium.

The book "*Advanced Aluminium Composites and Alloys*" is my another book published in my personal academic career and third prepared with IntechOpen. The topic is very familiar to me because I am interested in it as it is one of the main areas of my scientific interest for a long-time. This book contains a collection of studies by authors from 12 different countries. Despite the asymmetrical number of chapters on each fundamental topic, it means advanced aluminium-based composite materials and alloys of this metal, roughly half in volume was devoted to each of these topics.

The book opens with my original study on advanced composites based on aluminium alloys and their production processes. Composite materials were manufactured by gas pressure infiltration with liquid aluminium alloys of suitably formed porous skeletons sintered from a mixture of Al2O3 powder and carbon fibres then are thermally degraded, using halloysite HNTs nanotubes by mechanical milling, consolidation in press and sintering and selective SLS laser sintering of titanium powders. Another group of manufacturing technologies is the mechanical synthesis of a mixture of aluminium alloy powder and HNTs halloysite nanotubes or MWCNTs multi-wall carbon nanotubes, respectively, and subsequent consolidation with plastic deformation. The third group concerns composite surface layers on substrates of aluminium alloys produced by laser feathering of WC/W_2C or SiC carbides.

The next chapter in this part of the book, "The Theoretical Overview of the Selected Optimization and Prediction Models Useful in the Design of Aluminum Alloys and Aluminum Matrix Composites," was written by Halil Ibrahim Kurt et al. from Turkey. This chapter presents original research results from their own work and cited from the literature on the theory of artificial neural network (ANN), adaptive neural fuzzy inference systems (ANFIS) and Taguchi method and their applications in engineering design and manufacturing of aluminium alloys and AMC composites.

All other chapters deal with various aspects of aluminium alloys. The chapter titled "Effect of Zr Addition and Aging Treatment on the Tensile Properties of Al-Si-Cu-Mg Cast Alloys" is prepared by the international team of Jacobo Hernandez-Sandoval et al. from Canada, Mexico, Egypt and the USA. The chapter concerns the tensile strength of analysed materials containing aluminium at room and elevated temperatures. Zirconium forms phases with the participation of Ti, Si and Al, and their coagulation leads to a decrease in strength.

Rafał Hubicki and Maria Richert from Poland have prepared a chapter entitled "The High-Speed 6xxx Aluminum Alloys in Shape Extrusion Industry", where they analyzed alloys used in the automotive and construction industries.

The 9-person team of Uyime Donatus et al. from Brazil, South Africa, USA, UK and Canada wrote the next chapter entitled "Corrosion Resistance of Precipitation-Hardened Al Alloys: A Comparison between New Generation Al-Cu-Li and Conventional Alloys". The corrosion resistance of conventional alloys and new alloys of precipitation hardening alloys was compared. The AA6082-T6 alloy became the most resistant to corrosion, while the AA2024-T3 alloy showed the highest density of pitting spots.

The chapter "Machining of Al-Cu and Al-Zn Alloys for Aeronautical Components" by the team of Jorge Salguero et al. from Spain focused on the analysis of the relationship between drilling, milling and turning conditions, quality characteristics and the main wear mechanism during machining as factors influencing performance improvement and micro and macro geometric deviations.

In turn, in the chapter "Analysis of Surface Roughness of EN AW 2024 and EN AW 2030 Alloys after Micromachining" developed by Francisco Mata and Issam Hanafi from Spain and Morocco, the focus was on this technology suitable for the production of very small components in the industry. Very good surface properties can be achieved when turning aluminium alloys with a diameter of not less than 0.05 mm.

Zygmunt Mikno from Poland has prepared a chapter on "Resistance Welding of Aluminum Alloys with an Electromechanical Electrode Force System", which concerns the operation and depends on the new clamping solution in the welding machine and the optimization of the welding process of aluminium rods. The research consisted of the numerical analysis of two electrode pressure systems, i.e. conventional pneumatic and electromechanical, using the SORPAS software.

Last but not least is the chapter entitled "Applications of Aluminum Alloys in Rail Transportation" and was prepared in China by Xiaoguang Sun et al. This chapter focuses on the latest applications of aluminium alloys, including for the car body, gearbox and steering rack, and analyze key manufacturing techniques such as casting, forming and welding.

This book is a continuation of several books previously published in the last decade by InTech on various theoretical aspects, production, application and research of aluminium, its alloys and composites based on aluminium alloys, edited successively by Tibor Kvackaj (2011) [13], Zaki Ahmad (2011, 2012) [14, 15], Subbarayan Sivasankaran (2017) [16], Kavian Cooke (2020) [17].

Aluminium, its alloys and composites with aluminium participation undoubtedly belong to engineering materials of strategic importance for development in many areas. For about 150 years of practical use, they have found numerous applications, often competitive but in many cases unrivalled. Annual world production in 2015 has exceeded 62,500,000 metric tons. The main recipients are the automotive, aviation and transport industries, but also using these materials can be manufactured precision microelements.

At this point, I would like to thank the Authors for preparing individual chapters and the IntechOpen publisher for many months of cooperation in preparing this book for printing.

I am deeply convinced that this book is valuable and will be of interest to numerous PT Readers. Therefore, it remains for me to wish that my previsions meet with a friendly reception. I wish the PT Readers enjoy reading this book and hope it serves them in solving real engineering problems.

Leszek A. Dobrzański, Hon., Prof., Dr HC,
Director of Science Centre,
Medical and Dental Engineering Centre for Research,
Design and Production ASKLEPIOS,
Gliwice, Poland

Chapter 1

Advanced Composites with Aluminum Alloys Matrix and Their Fabrication Processes

Leszek A. Dobrzański

Abstract

This chapter introduces advanced aluminum alloy matrix composites and their manufacturing processes. In the beginning, the state of the art is characterized and the general characteristics of aluminum and its practical applications are presented, starting with the history of aluminum. The current approximate distribution of bauxite resources in the world and the production of bauxite and alumina in the leading countries of the world, as well as the production of primary and secondary aluminum and the range of aluminum end products, are presented. Aluminum alloys intended for plastic deformation and castings, and composite materials in general and with a matrix of aluminum alloys in particular, have been characterized in general. Against this background, a detailed review of the results of the Author's own research included in numerous projects and own publications on advanced composite materials, their production technology, their structure, and properties were done. The range of aluminum alloy matrices of composite materials was adequately characterized, which include AlSi12, AlSi7Mg0.3, AlMg1SiCu, AlMg3, AlMg5, and AlMg9, respectively. Composite materials tested in terms of manufacturing technology include three groups. The first group includes gas pressure infiltration with liquid aluminum alloys of suitably formed porous preforms. Porous frameworks as a reinforcement for pressure-infiltrated composite materials with a matrix of aluminum alloys are produced by three methods. Al_2O_3 powder with the addition of 30–50% carbon fibers is uniaxially pressed, sintered, and heated to thermally degrade the carbon fibers and create the required pore sizes. In the second case, the ceramic porous skeleton is produced with the use of halloysite nanotubes HNTs by mechanical milling, press consolidation, and sintering. A third method is SLS selective laser sintering using titanium powders. Another group of manufacturing technologies is the mechanical synthesis of the mixture of AlMg1SiCu aluminum alloy powder and respectively, halloysite nanotubes HNTs in a volume fraction from 5 to 15% or multi-wall carbon nanotubes MWCNTs in a volume fraction from 0.5 to 5%, and subsequent consolidation involving plastic deformation. The third group of analyzed materials concerns composite surface layers on substrates of aluminum alloys produced by laser feathering of WC/W2C or SiC carbides. The structure and properties of the mentioned composite materials with aluminum alloys matrices are described in detail. The chapter summary provides final remarks on the importance of advanced aluminum alloy composite materials in industrial development. The importance of particular groups of engineering materials in the history and the development of the methodology for the selection of engineering materials, including the current stage of Materials 4.0, was

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emphasized. The importance of material design in engineering design is emphasized. Concepts of the development of societies were presented: Society 5.0 and Industry 4.0. The own concept of a holistic model of the extended Industry 4.0 was presented, taking into account advanced engineering materials and technological processes. Particular attention was paid to the importance of advanced composite materials with an aluminum alloy matrix in the context of the current stage of Industry 4.0 of the industrial revolution. Growth in the production of aluminum, its alloys, and composites with its matrix was compared with that of steel. Despite the 30 times less production, aluminum is important due to its lower density. The challenges posed by the development in the Industry 4.0 stage, including the expectations of the automotive and aviation industry, force constant progress in the development of new materials with the participation of aluminum, including the composite materials with an aluminum alloy matrix presented in this chapter.

Keywords: Aluminum, Aluminum alloys matrix composite, pressure infiltration, halloysite nanotubes, multi-wall carbon nanotubes, additive manufacturing, selective laser sintering, mullite, mechanical synthesis, laser feathering, Industry 4.0, Sustainable Development Goals, materials science paradigm, aluminum market

Chapter 2

The Theoretical Overview of the Selected Optimization and Prediction Models Useful in the Design of Aluminum Alloys and Aluminum Matrix Composites

Halil Ibrahim Kurt, Engin Ergul, Necip Fazil Yilmaz and Murat Oduncuoglu

Abstract

The growing attention regarding aluminum alloy matrix composites within the aerospace, automotive, defense, and transportation industries make the development of new engineering materials with the improved mechanical properties. Currently, materials are selected because of their abilities to satisfy engineering demands high for strength-to-weight ratio, tensile strength, corrosion resistance, and workability. These properties make aluminum alloys and aluminum matrix composites (AMCs) an excellent option for various industrial applications. Soft computing methods such as the artificial neural network (ANN), adaptive-neuro fuzzy inference systems (ANFIS), and Taguchi with ANOVA are the most important approaches to solve the details of the mechanism and structure of materials. The optimal selection of variables has important effects on the final properties of the alloys and composites. The chapter presents original research papers from our works and taken from literature studies dealing with the theory of ANN, ANFIS, and Taguchi, and their applications in engineering design and manufacturing of aluminum alloys and AMCs. Also, the chapter identifies the strengths and limitations of the techniques. The ANFIS and ANN approaches stand out with wide properties, optimization, and prediction, and to solving the complex problems while the Taguchi experimental design technique provides the optimum results with fewer experiments.

Keywords: aluminum matrix composites, hybrid, modeling, engineering approaches, optimization, ANN, Taguchi, ANOVA, genetic algorithms, ANFIS

Chapter 3

Effect of Zr Addition and Aging Treatment on the Tensile Properties of Al-Si-Cu-Mg Cast Alloys

Jacobo Hernandez-Sandoval, Mohamed H. Abdelaziz, Agnes M. Samuel, Herbert W. Doty and Fawzy H. Samuel

Abstract

The present study focused on the tensile properties at ambient and high temperatures of alloy 354 without and with the addition of zirconium. Tensile tests were performed on alloy samples submitted to various aging treatments, with the aim of understanding the effects of the addition made on the tensile properties of the alloy. Zirconium reacts only with Ti, Si, and Al in the alloys examined to form the phases $(Al,Si)_2(Zr,Ti)$ and $(Al,Si)_3(Zr,Ti)$. Testing at 25°C reveals that the minimum and maximum quality index values, 259 and 459 MPa, are observed for the as-cast and solution heat-treated conditions, respectively. The yield strength shows a maximum of 345 MPa and a minimum of 80 MPa within the whole range of aging treatments applied. The ultimate tensile and yield strength values obtained at room temperature for T5-treated samples stabilized at 250°C for 200 h are comparable to those of T6-treated samples stabilized under the same conditions, and higher in the case of elevated-temperature (250°C) tensile testing. Coarsening of the strengthening precipitates following such prolonged exposure at 250°C led to noticeable reduction in the strength values, particularly the yield strength, and a remarkable increase in the ductility values.

Keywords: aluminum alloys, aging, thermal exposure, tensile testing, precipitation, fractography

Chapter 4

The High-Speed 6xxx Aluminum Alloys in Shape Extrusion Industry

Rafał Hubicki and Maria Richert

Abstract

This chapter describes and analyzes the 6xxx aluminum alloys used in the shape extrusion sector dedicated to automotive and construction industry. The division and application of 6xxx aluminum alloys are performed. The precipitation hardening of **6xxx** (Al-Mg-Si) alloys is presented as these alloys easily undergo deformation and present the potential for new kinds of alloys for high-speed extrusion. The mechanisms of strengthening are shown with the evolution of precipitation sequences. Also some examples of industry applications of 6xxx aluminum alloys are presented.

Keywords: aluminum alloys, extrusion, aging, microstructure

Chapter 5

Corrosion Resistance of Precipitation-Hardened Al Alloys: A Comparison between New Generation Al-Cu-Li and Conventional Alloys

Uyime Donatus, Michael Oluwatosin Bodunrin, Ayotunde Olayinka, Mariana Xavier Milagre, Olamilekan Rasaq Oloyede, Sunday Aribo, João Victor de Sousa Araujo, Caruline de Souza Carvalho Machado and Isolda Costa

Abstract

The corrosion resistance of conventional (AA2024-T3, AA6082-T6 and AA7050-T7451) and the new generation (AA2050-T84, AA2098-T351, AA2198-T8, and AA2198-T851) precipitation-hardened alloys has been studied and compared using electrochemical and non-electrochemical approaches. The AA6082-T6 was the most resistant alloy followed by the new generation Al-Cu-Li alloys, except the AA2050-T84. All the alloys exhibited pseudo-passivity, except for the AA2024-T3 alloy which presented the highest number of pitting sites per cm^2 and also exhibited the most insidious form of corrosion amongst the alloys tested. However, the alloy with the highest corrosion depth was the AA2050-T84 alloy followed by the AA2024-T3 and AA7050-T7451 alloys. Intergranular corrosion was associated with rapid rates of penetration. In addition to the microstructural features of the alloys before corrosion, the modes of localized corrosion in the alloys were also influenced by evolving microstructural features (such as re-deposited Cu) during corrosion.

Keywords: wrought Al alloys, new-generation Al alloys, localized corrosion, microstructure, SEM

Chapter 6

Machining of Al-Cu and Al-Zn Alloys for Aeronautical Components

Jorge Salguero, Irene Del Sol, Alvaro Gomez-Parra and Moises Batista

Abstract

Machining operations are chosen by aircraft manufacturers worldwide to process light aluminum alloys. This type of materials presents good characteristics in terms of weight and physicochemical properties, which combined with a low cost ratio making them irreplaceable in aircraft elements with a high structural commitment. Conventional machining processes such as drilling, milling and turning are widely used for aeronautical parts manufacturing. High quality requirements are usually demanded for these kinds of components but aluminum alloys may present some machinability issues, basically associated to the heat generated during the process. Among others, surface quality and geometrical deviations are highly influenced by the condition of the cutting-tool, its wear and the cutting parameters. Consequently, the understanding of the relationship among the process parameters, the quality features and the main wear mechanism is a key factor for the improvement in the productivity. In this chapter, the fundamental issues of drilling, milling and turning are addressed, dealing with the relationship between cutting parameters, wear phenomena and micro and macro geometrical deviations.

Keywords: aluminum, drilling, milling, turning, cutting tool, tool wear

Chapter 7

Analysis of Surface Roughness of EN AW 2024 and EN AW 2030 Alloys after Micromachining

Francisco Mata and Issam Hanafi

Abstract

Micromachining is the most suitable technology for the production of very small components (micro-components) in the industry. It is a high-precision manufacturing process with applications in various industrial sectors, including machine building. This chapter presents the experimental study of the roughness (Ra and Rt) of aluminum alloys using a specific micro-turning process. The roughness measurements carried out show how it is possible to achieve very good surface qualities up to 0.05 mm diameter. For lower diameters, the surface quality worsens and the shape defects increase (conicity) due to the very low rigidity of the workpiece, which makes it very sensitive when passing through the forming process. The fundamental objective of this research is to analyze the surface quality of the finishes obtained in these micromachining processes and to evaluate their suitability to the specifications required by the mechanical industry (roughness, presence of burrs, shape and geometry, etc.). Predictive roughness models are proposed, with a good degree of approximation, to help characterize micromachining processes.

Keywords: micromachines, micro-turning, miniaturization, models

Chapter 8

Resistance Welding of Aluminium Alloys with an Electromechanical Electrode Force System

Zygmunt Mikno

Abstract

The idea presented in this chapter is an innovative welding machine electrode force system. The operation, advantages of the new solution and the optimisation of the welding process were illustrated by the welding of aluminium bars (5182) (ø 4 mm). The solution involves controlling the force and/or displacement of welding machine electrodes. The modulation of electrode force significantly improves welding, particularly as regards aluminium alloys (requiring a very short welding process). The tests involved the numerical analysis of two electrode force systems, i.e. a conventional Pneumatic Force System (PFS) and an Electro-mechanical (Servomechanical Force) System (EFS). The numerical tests were performed using SORPAS software. FEM calculation results were verified experimentally. The technological welding tests were conducted using inverter welding machines (1 kHz) equipped with various electrode force systems. The research included metallographic and strength (peeling) tests and measurements of characteristic parameters. The welding process optimisation based on the EFS and the hybrid algorithm of force control resulted in i) more favourable space distribution of welding power, ii) energy concentration in the central weld zone, iii) favourable melting of the material within the entire weld transcrystallisation zone, iv) obtainment of the full weld nugget and v) longer weld nugget diameter.

Keywords: resistance welding of aluminium, electromechanical force system, cross-wire welding, projection welding, electrode force, FEM

Chapter 9

Applications of Aluminum Alloys in Rail Transportation

Xiaoguang Sun, Xiaohui Han, Chaofang Dong and Xiaogang Li

Abstract

This chapter focus on the latest applications of aluminum alloys in rail transportation field. The typical high-strength aluminum alloys used on high speed train is introduced. The unique properties of aluminum alloys are analyzed. The detailed application is illustrated including car-body, gear box and axle box tie rod. The main challenges encountered in the application are also mentioned. The key manufacturing techniques, such as casting, forming, welding, are analyzed. Finally, the future improvement directions for better application is summarized. It is expected to set up a bridge for materials providers, equipment manufacturers and end-users, thereby promoting the advance of manufacturing technology and application of aluminum alloys in wider fields.

Keywords: aluminum alloy, application, rail transportation

Edited by Leszek A. Dobrzański

Aluminium is an engineering material of strategic importance in the current stage of Industry 4.0. This book discusses advanced composites based on aluminium alloys. It also describes pressure infiltration of gas with liquid aluminium, the mechanical synthesis of aluminium alloy powder and halloysite nanotubes (HNTs) or multi-wall carbon nanotubes (MWCNTs) consolidated by plastic deformation, selected optimization and prediction models, casting aluminium alloys containing zirconium, aluminium alloys subjected to high-speed extrusion of shapes, corrosion resistance of alloys containing lithium, machining conditions of alloys with copper and zinc additions, and more.

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