Research Laboratory-Industry Interactions for Production of Speciality Wrought Aluminium Alloys

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Defence Research & Development Organisation
Ministry of Defence, New Delhi – 110 011

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Dedicated

to

my parents

&

wife Shobhana

Contents

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Foreword

I am happy to write the foreword to this Monograph authored by Dr. Ashim Kumar Mukhopadhyay, a renowned global expert in the field of aluminium alloys. Dr. Mukhopadhyay has been deeply involved in aluminium alloy research, development, and industrial scale production for the past four decades.

Among the known structural materials, aluminium alloys are increasingly being utilized for a variety of defence applications. Dedicated in-house research and development studies to understand the underlying principles of aluminium alloy design and the factors affecting microstructure-property relationships in these alloys are, therefore, crucial. The results of such systematic studies have been described in the first chapter of this Monograph.

The subsequent chapter describes the successful development and indigenization efforts to produce speciality wrought aluminium alloys using the existing infrastructure in large, medium and small-scale Indian aluminium industries. Aluminium alloys for BrahMos supersonic cruise missile, naval warship, futuristic infantry combat vehicle and military bridging systems are examples of major outcomes of his brilliant technical contributions and guidance. His work has created self-reliance in these specific areas of applications for India.

Finally, this Monograph catalogues the major investments made by both private industries and government agencies during the past twenty years and outlines areas of opportunity to improve and create optimal infrastructure for the manufacture of various aluminium alloy semi-products.

As proud partners on this journey, we are confident that this Monograph will have significant technical and archival value and it will continue to inspire students, scientists, and engineers to work for the indigenous production of aluminium alloys.

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Preface

A vast body of knowledge regarding various commercial wrought aluminium alloys in different semi-product forms and sizes and their properties in different heat treatment tempers, as required for defence and aerospace applications, already exists in published literature such as metal handbooks, review articles, technical papers, etc.

None of the published documents, however, discussed in particular the fundamental basis of elemental behaviour and its influence on properties and/or the methods of selection of major and minor alloying elements for alloy design purposes. The Chapter 1 entitled "Aluminium alloy design" of this monograph describes such details. The research-based understanding of the physical metallurgy of aluminium alloys is emphasised in this chapter. Crucial metallurgical factors influencing important engineering properties of high strength aluminium alloys, as realised based upon decades of in-house research and development studies carried out at Defence Metallurgical Research Laboratory (DMRL), Hyderabad [a laboratory under Defence Research and Development Organisation (DRDO), Ministry of Defence] are further detailed in this chapter.

The Chapter 2 entitled "Industrial scale development and production of aluminium alloys and their characterisation" describes the industrial scale development and production of aluminium alloys typically utilised for defence applications, and discusses the technical solutions provided by DMRL to circumvent specific metallurgical problems encountered during their production. This chapter further describes results of various mechanical, general corrosion, stress corrosion cracking, ballistic tests, etc., of the indigenised aluminium alloys.

The Chapter 3 entitled "Infrastructure requirement of Indian aluminium industries" assesses and discusses the infrastructure requirements of Indian aluminium industries with respect to the future course of direction for development and production of speciality wrought aluminium alloys in the country.

Hyderabad, 2022 AK Mukhopadhyay

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Defence Research & Development Organisation (DRDO) is gratefully acknowledged for the financial support to carry out basic research, applied research and industrial scale development and production work on aluminium alloys (for a period of about three decades) described in this monograph. Further gratefully acknowledged for their keen interest, involvement and encouragement are the present and former

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- Secretaries, Department of Defence Research & Development
- Scientific Advisors to Raksha Mantri
- Chief Controllers, Research & Development (Materials)
- Director Generals (Naval Systems and Materials)
- Chief Controllers, Research & Development (BrahMos) and CEO & MD (BrahMos)
- Chief Executives, CEMILAC
- Directors, DMRL, DRDL, ARDE, RDE(E), VRDE & ADA
- Program Directors, Akash, Astra, BrahMos (PJ-10), K-4 and NGAR missiles
- Executive Directors (Production), BrahMos Aerospace Private Limited, Hyderabad
- General Managers, Ordnance Factory Ambajhari, Nagpur and Ordnance Factory, Tiruchirapally
- Principal Directors Naval Architecture, Indian Navy, New Delhi
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Director General, HR, DRDO & Director, DESIDOC, and Co-ordinator, Publications Division, DESIDOC, DRDO are gratefully acknowledged for the timely approval and completion, respectively of this DRDO Monograph project. The present Heads, Knowledge Centre (KC) and Knowledge Management and Systems (KM & S), DMRL are gratefully acknowledged for enormous support in literature search and DRDO publications, respectively.

Finally, all former and present members of the participating groups of DMRL and the concerned DRDO laboratories are gratefully acknowledged for their co-operations.

Introduction to the Monograph

Light-weighting has been the concept behind the selection of structural materials for a wide range of defence and aerospace applications. The attractive physical properties of aluminium, compared to iron and titanium[1] based on which widely utilised structural materials have been realised, are note-worthy (refer to Table 1). Today, aluminium based alloys have been the over whelming choice for a variety of structural components of military aircrafts, military bridges, missiles, naval ships, coastguard boats, infantry combat vehicles, ammunitions, etc.

Table 1. Selected physical properties of high purity aluminium, iron and titanium[1].

Property	Unit	Aluminium	Iron	Titanium
Density (d)	kg/m^3	2700	7870	4540
Melting point (T_m)	K	933	1811	1941
Elastic modulus (E)	GPa	70	211	120
Specific modulus (E/d)	$GPakg^{-1}m^{-3} \times 10^3$	25.9	26.8	26.4
Thermal conductivity (λ)	$Wm^{-1}\ K^{-1}$	237	80	17
Electrical resistivity at 20 °C (ρ)	$\Omega\ m \times 10^{-8}$	2.8	10	42

Well known performance characteristics, inherent corrosion resistance, good weldability, high recycling rate, excellent formability, good machinability, known manufacturing processes together with known infrastructure and costs are the major advantages for increasing applications of aluminium alloys. A further major incentive for producing and utilising aluminium and its alloys in this country is that India has large bauxite (i.e., the aluminium ore, the hydrated oxides of aluminium, $Al_2O_3.3H_2O/Al_2O_3.H_2O$) reserves accounting for less than 5 % of the world's total bauxite deposits.

Consideration of Table 1 (showing the lower melting point of aluminium compared to both iron and titanium) and published literature on elevated temperature properties of medium to high strength aluminium alloys produced by the conventional ingot metallurgical route[2,3] point out that the strength properties fall off rapidly with increasing service temperatures of up to 200 °C (refer to Figure 1). Studies have shown that only specially designed aluminium alloys could be used for a long period of time, in terms of thousands of hours, at temperatures around 150 °C, and in terms of a few minutes at temperatures around 300 °C. Whilst, a majority of the aluminium alloys are best suited for applications in the temperature range of 0 to100 °C for a prolonged period of time, in terms of years, maintaining the desired strength. Furthermore, compared to steel, with decreasing temperatures (referring to sub-zero temperatures), aluminium alloys gain tensile strength properties, of course, depending upon the initial heat treatment tempers[4], without losing their ductility and/or toughness properties.

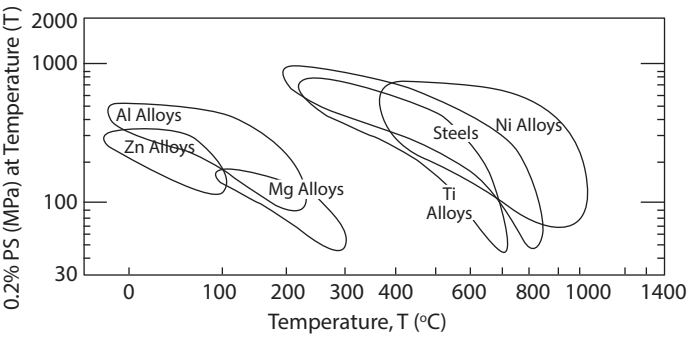

Figure 1. 0.2 % PS (MPa)-temperature (°C) relationships for metallic materials[2].

Source: adapted from Ref. 2.

Aluminium alloys, cast and wrought, as-fabricated and annealed, strain hardened and heat treated having a range of strength properties, rivetted and welded are utilised in both critical and non-critical structures of various defence and aerospace applications. While the use of premium castings such as those based on Al-Mg-Si alloy A357 for primary structures (i.e., whose failure endangers the flight) is very much restricted to only military applications, a wide range of wrought aluminium alloys dominate both primary and secondary structures in various defence and aerospace applications. This monograph describes the development and industrial scale production of several of such wrought aluminium alloys.

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About the Monograph

By virtue of several decades of fundamental and applied research carried out on a variety of wrought aluminium alloys, the Defence Metallurgical Research Laboratory (DMRL), Hyderabad has developed a comprehensive understanding of the microstructure-property relationships in these alloys. This Monograph discusses first the fundamental basis of aluminium alloy design with emphasis on the role of major and minor alloying elements, the influence of impurities, and the effects of variations in thermo-mechanical processes and heat treatment tempers on the development of microstructure and desired engineering properties in such alloys.

The Monograph describes next the efforts and achievements made by DMRL on the technology development and the industrial scale production of lithium-free speciality wrought aluminium alloys using the existing infrastructure in the country for crucial defence applications. Such applications include areas of armament, ammunition, missile, naval vessel, infantry combat vehicle, indigenously built fighter aircraft, military bridge, etc. During the course of the indigenisation programs, the crucial metallurgical solutions to the production-related issues were provided by DMRL. It follows that the lack of technological knowhow and not necessarily the lack of infrastructure had earlier prevented the production of these alloys in the country.

To realise self-reliance, the basic requirement is to have appropriate infrastructure in the industries. The last chapter of this Monograph catalogues the major investments made by private and government agencies during the last two decades and outlines areas of opportunity to improve and create optimal infrastructure to provide a complete solution to the manufacture of speciality wrought aluminium alloys in required semi-product forms.

About the Author

Dr AK Mukhopadhyay obtained a PhD in Physical and Process Metallurgy from the Department of Materials, Imperial College of Science and Technology, London, UK in 1988. He was an Assistant Research Professor in the Department of Materials Science and Engineering, the University of Virginia, Charlottesville, USA before joining DMRL, Hyderabad as Scientist 'C' in 1992. He rose to the position of OS/Scientist 'H' in 2014 and superannuated from DMRL in February, 2019.

He has been working exclusively on aluminium alloy research, design, development and industrial scale production of specialty wrought aluminium alloys for more than four decades. He featured among top 2 % of most-cited world scientists on a list prepared and published by Stanford university, USA in 2020.

He utilised his research aptitude and patented technologies for the development and indigenisation of aluminium alloys for crucial defence applications such as BrahMos supersonic cruise missile, naval warship, military bridging system, anti-tank ammunition, futuristic infantry combat vehicle, and several DRDO missiles such as Akash, Astra, NGARM, etc. The nation has achieved self-reliance in these specific areas because of his work. He further contributed towards the selection and quality control norms of indigenised aluminium alloys for ISRO's space programmes.

He was awarded VASVIK Industrial Research Award, DRDO Technology Leadership Award, SAME Lifetime Achievement Award, BrahMos Best Innovation Award, DRDO Agni Award for excellence in self-reliance, Metallurgist of the Year Award by Government of India and MRSI Medal. He is a fellow of National Academy of Engineering; ASM International, USA; Institute of Materials, Minerals and Mining, UK and Alexander von Humboldt Foundation, Germany. He is a member of Editorial Board, Materials Science and Engineering A, and Board of Review, Metallurgical and Materials Transactions A. Dr Mukhopadhyay is currently an Advisor to the Hindalco Industries Limited, Mumbai.

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