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COMPOSITE ARMOUR MATERIALS AND MODULES

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Defence Research & Development Organisation
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Composite Armour Materials and Modules

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Preface and Acknowledgements

Armour protection is one of the most vital requirements for a soldier or a battle platform during any combat situation. Every living being in this nature looks for protection from enemies. Mother nature has evolved many types of protective techniques for every living being, many of which are still unexplored. Armour too has been evolving through the history from the use of rudimentary materials like leather to metals and more recently, the composites. But the challenge for armour designer or developer is to make it the most effective and often with the least weight. The challenge is also to keep pace with the growing array of threats in ways better than the opponent and in keeping the actual level of protection, as also the exact nature of materials used, a secret.

In practice, armour uses ultra high strength fibres, composites, ceramics, and metallic materials. It may also use explosives or energetic materials in some limited ways to create reactive or active armours. While development of strong and tough materials is one aspect of armour development, increasing the volume that participates in energy absorption is a special aspect involving stress, strain, fracture, and shock wave motion not normally encountered in designing other engineering materials and structures. Combining the different materials to make effective modules to degrade, destroy or absorb the incoming threats such as high velocity projectiles is another important aspect. To design armour modules effective against a variety of threats, all in one, within the space and weight constraints, is another challenge. This also necessitates a need for understanding the behaviour of each of these materials when subjected to impact of the wide variety of threats. There is also a need to characterise the materials for their energy absorption under varying rates of loading and quantify their ballistic performance metric. To create armours against repeated attacks on spots close to each other is another big task, and especially while using ceramics or explosives. Inadequate knowledge about the possible as also the futuristic threats also poses a serious challenge, with secrecy at all levels being an additional factor. With all these, the subject of armour is highly specialised and interdisciplinary and protection is often a delicately balanced

feature in such an uncertain adverse environment. Yet, a very good armour system can not only save lives but also effectively frustrate all guns and bombs.

This book, 'Composite Armour Materials and Modules', is a small contribution in this exciting area of work. It is based largely on the work of the armour design and development team which we had the good fortune to be associated at DMRL for over three decades in developing armour materials and modules for many battlefield combat platforms such as battle tanks, infantry combat vehicles, light vehicles, helicopters and partly for body armour.

Contribution from all the scientists and technologists who worked with the team in some way or the other is gratefully acknowledged. In particular, the book draws heavily from the reports and works of a large number of our colleagues including Dr K Sivakumar, Dr M Srinivas, Shri K Ramanjaneyulu, Shri GP Sanghi, Shri R Nagabhushana Rao, Shri KS Raju, Shri P Rama Subba Reddy, Shri B Bhav Singh, Dr Hina Gokhale, Shri B Ramakrishna, Shri Ashish Paman, Shri SG Savio, Shri Bidyapati Mishra, Shri B Ravindranath, Shri MS Vaikuntam, Shri KK Pappukutty, Shri NT George, Dr BV Radhakrishna Bhat, Brig (Dr) SN Dikshit, Dr N Ramakrishnan, Shri YV Ramakrishna, Shri MN Saraf, Shri SR Sahay, Shri V Sambasiva Rao and many bright scientists and engineers from Defence Metallurgical Research Laboratory (DMRL), Defence Materials and Stores Research and Development Establishment (DMSRDE), High Energy Materials Research Laboratory (HEMRL), Proof and Experimental Establishment (PXE), and Heavy Vehicle Factory (HVF) and other collaborating production, research, and testing agencies. In some sense, this book is theirs too. Our special thanks to all our Directors who have supported the armour work throughout. We are also grateful to Dr M Vijayakumar for giving an overall reading of the manuscript. Special regards to Dr AM Sriramamurthy for his support to the armour programme and also for many of his suggestions regarding the book. Support of Shri K MothiLal in typing this document to the present form is gratefully acknowledged. Particularly acknowledged is the financial support of DESIDOC for writing the book and for publishing it. Special appreciation goes to family members of Dr Bhat – Mrs Shantha kumari Bhat and children Vidya, Chakrapani, Srivatsa, and Madhav, family members of Dr Madhu – Mrs Santi Sree and children Ravi Teja and Sai Vaishnavi and many friends and relatives for their wholehearted support. Salutations to our parents, this country and God, for giving us such great opportunities.

We are indeed grateful to Dr VS Arunachalam, former Director DMRL, for initiating this exciting area of armour research at DMRL which has not only become a passion for nearly four decades but has made our country truly indigenous in this domain. New areas of armour research have emerged from these experiences.

Academic collaborations and interactions with many sister laboratories have been fruitful and are thankfully acknowledged. This book is a report to them and to our users (Army and Air Force), DMRL, Combat Vehicles Research & Development Establishment (CVRDE), Vehicle Research & Development Establishment (VRDE), and DGOF who have generously appreciated and accepted many of the products of development making the exploration a wonderful, proud, deeply satisfying experience all through. If a little bit of the knowledge gained and the joy experienced during this work is felt by the reader to make him appreciate, and perhaps get stimulated to work in the area, or to generously support armour and protection-related research and development anywhere in the world, the purpose of the book would have been substantially served. This work is a small step forward to introduce the reader to this wonderful world of armour. The journey continues and we are sure many more experiences would continue to get added.

T Balakrishna Bhat
Vemuri Madhu

Acronyms

1.	ADDD	Armour Design and Development Division
2.	ANOVA	Analysis of Variance
3.	AP	Armour Piercing
4.	APDS	Armour Piercing Discarding Sabot
5.	ASP	Alloy Steel Plant, Durgapur
6.	BFS	Back Face Signature
7.	BHN	Brinell Hardness Number
8.	BP	Bullet Proof
9.	BPJ	Bullet Proof Jacket
10.	BUSK	BMP-11 Urban Survival Kit
11.	B_4C	Boron Carbide
12.	CVRDE	Combat Vehicles Research & Development Establishment
13.	DEF	Differential Efficiency Factor
14.	DMRL	Defence Metallurgical Research Laboratory
15.	DOP	Depth of Penetration
16.	DSC	Differential Scanning Calorimetry
17.	ERA	Explosive Reactive Armour
18.	ESEM	Environment Scanning Electron Microscopy
19.	FRP	Fibre Reinforced Plastics
20.	FSAPDS	Fin Stabilised Armour Piercing Discarding Sabot
21.	GSQR	General Staff Qualitative Requirement
22.	HAP	Hard Armour Panel
23.	HEAT	High Explosive Anti-Tank
24.	HEMRL	High Energy Materials Research Laboratory
25.	HESH	High Explosive Squash Head
26.	HNS	High Nitrogen Steels
27.	HPPE	High Performance Polyethylene
28.	HVF	Heavy Vehicles Factory
29.	ICVs	Infantry Combat Vehicles

30.	KALI-B	Kanchan Armour Light Improved for BUSK
31.	KE	Kinetic Energy
32.	MBT	Main Battle Tank
33.	MIDHANI	Mishra Dhatu Nigam Limited
34.	NDE	Non-destructive Evaluation
35.	PVA	Poly Vinyl Alcohol
36.	RHA	Rolled Homogenous Armour
37.	RPG	Rocket Propelled Grenades
38.	RSP	Rourkela Steel Plant
39.	SAIL	Steel Authority of India Limited
40.	SAP	Soft Armour Panel
41.	SEM	Scanning Electron Microscopy
42.	SHPB	Split Hopkinson Pressure Bar
43.	SiC	Silicon Carbide
44.	TBRL	Terminal Ballistics Research Laboratory
45.	UHMWPE	Ultra High Molecular Weight Polyethylene
46.	ZTA	Zirconia Toughened Alumina

CHAPTER 1

Introduction

Only Alternative for Protection Might be Extinction

Study of armour is an ancient subject. It is a highly classified area which evokes immediate interest and respect. In the battle field, armour is the last chance and close to the heart of soldiers. Armour protection actually increases battle field survivability manifold. It boosts the morale and confidence of the soldier and is a huge force multiplier. Besides, life is precious, and every soldier, his family, and fellow citizens are acutely aware of the situation in the battle field. Certainly, soldiers cannot be treated as cannon fodder any longer and lack of planning and protection cannot be tolerated.

A significant work in the area of armour protection has been done in India. A variety of effective armour materials have been developed. They have also been combined into high performance modules. This way, armour systems for main battle tanks (MBT), infantry combat vehicles (ICV), light vehicles, helicopters, and body armour have been developed, manufactured, produced, and used. Related testing, quality control, processing, and production facilities have been set up. Many useful basic studies in the area of armour materials have also been carried out.

This book is a technical narrative and an extract of the above work and briefly describes all the related aspects.

Chapter 2 describes the complex area of testing of the armour materials and modules. It outlines the related test methods and standards. Methods of characterising the mechanical properties at high strain rates are described. Methods of scaled down testing and computer simulation are also presented in some detail.

Chapter 3 describes armour grade fibre glass composites. Their nature, processing, properties, and ballistic behaviour are described. A few applications and results of some basic studies on the ballistic behaviour of fibre glass composites are also described.

Chapter 4 presents the processing, properties, and ballistic behaviour of light weight composites of ultra-high molecular weight polyethylene and a little of aramids, the two strong branches of composites for armour. Related applications and some basic studies on them are also given.

Chapter 5 deals with ceramic armour materials. It describes the processing and properties and ballistic behaviour of some of the ceramics used for armour applications.

Chapter 6 is about design and development of armour modules for withstanding small calibre threats. Related materials are described and the way they are combined together to yield high performance body armour and armour for light vehicles and helicopters is described.

Chapter 7 describes the design and development of armour modules for withstanding medium calibre threats. It presents the related materials and design concepts and the ways in which efficient, practical armour systems are created out of them.

Chapter 8 is devoted to heavy armour systems. It describes the materials and designs useful for building modules and systems required for providing protection against large calibre threats as in the case of modern MBT.

Chapter 9 is a brief narration of the overall armour programme in India. It also indicates possible trends for the future.

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About the Book

Design of protective armour requires a deep understanding of the various types of threats against which protection is demanded, the mechanisms of energy absorption in various materials, the testing techniques for assessing the ballistic performance and the principles of design of appropriate modules to withstand the impacting object. The monograph describes an overview of the general principles of armour design, ballistic testing standards for composites, an introduction into ceramic and polymer materials, their processing and design concepts related to their use in developing practical armour systems. Chapters have been devoted specific to design of armours against small, medium, and large calibre threats. Material responses to high strain rate loading conditions and their utility in simulations have been discussed. The monograph would assist beginners, academic students, Armed Forces, R&D professionals and also scholars and engineers of mechanical, aerospace and civil engineering. General readers would also find this book to be accessible and interesting. It would also benefit the teaching fraternity which has immense potential to generate a deep scientific base in the field of armour.

About the Authors

Dr T Balakrishna Bhat

Dr T Balakrishna Bhat obtained his PhD from Indian Institute of Technology, Madras and worked at Defence Metallurgical Research Laboratory (DMRL), Hyderabad and Jet Propulsion Laboratory (JPL), Pasadena, USA. He has vast experience in armour research. At DMRL, he led the Armour Division, and designed and developed a wide range of materials and modules which have found many applications. He is a Fellow of the Indian National Academy of Engineering.

Dr Bhat is a recipient of several awards for his professional contributions and has published several research papers in international journals and also patented some of his inventions. He has published few books such as 'Explosive Compaction of Powders and Composites', 'Disunity or Unity ?', 'Gita in 5 Minutes', 'Engineering Our Way to Wealth', 'Science for Babies', 'Engineering for Babies' and 'Morals and Philosophies by Babies'. He has a keen interest in analysing societal problems. He practices and teaches yoga.

Dr Vemuri Madhu

Dr Vemuri Madhu obtained his PhD from the Indian Institute of Technology, Delhi and also worked as Post Doctoral Research Fellow at University of California, Los Angeles, USA. He currently heads the Armour Technology Centre of DMRL. His areas of research interests include: Development of protective armour materials and composite armour systems for various combat platforms, high strain rate characterisation of materials, shock behaviour of materials, blast mitigation in materials & structures, and modelling & simulation of impact and blast. His research has led to a number of successful protective armour solutions for combat platforms.

Dr Madhu is a recipient of a number of DRDO awards which include Technology Group Award in 2015 and 2013, DRDO Performance Excellence Award in 2008, Laboratory Scientist of the Year Award in 2007, and National Technology Day Award in 2003. He has more than 70 research publications and a patent to his credit.

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