Book Review

DMR-1700: Low Cost High Performance Steel for Defence Applications

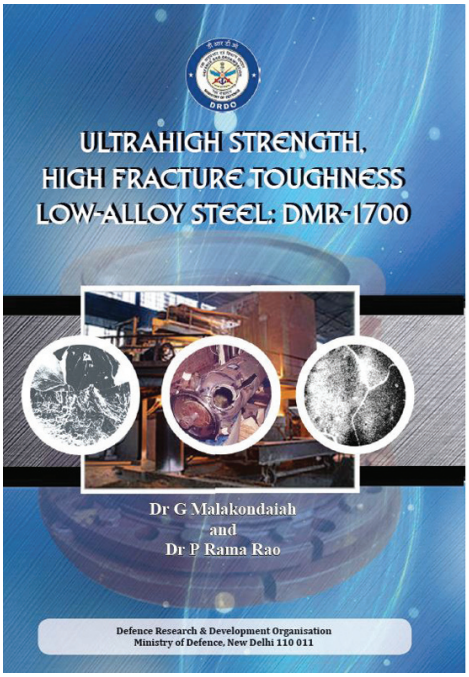
V.V. Kutumbarao

Formerly Professor, Department of Metallurgical Engineering, Indian Institute of Technology, Varanasi, India

A startling prediction has been recently essayed by Chris Anderson, Chief Editor of the Technology Review Journal "Wired" ((https://www.wired.com/2008/06/pb-theory/). He pronounced *"The End of (Scientific) Theory"* as we know it, and envisaged "a *future in which the long-established way of doing scientific research is replaced by computers that divulge knowledge from data at the press of a button"!* This provocative assertion was based on the perceived dawn of an era of peta-bytes of information (data), supercomputing capabilities, sophisticated algorithms and novel statistical tools to sift through massive amounts of data.

Important as it may be from an epistemological point of view, the "Big Data- No Theory" thesis has been contested by several commentators (see for example, Fulvio Mazzochi (https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4766450/). The emerging consensus is that the data-driven approach constitutes at best a new tool for scientific research, which can complement but not supersede cognitive and methodological procedures - both the strategies are necessary for the progress of science and technology.

The Monograph under review "Ultra High Strength, High Fracture Toughness Low-Alloy Steel: DMR-1700" is an outstanding illustration of how the synergic action of data-driven and methodological procedures can be used to develop a new technological material. This book, authored by Dr G Malakondaiah and Dr P Rama Rao, is published by the Defence Research & Development Organisation, Ministry of Defence, Government of India (2019). It describes a long drawn-out research programme (carried out over the past thirty years and counting) anchored at DMRL, Hyderabad, with the support of a multitude of sister oragnisations and industries. As pointed out by the authors themselves (p.194) *"no such comprehensive effort has ever been undertaken in any Indian academic institution, in any national laboratory or any Indian industry and therefore the work at DMRL can be regarded as truly pioneering".*



It is instructive to follow the sequence of increasingly complex stages in the evolution of this Project.

Stage 1: Identifying a clearly stated objective: in the present case the objective was the development of an ultra-high strength (> 1550 MPa YS) and high fracture toughness (> 85 MPa.m$^{-1/2}$) steel for structural applications in Defence hardware. It should be amenable to easy processing on an industrial scale, and possess good formability, weldability and acceptable resistance to fatigue crack growth and stress corrosion, all at a low cost.

Stage 2: Experimenting with a new idea: (a) *Identify one major problem in achieving the objective*: Here the identified problem is that efforts to increase strength generally result in a loss of toughness. (b) *Search for a novel solution:* The authors hit upon the idea of initiating de novo research on the effect of selected alloying elements on toughness of dilute binary solid solutions of iron. (c) *Pay attention to fine details while doing this research:* This hallmark of true excellence is evident at every step of the present effort. (For example, dozens of experiments were conducted just to ensure a reproducible common grain size for all the compositions tested). This work is described in detail in Chapter 3 of the book.

Stage 3: Selecting the best material and generating relevant data: The insights gained from the previous step were used to select the best material - a high strength low alloy steel consisting of Ni, Si, Cr, Co and Mo (total alloy content < 7%) *designated as DMR-1700*. Extensive experimentation on the new steel was carried out to evaluate its mechanical and other properties. This work involved 100s of carefully designed experiments, using a wide variety of sophisticated equipment, followed by intensive analysis of the results (partly aided by innovative computer algorithms).

Stage 4: Scaling up the laboratory effort to industrial level production: In the present case, scaling-up involved optimization of the processes of making, shaping and treating of the new steel. The laboratory-produced DMR-1700 steel

successfully achieved the target properties of about 1600 MPa yield strength and 85-90 $MPa.m^{-1/2}$ fracture toughness in the optimum heat-treated condition. Reproducing these properties in industrial melts required the use of premium production processes to give clean inclusion-free material. Two different processing routes were used. The first was Electric Arc Furnace (EAF) melting followed by Vacuum Arc Refining (VAR) / Electro Slag Refining (ESR) for melts of 5 ton size. The second route employed the two-stage process of EAF followed by Ladle Refining & Vacuum Degassing (LR&VD) for larger melts of 150 tons. The satisfying outcome of both the routes was a steel plate which proved to be a one-to-one replacement for 18Ni1700 maraging steel matching its mechanical properties in the same section thickness. Importantly, it was achieved *at one half to one third the cost of the maraging steel in the first processing route. The cost reduction was even more dramatic at one tenth that of maraging steel in the larger 150 ton melts when melting and refining were followed by continuous casting (a process used for the first time with steels of this type).* Chapter 4 of the monograph gives a detailed description of the work listed in items 3 and 4 above.

Stage 5: Producing components for practical applications: The intended main application of the new steel was for rocket motor casings (for AKASH and AGNI missiles) as a low cost one-to-one replacement for the presently used but expensive 18Ni1700 maraging steel. Extensive work was carried out on the new steel to successfully optimize the conditions during fabrication of missile casings and subsequent heat treatment schedules. Suitability of the steel for other applications such as for reducing the weight of the base plate for 120mm Long Range Mortar (LRM) and as armour plate for India's Main Battle Tank has also been established. Chapter 5 of the monograph gives a captivating step-by-step account of the work carried out in this regard.

Stage 6: Achieving acceptance by the end- user: This is the ultimate requirement before the component can be taken into actual service. The DMR-1700 Project is no doubt a sparkling crown jewel of Defence Research in India. But achieving acceptance by the end-user could be an intractable problem. This has been pointed out by the authors themselves when they pose the rhetorical question *"DMRL has done all that one may possibly envisage for demonstrating large scale utilization of DMR-1700 and for clearly establishing its cost advantage. Adoption of DMR-1700 for rocket motor casings would be in the nature of crowning the DMRL long-drawn out programme. The question is, will it happen?" (*Epilogue, p.294).

The DMR-1700 Monograph should be of immense interest to various categories of readers. On the primary level there are the numerous investigators partly associated with the Project at various stages, who will be able now to get a picture of the entirety of the work. Scientists in metallurgical Institutions engaged in developmental research will find the book to be a highly instructive guide on how to carry out purposeful research. For students of metallurgy at any level including undergraduates, the book in effect is a summary of a substantial part of metallurgy in the guise of a complete case study. In aid of such students, the authors have included at the beginning two chapters dealing with the principles of ultra high strength steels and ductile fracture of steels respectively. In addition Appendices at the end of each subsequent Chapter explain in detail some of the concepts / processes mentioned in that Chapter. A comprehensive stand-alone summary at the end of each Chapter is a major highlight of the book. Other value additions that enrich the text include a large number of data tables, appropriately composed illustrations, an alphabetical index of topics and Lists of Symbols, Acronyms and References.

It is a pleasure and an education to read this well- written DRDO monograph.