Books and Other Major Sources

in alphabetical order according to first author / editor / title

Science

Georgius Agricola,
De Re Metallica published 1555

- If you haven't heard about this book, I can't help you much here. A rather illustrious person considered it important enough to translate the Latin original it to English in 1912: Herbert Hoover, the 31st President of the United States from 1929 to 1933.
- Agricola (24 March 1494 – 21 November 1555) was a German Catholic, scholar and scientist. Known as "the father of mineralogy", he was born at Glauchau in Saxony. His birth name was Georg Pawer ("Bauer"=farmer) in modern German); Agricola is the Latinized version of his name. De Re Metallica is his most famous book; it was finished around 1550 but did not appear in print before 1555.
- De Re Metallica covers how to extract ores from the ground and metals from the ore in considerable detail and in an scientific way without (as usual) referring to all kinds of spirits and magic. It is lavishly illustrated by wonderful woodcuts; here is a sample.

Michael F. Ashby and **David R. H. Jones**
Engineering Materials I and II

- The Materials Science and Engineering "Bible" for Beginners. Among the most important early books (first issued 1986) about (mechanical or structural) Materials Science. I owe a lot to these books.
  There are a lot more good Materials Science books around in 2011 when I'm writing this. But "Engineering Materials I and II" are still and among the best and an easy read for anybody with a background of physics and math only slightly above a German High School level.

Peter Atkins
authored not only "the" text book about Physical Chemistry (**Physical Chemistry**, *9th ed.!!*) and many more "serious" books but several popular science books, like:

- "**The Creation**", "**Creation revisited**" or **Galileo's Finger: The Ten Great Ideas of Science**".
  I owe a ot to these books and recommend them heartily

Ludwig Beck
Die Geschichte des Eisens (The history of iron).

- The 5 ponderous volumes from just before 1900 still provide for good reading (provided you're fluent in German) even so the author can't tell you much about the science of steel. That is not Beck's fault: In 1900 the basics for materials science had not yet been discovered.

Elis Behmer
Das zweischneidige Schwert der Völkerwanderungszeit (The double-edged sword of the migration period)
A PhD thesis, as far as I can make out, University Stockholm, 1939

- A 1939 study of the sword remains found in essentially Northern Europe that date to the migration period, roughly 300 AD - 700 AD. Behmer looks at stylistic and technical details of all the parts around a sword and no just the (often missing blade). We have in particular the pommel, crossguard, handle parts and the many metal parts found around a scabbard.
- Behmer distinguishes 3 major groups, further subdivided in 11 sub-groups. His system overlaps to some extent with the more modern system that looks at the blade. He relates certain styles to certain areas, cultures and times. His interpretations, it seems, are still setting the standard in many cases.

Vanoccio Biringuccio
De la Pirotecnica

- Biringuccio was an Italian metallurgist. His best known manual on metalworking "De la pirotechnia" was ,published posthumously in 1540, 14 years before Agricola.
  In contrast to Agricola, Biringuccio puts a lot of emphasis on casting metals; "De la pirotechnia" is the first printed account of proper foundry practice. But like Agricola, it also gives details about mining, smelting, and processing of many metals and alloys such as brass.

Vagn Fabricius Buchwald ,
Iron and steel in ancient times (I), and **Iron, steel and cast iron before Bessemer** (II)
Histrik-filosofiske Skrifter **29** and **32**, The Royal Danish Academy of Sciences and Letters

- One of the best books as far as most aspects of the topic go. They contain many pictures, in particular structural micrographs, especially of slag.
  Buchwald covers mostly northern topics that he investigated himself, for example pattern welding, but does not deal much with wootz.
  The books presuppose familiarity with phase diagrams, metallography etc.
- Vagn Fabricius Buchwald was born in 1929. The books were published in 2005 or 2008, resp. Buchwald also published a lot of scientific papers. His life as scientist was dedicated to the science and history of metals, in particular meteorites and iron and steel. There is no way that somebody like me, who looks into the issue just "on the side as a kind of hobby, can match Buchwald's experience and knowledge. After you have familiarized yourself with the basics of iron and steel metallurgy by going through this hyperscript. You should read Buchwald's books to learn far more.

Robert W. Cahn
The Coming of Materials Science,
Pergamon Materials Series, Volume 5

- This is a wonderful and monumental book about the birth of Materials Science as a new branch of Science and the subsequent evolution into a mature and thriving discipline.
- Robert W. Cahn (* 1924 in Fürth; Germany; † 2007 in Cambridge, England) wrote the " Coming of Materials Science" in 2001. It was the product of a lifetime's involvement in this field and his close personal friendships with many of its leading pioneers.

Constitution and Properties of Steel
Edited by F.B. Pickering
Vol 7 in the series" Materials Science and Technology", edited R.W. Cahn, P. Haasen and E.J. Kramer.

- A "textbook" containing all you ever wanted to know about the science of steel - and a lot much more!
  I recommend to study Materials Science for a while before reading this book.

Vic Diehl and **Hermann Hampe**
with a little help from **H. Föll** (yours truly) and **Gözde Yasar** .
Weapons of Warriors
Initiated, photographed and assembled by
Schiffer Publ. LTD

- A large size "picture" book containing professional pictures (some folding out to almost 1 m / 3 feet) of swords and a few other objects. Most of the swords shown are famous pieces from the **Askeri Museum**, Istanbul.
- In addition, the book features an article about Yatagans from Gözde Yasar, one of the museum experts, and an article written by me about "Iron, Steel and the Art of Swordmaking". This article is a kind of (very) abridged version of this hyperscript. You should definitely buy several copies of this book; it make a great present.

Conrad Engelhardt
Denmark in the early iron age illustrated by recent discoveries in the peat mosses of Slesvig
London 1886

- Engelhardt, a teacher, was about the first "scientist" digging in the bogs of Denmark that yielded all those amazing (mostly Roman) treasures including extremely well preserved pattern welded swords.
  The book is classic, kept in the treasure rooms of the libraries that have it - and not easy to get. It is one of several Engelhard books (mostly in Danish).
  There si a modern paper back reprint that cannot, however do justice to the marvellous steel engravings in the original.

Andreas Hauptmann
The Archeometallurgy of Copper
Springer, 2007

- The book is first of all a compilations of data about copper archeometallurgy gained from major digs in the area of Fayan (Jordania). It also discusses in detail the development of copper technology from the very beginning and relates about everything that is known about the topic.
  The book is written for scientists and not all that easy to read.
- The author is a well-known archeometallurgist and a leading expert in his field. From what he writes it becomes rather clear that there are still many conflicting views, that much that was considered to be solid knowledge a generation ago must be reconsidered, and that one needs to dig rather deep into the science of smelting, including doing experiments, if one wants to understand what really happened some thousand years ago. Together with his colleague *Ünsal Yalcin*, I count him among the heroes of archaeometallurgy

J.P. Hirth and **J. Lothe**
Theory of Dislocations
Second edition (Krieger Publishing, Malabar Florida 1982)

- The "bible" as far as dislocations are concerned. Not for the faint of heart; full of long equations

D. Hull and **D.J. Bacon**:
Introduction to Dislocations
Int. Series on Science and Technology, Vol. 37, Butterworth

- The easy-to-read "dislocations book" for beginners. Very well written and lavishly illustrated.

Rolf Hummel
Understanding Materials Science; History, Properties, Applications,
Springer 1998

- This is maybe the first book that does not only give a "*popular science*" account of Materials Science topics (including a lot about metals) without math and equations but backs it up in separate "modules" with a more scientific rendering, including some math.
- I have known and estimated Rolf Hummel for quite a while since his research interests concerning semiconductors coincided with mine to some extent. And he issued from the Max Planck Institut für Metallforschung, Stuttgart, just like me.

Illerup Ådal (Marcin Biborkis and Jørgen Ilkjær)
Volume 11-12: Die Schwerter und Die Schwertscheiden. Katalog, Tafeln und Fundlisten", Jutland Archaeological Society Publications, 2006

- Two volumes of a scholarly series that describes and discusses Danish bog finds. Drawings of most of the artifacts are given plus many photographs. Everything is discussed in great detail. I did learn a lot from this books. .
- On the negative side, they are difficult to "read", in particular if one wants to find out something about a special issue, like chevron or palmette patterning. It is easy to find pictures, but difficult to find the texts to a picture since there is no cross-referencing between the picture / documentation volume 12 and the text volume 11. There are also a couple of mistakes, rooted in the unfortunate tendency of archaeologists to write five pages of terse prose around numbers instead of giving a concise table / graphic.
  The discussion of pattern welding / iron technology is behind the state of the art and hampered by the other unfortunate tendency of of archaeologists: never admit that you do not know something. How all those "chevrons filled with palmettes" have been made is simply not mentioned. One should also discard all statements of relations between blade shapes / pattern welding and mechanical properties of the swords. Some examples (in the true language):

  - "um eine ausreichende Biegefestigkeit zu erreichen...schmiedet man Blutrinnen und -rillen. p. 281 (11).
  - Das Schwert aus ISEP ... wurde aus einem gleichmäßig aufgekohlten Hartstahlstück geschmiedet und .... Trotz seiner guten Qualitäts- und Gebrauchseigenschaften kann es jedoch nicht mit damaszierten Exemplaren gleichgesetzt werden, die insbesondere weitaus biegefester waren. p.253 (11).
  - Es muss an dieser Stelle unterstrichen werden,.dass sich die Schwerter mit damaszierten Klingen nicht allein durch ihre äußeren Merkmale --- auszeichneten. Ferner wiesen sie sehr gute Gebrauchseigenschaften auf, wenn die sogenannte Schwingungsdämpfung beim Austeilen und Abwehren von Hieben genutzt wurde, die sich aus dem differenzierten inneren Klingenaufbau ergibt. p. 281 (11).
  - Auch Schichtpakete mit dickem Streifendamast der quer über die Klingenfläche verläuft dämmte die Aufprallwellen bei Hieben mit einer Schwertschneide. p.294 (11).

  The latter two statements sound very scientific but to the best of my knowledge are just guesses that are not

justified by "theory".

Manouchehr Moshtagh Khorasani
Arms and Armor from Iran
Legat Verlag 2006

- A 775 page large-format affair with hundreds of full-size color pictures. A magnificent book with plenty of explanatory text from specialists.

Stefan Mäder
Stähle, Steine und Schlangen. Zur kunst-, kultur- und technikgeschichtlichen Einordnung dreier Schwertklingen aus dem alamannischen Siedlungsraum“ (Steels, stones and serpents. How do three sword blades from the Alemannian settlement region fit into the context of art, culture and technology history?)
Ph.D thesis

- The thesis deals with "the cultural and technological significance of early medieval sword-blades". It is pretty long and gives a lot of historical details. Maeder had three early sword parts polished and evaluated by a Japanese expert. This provided for new insights, in particular as far as "faggoting" is concerned.
  The links provide for details.
- See also Mäders's Internet contribution to the general topic.

Wilfried Menghin
Das Schwert im frühen Mittelalter, 1982
Konrad Theiss Verlag Stuttgart

- The book continues and updates to some extent Behmer's seminal work. It contains full listings and drawings of sword found in essentially Northern Europe from the 5th to 7th century. It offers a system for classifying swords and gives a wealth of graphic data, e.g. distribution maps and drawings of many items.
- From a metallurgical point of view the book as little to offer (besides the information that many blades had not been investigated with respect to possible pattern welding). The book has its roots in research work that culminated in a 1971 PhD thesis, and that explains to some extent why the remark to pattern welding rehashes the typical nonsense prevalent then (and now).
  More to that in the text.

Franz Sales Meyer
"Handbuch der Schmiedekunst" (handbook of the smiths' art) from 1888

- Probably lthe book my Grandfather used. Meyer states: "Wrought iron melts at (1800 - 2250) ^{o}C ((3416 - 4082) ^{o}F). Seen practically, wrought iron can't be melted".
  This gives some idea about the long, long way we have come since then.

Eric J. Mittemeijer
Fundamentals of Materials Science.
The Microstructure - Property Relationship Using Metals as Model Systems
Springer, 2010

- A rather new and excellent text book for beginners. Easy to read even for people who don not want to become Materials Scientists

Lars Christian Nørbach (editor)
Prehistoric and Medieval Direct Iron Smelting in Scandinavia and Europe
Proceedings of the Sandbjerg Conference 16th to 20th Sept. 1999
ACTA JUTLANDICA LXXVI:2, Humanities Series 75, Aarhus University Press

- The book contains 35 contributions from about 50 participants in three languages (no, not Latin or ancient Greek but just modern German and French besides English).
- I do not suggest that you buy and read this 335 pages volume; it is far too detailed and specific and not easy reading. I just include it to give an idea of what is going on in serious archeology with respect to iron and steel.

R. Ewart Oakeshott
The Archaeology of Weapons
Originally published in 1960; reprinted in 1996

- A popular, easy to read and very interesting book that has a few colleagues, too.
  You can't look into the history of swords without encountering Oakeshott rather sooner than later, and his contribution to the field has been acknowledged by all and sundry
  However, metallurgy was not in Oakeshott's focus and we learn little about this topic.
  The book (and others from Oakeshott) is available in a paper back edition that you should buy and read.

Bruno Overlaet
Luristan excavation documents
Acta Iranica, Vol. XXVL, 2003

- A large and heavy volume covering in detail the results of excavations in Luristan.
  The iron swords from Luristan are still an enigma. They go back to the very beginning of the "serious" iron age i.e. the time around 800 BC when the first complex iron objects appeared.
  Prof. Bruno Overlaet is the expert in this area and will come up prominently in the many Luristan pages in chapter 10 and beyond.

Brian F. Pickering, Volume editor:
Constitution and Properties of Steels; Volume 7 of the series "Materials Science and Technology"; Series editors: **Cahn, R. W., Haasen, P., Kramer, E. J.**

- One of those "comprehensive" text books on a special topic in Materials Scienc and Engineering. The book contains 17 articles written by eminent scientists on about 800 pages. Published 1991 and thus already a bit out of date.
  The book is rather scientific but still carried by "engineering". For example, while movement of atoms is the key to everything, you will not find any diffusion data in the book. Nevertheless, you find more than you ever wanted to know.
- Even so I had never anything to do with steel, I know Peter Haasen (died 1993) and Ed Cramer quite well from my past.

Radomir Pleiner
The Celtic Sword; Clarendon Press, Oxford 1993

- A classic - and completely sold out; you can't get it. Pleiner metallographically investigated a large number of Celtic swords in some detail and showed that Celtic sword smiths used technologies like piling and even pattern welding rather early.
  I have much to say about this here.
- Pleiner has published numerous articles and books; his contribution to the archaeometallurgy of iron are momentous. His book below is still available:

Radomir Pleiner:
Iron in Archaeology - Early European Blacksmiths
A book, published in Praha **2006**

- Covers everything about blacksmithing and how it developed.

Rehder, J. E.
The Mastery and Uses of Fire in Antiquity
McGill-Queen's University Press

- The beginners "Bible" about fire! Fire is described from a scientific point of view. A real eye opener if you are interested in pyrotechnology including smelting.
  What is the highest temperature you can achieve with a given fuel? What determines the temperature you really get in a furnace or other contraption? Are all charcoals created equal? What is really happening during smelting? What is slag good for? And so on.
- Rather easy to read; Rehder makes a valiant attempt to write for the "interested layman". However, you should have some basic knowledge of physics and chemistry and not be afraid of a few simple equations that come up on occasion.

Manfred Sachse,
Damaszener Stahl Mythos, Gechichte, Technik, Anwendung
(also available in English: **Damascus Steel**)
Verlag Stahleisen Düsseldorf, 1989, 2nd edition (my edition) 1993

- A definite "must have"! Go get one if you don't have it already.
  An extraordinary book that was not only instrumental for turning me onto the path of "Iron, Steel and Swords" but has the distinction to be one of the very few if not the only in-depth book written by a practicing master smith for the general public!
  It is full of information and great pictures and I will get back to it many times.

Stephen Sass,
The Substance Of Civilization: Materials and Human History from the Stone Age to the Age of Silicon Published August 1st 2011 by Arcade Publishing.

- Steve studies why materials break, bend, or behave the way they do. He also goes thoough the history of materials and gives a good general idea about the development of metals, ceramics and other stuff.

David Scott
Metallography and Microstructure of Ancient and Historic Metals
Marina del Rey, CA. Getty Conservation Institute in association with Archetype Books
Online under http://www.getty.edu/conservation/publications_resources/pdf_publications/pdf/metallography.pdf

- A book full of high quality structure pictures of various ancient metals. There is also a very good introduction into metallography and what you can expect to see for various treatments (e.g. annealed or cold-worked).

Cyril Stanley Smith (1903 – 1992)
A History of Metallurgy The development of ideas on the structure of metals before 1890
University of Chicago Press, 1960

- The title says it all. The book is form on of the great old men of iron and steel science, and of considerable interest for the history of metals, but must be taken with a grain of salt because it portrays uncritically (how else) a number of outdated vies (to say it politely).

Ronald FrankTylecote (15 June 1916 – 17 June 1990)
A History of Metallurgy
First published in 1976.
MANEY for the Institute of Materials

- Tylecote, a British archaeologist and metallurgist, was the great old man of experimental iron archaeometallurgy; he is recognized as the founder of archaeometallurgy. He investigated many early mining and smelting sites around the world and did early smelting experiments of his own. He has published many scientific paper and books but his "A History of Metallurgy" addresses non-scientists. It was (or better still is) the standard in the field.
  You better get it and read it; you'll find it in the Net for downloading.
  However, what Tylecote started has moved on quite a bit since 1976 and the book, naturally, is not up to date any more.

John D. Verhoeven
Steel Metallurgy for the Non-Metallurgist
ASM Inernational; Materials Park, Ohio, 2007

- John D. Verhoeven is a renowned (now retired Professor of Materials Science and Engineering at Iowa State University and one of the combatants in the The Great Verhoeven - Wadsworth Jousting Tournament. The topic is the forging of wootz blades from hypereutectoid steel. Verhoeven has published a tremendous amount of hard-core science paper an a large amount of papers discussing the making of wootz blades. The link leads to a lot of details
- At some point in time Verhoeven decided to write the book above for *Non-Metallurgists* . He failed. The title is utterly misleading. The first phase diagram appears on page 6, for example. I can see what happened. There is simply no shortcut to things like phase diagrams, deformation and hardening mechanisms, and so on, and going into that in any detail is far more work (and needs far more room) than Verhoeven bargained for when he started The book is still a good and relatively easy read - provided you have worked your way through this hyperscript first.

Theodore A. Wertime, T. A.
The Coming Of The Age Of Steel
The University of Chicago Press, 1962

- A highly entertaining and interesting book, with lots of good details about the history of iron and steel. I have used it extensively.
  It also illustrates what I have stated in various parts several times: it takes a while before scientific insights trickle down to the practitioners. Wertime simply ignores about everything that was known in 1962 about the inner workings of iron and steel. You will not find a phase diagram in the book, and words like "dislocation", "vacancies", "segregation" etc. are never mentioned.

Werkstoffkunde Stahl, Band 1: Grundlagen
Issued by: Verein Deutscher Eisenhüttenleute ("Club of German Iron Smelters")
1984, Springer-Verlag

- Another one of those "comprehensive" books on steel, like the "Constitution and Properties of Steels" above. It is written in the true language of iron and steel, like many steel books, especially those of old.

  It contains three main parts, consisting of many articles written by eminent scientists / engineers on about 700 pages. Published 1984 and thus quite out of date except that it contains a lot of basic, never out-of-date stuff. The book is written from an engineering point of view but carries a lot of deep science around, including diffusion data.

Alan Williams
The Sword and the Crucible A History of the Metallurgy of European Swords up to the 16th Century

- The book starts with a bit on the history of iron and steel but is focussed on the detailed metallurgical analysis of "Ulfberht" swords from the Viking time period as well as many other medieval swords. It pushes the revolutionary view that the better European swords in the 9th - 10th century were actually made from crucible steel that originated somewhere in India or thereabouts. This claim has triggered a large media response that is still going on.
  It is, however, not yet believed by all and sundry and the non-believers are gaining momentum and strength. The links given will provide details.
  You should know the basics of metallurgy for reading this book.

Internet Sources

in alphabetical order according to some (more or less arbitrary) name

Key to Metals
Many articles about general and specific topics in varying but generally good quality.

- http://www.keytometals.com/page.aspx?ID=Home&LN=DE

Metallurgy for Dummies
Unassuming but often fairly good articles about a lot of topics.

- http://metallurgyfordummies.com/

Dierk Raabe's private Website
Prof. D. Raabe heads a department at the Max-Planck-Institut für Eisenforschung, Düsseldorf, Germany. His private website is a treasure trove of information about iron and steel and a few other things).

- http://dierk-raabe.com/

Richard Cowen's essays on Geology, History, and People
Richard Cowen is a (retired) UCDavis, Department of Geology Professor. His essays are the foundations for a book he plans to write and provide for easy reading about the history of metals.

- http://mygeologypage.ucdavis.edu/cowen//~GEL115/

And many, many more. Go, find them yourself.