Research and Innovation
2026, Vol. 2, No. 1, pp. 55–59
https://doi.org/10.11648/j.ri.20260201.17

Review Article

Advances in Metallurgy and Materials from Ancient Times

Dattaguru Ananthapadmanaban[1, *], Thogulva Raghavan Vijayaram[2], Venu Arvind[1]

[1]Department of Mechanical Engineering, Sri SivaSubramaniya Nadar College of Engineering, Chennai, India
[2]Department of Mechanical Engineering, Bharath Institute of Higher Education and Research, Chennai, India

Abstract

Ancient metallurgy was advanced in some ways. Not much is known about ancient metallurgy since most of the knowledge is lost due to various factors. There has been recent interest that has been kindled in ancient metallurgy. Western ideas crept in, in recent times and made the art of metallurgy more productive and profitable and now Metallurgy has changed to Materials Science. Evolution of Some of the ancient alloys, like Wootz steel are discussed. Their progress through the ages has been identified and advancements in furnaces are outlined. reviews the art of metallurgy and suggests how ancient arts could be blended with modern technology. The purpose of this paper is to rekindle interest in the ancient metallurgy and also supplement ancient ideas with modern ones. Terms like Nanotechnology are fairly new, but the concepts existed in ancient times in another form. Similarly, furnace technology has evolved from ancient times till now. It is felt that rekindling interest in ancient metallurgy will somehow help to blend these ancient technologies with modern technologies.

Keywords

Materials Science, Nanotechnology, Wootz Steel, Ashtabandanam

1. Introduction

The paper has been divided into -Introduction, Advances, giving a comparison between ancient and modern techniques, suggestions for improvement and Conclusions.

Ancient times saw many great civilizations like The Indus Valley, Mesopotamia, Persia, South America and many not so often mentioned civilizations. All of them were well versed in the art of metallurgy. In fact, some periods of civilization have been named the Iron age and the bronze age. In India, there could well have been a brass age going by the use of brass in vessels and many other articles of ancient India. Most of the ancient civilizations developed without tampering much with nature. In recent times, we have exponential material growth with the discovery of super strong, superplastic and super-conducting materials, but the moot point is-Are we carrying it too far in our quest to outdo each other in discoveries. While, it is always good to be research minded and publish papers in reputed Journals, this should not be the final aim of our work. Environmental consciousness must be built into each and every step that we take in our life, which brings us back to the questionIn recent times, the world has realized the importance of green manufacturing and green materials. [1, 2]

*Corresponding author: ananthapadmanaband@ssn.edu.in (Dattaguru Ananthapadmanaban)

Received: 17 September 2025; **Accepted:** 10 October 2025; **Published:** 26 December 2025

2. Advances in Metallurgy and Materials Science

When the author of this article was studying at at I.I.T, Madras (now Chennai), we had our good old Metallurgy Department. Now, it has progressed and expanded to Metallurgy and Materials Science which is good. Any expansion in any field of knowledge is always welcome. Now, Physics, Chemistry, Mechanical Engineering, Chemical Engineering and Bio Technology have combined together, not to mention Electronic Materials. That way, there is progress. Materials Science is a multidisciplinary field. Research in Materials Science would have scholars from as diverse fields as Civil Engineering to even Biology. Nano-Materials are being used in water filters.

While there is no doubt that Metallurgy and Materials Science has advanced rapidly after the Industrial revolution and especially during the last 2 decades, some of the ancient methods of metallurgy has been lost. The lost wax process was used in ancient times very effectively and it is being used by the U.S Military and air force to make precision cast engines. Objects discovered in Southern Israel dating back to 5700 years back and Mesopotamia, also around the same period confirm that this process was fairly widely used in ancient times. [1, 2]

2.1. Metals Used in Ancient Times

Ayas is the Sanskrit word for metal, which was used mainly for vessels, weapons and statues. This was again classified as lohitayas (red metal) and krishayas (black metal).

The word used for Fire related activitiesis Vahni Karmani. Rasa Bhairava indicates king among chemicals-Mercury.

Sulba arih-Enemy of Metals- Sulphur. Even in ancient times, it was a well known fact that Sulphur is an enemy of Metals, as is well known today. In modern times, we know that steels with High Sulphur will have lower strength and so it can be inferred that Sulphur is not good for steel. More-ever, Indian coal also contains high sulphur and so sulphur can also come into steel while processing the iron ore. But, it is a wonder how the ancients came to the conclusion that Sulphur was the enemy of steel without any technologically advanced testing equipment. It is probable that they observed Sulphur reacting vigorously with many metals forming Sulphides and also noted the deterioration of properties after Sulphide formation.

The use of iron in southern part of India is datable to the period pre-1000 BCE and in the upper Gangetic valley and eastern part of India the use of iron began around 1000 BCE [3].

on beams have been used in the Konark temple and Jagannath temple. Iron pillar has also been seen in Mokkambika temple. Iron objects were also found in Kadabekale and Mel-Siruvur. [4] Lamination technique was found to be widely practiced in ancient India, to manufacture iron artifacts. Damascus steel possessed high-strength, brittleness and banding. This steel was supposed to have originated in India. [5]

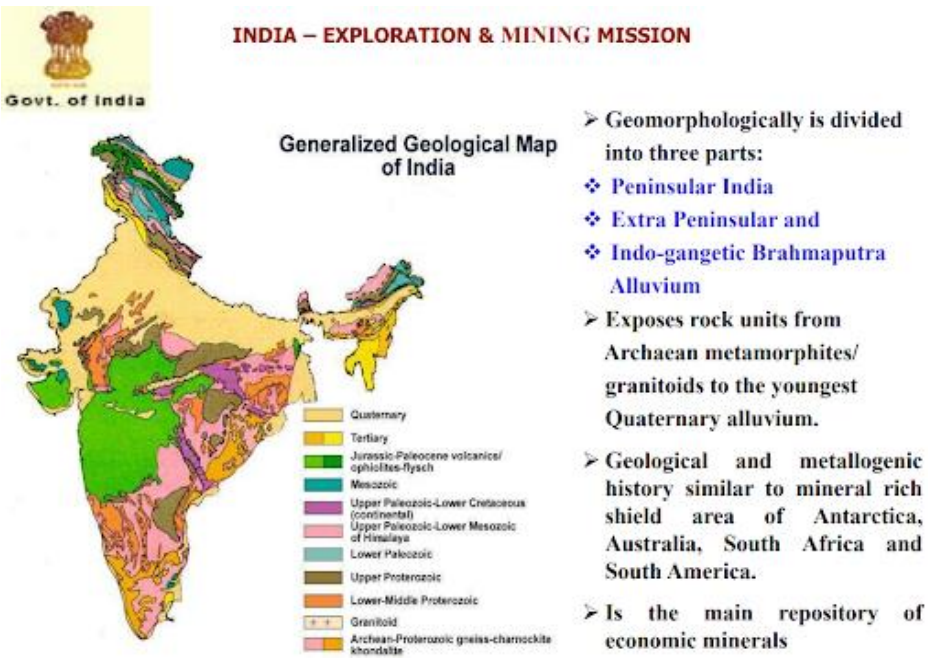

Figure 1. *Shows geological sites in India.*

2.2. Furnaces

After the invention of blast furnaces, there have been many developments and improvements in furnace design. Induction furnaces gave clean melting. Electrical furnaces gave cleaner melting. All these European style furnaces were very good advancements that are being used today for batch production of steel. But, unfortunately, these developments killed the native steel making in India. All of us know that Wootz steel (derived from urukku in Kannada) was very famous in India and Persia. Similarly, our ancient texts talk about crucible furnaces which were tortoise shaped (Kurma in Sanskrit). In the olden days, almost all practical discoveries were inspired by nature. So, the tortoise shape came into existence. It is possible that air blowers were placed at the positions where the tortoise's legs are positioned. Srinivasan and Grifith have discussed in their paper about the archeological evidence about steel making in South India, even well before the Christian era. [6]

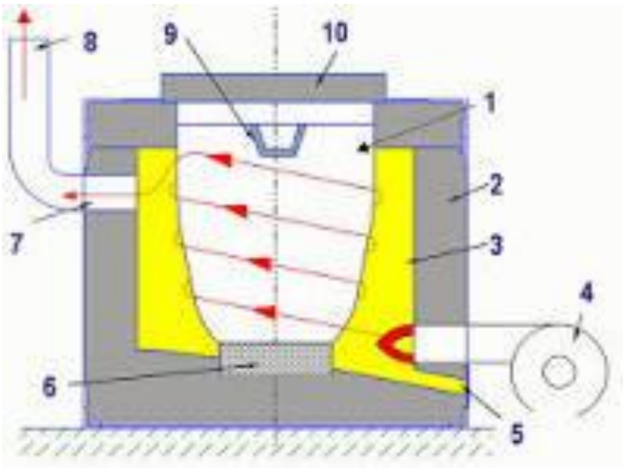

Figure 2. *Shows crucible furnace.*

2.3. Development and Metals

Development in the modern world is related to higher GDP, Per Capita income and other modern economic criteria. However, any development which is non-inclusive of the lowest of the low cannot be called true development, in my view. In ancient India, there was the concept of Vasudeva Kutumbakam. The whole Universe was one family. So, everyone should be treated as our own family member. In recent times, this has not been so and capitalist ideas have made the rich richer and the poor poorer. Exploitation is considered normal, be it exploitation of people or mother nature herself. Man has exploited and mined the earth so much and so fast, especially over the last 20 years that now the idea of sustainable development is forced upon all of us. How long can the Earth sustain this massive expansion of exploitation over such a large, global scale. No wonder, earthquakes are reported in earlier strong seismic zones.

2.4. Nanotechnology

Nano was also known in the ancient days, albeit by a different name. Astabandanam, the glue used to secure deities to their seats is supposed to be a nanomaterial.

Meanwhile in Sanskrit Asta means Eight and Bandhanam means tying or fixing. Ashtabandhanam is the process of affixing an idol to its pedestal (Peetham) with clay-like paste made of eight specific herbs mixed with wood lac, limestone powder, resin, sandal paste, red ochre, beeswax, butter and oil.

The paste is formed into long rolls about 2 cm thick and applied directly around the base of the idol, so that the cemented joints become watertight. This process is believed to keep the idol rejuvenated for many years.

The "Ashtabandhanam" paste is pliable like rubber. Through repeated interactions with abhishekha dravyams - materials used to bathe the idol during daily worship like water, milk, buttermilk, sandal paste and oils - and atmospheric oxidants, the paste loses its flexibility, becomes rigid and gets riddled with a lot of fissures.

2.5. Production of Wootz Steel

Wootz steel is widely regarded as one of ancient India's most remarkable metallurgical achievements, For over two thousand years, Indian metalworkers safeguarded the secrets behind one of history's most extraordinary materials: Wootz steel. Celebrated for forging some of the finest swords ever made, this legendary steel was admired not only for its unmistakable flowing patterns—often described as "watered silk"—but also for its incredible combination of strength, sharpness, and flexibility [7, 8].

The process began with carefully selected iron ore, typically magnetite, which was smelted in traditional furnaces using charcoal instead of coal [9]. Unlike modern methods, which often rely on limestone flux and blast furnaces, this technique produced iron with a high phosphorus content—a trait that, we now know, contributed to Wootz steel's impressive resistance to corrosion [10]. After smelting, the metal was hammered repeatedly to remove slag and other impurities, forming dense iron cakes—the raw material for transformation [11].

The true magic happened inside small sealed clay crucibles, often shaped like tortoise shells—a design inspired, perhaps, by nature itself [12]. Inside these vessels, the iron cakes were packed along with carbon-rich organic materials such as dried leaves, wood chips, or husks [13]. When heated to temperatures nearing 1200℃, the carbon from the organic matter slowly diffused into the iron. Over several days of slow, controlled cooling, this process transformed the metal into ultra-high-carbon steel with around 1.5-2% carbon content [14, 15].

As the steel cooled, cementite particles (Fe_3C) began to form within the iron matrix. These tiny bands created the wavy, ladder-like patterns that became the signature of Wootz steel blades [10]. More than just beautiful, these microstructures were responsible for the steel's unique blend of hardness and resilience—making Wootz blades capable of holding a keen edge while withstanding intense stress in battle [17].

But the process didn't end with chemistry. It took the hands of master blacksmiths to bring out the full potential of Wootz [4]. Forging the steel at precise temperatures, they ensured the delicate microstructure was preserved rather than destroyed [5]. Recent metallurgical studies have revealed that trace elements like vanadium, naturally present in Indian iron ores, helped stabilize the carbide patterns during forging, locking in the mechanical performance and visual allure of each blade [9].

When European scientists and explorers first encountered Wootz swords, they were astonished. Many believed such quality could not have come from traditional furnaces—let alone ones developed centuries before industrialization [18]. Yet, the steel spoke for itself. Its superior qualities couldn't be denied. Even today, researchers continue to study Wootz, applying its lessons to develop next-generation high-performance alloys used in everything from jet engines to surgical tools [16].

From the ancient foundries of South India to modern materials laboratories, Wootz steel stands as a powerful testament to the ingenuity and precision of early Indian metallurgists. It remains not only a technological marvel of the past, but also a source of inspiration for the future [19].

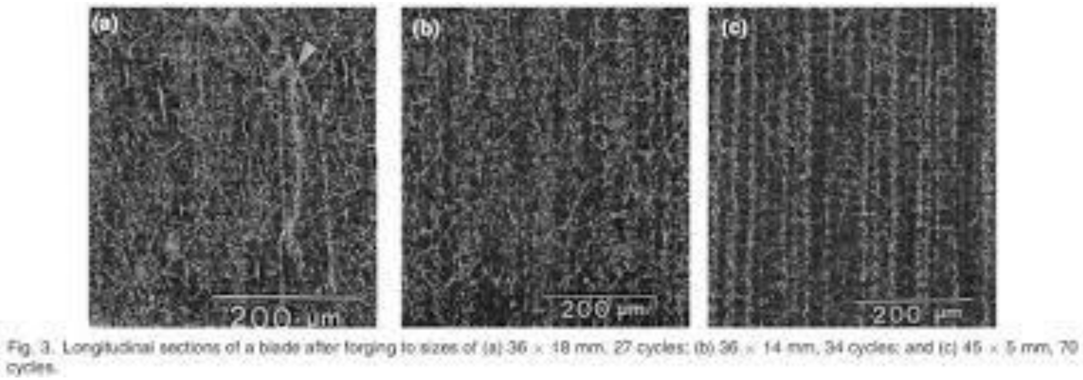

Figure 3. *Microstructure of Wootz steel.*

It needs to be mentioned here that a lot of research has been done on the microstructure of Wootz steel and the manufacturing processes used to obtain the microstructure.

3. Suggestions for Improvements

While latest technological developments have helped the growth of GDP of India and mostly the elite in India, I believe that for real development, all sections of society have to develop equally. Why don't we revive the ancient metallurgical techniques on a small scale in rural areas to help the artisans and craftsmen? There may still be some families in rural India who are descendants of the old craftsmen and who may have access to ancient techniques. Unfortunately, in ancient India, most of the crafts were closely guarded secrets and only particular family members or next of kin were aware of these techniques. This will be a very good way of employment generation at the rural scale. In South India, parts of Tamil Nadu and Karnataka were well versed in metallurgical crafts as evidenced by the artifacts that have been discovered here.

My idea is-to have large blast furnaces and electric arc furnaces mainly to export steel in large quantities. This will bring us valuable foreign exchange. This idea is already being pursued by big companies like Tatas and Essar In addition, for the local needs of people, local technologies can be once again revived in line with The Make in India policy. Household items like vessels, structural steel for rural construction etc can be done using indigineosly made steel.

The main feature observed in furnaces of yore are that there were plenty of small furnaces, thereby employing many people at the same time. The output of the furnaces could have been used for many different purposes or further processed. This model of many small furnaces reminds one of the Japanese model of many small scale anciliary Industries that supply parts to a large Industry.

4. Conclusions

This paper traces the history of metallurgy from ancient times. It discusses certain methods of manufacture and concepts and traces their evolution from ancient times. It tries to compare the advantages and disadvantages of ancient and nodern metallurgy. Lot of research can be done with ancient metallurgy as base. Currently, interest in ancient materials has been revived, the world over. However, this has to be blended with modern techniques of manufacture to obtain meaningful results.

Abbreviations

I.I.T	Indian Institute of Tecnology
BCE	Before Christ
GDP	Gross Domestic Product
Fe3 C	Iron Carbide

Conflicts of Interest

The authors declare no conflict of interest.

References

[1] Encyclopedia of green materials. C. Basker, 2025.

[2] F. Mohamed, M. Jamil M. F. M. Zain, Sustainable Material: Challenges and Prospect, Journal of Advanced Research in Materials Science, Volume 57, Issue 1 (2019) 7-18.

[3] D. K. Chakravarty, The early use of iron in India, 1992, Oxford University.

[4] S. Srinivasan, C. M. Sinopoli, K. D. Morrison, R. Gopal, S. Ranganathan South Indian Iron Age Iron and High Carbon Steel: With Reference to Kadebakele and Comparative Insights from Mel-Siruvalur Metallurgy and Civilisation: Eurasia and Beyond, J. Mei and Th. Rehren, London (2009), pp. 116-121.

[5] J. D. Verhoeven, A. H. Pendray, W. E. Dauksch, The Key Role of Impurities in Ancient Damascus Steel Blades, JOM 50 (1998) pp 58-64.

[6] S. Srinivasan, Sharda, India ‘s legendary Wootz steel, National Institute of Advanced Studies, 2004.

[7] Ranganathan, S., & Srinivasan, S. (2006). A Tale of Wootz Steel. Resonance: Journal of Science Education, 11(6), 67-77.

[8] Verhoeven, J. D., Pendray, A. H., & Dauksch, W. E. (1998). The Key Role of Impurities in Ancient Damascus Steel Blades. JOM, 50(9), 58-64.

[9] Balasubramaniam, R. (2002). Delhi Iron Pillar: New Insights. Aryan Books International.

[10] Srinivasan, S. (1994). Wootz Crucible Steel: A Newly Discovered Production Site in South India. Papers from the Institute of Archaeology, 5, 49-59.

[11] Feuerbach, A. M. (2002). Crucible Steel in Central Asia: Production, Use, and Origins. University College London.

[12] Bronson, B. (1986). The Making and Selling of Wootz, a Crucible Steel of India. Archeomaterials, 1(1), 13-51.

[13] Lowe, T. (1989). Damascus Steel: The Story of Wootz Steel. JOM, 41(4), 64.

[14] Wadsworth, J., & Sherby, O. D. (1980). On the Bulat - Damascus Steel Revisited. Progress in Materials Science, 25(1), 35-68.

[15] Reibold, M., et al. (2006). Carbon Nanotubes in an Ancient Damascus Sabre. Nature, 444(7117), 286. https://doi.org/10.1038/444286a

[16] Park, J. S., & Shinde, V. (2013). Technology, Chronology and the Role of Crucible Steel as Inferred from Iron Objects of the Ancient Site at Junnar, India. Journal of Archaeological Science, 40(11), 3991-3998. https://doi.org/10.1016/j.jas.2013.05.018

[17] Smith, C. S. (1981). A Search for Structure. MIT Press.

[18] Faraday, M., & Stodart, J. (1820). Experiments on the Alloys of Steel. Philosophical Transactions of the Royal Society, 110, 253-270.

[19] Olson, G. B. (2013). Genomic Materials Design: The Ferrous Frontier. Annual Review of Materials Research, 43, 1-23. https://doi.org/10.1016/j.actamat.2012.10.045