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Innovations and Evolution of Metallurgy in Islamic Civilization of the Nusantara Region

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Abstract
The study explores the transformation of metallurgy in Islamic civilization and its influence on the development of metalworking in Nusantara. Beginning with pioneers such as Khabab bin Al-Arat and Salman Al-Farisi, who introduced alloy technologies such as the creation of Zulfikar's sword, Islamic metallurgy advanced significantly with contributions from Jabir Ibn Hayyan and Reyhan Al-Biruni. This knowledge developed innovative methods, such as sublimation and nanostructure technologies, which found applications in weapons like the Damascus sword. The knowledge was later disseminated to Java by Sheikh Sadzali, who merged Islamic spiritual teachings with local traditions, particularly in keris-making, through figures like Mpu Supo Driyo and his son, Mpu Supo Mandraki. Collaborating with Sheikh Abdul Jalil, they integrated Islamic values into the symbolic designs of keris, blending functionality and spirituality. This research highlights the continuity of Islamic knowledge in advancing global technology while enriching local cultural heritage in Nusantara.

Keywords: *metallurgy, islamic civilization, keris, archipelago, damascus sword*

Abstrak
Penelitian ini mengeksplorasi transformasi metalurgi dalam peradaban Islam dan pengaruhnya terhadap perkembangan pengerjaan logam di Nusantara. Dimulai dengan para pelopor seperti Khabab bin Al-Arat dan Salman Al-Farisi, yang memperkenalkan teknologi paduan seperti pembuatan pedang Zulfikar, metalurgi Islam mengalami kemajuan signifikan dengan kontribusi dari Jabir Ibn Hayyan dan Reyhan Al-Biruni. Pengetahuan ini mengembangkan metode inovatif, seperti teknologi sublimasi dan nanostruktur, yang menemukan aplikasi pada senjata seperti pedang Damaskus. Pengetahuan tersebut kemudian disebarkan ke Jawa oleh Sheikh Sadzali, yang menggabungkan ajaran spiritual Islam dengan tradisi lokal, khususnya dalam pembuatan keris, melalui tokoh-tokoh seperti Mpu Supo Driyo dan putranya, Mpu Supo Mandraki. Bekerja sama dengan Sheikh Abdul Jalil, mereka mengintegrasikan nilai-nilai Islam ke dalam desain simbolik keris, memadukan fungsionalitas dan spiritualitas. Penelitian ini menyoroti kesinambungan pengetahuan Islam dalam memajukan teknologi global sekaligus memperkaya warisan budaya lokal di Nusantara.

Kata Kunci: *metalurgi, peradaban islam, keris, nusantara, pedang damaskus*

INTRODUCTION

Metallurgy is a scientific discipline covering metals' processing, properties, and behaviour, which significantly advance human civilization [Pramono, A. 2018]. In the history of Islamic civilization, metallurgy has made important contributions, especially in the Abbasid era through Baitul Hikmah, which became the centre of research, science, and technology development. Scientists Jabir bin Hayyan (721-815 AD) and Reyhan Al-Biruni (973-1048 AD) introduced various innovations in metal technology, including carbonization techniques and the development of nanostructures in Damascus swords that are now applied in modern technologies such as *accumulative roll bonding* (ARB) [Pramono, A. 2022].

Over time, the concept of science continued to develop, not only in the Islamic world but also in the Western world. One example is the

influence of Islamic texts such as Jabir bin Hayyan's Kitab Al-Kimya, which became the basis of modern chemical theory, including Dmitri Mendeleev's periodic table of elements (18341907). Jabir bin Hayyan had even developed diffusion theories relevant to metal processing, showing that the fusion between metal science and chemistry had begun long before the Industrial Revolution [Pramono, A. 2021].

During the Industrial Revolution, concepts developed by Muslim scientists inspired Western scientists to build modern technology. Scientists such as Dimitry Chernov (1839-1921) utilized the theory of allotropy and iron-carbon phase diagram, which is highly relevant in steel production, while Vladimir Segal developed *equal channel angular pressing* (ECAP) technology to improve the mechanical properties of metals. These developments reflect the continuity of science from the classical Islamic era to the modern [Pramono, A. 2022].

Science is not only a milestone of technological progress, but also aims to build the welfare of humanity. The book The Development of Science & Technology in an Islamic Perspective [Pramono, A. 2021] emphasizes the importance of integrating spiritual values in science so that technological products not only fulfill material needs but also maintain social and environmental balance. Through this long search, metallurgy has proven its role as a bridge between past civilizations and modern technology. The innovations passed down from generation to generation not only elevate the strategic value of metals in various aspects of life, but also emphasize that science always develops based on experimentation, observation, and deep contemplation.

As the influence of Islamic civilization expanded, this metal science crossed geographical and cultural boundaries, including the archipelago. Java, an important centre of civilization in Southeast Asia, was influenced by this metal technology through trade networks, cultural interactions, and da'wah. The Nusantara's ancestors not only adopted the technologies introduced in their time, but also adapted them to local needs. This can be seen in the manufacture of Keris, spears and various other metal artifacts, which show a high level of metallurgical skills.

The Keris, for example, serves not only as a weapon but also as a cultural symbol rich with philosophical values and spirituality. The process of making Keris involves the techniques of smelting, forging, and combining various metals, which is clear evidence of technological transfer from Islamic civilization [Sunyoto, A. 2012].

This scientific journal aims to bridge the gap between historical and scientific facts by presenting evidence-based research that can strengthen the understanding of how metal technology from Islamic civilization has contributed to technological development in the archipelago. The transition of metal science (Metallurgy) from Islamic civilization to Nusantara shows that science develops collaboratively and cross-culturally. The innovations passed down from generation to generation became an integral part of global technology and played a strategic role in building local civilization through a scientific and comprehensive approach. This article affirms the importance of integrating the values of history, culture, and science to understand the traces of the development of metal science (metallurgy) as a common heritage of humanity.

METHODS

The scientific inquiry adopts a philosophical and historical approach based on analysing Qur'anic verses relevant to metal science, especially Q.S. Al-Hadid verse 25 and Q.S. Al-Kahf verse 96.

In Q.S. Al-Hadid verse 25, Allah S.W.T says;

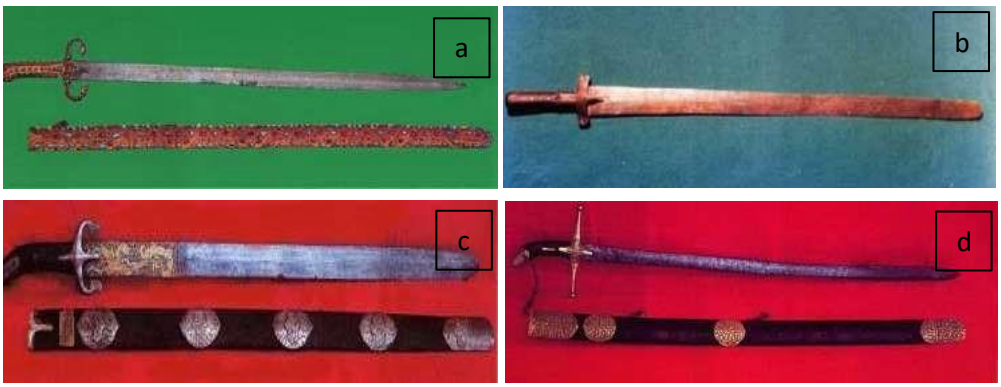
لَقَدْ اَرْسَلْنَا رُسُلَنَا بِالْبَيِّنٰتِ وَاَنْزَلْنَا مَعَهُمُ الْكِتٰبَ وَالْمِيْزَانَ لِيَقُوْمَ النَّاسُ بِالْقِسْطِۚ وَاَنْزَلْنَا الْحَدِيْدَ فِيْهِ بَأْسٌ شَدِيْدٌ وَّمَنَافِعُ لِلنَّاسِ وَلِيَعْلَمَ اللّٰهُ مَنْ يَّنْصُرُهٗ وَرُسُلَهٗ بِالْغَيْبِۗ اِنَّ اللّٰهَ قَوِيٌّ عَزِيْزٌ ﴿٢٥﴾

"Indeed, We have sent Our messengers with clear proofs, and We have *sent down with them the Book and the balance so that man may execute justice. And We have created iron, which has great strength and many benefits for mankind, and that Allah may know who helps Him and His messengers without seeing Him. Indeed, Allah is the Strongest, the Mightiest."*

This verse explains the great benefits of iron in human life, including in the manufacture of weapons. At the time of the Prophet,

iron was the main ingredient in manufacturing important swords used to defend Islam.

Some of the Prophet's swords recorded in history were made of iron, among others: 1) *Al-Ma'thur Sword*: The Prophet's first sword was inherited from his father, Abdullah bin Abdul Muttalib. This sword has a strong iron blade; 2) *Al-Adb Sword*: A sword known for its sharpness, made from quality iron; 3) *Al-Rasub Sword*: An elegantly shaped sword the Prophet used in several battles; and 4)*The Sword of Al-Qadib*: A sword used for symbolic purposes, also made of iron.



His Majesty's Sword made of Iron; a) *Al Ma'thur***;** b) *Al-Adb***;** c) *Al-Rasub***;** and d). *Al-Qadib*. The swords demonstrate the extraordinary skill in ironworking at that time, and reflect the application of metal technology for defense purposes and symbols of majesty. After the revelation of Q.S. Al-Kahf verse 96, there was a significant development in metal technology. Allah's words read:

اٰتُوْنِيْ زُبَرَ الْحَدِيْدِۗ حَتّٰٓى اِذَا سَاوٰى بَيْنَ الصَّدَفَيْنِ قَالَ انْفُخُوْاۗ حَتّٰٓى اِذَا جَعَلَهٗ نَارًاۙ قَالَ اٰتُوْنِيْٓ اُفْرِغْ عَلَيْهِ قِطْرًا ۝٩٦

"Give me pieces of iron." When the iron was even, Dzulkarnain said: "Blow on it. When the iron had become (red like) fire, he said: "Give me some boiling copper that I may pour over the iron".

This verse provides inspiration to combine iron with copper, creating a mixed metal with superior mechanical properties, such as strength and elasticity. Khabbab bin Al-Arat introduced the use of copper, a Companion known as a skilled blacksmith, with the guidance

of Salman Al Farisi as the concept [Republika Khazanah. 2011]. Through this collaboration, the sword of Zulfikar was successfully created. The Zulfikar sword had a strong and flexible blade, making it a superior weapon in battle [Ibn Hisham. 1955]. This exploration combines historical and empirical analysis of metal artefacts and the study of Qur'anic verses to show how metal technology during the time of the Prophet developed with spiritual and material-based innovations. This reinforces that science and technology in Islam have always been based on a balance between material needs and religious values.

Development of Sword-Making Methods: The Transition of Zulfikar's Sword-making Method to the Sword of Damascus

Zulfikar's sword-making process has a strong scientific basis in metal technology as stated in classical texts such as *Al-Jamahir fi Ma'rifat al-Jawahir* [Pramono, A. 2022]. Zulfikar's sword-related experiments show similarities with the *accumulative roll bonding (ARB)* method. In this method, metal plates are stacked, pressed, and bent with a rolling load to produce a fine-grained metal with superior mechanical properties [Tsuji, N. 1999]. This technique creates sword blades that are strong, flexible and durable. This approach was used not only in making Zulfikar's sword but was further developed in making the Damascus sword by Al-Qashani, famous for its *flowing water pattern* [Rahman, A. 2015].

Modern research also provides additional scientific evidence, such as the discovery of *Carbon Nanotubes* (CNTs) in Damascus swords. CNTs give the sword significant advantages, including exceptional sharpness and high flexibility. Elements such as carbon, chromium, manganese, and cobalt play an important role in the strength and sharpness of these swords. Based on the theory of [Hoyland, R.G., 2012] and modern scientific research, it is evident that Zulfikar's sword is a masterpiece of metalworking that is highly useful in both military and scientific contexts. Based on [Paufler, P., 2006] it is stated that the prowess of the Damascus sword comes from CNTs that provide exceptional strength, sharpness, and flexibility. Made from

wootz steel with carbon and other metals, the sword reflects the superior nanotechnology of the now lost Islamic civilization.

Figure 2. Zulfikar's sword made by Khabab and Salman

Figure 3. Salahudin Al Ayubi's Damascus sword which has similarities to the ARB process.

The development of metal technology in manufacturing the Zulfikar and Damascus swords reflects metallurgical advances rooted in experimentation and innovation across the ages. With its exceptional strength, the Zulfikar sword demonstrates the utilization of advanced metalworking techniques, such as accumulated plating and re-forging, to produce a flexible and durable blade. These techniques were later refined in manufacturing the Damascus sword, which relies on superior mechanical properties and the unique flow patterns that characterize it. The integration of modern findings, such as the discovery of CNTs in Damascus sword blades, shows how Islamic civilization not only mastered metallurgical technology, but also intuitively applied the newly scientifically proven nano-principle.

Development of Sword Manufacturing Process Method: Results of Nano Technology Development

ARB technology, developed by Nobuhiro Tsuji in 1997, became the cornerstone of developing nanotechnology-based materials. This method resembles Zulfikar's sword-making technique and Damascus's sword, which was started by Khabab bin Al-Arat and later developed by Al-Qashandi. In the process, a stack of metal plates is pressed using a rotary roll load, resulting in the formation of fine grains that improve the mechanical properties of the metal to the nanometer scale. Jabir Ibn Hayyan's *Al-Kimya* became an important milestone in the development of chemistry, covering techniques such as sublimation, crystallization, filtration, extraction, and distillation. Through in-depth laboratory experiments, Jabir separated pure minerals and metals, creating the foundation of experiment-based scientific research. These separation techniques showed their relevance in metal processing for manufacturing the Zulfikar and Damascus swords, which were renowned for their strength.

Zulfikar's sword, symbolic of Islamic technology, was designed using approaches that can now be linked to modern principles in metallurgy. The combination of Jabir Ibn Hayyan's traditional knowledge and the continued development by his students, such as Al-Kindi and Al-Biruni, reflects the close relationship between classical science and cutting-edge technology. It shows how Islamic knowledge pioneered the development of material technology, in this case, how iron was developed into valuable products and brought benefits to mankind.

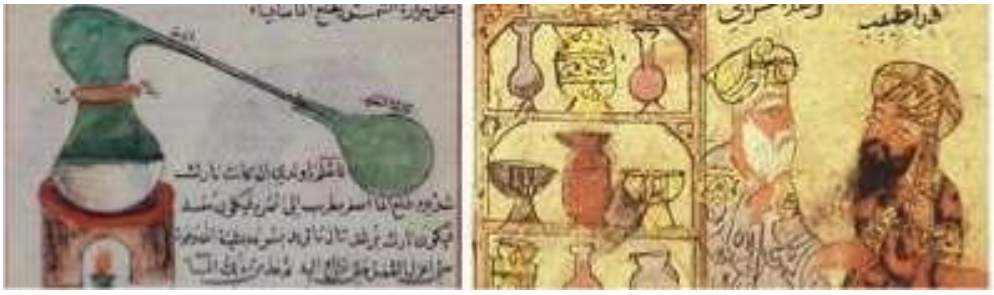


Illustration of Chemical and Technological Processes in the Book of Al-Kimya.

The Making Process and Advantages of the Damascus Sword Based on Kitab *Fi Ma'rifat* Al-Jawahir

The Theory of Sublimation and Metal Processing as a Basis for Scientific Expeditions to the Land of Java

Jabir Ibn Hayyan's *Al-Kimya* and Reyhan al-Biruni's *Makrifat* al-Jawahir became important scientific foundations in Islamic civilization. *Al-Kimya* introduced the theory of sublimation, a method of separating gases from solids through heating, as part of scientific laboratory experiments. This technique became an important basis in metal refining to produce high-quality materials. Meanwhile, *Makrifat al-Jawahir* outlines the processing of metals through *pressing* and layered stacking methods that produce nanometer-fine grains, which is relevant to modern technologies such as *accumulative roll bonding (ARB)*.

In the era of Islamic glory, these sciences became the cornerstone of technological advancement and were used as a medium to spread Islamic values. Muslim scholars and scientists such as Al-Qashandi and Reyhan al-Biruni utilized this knowledge to demonstrate the harmony between science and spirituality. Metal science, which was able to produce the sword of Zulfikar and the sword of Damascus, was not only a symbol of strength, but also a symbol of Islamic intellectual excellence.

This knowledge then became the provision of scholars and scientists to spread Islam to the archipelago. One of them was Sheikh Sadzali, a scholar who brought the message of Islam to Java; armed with the Islamic scientific tradition inherited from the books of *Al-Kimya*

and *Makrifat al-Jawahir*; in his preaching, Sheikh Sadzali used this metal science to show the superiority of Islamic civilization to the local community. The metalworking techniques introduced also influenced the tradition of making Keris, spears and other metal tools in Java, which have spiritual and philosophical values.

DISCUSSION

The development of Metallurgy in Islamic history shows remarkable continuity. It started with Khabbab bin AlArat, a master blacksmith, and Salman Al-Farisi who introduced the alloying of iron and copper to create superior mixed metals such as the Zulfikar sword. In the following century, Jabir Ibn Hayyan through *his* book *Al-Kimya* developed metal technology with techniques such as sublimation, crystallization and distillation, which was later perfected by Reyhan Al-Biruni in *Ma'rifat al Jawahir* through pressure methods and nanostructures, as seen in the Damascus sword.

This scientific legacy was brought to the archipelago by Sheikh Sadzali, an emissary of the Ottoman Turkish Caliphate during the era of Sultan Mehmed I, who combined metal technology with Islamic preaching, teaching techniques such as sublimation and pressing to local communities. This teaching gave birth to the tradition of Keris-making in Java, which symbolizes the harmony between technological innovation and Islamic spiritual values.

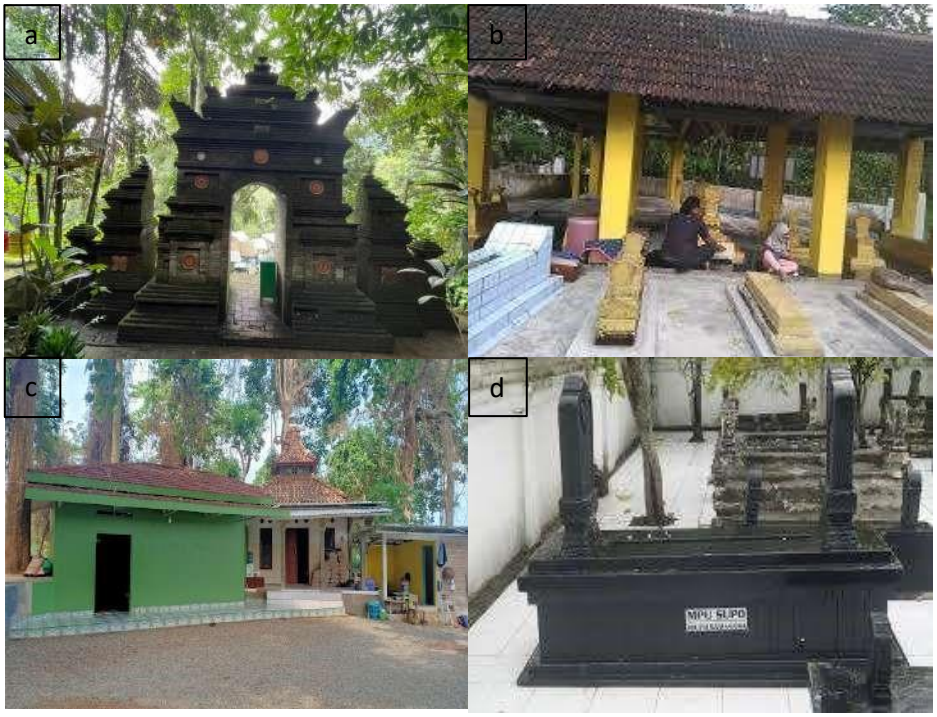
Metal Science (Metallurgy): Sheikh Hasan Sadzali and the Local Heir - Mpu Supo Driyo

The metal science introduced by Sheikh Sadzali through the Islamic intellectual tradition found its acceptance among local experts such as Mpu Supo Driyo who became local heirs who not only accepted the science, but also developed metal technology to create a profound cultural heritage in the archipelago, especially in the tradition of Keris making. Sheikh Sadzali, through his science-based proselytizing approach, introduced metalworking techniques to the people around Mount Muria. In this context, Mpu Supo Driyo, a famous blacksmith in Java, was directly influenced by the teachings of Sheikh Sadzali. Mpu Supo Driyo not only adopted metalworking techniques such as

sublimation, distillation and layered forging, but also combined them with the local tradition of Keris-making.

The Keris produced by Mpu Supo are known to have a unique pattern called *pamor*, which reflects a high-level metalworking technique. This pattern is produced through a process of stacking and layering metals, which is similar to the technique described in Reyhan Al-Biruni's *Makrifat* al-Jawahir. In addition, techniques such as repetitive *pressing* and the use of mixed metals are also applied to create strong, flexible and aesthetically pleasing Keris blades. All of which resulted from the exploration of metal scientists (Metallurgy) in the golden age.

In its development, the metal science taught by Sheikh Sadzali and developed by Mpu Supo Driyo provided an important foundation for the Nusantara metallurgical tradition, especially during the transition from the Majapahit Kingdom to the Demak Sultanate. This tradition also emphasizes that technology can be a medium to convey spiritual values and harmony in people's lives.



Tombs of metal science scholars: a). Sheikh Sadzali b). Mpu Supo Driyo c). Sheikh Abdul Jalil d). Mpu Supo Mandrangi

Mpu Supo Mandraki's Role in Continuing the Metalworking Tradition

Mpu Supo Mandraki, the son of Mpu Supo Driyo, is known as the successor to the metalworking tradition inherited from his father. He played a central role in continuing and enriching metalworking skills such as the famous Keris. The Keris made by Mpu Supo Mandraki not only had the technical advantages of strength and sharpness, but also carried symbolic values that reflected Islamic philosophy. The intricate *pamor* patterns on Keris blades often symbolize the teachings of monotheism, piety and harmony of life, making Keris not just tools or weapons, but also spiritual artifacts that connect local communities with Islamic values. One interesting story about Mpu Supo Mandraki's skill is when Sheikh Abdul Jalil gave him a small piece of iron the size of a candlenut seed to make into a Keris. As a result of discussions with Sheikh Abdul Jalil as the Conceptor, Mpu Supo Mandraki forged the iron into a bar that resembled a suduk sword. After the bar was completed, Sheikh Abdul Jalil suggested a name for the weapon called *Kyai Carubuk*, reflecting both simplicity and deep meaning as a spiritual tool and symbol of courage.

Collaboration with Sheikh Abdul Jalil

Mpu Supo Mandraki's role in integrating Islamic values into local traditions is inseparable from the guidance of Sheikh Abdul Jalil, who was one of the ulama who played a significant role in spreading Islam through a humanist and transformative approach. He assisted Mpu Supo Mandraki in giving spiritual meaning to the Keris-making tradition, making it an effective proselytization tool. Sheikh Abdul Jalil taught the concept of monotheism and harmony of life through the symbolism of the Keris *pamor*, which the Javanese people accepted as an expression of Islamic values in harmony with local traditions. His assistance helped Mpu Supo Mandraki understand that the Keris is not only a physical artifact, but also a medium of da'wah that teaches noble values.

The Existence of Sheikh Abdul Jalil

Sheikh Abdul Jalil is known as one of the ulama with a unique approach to da'wah. He often conveyed the teachings of Islam through local cultural symbolism, making it easily accepted by Javanese people who already had a strong tradition of spirituality. About metalworking, Sheikh Abdul Jalil embedded Islamic values in the creative process of making Keris, making this metal art an effective medium of da'wah. Sheikh Abdul Jalil is also known for his teachings on existential unity (*wahdatul wujud*), which teaches humans to live in harmony with God, others and nature. This thought is reflected in Mpu Supo Mandraki's Keris works, where each blade and pattern contains symbolic spiritual and material balance values. On the other hand, the meaning of Carubuk is 'Like the Earth'.

The philosophy is that humans can accept any situation with grace.

The Nusantara Metal Heritage Collection: Legendary Keris and Traditional Artifacts by Mpu Supo Mandraki, Mpu Supo Driyo, and Contributions of Islamic Scientists

Technological and Spiritual Heritage

The collaboration between Mpu Supo Mandraki and Sheikh Abdul Jalil created a legacy of metal technology that was technically superior and rich in spiritual values. The tradition of metalworking passed down from Sheikh Sadzali through Mpu Supo Driyo to Mpu Supo Mandraki shows the continuity of Islamic science that is able to adapt to local culture. The resulting Keris symbolizes the harmony between technological innovation and Islamic spiritual teachings.

This legacy reinforces Islam's position as a religion that supports technological innovation and local culture. Metalwork is a medium of da'wah that not only enriches local traditions but also spreads the universal values of Islam that continue to be respected today. The Keris, as a product of this tradition, is clear evidence of the collaboration between spiritual values and technological excellence passed down by scholars and blacksmiths.

Traces of Islamic Metal Science in the Archipelago

No.	**Metal** Scientist	Work**s**
1	Sheikh Sadzali	Keris Pamor, Mixed Metal Processing
2	Sheikh Abdul Jalil	Keris Wahdatul Wujud Symbolism in Patterns Keris
3	Mpu Supo Driyo	Keris Nogososro Keris Sabuk Inten
4	Mpu Supo Mandraki	Keris Sengkelat Pusaka Carubuk
	Age	**Demak Sultanate**

Table 1. Metal Science Scholars of the **Demak** Sultanate Period

Demak Sultanate-era Military Device Production: Various Metal Science products in Metallurgy

The Sultanate of Demak, as the first Islamic kingdom in Java, had an important role in Islam's spread and technology's development in its time. One aspect that stands out is the production of military equipment that utilizes Metal Science (Metallurgy). The Sultanate of Demak, the first Islamic kingdom in Java, was not only known as a center for the spread of Islam, but also as an important player in Asian maritime trade and technology transfer networks in the 14th to early 16th centuries [Sunyoto, A. 2018]. With high expertise in Metal Science (Metallurgy), Demak produced a variety of advanced military devices, such as cannons, firearms, Keris and spears. These products were not only used for internal purposes but also traded to various countries, including Japan. This is recorded in the ancient manuscript *Poda Obunawa*, which provides a fascinating picture of the trade relations between the two Regions [Reid, A. 1988].

At that time, Japan was in the Sengoku period, where inter-clan conflicts and civil wars fueled an excellent need for high-quality military hardware. The Sultanate of Demak, with its advanced metal casting technology, became one of the important suppliers of military hardware to Japan. The Poda Obunawa manuscript records that the Japanese imported Demak-made cannons, which were known for being light in weight but high in destructive power. These cannons were superior to local Japanese products or imports from China [Poda Manuscript Notes, Obunawa. 2006].

In addition, Demak-made Keris and carubuks, produced with unique metal forging techniques, also became important commodities. Japanese blacksmiths even studied these Keris-making techniques, indicating a transfer of technology from the archipelago to Japan. Not only trade, some military hardware was also given as diplomatic gifts to strengthen political and cultural relations between Demak and Japan.

Records in the Poda Obunawa manuscript show how close maritime trade relations were at that time, with the Sultanate of Demak playing a strategic role as a centre of distribution and technological

innovation. This trade in military hardware reflects Demak's excellence in Metallurgy and its ability to compete internationally [Ricklefs, M. C. 2008].

This narrative also confirms that technology transfer in the past did not only come from the West to the East, but also from the archipelago to East Asia. The Sultanate of Demak, with its technological heritage and trade diplomacy, proved itself to be a significant force in Southeast Asia's maritime and military history. This relationship between Demak and Japan is one proof that the history of the archipelago has an important contribution to the development of global technology.

The Demak Sultanate's mastery of metalwork was not only limited to weapon-making but also to infrastructure development. For example, the Great Mosque of Demak was constructed using metal nails and joints. This shows a deep understanding of metal properties and processing techniques.

Figure 8: Military Devices of the Demak Sultanate Era: Metallurgical Expertise in the History of the Archipelago, a Product of Technology Imported to the Kingdom of Japan during the 14th-16th Centuries [Poda Manuscript Records, Obunawa. 2006].

The Petilasan of Mpu Supo Driyo in Tuban and Mpu Supo Mandraki in Central Java regions, such as Kudus, are clear evidence of the important role of metal science (metallurgy) in the history of the archipelago, especially during the transition from the Majapahit Kingdom to the Demak Sultanate. In a modern context, this petilasan can be understood as a traditional laboratory, where mpu and ulama developed metal technology to create sophisticated military devices, such as *Barunaja*, spears, torpedoes, and pamor Keris. The presence of natural resources such as copper, eternal fire and dyeing ponds around the petilasan reinforces the function of this place as a center of metal experimentation.

Figure 9: The Glory of the Demak Sultanate: A Legacy of Metallurgical Technology in Military Devices and Mosque Construction.

Figure 10: Petilasan as Metal Experiment a). Mpu Supo Driyo in Bojonegoro: Kayangan Api Site as a Center for Experimentation in weapon making b). Mpu Supo Mandraki in Tuban with Spiritual Symbol of Big Tree c). CuS Mineral in Dermawuharjo Grabagan Tuban d). Natural Landscape of Copper and Sulfur Mine: Mineral Deposits in Traditional Metallurgical Zones of the Archipelago.

The next generation, Mpu Supo Mandraki, continued this tradition under the guidance of Sheikh Abdul Jalil. Together, they created metal devices and artifacts such as spears, swords and pamor Keris. The pamor patterns on Keris are aesthetically pleasing and improve the distribution of stress on the blade, reflecting the advancement of the Nusantara's metallurgical technology. Sheikh Abdul Jalil reinforced the spiritual dimension of this technology by teaching the concepts of tawhid and harmony through the symbolism of the Keris pamor.

Scientific evidence of the existence of this petilasan, such as the Copper-Sulphur Cus content in Tuban and the pattern of artifacts found, shows that Metallurgical technology in the archipelago had reached a very advanced level at that time. The collaboration between mpu and ulama not only resulted in technical innovations but also made an important contribution to the spread of Islamic values. This petilasan symbolizes the harmony between technological innovation and

spirituality passed down to the Demak Sultanate, making the Nusantara's military hardware a testament to the excellence of metal technology in its day.

CONCLUSION

The transformation of metal science in Islamic civilization reflects the continuity between technological innovation and spiritual values. From the development of metal technology by Khabab bin Al-Arat to Jabir bin Hayyan and Reyhan Al-Biruni, this science contributed significantly to the development of technology in the archipelago. Sheikh Hasan Sadzali integrated this scientific tradition with local culture, creating artefacts such as the Keris that combines technical excellence and spiritual value.

Collaborations between Mpu Supo Driyo, Mpu Supo Mandraki, and scholars such as Sheikh Sadzali and Sheikh Abdul Jalil enriched the Nusantara's metallurgical tradition. Works such as Kyai Sengkelat, Kyai Carubuk, and the military hardware of the Demak Sultanate are evidence of technological excellence and spiritual integration in local traditions.

The Sultanate of Demak played an important role as a centre of technological and cultural innovation, demonstrating that Islam brought spiritual values and drove global technological progress. Metal science from Islamic civilization has proven its ability to adapt to local cultures, making this heritage an integral part of the Nusantara's history of technology and spirituality.

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