Millatī, Journal of Islamic Studies and Humanities
Vol. 7, No. 1, June 2022: p. 33-51. DOI: 10.18326/mlt.v7i1.7048
p-ISSN : 2541-3627 ; e-ISSN 2540-9964
Website: http://millati.iainsalatiga.ac.id/index.php/millati/index

The Classical Book of the Abbasid Period as a Reference for Advanced Military Technology: A Thought Genealogy Study

Agus Pramono
Fakultas Teknik Jurusan Metalurgi Universitas Sultan Ageng Tirtayasa Cilegon, Banten, Indonesia
agus.pramono@untirta.ac.i

Abstract
The most effective metal manufacturing process is double pressing, which is capable of bending metal. The bending of the metal will cause a reaction that can improve its mechanical properties. In the book Al-Jamahir fi ma`rifat al-Jawahir there are three patterns that explain the process methodology, they are; لملك Al mil'k: Tension, الفقلو Al Fiqlu: bending, الإنفيل Al infial: Reaction. This is in line with the development of the equal-channel angular pressing (ECAP)'s method: if the metal is bent, a reaction will occur which can improve its mechanical properties. In Kitab Al-Hiyal there is a hypothesis of the existence of an attraction in the movement of celestial bodies which is able to provide an explanation of the movement of large forces. Then, another discussion is about the motion of stars and the law of attraction, where there is a force of attraction between celestial bodies. According to the book of Al Hiyal, the greatest force is the earthquake movement which causes a circular rotary force effect, this also underlies the high pressure torsion (HPT) method by PW Bridman who discovered the HPT method with a narrative that HPT is initiated by earthquake movements and in his scientific article explains that the earthquake movement as a torsional motion. In another experimental reference, accumulative roll bonding (ARB) technology is the basis of the material development method which is carried out by stacking plates that are loaded with roll compression loads. Based on the double-edged sword experiment, the zulfikar sword, which is explored by Khabab bin Art as a practitioner and Salman Al Farishi as a drafter, this method has similar procedures for stacking and finalizing the base plate. The development of the Zulfikar sword continued with Al Qashhandi who developed the Damascus sword used by Salahuddin Al Ayubi, from the perspective of the metal plate bending stress originating from the roll compression stress, where there is a deflection of the tip of the plate on the blade. The results of the characterization of the ECAP, HPT and ARB methods show that HPT has superior mechanical properties characterization results compared to other methods, but HPT has limited dimensions which can only be applied to components that have a size of less than 5 cm, with a powder base material. Meanwhile, ECAP and ARB dominate in many applications because they can be applied to large dimensions, as well as the availability of materials and the flexibility of raw materials into application products.

Keywords: *Baitul hikmah; Muslim reference books; ECAP; HPT and ARB.*

Abstrak
Proses pembuatan logam yang paling efektif adalah pengepresan ganda, yang mampu menekuk logam. Pembengkokan logam akan menimbulkan reaksi yang dapat memperbaiki sifat mekaniknya. Dalam kitab Al-Jamahir fi ma`rifat al-Jawahir ada tiga pola yang menjelaskan tentang metodologi proses, yaitu; لملك Al mil'k: Ketegangan, الفقلو Al Fiqlu: membungkuk, الإنفيل Al infial: Reaksi. Hal ini sejalan dengan perkembangan metode equal-channel angular pressing (ECAP): jika logam dibengkokkan, akan terjadi reaksi yang dapat

memperbaiki sifat mekaniknya. Dalam Kitab Al-Hiyal terdapat hipotesis adanya suatu gaya tarik dalam pergerakan benda-benda langit yang mampu memberikan penjelasan tentang pergerakan gaya-gaya besar. Kemudian pembahasan lainnya adalah tentang gerak bintang dan hukum tarik-menarik, dimana terjadi gaya tarik menarik antar benda langit. Menurut kitab Al Hiyal, gaya terbesar adalah gerakan gempa yang menimbulkan efek gaya putar melingkar, hal ini pula yang mendasari metode puntir tekanan tinggi (HPT) oleh PW Bridman yang menemukan metode HPT dengan narasi bahwa HPT diprakarsai oleh gerakan gempa dan dalam artikel ilmiahnya menjelaskan bahwa gerakan gempa sebagai gerakan puntir. Dalam referensi eksperimental lain, teknologi akumulatif roll bonding (ARB) adalah dasar dari metode pengembangan material yang dilakukan dengan menumpuk pelat yang dibebani dengan beban kompresi rol. Berdasarkan eksperimen pedang bermata dua yaitu pedang zulfikar yang dieksplorasi oleh Khabab bin Art sebagai praktisi dan Salman Al Farishi sebagai drafter, metode ini memiliki prosedur yang sama untuk menyusun dan menyelesaikan pelat dasar. Perkembangan pedang Zulfikar dilanjutkan dengan Al Qashhandi yang mengembangkan pedang Damaskus yang digunakan oleh Salahuddin Al Ayubi, ditinjau dari tegangan lentur pelat logam yang berasal dari tegangan tekan gulungan, dimana terjadi defleksi ujung pelat pada Pedang. Hasil karakterisasi metode ECAP, HPT dan ARB menunjukkan bahwa HPT memiliki hasil karakterisasi sifat mekanik yang unggul dibandingkan dengan metode lainnya, namun HPT memiliki keterbatasan dimensi yang hanya dapat diterapkan pada komponen yang memiliki ukuran kurang dari 5 cm, dengan bahan dasar bubuk. Sementara itu, ECAP dan ARB mendominasi di banyak aplikasi karena dapat diterapkan pada dimensi yang besar, serta ketersediaan bahan dan fleksibilitas bahan baku menjadi produk aplikasi.

Kata Kunci: *Baitul hikmah; buku referensi Muslim; ECAP; HPT dan ARB.*

INTRODUCTION

Harun Ar-Rashid was the fifth caliph of the Abbasid caliphate and ruled between 786 and 803. Harun learned a lot from Yahya ibn Khalid Al-Barmak. The era of Harun's reign, which was continued by Ma'mun Ar-Rashid, is known as The Golden Age of Islam, at that time Baghdad became one of the world's scientific centers [1]. Through Baitul Hikmah, as an educational and research institution that has a role and function for the development of research and civilization[2]. Among the famous scientists who became the central figure of Baitul Hikmah was Sheikh Ja'far bin Muhammad bin Ali bin Husayn bin Ali bin Abu Talib, born in Medina on 17 Rabiul Awwal 83 Hijriyah/20 April 702 AD (M), and died on 25 Shawwal 148 Hijriyah/December 13, 765 M. He is an expert in science whose ideas become the main basis for the Imams of the Madhhab and is a teacher for the Imams of the Maddhab such as: Abu Hanifah or Imam Maliki[3]. Jakfar Sadiq, who is also the great-grandson of Sayidina Ali, is an expert in science and knowledge, gaining knowledge from

[1] As-Suyuthi Imam, *Tarich Culafa - Sejarah Para Penguasa Islam*, ed. by Imam Sulaiman, 1st edn (Jakarta: Jakarta : Pustaka Al-Kautsar, 2001, 2006), XXI.

[2] Agus Pramono, *ILMU PENGETAHUAN & TEKNOLOGI DALAM PERSPEKTIF ISLAM* (Deepublish, 2021) <https://doi.org/https://books.google.co.id/books/about/Buku_Perkembangan_Ilmu_Pengetahuan_Tekno.html?id=GaA9EAAAQBAJ&redir_esc=y>.

[3] A. Y' 'Al-Hassan, *The Different Aspects of Islamic Culture: Science and Technology in Islam* , ed. by A.Z. Iskandar Maqbul Ahmed (United Kingdom (U.K): Pt.1. The exact and natural sciences -- v. 2. Technology and applied sciences., 2001).

the great-grandson of Caliph Umar bin Khatab, namely Salim Abdullah bin Umar. Salim bin Umar, who is also a scholar of Islamic jurisprudence, got knowledge and science from Khabab bin Art and Salman Al Farishi. At that time there was no writing of books, but after the era of Caliph Harun al Rashid, there was Baitul Hikmah. After massive funding related to science was carried out at that time, then a student from the Jakfar Sadiq generation, Jabar Ibn Hayan wrote in the book *Al Sab'een*. Jabar Ibn Hayan had several students who succeeded in exploring the science. Through Al Qalqashandi in the book *Subh Al-Asha*, which initiated the birth of nano-material technology. One of Shaykh Jafar Ash Shodiq's students was Jabar Ibn Hayan who was the inventor of chemistry before the Russian scientist Dimitry Mendeleyev was born [4]. Jabr Ibn Hayan had several students who succeeded in exploring scientific knowledge, through Al Qalqashandi, Reyhan al Biruni and others[1-3] . In 1258, there was an invasion, siege, and destruction of the city of Baghdad, the capital of the Abbasid Caliphate by the Mongol Ilkhanate troops with allied forces under Hulagu Khan to establish a strong imperial and expand the empire this was followed by the total destruction of the city. The city was destroyed and burned. Even the libraries in Baghdad, including the baitul-hikmah, were not spared the attacks of the Ilkhanate troops, who destroyed the libraries and dumped their valuable books into the Tigris river. century, and this event is widely referred to as the end of the Islamic Golden Age [5] [6]. The Muslim scholar in the field of science, Al-Qalqasyandi, a student of Jabr Ibn Hayan who was learnt in metal science, stated that all the books in the caliph's library were destroyed. All traces and various kinds of knowledge contained in it were also destroyed. The same thing happened in other Iraqi cities, such as in Mosul. However, the Nizamiyah and Mustansiriya libraries were not destroyed because the books in this assembly were fiqh and literary books. Before the fall of Baghdad, a similar disaster befell a number of libraries in Islamic areas. Then, among of them, there was the burning of certain books in Al Hakam, Cordoba, in the 11th century. In Rayy, it happened in 1027 AD. Also, the burning of books by the Crusaders in Tripoli, Lebanon. Caliph Al-Mustasim of the Abbasid dynasty was unable to stem the attacks of the Mongol army and its allies led by Genghis Khan's grandson. In February 1258, Hulagu Khan's army managed to defeat the caliphate army and burnt the city of Baghdad. The 8th century city in Dakhu as the center of Middle Eastern and Islamic culture was destroyed in just a few weeks. Based on reference studies, the moment of the collapse of the Abbasid Caliphate and the city of Baghdad was the end of the glory of the Islamic culture. However, in fact the heyday of Islamic culture has long since decayed. When Al-Mustasim ascended the throne in 1242, the political power of this dynasty had been greatly eroded. The Abbasid Caliphate at that time was not the same caliphate as it was during its heyday in the late 8th and early 9th centuries. Baghdad as the capital of the caliphate may remain a metropolitan city compared to other cities in the entire Arabian Peninsula. However, it is different from the time of Caliph Harun Al-Rashid

[4] Agus Pramono, *ILMU PENGETAHUAN & TEKNOLOGI DALAM PERSPEKTIF ISLAM.*

[5] 'Matthew E Falagas' 'Effie A. Zarkadoulia' 'George Samonis', 'Arab Science in the Golden Age (750–1258 C.E.) and Today ', *The FASEB Journal* , 1.1 (2006), 1581–86.

[6] 'Geertz Clifford', 'Religion: Anthropological Study ', in *International Encyclopedia of the Social Sciences*, ed. by David L. Sills, 1st edn (London: Collier-Macmillan Publishers, 1965), I, 2–20.

(786-803) or Abdullah Al-Ma'mun (813-833). A century after the era of Harun al-Rashid, the city's influence and glory had declined. Political changes made the political power of the caliph eroded and its territory narrowed. In the mid-13th century, the effective domain of the Abbasid Caliphate was confined to central and southern Iraq, the caliph's traditional title of amir al-mu'minin—The Ruler of The Faithful—was ultimately a pseudo-authority. Especially after the emergence of the Umayyad Caliphate in Spain and the Fatimid dynasty in Egypt. The most substantial thing in the decline of this civilization is because the ummah (societies) is kept away from science and knowledge. Funding for research and experiments in educational institutions/science assemblies began to be eliminated since the end of the Al Makmun caliphate, books and scientific references were no longer taught among the people. Other libraries that suffered the same fate were Banu Ammar in 1109 AD, Nishapur in 1153 AD, due to the burning of the Ghazna Library in 1155 AD, and the destruction of the Merv Library in 1209 AD, the ummah had no longer studied scientific principles related to the natural phenomena.

Overview of the Book of Science and Technology

The first book that became a reference for science was Al-Kitab al-mukhtasar fi hisab al-jabr wa'l-muqabala written by Muhammad bin Musa Al-Khwarizmi (780-850), in Russia known as Al-Ghorizma. In several chapters described are numbers algorithms in mathematical calculations. This book is a series of discussions of systematic solutions of linear equations and quadratic equations. This is the reason why Khwarizmi is called of the father of Algebra. Al-Khwārizmī also played an important role in introducing Arabic numerals through the work of Kitāb al-Jam'a wa-l-tafrīq bi-ḥisāb al-Hind which was later adopted as the standard number used in various languages and was later introduced as the decimal position numbering system in the world. west in the 12th century. He revised and adapted Ptolemaic geography as well as writing on astronomy and astrology.

Figure 1. The Sheet of Al-mukhtasar fi hisab al-jabr wa'l-muqabala's Kitab

Contributions to mathematics are the subtraction of random quadratic equations to one of the six basic types and to provide algebraic and geometrical methods for solving the principal basis. The subtraction of modern abstract numbers in Khwarizmi's algebra is thoroughly rhetorical, with nothing syncopated to be found in Greek Arithmetic or Brahmagupta's work. Even the numbers are written more in words than symbols[7]. The six types of equations with modern numbers, are:

* square is equal to root ($ax^2 = bx$)
* square is equal to number ($ax^2 = c$)
* root is equal to number ($bx = c$)
* square and root are equal to number ($ax^2 + bx = c$)
* square and number equal to root ($ax^2 + c = bx$)
* root and number equal to square ($bx + c = ax^2$)

The following sections provide practical examples of the application of regulations relating to the application of the problem of measuring area and volume or content. The last section deals with calculations that involve the difficult rules from the Islamic inheritance, such as the division and distribution of inheritance according to mathematical rules. Because of his great service to the world of mathematics, several books by Khwarizmi were reprinted from 1906-1983 at the Science of Petersburg, Russia University[8].

Al Kimya, The book on chemistry written by Jabr Ibn Hayyan, is a formulation of the difference between elements, chemical bonds, between astronomy and astrology. In the Western world, Jabr is better known as The Jabirian corpus for the overall center of his experimental activities. His work has been translated into various languages including English, Spanish, French, Dutch, Greek and Germany. Al Kimya has been adapted into several volumes, namely: Book af The Composition of Alchemy, The Work of Geber, Sun of Perfection, book of Stone[9]. Jabr succeeded in giving the foundations of scientific and experimental chemical research methods. In the laboratory established through experiments of sublimation, crystallization, filtration, extraction, and distillation or distillation, those aim is to to obtain pure minerals and metals from various mixtures. Raw

[7] 'Uta C. Merzbach' 'Carl B. Boyer', *A History of Mathematics* , ed. by Uta C. Merbach, 2nd ed (New York: John Wiley & Sons, 1991), I.

[8] Gerald J. Toomer, *Al-Khuwārizmī, Abu Ja'far Muḥammad Ibn Mūsā* , ed. by Charles Coulston, 1st edn (Gillispie: Dictionary of Scientific Biography, 1970), VII.

[9] Jābir Ibn Ḥayyān, *Contribution à l'Histoire Des Idées Scientifiquesdans l'Islam: Jābir et La Science Grecque* , ed. by Paul Kraus, 2nd edn (Paris: Global Scholarly Publications, 1935), IV.

materials that are mixed with various objects and other inherent substances can be sorted through the laboratory so that metallic purity can be obtained. Sublimation to separate the gas content of a solid, crystallization to separate a substance from a mixed solution by turning it into particles/solids, filtration to separate substances through differences in particle size, extraction to take a compound contained in an object, such as separation alcohol from a mixture of alcohol water, distillation to separate the liquids by using different boiling points. Water can be purified simply by using the distillation process[10].

(a) (b)

Figure 2. Al Kimya's Kitab: (a). The explanation of the theory of sublimation and metal melting experiments (b). Arrangement of elements in shelving/certain devices

A further reference to the Al-Kimya' Kitab is the Al Sab'een's Kitab, which has also been translated into Latin. Translated by the English scientist, Robert Chester in 1444, with the title The Book of the Composition of Alchemy. Meanwhile, the second book, Kitab Al Sab'een, was translated by Gerard Cremona. Then in 1678, another English scientist, Richard Russell, translated another of Jabir's works under the title Summa of Perfection. Unlike the previous authors, Richard is the scientist who first referred to Jabir as Geber, and praised Jabir as an Arab prince and philosopher[11]. In the introduction of Al Kimya's Kitab Jabr wrote his experience in the experiment, *"I first found out with my hands and brain and I researched it to be as true as possible and I looked for errors that might still be hidden"*. The instruments used are mostly cutting, melting and crystallizing equipment. In the book Al Kimya managed to modify and correct Aristotle's theory of the metal base, which has remained unchanged since the early 18th century AD[12].

The book that describes metal science, especially in terms of blacksmithing in the Islamic world is Al-hadid's Kitab (Book of Iron) by Al-Jildaki, who is also a student of Jabr Ibn Hayan. In this book, a lot of information is disclosed about the ability of the Muslim community in the golden era in processing iron and steel. In the next experiment, Ibn Ishaq Al-Kindi, who is also a student of Al Jidaki, found the firind pattern found in his experiments on all types of artificial iron. Meanwhile, swords made of natural iron that do not have decorative patterns are called firind[13]

[10] Heriyanto Husain, *Menggali Nalar Saintifik Peradaban Islam* (Jakarta2011: Mizan Publika, 2011).

[11] Agus Pramono, *ILMU PENGETAHUAN & TEKNOLOGI DALAM PERSPEKTIF ISLAM*.

[12] Jābir Ibn Ḥayyān, IV.

[13] Alan Williams, *The Sword and the Crucible A History of the Metallurgy of European Swords up to the 16th Century Series*, ed. by Kelly De Vries (Maryland: Loyola University Maryland , 2012), LXXVII.

(a) (b)

Figure. 3 (a) Ferrous metal processing (b) Pembuatan senjata Damaskus sword weapon processing.

Al-Qalqashandi who is also a student of Al-Jidaki wrote a book, it is: Subh Al-Asha, In his introduction it is explained that in the 12th century AD Damascus became a very famous center for iron and steel processing. In the description of this book also clarifies various types of iron and steel, namely: natural iron and artificial iron. Shaburqan or male iron is a type of hard iron that is processed in hot conditions. Narmahin or women's iron is soft iron that cannot be processed in hot conditions. According to Al-Kindi's perspective, unnatural iron is called fuladh. Kinds of Iron; antique (ancient/pure), modern, nonantique (not ancient), and nonmodern (not modern) [14]. The quality of antique swords is also divided into three types. The most high-quality ones are called Yemenite. The second quality is called Qal'i and the third is called Indian. various types of non-ferrous metals which are the result of metallurgy that has been achieved in the golden era of Islam. These metals are gold, silver, lead, tin, zinc, antimony, arsenic, copper, bronze, brass and kharisini. The experiment in the Al-Hadid's Kitab which was perfected in the book of Subh Al-Asha, was applied to the application of Salahuddin Al-Ayyubi's sword, which is famous in the Western world as the superior and most powerful sword called the Damascus sword[15]. This method is the development of nano-material-based materials that are currently being developed by the West. The pieces of steel, stacked one on top of the other, bonded together by metal wire, and forged are welded and manipulated to create patterns, hence the term "pattern weld". As one prepares to forge a knife, patterns and tones will be created by the different metallurgical content contained in the alloy pile. Manganese will produce a dark/black tone; Nickel will produce a bright silver tone, Chromium will produce a light gray color and High Carbon will produce a dark gray color, with a medium carbon content, Steel with the highest melting point will be placed close to the outer walls of the pile (which will cause it to heat up faster), the lowest melting point should be closer to the center of the pile. When the pile turns red, it is ready to be welded. After this step, the pile is removed with a hammer, up to half its original thickness, if the blade is too hot it will crack during the hardening process. The rapid dipping process in water or called quenching will cause the metal's molecular structure to crystallize and harden.

Therefore, in the Islamic history it is evident that the Damascus sword became famous when it was used by Salahuddin Al-Ayyubi, a Muslim leader, with his troops in the face of the attacks of Richard the Lion Heart's army during the Third Crusade. King

[14] Aḥmad ibn ʻAlī, ʻQalqashandī: Die Geographie Und Verwaltung von Ägypten', in *Ferdinand Wüstenfeld.*, ed. by Ferdinand Wüstenfeld. (Göttingen, Dieterich, 1879).

[15] Aḥmad ibn ʻAlī, ʻQalqashandī: Ṣuhḥ Al-Aishā', 6th edn, 1913, I.

Richard The Lionheart had time to show off the prowess of his sword to Salahudin Al-Ayubi. Richard arrogantly slashed his sword at a piece of steel. In one slash, Richard's 'Lionhearted' sword was able to slash through the steel. Salahudin smiled and then threw the silk cloth into the air. Then, the sword he was carrying was unsheathed. When it hit Salahuddin's blade, the silk was cut in two[16]. In particular, Robert Hoyland and Brian Gilmore wrote a book entitled, Medieval Islamic Swords and Swordmaking, consisting of 216 pages, treatises written by prominent Muslim scholars in the 9th century AD; Ya'qub Ibn Ishaq Al-Kindi, about sword technology and its various types[17]. This was also verified by German scientist Peter Paufler and his colleagues from a German university who were interested in conducting research related to Salahuddin Al Ayubi's sword. The results revealed that the Damascus sword was the most powerful compared to the katana (sword of the Japanese samurai) and excalibur (sword of King Arthur, the British leader). Based on the metallurgical science that was researched in depth, it was concluded that the Damascus sword was the most powerful sword with amazing sharpness. It was so sharp, the silk handkerchief that floated in the air could be split lightly by this sword. The main material in making this sword is wootz steel. However, because of the fighting between Muslim fighters and Christian soldiers, people began to refer to the steel as Damascus steel, after the Syrian capital. In fact, this steel is supplied from India. The original Damascus sword has a flowing water pattern[18].

Technology Product Development

The scientist who was famous when technological civilization was developing rapidly was Reyhan al-Biruni (973 AD-1048 AD). Continuing the experiments of his teacher Jabr Ibn Hayyan, Al Biruni developed an experiment on gold which at the time of the heyday of Islam obtained from gold mines, was found in mixed form, therefore it needed to be purified by smelting or other techniques. Al-Biruni also explained about the amalgamation method (the process of coating gold particles by mercury and forming an Au-Hg amalgam). This amalgamation is carried out in commercial mines. "After crushing or grinding the gold ore, the ore is separated from the rock and the gold and mercury are mixed and then squeezed in a piece of skin until the mercury drips through the pores of the skin. The remaining mercury is removed by burning," stated by al-Biruni[19]. Naturally, gold is often mixed with silver, because of that Muslim scientists have succeeded in carrying out a second purification process, namely cementation. This is done to separate the silver and this process is called tabkh or tas'id. Al Biruni's student, al-Hamadani, developed the tabkh experiment, by experimenting with thin sheets of gold interspersed with a cementation compound called dawa'. "This compound consists of a mixture of bitriol (sulfuric acid), salt and brick sand. All of these are then heated. The mixture contains sulfuric acid and hydrochloric acid vapors. These vapors do not damage the gold but turn the surface of silver and copper into exfoliating chloride compounds, "To produce very pure gold, cementation can be carried out more than once. A number of historians until now have argued that the advanced process was described by Theophilius (1150-1200). But in fact the basic theoretical concept was developed by al-Hamadan who described the cementation

[16] Amad ibn Abd al-Munim; Qalqashandī Aḥmad ibn ʻAlī; Ibn Jbir, Muammad ibn Amad Damanhr, *Sabl Al-Rashd Ilá Naf' Al-'ibd.*, 1871.

[17] Robert G. Hoyland and Brian Gilmour, 'Medieval Islamic Swords and Swordmaking ', ed. by James Allan, 1st edn (London: GetTextbooks.com, 2012), I, 1–200.

[18] Peter Paufler, Alexander A. Levin, W Kochmann and N Pätzke M Reibold, 'Materials - Carbon Nanotubes in an Ancient Damascus ', *Nature 444 (7117):286*, 444.7117 (2006), 1–286.

[19] Donald R. Hill Ahmad Y. al-Hassan, *Islamic Technology: An Illustrated History Pbk Ed. Edition* (English: Cambridge University Press, 1992).

method. In this reference[20] it states that al-Hamadani did so two centuries before Theophilius.

Military equipment development

Al-Biruni in his book Al-jamahir interestingly explains the background behind making decorative patterns on swords. The first copper guide metal was bronze (Safr-Isfidruf). Bronze is a guide of copper and tin. Bronze is used for kitchen utensils, cooking utensils, and craft items. The second metal, brass (shabah, birinj), is an alloy of copper and zinc. Zinc is an additional factor for producing a metal that is stronger, harder, and more malleable than just pure copper [[21], different types of brass are obtained by varying the zinc content. Copper 20% zinc produces brass that is almost gold in color. Before zinc was known as a metal, brass was made by heating copper in a mixture of ground zinc ore and coal. As a result, some of the zinc that forms around the copper dissolves chemically, known as cementation. The next metal is brass. Perfected by the book 'Ayn al-Akhbari[22]. It is stated that there are three grades of brass quality according to the amount of zinc content. First, brass is soft when cold. Second, brass is malleable (moldable) when heated. Third, brass that is not at all shaped (not flexible), but can be cast. Referring to the book *"Al-Jamahir fi ma`rifat al-jawahir***"** by Raihan Al-Biruni, in the ECAP method if the metal is bent there will be a reaction that can improve its mechanical properties, as shown in the Figure 4[23]. The Seagal experiment was continued by Ruslan Z Valiev, who successfully applied the ECAP method to military devices in various applications, not only in the military field, but also in the medical field[24]. The experimental narrative on ECAP is also found in the Al-Jamahir fi ma`rifat al-Jawahir's Kitab by Reyhan Al Biruni, as follows:

" اسأل ماكولاتون فهاديهي تاوا فال لوهو سيفول بيادي المثكي بالأمسيسيا فبيثي ماليقي دوبنو أبيا لول تويني زيدود سوا أركض "

The most effective metal manufacturing process is by double pressing, which is able to bend a metal, by bending the metal there will be a reaction that can improve its mechanical properties[25] [26]. In Al-Jamahir fi ma`rifat al-Jawahir's Kitab there are 3 patterns that explain the process methodology, namely; (لملك) Al mil'k = Tension, (الفقلو) Al Fiqlu = to bend, (الإنفيل) Al infial = Reaction.

[20] donald r.hill ahmad y.al-hassan, *Islamic Technology an Illustrated History*, ed. by Donald R Hill (Cambridge University Press, 2017).

[21] 'Al-Hassan.

[22] [Ali bin Sultan Muhammad al-Qari, 1998]

[23] V M Segal, 'Severe Plastic Deformation: Simple Shear versus Pure Shear', *Materials Science and Engineering*, A338.1 (2002), 331–44.

[24] Ruslan Z. Valiev and Terence G. Langdon, 'Principles of Equal-Channel Angular Pressing as a Processing Tool for Grain Refinement', *Progress in Materials Science*, 2006, 881–981 <https://doi.org/10.1016/j.pmatsci.2006.02.003>.

[25] Agus Pramono, *TEORI & APLIKASI TEKNIK PEMBENTUKAN LOGAM LANJUT (SEVERE PLASTIC DEFORMATION)*.

[26] Agus Pramono, *Investigation of Severe Plastic Deformation Processes for Aluminum Based Composites AGUS PRAMONO THESIS ON MECHANICAL ENGINEERING E106*, 2016, I.

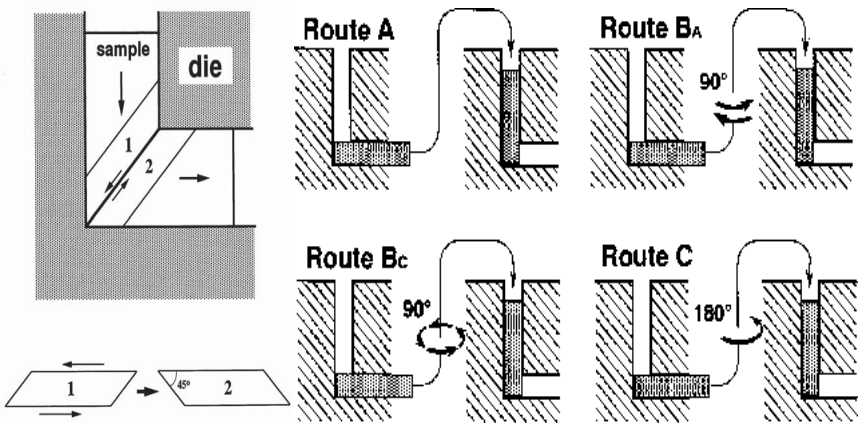

Figure 4. ECAP method by bending the metal so there will be a reaction between the metal to increase its strength significantly.

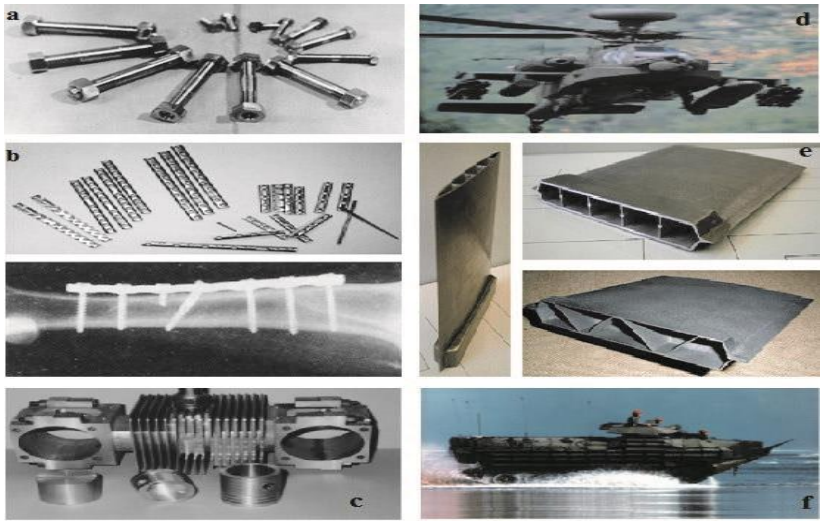

Figure 5. Application areas of ECAP and ARB: (a) high-strength thread developed in Russia (b) plate implant made of SPD nanostructure developed in Europe (c) engine block machine made of AA1420 nanostructure developed in Russia (d) military helicopter body of high-strength material developed in collaboration by Russia Europe and the UK (e) UFG Ti-6Al-4V superplastic sheet material for Hollow blade model developed by Japan and several European countries (f) military device - amphibious assault vehicle, belonging to BAE Systems developed by a joint project between Russia, USA, Japan and England. Sources are taken from[27] and[28] .

The reference book that discusses the style and field of earth science falakh, written by the scientist Abu Ja'far Muhammad ibn Musa ibn Shakir 803-873 Baghdad in the Kitab al-Hiyal. Creating the hypothesis that there is an attraction in the movement of celestial bodies. He has special expertise in astronomy, engineering, geometry, and physics. Then, Al-Hiyal's kitab, provides an explanation of the motion of the ball. In the book, he also wrote his discoveries about celestial bodies which were the subject of the laws of physics

[27] Agus Pramono, I.

[28] A. Azushima and others, 'Severe Plastic Deformation (SPD) Processes for Metals', *CIRP Annals - Manufacturing Technology*, 57.2 (2008), 716–35 <https://doi.org/10.1016/j.cirp.2008.09.005>.

on the earth. Another thing is a discussion of the motion of stars and the law of attraction. It reveals the force of attraction between celestial bodies. According to Al Hiyal's kitab, the greatest force is the earthquake movement which causes a circular rotary force effect, this is the initiation of the high pressure torsion (HPT) method. PW Bridman who discovered the HPT method very clearly gave a narrative that HPT was initiated by the earthquake movement and in his first scientific article he entitled Earthquake movement as a torsional movement[29].

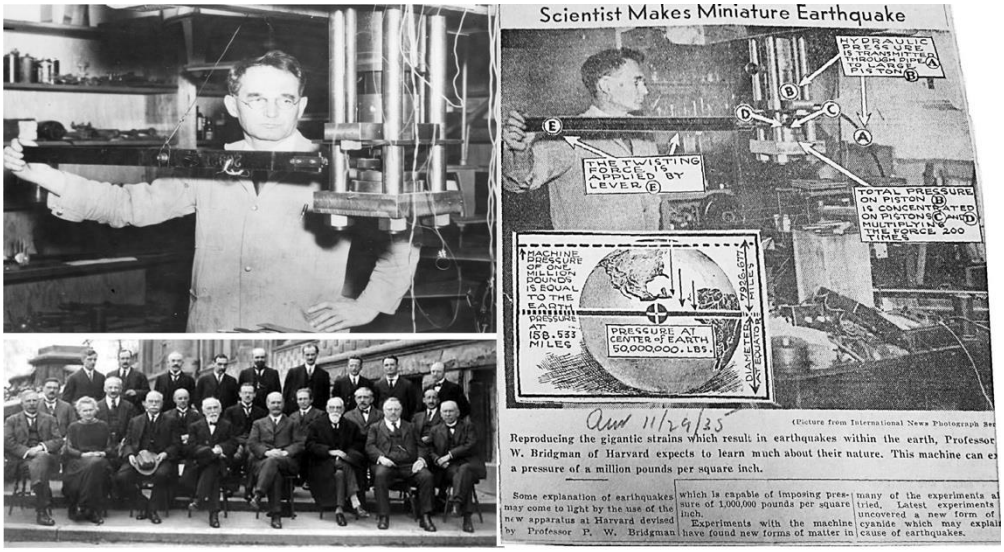

Figure 6. HPT and PM Bridman devices as copyright holders

The basic idea of using a combination of high hydrostatic stresses and large shear strains using a rotational basis was first introduced in 1935 by Bridgman, shown in the figures. His 6 findings released under the catchy title "Scientist Makes Miniature Earthquake" show great stresses under high pressure, analogous to the earth producing large earthquake motions (Fig. 6. Is taken from Harvard University archives). Bridgman analyzed several hundred materials using the facility and reported his new findings refined by Valiev who was also a pupil of Seagal. He was very interested in torsional stresses for investigating polymorphic phase transformations under high pressure, the first literature to which he referred was the allotropy theory of steel written by Dimitry Chernov in 1858 and also the invention of the first forging tools by Nikolav Lomonosov. Bridgman predicted the occurrence of various polymorphic phase transformations under high pressure in different pure elements and compounds. Interestingly, other scientists were then able to examine some of these polymorphs with other techniques. The Bridgman method has been used not only as a high-pressure process but also as an important scientific tool in various fields of science and engineering including physics, chemistry, geology, cosmology, biology, materials, tribology, and others.

[29] Agus Pramono, *TEORI & APLIKASI TEKNIK PEMBENTUKAN LOGAM LANJUT (SEVERE PLASTIC DEFORMATION).*

The newest ARB Technology started from Zulfikar's Sword Idea

The accumulative roll bonding (ARB) technology copyrighted by Japanese scientists[30]. It is the basis of the material development method which is carried out by stacking plates that are given a roll[31] compression load as shown in figure 7. Based on the experiment of a double-edged sword, namely the zulfikar sword which was explored by Khabab bin Art as a practitioner and Salman Al Farishi as a drafter who is also a military strategist , this method has similarities in the procedure for stacking and finalizing the base material plate. The next experiment was continued by Syalim bin Umar (grandson of Sayidina Umar bin Khatab) to Jakfar Shodiq (grandson of Sayidina Ali bin Talib)[32], Jakfar Ash Shodiq had several students who developed metal science, including Al Khindi who had students Reyhan Akl Biruni[33], sword development Zulfikar continued on Al Qashandi who developed the Damascus sword used by Salahuddin Al Ayubi[34], from the perspective of the bending stress of the metal plate from the roll compression stress, where there is a deflection of the tip of the plate, on the blade[35,5]. If the ends of the clips are put together, there will be a grain refinement that can make the size reach nanometers, as researched by British scientists[36].

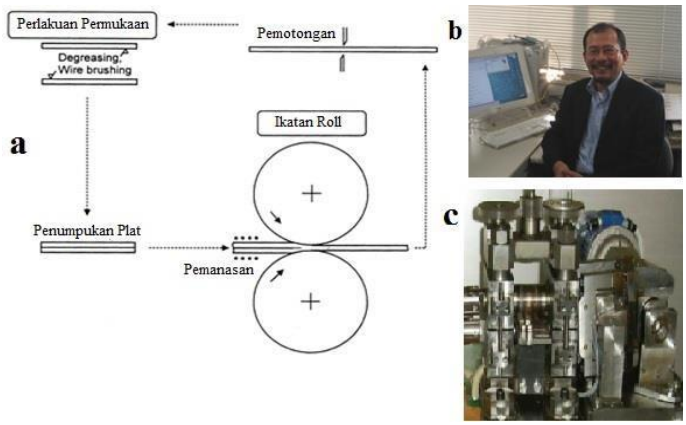

Figure 7. (a). Schematic of the Accumualtive Roll Bonding (ARB) stage process (b). Nobuhiro Tsuji initiator of the ARB process (c). Rolling machine for ARB devices

[30] Agus Pramono and others, 'Characteristics of Aluminum-Based Composites Reinforced of Al2O3/B4C by Accumulative Roll Bonding (ARB)', *Teknika: Jurnal Sains Dan Teknologi*, 17.2 (2021), 119 <https://doi.org/10.36055/tjst.v17i2.12156>.

[31] Agus Pramono, *TEORI & APLIKASI TEKNIK PEMBENTUKAN LOGAM LANJUT (SEVERE PLASTIC DEFORMATION)*.

[32] Gus Pram. Sanad Ilmu Metalurgi dan Manufaktur dalam Perspektif Islam, Pengajian online PCI NU UK. 5 Januari 2017.

[33] Gus Pram, Metamorfosa Ilmu Pengetahuan dan Teknologi dalam Perspektif Islam, Pengajian Online Rusia (PORSA) PCI NU FREU 9 Okt 2016.

[34] Russian chemist Dmitri Mendeleyev discovered the periodic law and created the periodic table of elements, Dmitri Mendeleyev Biography. www.famous scientists.org/dmitri-mendeleev/.

[35] www.nu.or.id/Gus Pram Ungkap 3 Klasifikasi Perangkat Teknologi Militer oleh Ilmuwan Muslim, 17 Januari 2017.

[5] Ibn Khallikan, The Prehistory of Saladin, Studies in Caucasian History, Cambridge University Press, 1957, pp. 124-132.

[36] T. G. Langdon, 'Processing of Ultrafine-Grained Materials Using Severe Plastic Deformation: Potential for Achieving Exceptional Properties', *Revista de Metalurgia (Madrid)*, 44.6 (2008), 556–64 <https://doi.org/10.3989/revmetalm.0838>.

Between the ARB technology and the manufacture of Zulfikar's sword and the Damascus sword of Salahudin Al Ayubi has a methodological similarity, where the two swords are the same from a pile of pressed metal plates. The pressure uses a swivel roll load, so that the plate becomes bent, like the double-edged sword of Zulfikar. After the end of the plate is subjected to roll compression, the ends become one as shown in the picture below.

Figure 8. Sayyidina Ali's Zulfikar sword created by Khattab and Salm

Figure 9. Saladin Al Ayubi's Damascus sword which has the same ARB process.

The greatness of Salahuddin Al-Ayyubi's sword has been found by Prof. Dr. Peter Paufler from Germany. The professor found a carbon nano tube (CNT) in the sword along with the weapons used by Islamic armies during the Crusades. CNT is what makes the sword of the Islamic army very sharp but flexible. CNT is a chain of carbon atoms bonded to each other in a hexagonal cylindrical shape with a diameter as small as 1-2 nanometers. These CNT cylinders can reach tens of microns in length and are closed at the ends as if a pipe were closed at both ends. Research conducted on this material also explains that CNT has the highest strength compared to other materials. CNTs have higher electrical conductivity than metals. Another uniqueness of CNT is that it is resistant to high temperatures and is lighter than aluminum. This nanotechnology uses "damascus" steel which is often called wootz. This iron ore contains hundreds of elements Carbon. In addition to iron and carbon, elements such as Chromium, Manganese, Cobalt also bias the strength, sharpness and flexibility of the sword. This sword-making technique is so secretive that only a few blacksmith families in Damascus have mastered it. Finally in the 18th century, this sword-making technology has disappeared. What remained were the

swords, spears and knives which are now scattered in various museums around the world. Just to remind us that this great technology of Islamic civilization has been lost in time[37].

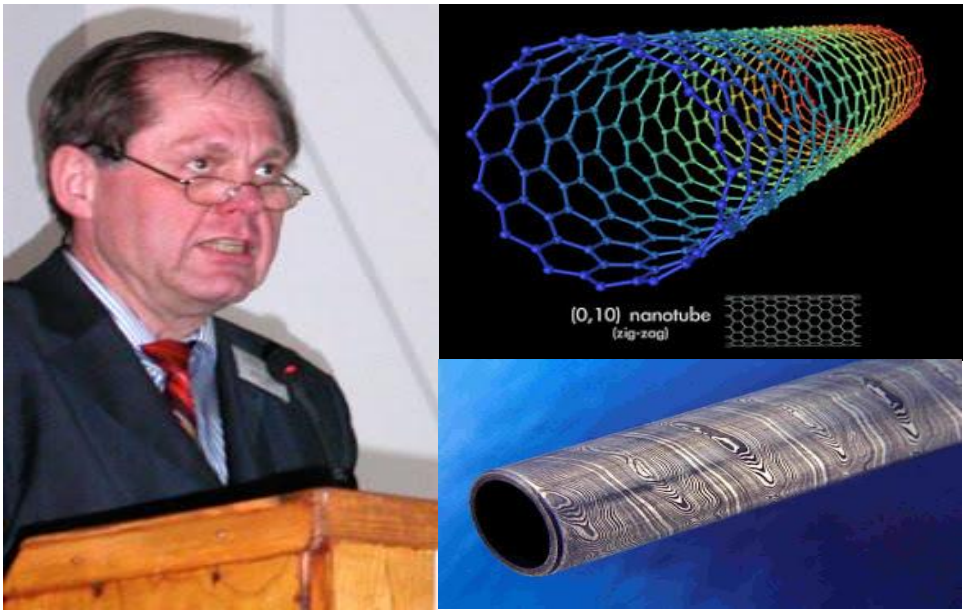

Figure 10. The presentation of Prof. Peter Paufler in his exposition of his experiment on the research of Salahudin Al Ayubi's Damascus sword, which uses CNT.

Characteristics of Supporting Materials for Technological Devices

Several experiments and tests related to the 3 methods developed through ECAP, HPT and ARB have been carried out during 2013-2021 by the authors. In several characterizations, ideal properties are produced that meet the rules of application in the military field. For the ECAP method, some experimental results are presented in table 1 which shows the mechanical properties of the ECAP processed material. An important influencing factor in industrial applications is the consolidation process, a fabrication process with good parameters by increasing the bond strength on the surface to reduce the number of pores. In particular. ECAP overcomes a number of difficulties associated with residual porosity in compacted samples.

ECAP-processed base metals usually has unique mechanical properties such as; high yield stress at low strain hardening, good ductility at low temperature and high strain rate super plasticity at high temperature. Heat treatment is able to improve material properties when processed by ECAP[38]. The processing of metals through the application of ECAP is attracting much attention because of the potential to achieve significant grain refinement down to the submicrometer or nanometer level, resulting in a fine grained metal. The principles of this type of processing equal-channel angular pressing (ECAP) can be achieved including high strength at ambient temperatures and the ability to form superplastic rapidly at high temperatures. Based on the results of the ECAP[39], [40], [41], [42] HPT[43] and ARB[44] experiments, the characteristic results are presented in table 1-4 below:

[37] M Reibold.

[38] Agus Pramono, Anistasia Milandia, and Kurnia Nugraha, 'ALUMINUM ALLOYS BY ECAP CONSOLIDATION FOR INDUSTRIAL APPLICATION VANOS JOURNAL OF MECHANICAL ENGINEERING EDUCATION', *VANOS Journal of Mechanical Engineering Education*, 2.2 (2017), 117–26.

[39] Agus Pramono, I.

Table 1. Characterization of ECAP with various heat treatment treatments

Metal Heat Treatment	Hardness HV10	Strength (MPa)	Elasticity (%)	Grain Size (μm)
AA6061-ECAP	141±5	250	25	0.1
AA6061-Anil	88±1	97	45	8.9
AA6061-Artificial	128±3	225	29	1.3
AA7075-ECAP	121±4	395	2.5	0.7
AA7075-Anil	99±2	226	14	4.6
AA7075- Artificial	105±4	283	18	4.4

Table 2. Characterization of HPT with certain heat treatment

Treatment	Hv, MPa	YS, MPa	UTS, MPa	El., %
HPT	1730±18	660±21	690±28	5.5±0.3
T6	1175±12	276±14	365±16	14.0±1.0
ST+WQ	750±8	150±7	275±10	23.0±1.0

Table 3. Characterization of ARB with ceramic reinforcement

Metal Material	Metal Hardness (*BHN*)	Dencity (gr/mm^2)	Porosity (%)
ARB-AA7075/without reinforcement	43.60	2.79	**0.9**
ARB-AA1070/ without reinforcement	30.12	2.63	**0.7**
ARB-AA7075/Al_2O_3	87.20	2.81	**1.2**
ARB-AA7075/B_4C	105.02	2.88	**2.8**
ARB-AA1070/Al_2O_3	43.36	2.66	**1.1**
ARB-AA1070/B_4C	**53.50**	**2.76**	**2.4**

[40] A. Pramono and others, 'High-Strength Aluminum Alloy of Ultrafine Grained by Consolidation-ECAP', in *IOP Conference Series: Materials Science and Engineering* (Institute of Physics Publishing, 2019), CDLXXVIII <https://doi.org/10.1088/1757-899X/478/1/012035>.

[41] A. Pramono and others, 'Investigation of Mechanical Properties on Composite Materials by Several of Severe Plastic Deformation (SPD) Methods', in *IOP Conference Series: Materials Science and Engineering* (IOP Publishing Ltd, 2019), DCLXXIII <https://doi.org/10.1088/1757-899X/673/1/012120>.

[42] Pramono and others.

[43] Gulnaz Nurislamova and others, 'Nanostructure and Related Mechanical Properties of an Al-Mg-Si Alloy Processed by Severe Plastic Deformation', *Philosophical Magazine Letters*, 88.6 (2008), 459–66 <https://doi.org/10.1080/09500830802186938>.

[44] Pramono and others.

Table 4. The results of the recapitulation of the characterization of the ECAP, HPT and ARB's methods

Process	Strength (MPa)	Hardness (Hv)
ECAP	250 – 450	121 – 148
HPT	600 – 660	187 – 540
ARB	96 – 148	45 – 128

Based on the results, the HPT method is the highest compared to other methods, but in applicability the HPT method is difficult to apply to large-sized materials, the average HPT application is applied to small-sized materials with a size of 5 cm. However, the ECAP and ARB methods can be applied to materials with the large sizes. The ECAP specification is applied to components in the form of plates or bars. ARB is applied to sheet materials, while HPT is applied to materials in powder form. Heat treatment of metalworking processed ECAP, HPT and ARB is required for certain product applications, according to article [45]. An important influencing factor in industrial applications is the consolidation process, a fabrication process with good parameters on heat treatment by increasing the bond strength on the surface to reduce the number of pores. In the manufacturing process, the product shows unique mechanical properties as presented in table 1-3; The production of metal processed by ECAP, HPT and ARB is growing rapidly, especially in the military industry. Therefore, much research has focused on improving the formability of these alloys through the necessary heat treatment to improve the material properties when processed by ECAP, HPT or ARB.

CONCLUSION

The first book/Kitab that became a reference for science was Al-Kitab al-mukhtasar fi hisab al-jabr wa'l-muqabala written by Muhammad bin Musa Al-Khwarizmi (780-850), some of the chapters described are algorithmic numbers in calculations mathematical. This book is a series of discussions of systematic solutions of linear equations and quadratic equations. So he is called the father of Algebra.

The next book is a reference that discusses chemistry, namely Al Kimya, which was written by Jabr Ibn Hayyan. Al Kimya's reference is a formulation of the difference between alchemy and chemistry and between astronomy and astrology. Jabr succeeded in putting the foundations of scientific and experimental chemical research methods. In the laboratory he founded, he began to carry out experiments on sublimation, crystallization, filtration, extraction, and distillation or distillation. All of this is done to obtain pure minerals and metals from various mixtures.

The book that describes metal science, especially in terms of blacksmithing in the Islamic world is the Kitab Al-hadid (Book of Iron) written by Al-Jildaki. Al Jidaki discovered the firind pattern found in his experiments on all types of artificial iron. Meanwhile, a sword made of natural iron that does not have a decorative pattern is called a firnd.

[45] Pramono, Milandia, and Nugraha.

Abu Raihan al-Biruni, the author of the book Al-Jamahir fi ma`rifat al-Jawahir, explains the background behind making decorative patterns on swords. In the mukodimah of the book of al-Jamahir objectively, there is a special treatment formula for metals, which explains how metals are treated to increase their strength, namely: Al mil'k = stress on the metal, Al Fiqlu = bending and al infial = Reaction. This is in line with the Russian military apparatus researcher, Vladimir Seagal, namely the equal channel angular pressing (ECAP) method. In the ECAP method, if the metal is bent in the dies, a reaction will occur which can increase the metal significantly.

Reference book that discusses the style and field of earth science falakh, written by the scientist Abu Ja'far Muhammad ibn Musa ibn Shakir 803-873 Baghdad in the Kitab al-Hiyal. Creating the hypothesis that there is an attraction in the movement of celestial bodies. He has special expertise in astronomy, engineering, geometry, and physics. in Kitab al-Hiyal, provides an explanation of the motion of the ball. In the book, he also wrote his discoveries about celestial bodies which were the subject of the laws of physics on the earth. Therefore, another discussion is the motion of stars and the law of attraction. It reveals the force of attraction between celestial bodies. According to the book of Al Hiyal, the greatest force is the earthquake movement which causes a circular rotary force effect, this is the initiation of the high pressure torsion (HPT) method. PM Bridman who discovered the HPT method very clearly gave a narrative that HPT was initiated by the earthquake movement and in his first scientific article he entitled Earthquake movement as a torsional movement.

Accumulative roll bonding (ARB) whose copyright by Japanese scientists is the basis of the material development method carried out by stacking plates that are given a roll compression load, this is in accordance with the Zulfikar sword experiment explored by Khabab bin Art as a practitioner and Salman Al Farishi as a drafter who also a military strategist. The development of the Zulfikar sword continues with Al Qashhandi who developed the Damascus sword used by Salahuddin Al Ayubi, from the perspective of the bending stress of the metal plate comes from the roll compression stress, where there is a deflection of the tip of the plate, on the blade, if the edges are clipped together it will there is a grain refinement that can make the size reach nanometers as studied by British scientists.

Metal processing through the application of ECAP, HPT and ARB is attracting a lot of attention because of the potential to achieve high strength of grain refinement in the metal being processed. The principles of this type of processing can be achieved including high strength at ambient temperature and the ability to form a superplastic rapidly at high temperature. HPT applications are applied to powder-based materials. The ECAP specification is applied to components in the form of plates or bars, while the ARB is applied to sheet materials. Heat treatment of metalworking processed by ECAP, HPT and ARB is required for process finishing in certain product applications. An important influencing factor in industrial applications is the consolidation process, a fabrication process with good parameters on heat treatment by increasing the bond strength on the surface to reduce the number of pores. The production of metal processed by ECAP, HPT and ARB is growing rapidly, especially in the military industry.

REFERENCE

'Al-Hassan, A. Y', *The Different Aspects of Islamic Culture: Science and Technology in Islam* , ed. by A.Z. Iskandar Maqbul Ahmed (United Kingdom (U.K): Pt.1. The exact and natural sciences -- v. 2. Technology and applied sciences., 2001)

Agus Pramono, *ILMU PENGETAHUAN & TEKNOLOGI DALAM PERSPEKTIF ISLAM* (Deepublish, 2021) <https://doi.org/https://books.google.co.id/books/about/Buku_Perkembangan_Ilmu_Pengetahuan_Tekno.html?id=GaA9EAAAQBAJ&redir_esc=y>

———, *Investigation of Severe Plastic Deformation Processes for Aluminum Based Composites AGUS PRAMONO THESIS ON MECHANICAL ENGINEERING E106*, 2016, I

———, *TEORI & APLIKASI TEKNIK PEMBENTUKAN LOGAM LANJUT (SEVERE PLASTIC DEFORMATION)*

Aḥmad ibn ʻAlī, 'Qalqashandī: Die Geographie Und Verwaltung von Ägypten', in *Ferdinand Wüstenfeld.*, ed. by Ferdinand Wüstenfeld. (Gœttingen, Dieterich, 1879)

———, 'Qalqashandī: Ṣuḥḥ Al-Aishā', 6th edn, 1913, I

Ahmad Y. al-Hassan, Donald R. Hill, *Islamic Technology: An Illustrated History Pbk Ed. Edition* (English: Cambridge University Press, 1992)

ahmad y.al-hassan, donald r.hill, *Islamic Technology an Illustrated History*, ed. by Donald R Hill (Cambridge University Press, 2017)

Alan Williams, *The Sword and the Crucible A History of the Metallurgy of European Swords up to the 16th Century Series*, ed. by Kelly De Vries (Maryland: Loyola University Maryland , 2012), LXXVII

As-Suyuthi Imam, *Tarich Culafa - Sejarah Para Penguasa Islam*, ed. by Imam Sulaiman, 1st edn (Jakarta: Jakarta : Pustaka Al-Kautsar, 2001, 2006), XXI

Azushima, A., R. Kopp, A. Korhonen, D. Y. Yang, F. Micari, G. D. Lahoti, and others, 'Severe Plastic Deformation (SPD) Processes for Metals', *CIRP Annals - Manufacturing Technology*, 57.2 (2008), 716–35 <https://doi.org/10.1016/j.cirp.2008.09.005>

by Ali bin Sultan Muhammad al-Qari, Imam Abu Hanifa al-Nu'man bin Thabit, 'Minah Al-Rawd Al-Azhar Fi Sharh Al-Fiqh Al-Akbar', in *This Is Mulla 'Ali Al-Qari's (d. 1014 h)Commentary on Imam A'ẓam Abu Hanifa's (d. 150 h) Short Work on Islamic Doctrine ('aqida).*, ed. by Dar al-basha'ir, 1st edn (Hardback Published , 1998), I

'Carl B. Boyer', 'Uta C. Merzbach', *A History of Mathematics* , ed. by Uta C. Merbach, 2nd ed (New York: John Wiley & Sons, 1991), I

Damanhr, Amad ibn Abd al-Munim; Qalqashandī Aḥmad ibn ʻAlī; Ibn Jbir, Muammad ibn Amad, *Sabl Al-Rashd Ilá Naf' Al-'ibd.*, 1871

'Geertz Clifford', 'Religion: Anthropological Study ', in *International Encyclopedia of the Social Sciences*, ed. by David L. Sills, 1st edn (London: Collier-Macmillan Publishers, 1965), I, 2–20

Heriyanto Husain, *Menggali Nalar Saintifik Peradaban Islam* (Jakarta2011: Mizan Publika, 2011)

Jābir Ibn Ḥayyān, *Contribution à l'Histoire Des Idées Scientifiquesdans l'Islam: Jābir et La Science Grecque* , ed. by Paul Kraus, 2nd edn (Paris: Global Scholarly Publications, 1935), IV

Langdon, T. G., 'Processing of Ultrafine-Grained Materials Using Severe Plastic Deformation: Potential for Achieving Exceptional Properties', *Revista de Metalurgia (Madrid)*, 44.6 (2008), 556–64 <https://doi.org/10.3989/revmetalm.0838>

M Reibold, Peter Paufler, Alexander A. Levin, W Kochmann and N Pätzke, 'Materials - Carbon Nanotubes in an Ancient Damascus ', *Nature 444 (7117):286*, 444.7117 (2006), 1–286

'Matthew E Falagas' 'Effie A. Zarkadoulia' 'George Samonis', 'Arab Science in the Golden

Age (750–1258 C.E.) and Today ', *The FASEB Journal* , 1.1 (2006), 1581–86

Nurislamova, Gulnaz, Xavier Sauvage, Maxim Murashkin, Rinat Islamgaliev, and Ruslan Valiev, 'Nanostructure and Related Mechanical Properties of an Al-Mg-Si Alloy Processed by Severe Plastic Deformation', *Philosophical Magazine Letters*, 88.6 (2008), 459–66 <https://doi.org/10.1080/09500830802186938>

Pramono, A., K. Dhoska, A. Alhamidi, A. Trenggono, and A. Milandia, 'Investigation of Mechanical Properties on Composite Materials by Several of Severe Plastic Deformation (SPD) Methods', in *IOP Conference Series: Materials Science and Engineering* (IOP Publishing Ltd, 2019), DCLXXIII <https://doi.org/10.1088/1757-899X/673/1/012120>

Pramono, A., L. Kollo, L. Kommel, and R. Veinthal, 'High-Strength Aluminum Alloy of Ultrafine Grained by Consolidation-ECAP', in *IOP Conference Series: Materials Science and Engineering* (Institute of Physics Publishing, 2019), CDLXXVIII <https://doi.org/10.1088/1757-899X/478/1/012035>

Pramono, Agus, Anistasia Milandia, and Kurnia Nugraha, 'ALUMINUM ALLOYS BY ECAP CONSOLIDATION FOR INDUSTRIAL APPLICATION VANOS JOURNAL OF MECHANICAL ENGINEERING EDUCATION', *VANOS Journal of Mechanical Engineering Education*, 2.2 (2017), 117–26

Pramono, Agus, Anne Zulfia, Ali Alhamidi, Alfirano Alfirano, Suryana Suryana, and Anistasia Milandia, 'Characteristics of Aluminum-Based Composites Reinforced of Al2O3/B4C by Accumulative Roll Bonding (ARB)', *Teknika: Jurnal Sains Dan Teknologi*, 17.2 (2021), 119 <https://doi.org/10.36055/tjst.v17i2.12156>

Robert G. Hoyland and Brian Gilmour, 'Medieval Islamic Swords and Swordmaking ', ed. by James Allan, 1st edn (London: GetTextbooks.com, 2012), I, 1–200

Segal, V M, 'Severe Plastic Deformation: Simple Shear versus Pure Shear', *Materials Science and Engineering*, A338.1 (2002), 331–44

Toomer, Gerald J., *Al-Khuwārizmī, Abu Ja'far Muḥammad Ibn Mūsā* , ed. by Charles Coulston, 1st edn (Gillispie: Dictionary of Scientific Biography, 1970), VII

Valiev, Ruslan Z., and Terence G. Langdon, 'Principles of Equal-Channel Angular Pressing as a Processing Tool for Grain Refinement', *Progress in Materials Science*, 2006, 881–981 <https://doi.org/10.1016/j.pmatsci.2006.02.003>