Research Journal of Applied Sciences 9 (9): 549-555, 2014
ISSN: 1815-932X

The Metallurgical Aspects of the Malay Keris

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Abstract: The keris or the dagger is an illustrious weapon renowned for its capacity as an object of cultural heritage and priceless heirloom amongst the Malay people throughout the history of their civilization. Given that there are no documented records as to when the keris was made, reference was made to the reliefs of the keris as depicted at ancient places of worship, namely Candi Sukuh, Candi Borobudur and Candi Prambanan in Java, Indonesia. The keris was crafted and designed by master blacksmiths or Empu by means of several types of metal available at his disposal. There have been very few articles or research published in regards to the metallurgical aspect of the keris. Therefore, this study aspires to unearth the types of metal forged in the blade of the keris by the earlier-mentioned skilled Malay blacksmiths or Empu. In order to achieve the said objective, several laboratory tests were conducted in collaboration with SIRIM BHD (Standards and Industrial Research Institute of Malaysia). The laboratory test involve the usage of X-ray Fluorescent Innova-8000 LXZ equipment, a non-destructive technique use for determine the elemental content of the keris, Spectrotest Spark Analyzer (Mobile Edition) SN.4N0088 equipment also use to determine the elemental content of the keris but the technique is a destructive technique. The morphology analysis of the keris is studied by using the Microstructure Analysis test and Hardness test (profile) was done in order to scrutinize the solidity and resistance of the keris blade. Elemental analysis shows that the Iron (Fe) content forms >99% of the content of all the keris that have been analysed. Other elements that exist in Malay keris are silicon, nickel and copper. The evaluation of the Hardness test (profile) illustrated that the blade of the keris had different hardness value or level in the process of its forging and microstructure analysis show that pearlite structure changes and became harden due to the process of forging. It can be concluded here that the Malay keris contain >99% of Iron (Fe) and other elements that exist in the keris are silicon, copper and nickel which is very small on percentage range between 0.1-0.5%. The traditional method of keris making is testament to the Malay blacksmiths or Empu's impeccable capabilities in forging the blade resulting in the different levels of Hardness Value (HV).

Key words: Keris, Malay, Candi Sukuh, Candi Borobudur, Candi Prambanan, X-ray fluorescent, Hardness Value (HV)

INTRODUCTION

The method of making and forging a traditional Malay keris by a blacksmith maestro or Empu is very much associated with the concept and principles of modern science and technology. In the process of crafting the keris, four facets of material properties, i.e., chemical, physical, mechanical and dimensional and five elements of mechanical properties, i.e., strength, formability, rigidity, toughness and durability were applied (Budinski, 1979). The Empu, through his years of experience and insurmountable exposure in making the keris had also understood the characteristics of metal in making the blade of the keris. The principles of metal that were related in the process include the tensile strength, plasticity, ductility, brittleness, hardness, fatique, corrosion resistance, heat resistance, heat treatment, tempering, Spark test, density, tenacity, malleability, thermal conductivity, thermal expansion, fusibility and creep (Ableson and Pateman, 1974; Draeger, 1972; Duuren, 1998; Frey, 1988; Noor *et al*., 2003; Adams, 1976). It is a considerable point to note that although the Empu did not have any formal education, it appeared that his method of making the keris was highly consistent and parallel with the principles of contemporary science.

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The creation and forging of keris did involve the basic tenets of science such as forging, quenching, tempering and etching. It is a proven fact that the dramatic forging of Laminated Metal Composite (LMC) did significantly strengthen the structure of the metal utilised. The enhancement of the metal's potency was in regards to fracture toughness, fatigue behaviour, impact behaviour, formability and ductility (Gardner and Milne, 1973; Mielnik, 1991). Through the sustained cycle of heat treatment and quenching, the contents and properties of the metal were improvised by the Empu in the formation of the blade of the keris.

Scientific analysis or compositional analysis on the heritage artefacts seem to be important under archaeological research or research involve national heritage and culture. Most of the analysis involved analysis on prehistoric potteries (Ramli *et al*., 2011a; Moradi *et al*., 2013) ancient glass beads of Indo-Pacific beads (Ramli *et al*., 2009, 2011b), bricks used to build ancient temples (Ramli *et al*., 2012, 2009, 2011a-c, 2013a-c; Ramli and Abdul Rahman, 2013), ancient bronze drums (Jusoh *et al*., 2012, 2013) and traditional boats (Abdul Rahman *et al*., 2013). Compositional analyses on artefacts usually showed us the chemistry of the artefacts and can determine whether the artefact is locally made or imported elsewhere. Scientific analysis on the keris however is done to determine the type of metal or alloy by analysed their elemental content. On morphological aspect, the microstructure analysis test will demonstrate the changes of pearlite and ferrite structure and how this affects the hardness of the keris due the process of forging.

MATERIALS AND METHODS

In determining the perception and principles of modern science and technology to be parallel and constantly consistent with the techniques practiced by the Empu in constructing the keris, three types of tests were carried out with the cooperation of SIRIM BERHAD (Standards and Industrial Research Institute of Malaysia). The highly-specified tests were Non-Destructive Testing, High Magnification Testing and Destructive Testing. The tests were conducted under SIRIM's in-house test method via JIS-F1-2a adapted from OEM (Optical Emission) (Ref: MS ISO/IEC 17025, SAMM No.313).

The Non-Destructive Testing process was brought into play to analyse seven samples of keris by using the X-Ray Fluorescent Innov-a-8000 LXZ apparatus. The seven samples were Keris Pattani, Keris Semenanjung, Keris Sumatera/Minang, Keris Jawa, Keris Bali, Keris Lombok and Keris Bugis. This method was conducted by pointing the equipment 'gun' to each of the keris blade for about 3-4 min. The purpose of the test was to verify the variety of metal being used in each of the keris blade.

The Destructive Testing was done to compliment the Non-Destructive Testing made earlier which did not reflect fairly in terms of capturing the required data on the type of materials used in the making and forging of the keris blade. The sample was Keris Bugis-Semenanjung which was found during the excavation of Dataran Pahlawan in the State of Melaka. The sample was then dissected into three pieces before being put through three tests, i.e., the test of material composition, hardness test (profile) and microstructure analysis test. The Material Composition test was made possible with the use of Spectrotest Spark Analyser (Mobile Edition) SN.4N0088 equipment. The objective of the Hardness test (profile) was to scrutinize the solidity and resistance of the keris blade. The test piece was sectioned, mounted, grounded and polished prior to the hardness test. This profile test was done using the WOLPERT Vickers Hardness Tester with 500 gf load of diamond indenter.

The High Magnification Testing was assisted with the use of the Microscope Keyence equipment. The samples were obtained from three blades of Keris Bugis, one blade each of Keris Jawa, Keris Pattani/Pekaka and a Kelewang. This technique is applied by magnifying thus zooming in on each blade by between 150-200% with the main objective of analyzing the structure of the blade with the possibility of detecting foreign elements that could exist while in the process of making and forging of the keris blade.

RESULTS AND DISCUSSION

The Non-Destructive Testing shows rather substantially that Iron (Fe) was the prevailing metal/material in making the keris which represents 99% of the content (Fig. 1). Whilst other contents such as Silicon (Si), Nickel (Ni) and Copper (Cu) represent only <1%. It was also discovered that four samples of the keris, i.e., Keris Pattani, Keris Sumatera/Minang, Keris Jawa and Keris Bugis had Silicon (Si) content in its blades creation. Nickel content, on the other hand was found in the Keris Semenanjung while the Keris Lombok had two contents, i.e., Nickel (Ni) and Silicon (Si). Keris Bali, meanwhile had three contents, i.e., Nickel (Ni), Copper (Cu) and Silicon (Si) on top of the predominant Iron (Fe) content.

As much as the Non-Destructive Testing Method enabled the compilation of selective data through its modern machinery, it was not really representative of the bigger picture. However, it is rather fascinating to point out the highlight discovery when it comes to the

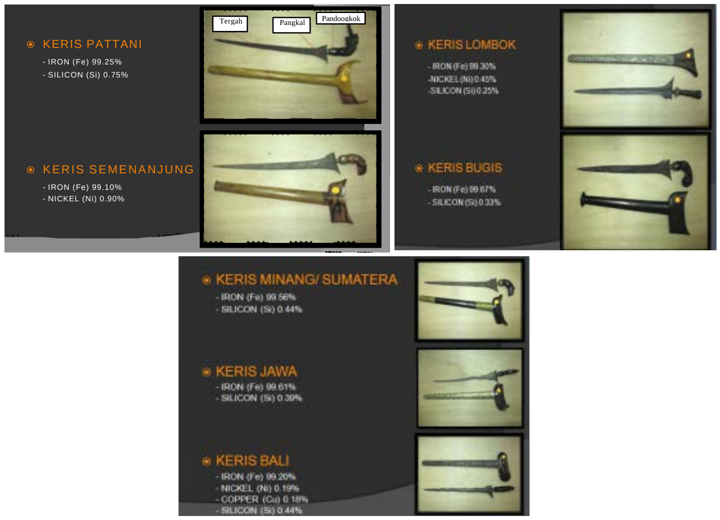


Fig. 1: Samples of non-destructive testing

pendongkok/mendak (Melaka cup) of the keris. The test clearly spelled out various types of elements exist in the pendongkok/mendak (Melaka cup) such as Nickel (Ni), Silicon (Si), Copper (Cu), Aluminum (Al), Silver (Ag), Iron (Fe), Tin (Sn), Lead (Pb), Zinc (Zn) and Niobium (Nb).

High Magnification Testing: The High Magnification Testing was assisted with the use of the Microscope Keyence equipment. The samples were obtained from three blades of Keris Bugis, one blade each of Keris Jawa, Keris Pattani/Pekaka and a Kelewang. The assessment resulted in revealing four of the blades detected no faulty formation. On the other hand, two blades, i.e., Keris Bugis (Fig. 2) and Keris Jawa (Fig. 3) were found to have apparent of impurities materials exists in its formation. Several attempts were made to determine these supposed foreign elements, alongside what might have caused its' formation but to no avail. Optimistically this unsolved mystery will be conceivably answered with the introduction of more state of the art technology in the near future.

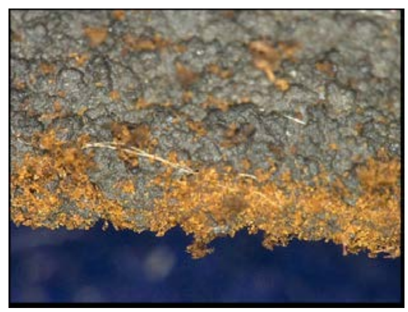


Fig. 2: Impurities of Keris Bugis

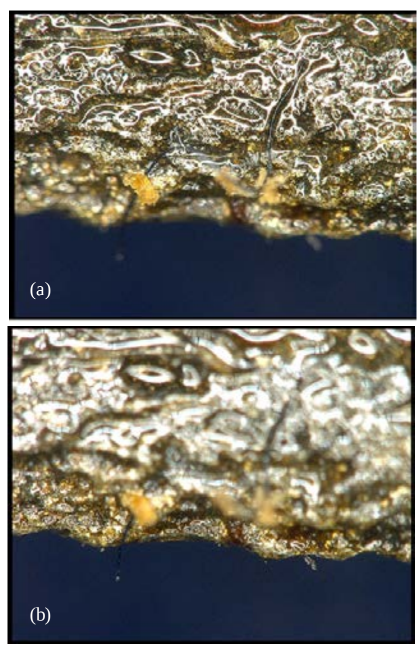


Fig. 3: a, b) Impurities of Keris Jawa

The Destructive Testing

Material Composition test: The result shows that Keris Bugis Semenanjung (Fig. 4) consist of 99.8% of Iron (Fe) content and it almost pure iron. Other 20 elements or materials made up <1% of its composition, the material composition test provided a better and relevant reading in the comprehension and compilation of the data. The materials detected were as follows: Carbon (C) 0.140, Lead (Pb) <0.010, Tin (Sn) 0.009, Manganese (Mn) 0.008, Nickel (Ni) <0.008, Silicon (Si) 0.008, Phosphorus (P) 0.016, Chromium (Cr) <0.006, Sulfur (S) 0.006, Molybdenum (Mo)

Fig. 4: Keris Bugis-Semenanjung

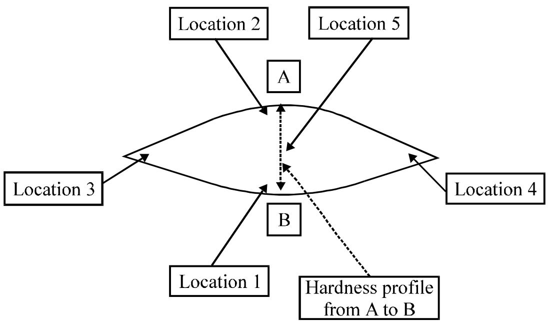


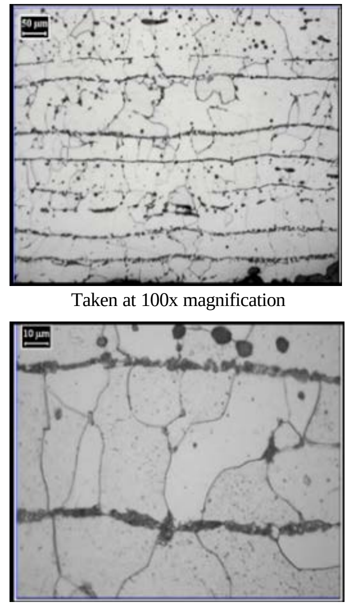
Fig. 5: Schematic diagram of cross-sectional and hardness profile

0.004, Niobium (Nb) <0.005, Cobalt (Co) <0.009, Aluminium (Al) <0.002, Titanium (Ti) <0.001, Cooper (Cu) 0.008, Vanadium (V) <0.002, Tungsten (W) <0.040, Arsenic (As) 0.013, Zirconium (Zr) <0.003 and Boron (B) 0.002.

Hardness test (profile): The Hardness test (profile) was thoroughly performed to the blade from location A to B in cross-sectional dimension. The distance of measurement from location A to B was 5.3 mm. The test result showed that the Hardness Value (HV) in location A (top) was 127.7HV whereas in location B (bottom), the Hardness Value (HV) was 177.3HV. However, it was found out that at the centre of the cross-section of the blade had a lower hardness value at 98.8 HV (Fig. 5).

The evaluation of the Hardness test (profile) illustrated that the blade of the keris had different hardness value or level in the process of its forging (Table 1). During the forging stage, location A and B hardened due to the process of quenching that resulted in trapping both the atomic carbon and metal components. This caused the blade to increase in strength at ambient temperature thus producing a different hardness value.

Photomicrograph of location 1



Taken at 100x magnification

Taken at 500x magnification

Fig. 6: The structure deformed the pearlite structure due to the forging process

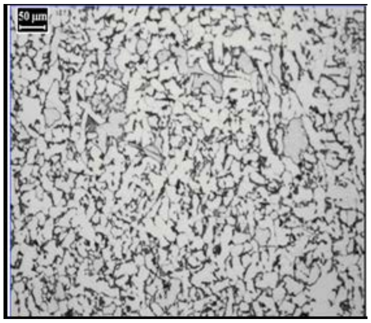
Table 1: Result of hardness test (profile)

Distance from surface (mm)	Hardness Value (HV)
0.3 (location A)	127.7
0.8	134.7
1.3	134.9
1.8	124.4
2.3	113.4
2.8	98.8
3.3	99.6
3.8	106.4
4.3	114.5
4.8	124.7
5.3 (location B)	177.3

Microstructure Analysis test: The microstructure analysis test was conducted by way of the sample being sectioned, mounted, grounded and polished according to metallographic sample preparation, ASTM E-3. Cross-sectioned micrographs were taken for documentation. The cross-section was marked with five locations, i.e., location 1-5 in order to generate its micrograph documentation through a schematic diagram. In each location of the blade, photomicrograph documentations were taken at 100x and 500x magnification, respectively.

Based on the photomicrograph documentations taken, the microstructure analysis revealed that at location 1 and 2, i.e., the top and bottom of the blade, the 'pearlite' structure changes and became harden due to the process of forging. As for location 3 and 4, i.e., both sides of the blade, the structure of 'ferrite and pearlite' surfaced together with a bigger structure of the 'grain

Photomicrograph of location 2



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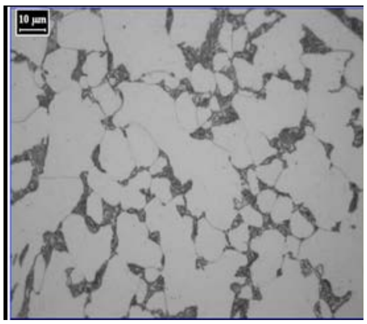
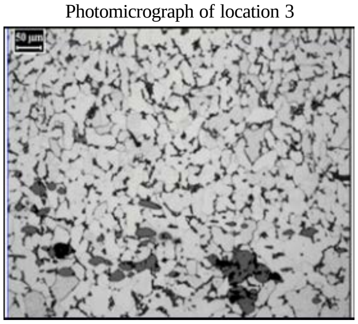


Taken at 500x magnification

Fig. 7: The structures comprise of ferrite and pearlite structure

Photomicrograph of location 3



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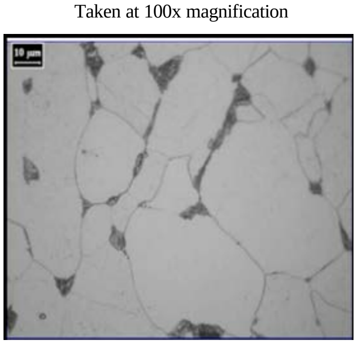
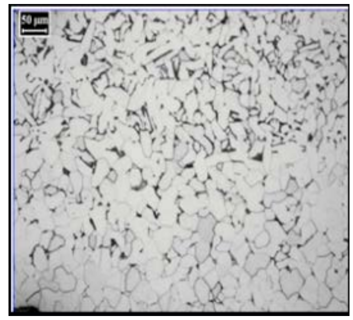


Taken at 500x magnification

Fig. 8: The structure comprise of ferrite and pearlite. The grain size of the structure bigger than location 2

Photomicrograph of location 4



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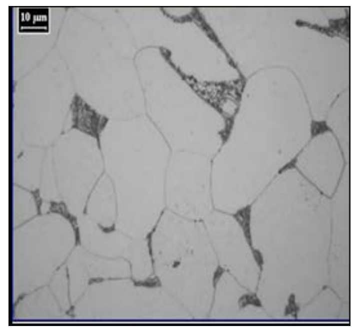
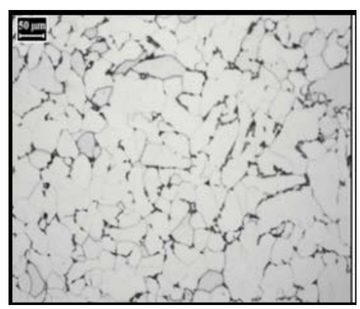


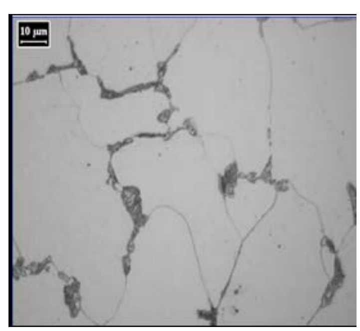
Taken at 500x magnification

Fig. 9: The structure comprise of ferrite and pearlite. The grain size of the structure bigger than location 2

Photomicrograph of location 5



Taken at 100x magnification



Taken at 500x magnification

Fig. 10: The structure of ferrite and pearlite structure

size'. At location 5, i.e., the centre part of cross-sectioned of the blade, the formation of 'ferrite and pearlite' structure existed which had a low Hardness Value (HV).

What can be said about the microstructure analysis test was that the forging process of the keris blade had a different content of Hardness Value (HV) as a result of continued forging, quenching, tempering and etching made by the Malay blacksmith or Empu (Fig. 6-10).

CONCLUSION

The attempt made to classify the type of materials used in the making and forging of the keris blade with limited resources available had achieved its objectives. Based on non-destructive and destructive test shows that mostly of the keris contain >99% of iron. Other elements that exist in the keris are silicon, copper and nickel which is very small on percentage range between 0.1-0.5%. The traditional method of keris making is testament to the Malay blacksmiths or Empu's impeccable capabilities in forging the blade resulting in the different levels of Hardness Value (HV). The Malay blacksmiths or Empu had demonstrated skills second to none in making and forging the keris blade through his lifetime of experience and exposure. Though they may not have honed their proficiency formally, they still managed to manufacture blades that were structurally strong, imaginatively artistic with various pamor patterns and had successfully embedded symbolic philosophical and mystical elements into the keris.

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