วิศวกรรมสารฉบับวิจัยและพัฒนา
Engineering Journal of Research and Development
วิศวกรรมสถานแห่งประเทศไทย ในพระบรมราชูปถัมภ์
The Engineering Institute of Thailand under H.M. The King's Patronage
ปีที่ 29 ฉบับที่ 4 ตุลาคม-ธันวาคม 2561
Volume 29 Issue 4 October-December 2018
Received 13 February 2018
Revised 29 March 2018
Accepted 5 April 2018

THAI LOCAL NAM PHI IRON ORE AND FURNACE SMELTING COMBINED WITH SUSTAINED ANCIENT METHOD

Adul Phuk-in
Industrial Technology Program, Faculty of Industrial Technology, Uttaradit Rajabhat University,
27 Injaimee Road, Tha-It Sub-District, Mueang District, Uttaradit Province
Tel. (055)416629, Fax. (055) 416629 # 17, E-mail: Adun999@gmail.com*

ABSTRACT

This research was about the development of the furnace for Nam Phi iron ore. The modern smelting technique was applied to the local smelting workshop by combining the ancient and modern approaches to develop the furnace. In the design phase, the furnace lining material and air pressure control were developed for the higher efficient furnace. The smelting provided 2.3 kilograms of molten Nam Phi iron per furnace that also had the equal efficiency compared with current general furnaces then divided the molten iron for testing into two groups (A, B). Group A iron was tested for the chemical composition and found that there was an iron (Fe) in amount of 99.5 wt% with other elements that made the Nam Phi iron became the high quality metal such as Carbon (C) in amount of 0.0311 wt%, Silicon (Si) in amount of 0.0353 wt%, and Nickel (Ni) in amount of 0.0292 wt% that conformed to the research of Mr. Anuwat Jutilaptaworn .2010, Singhadech Tangjuang .2006, and Mr. Adul Phuk-in .2014 while Group B iron was tested the Vickers Hardness test : HV and the result was found that the Vickers Hardness : HV value before and after the attribute addition by Heat-treatment were 105.67 HV and 771 HV respectively. This could be concluded that molten Nam Phi iron from mixed furnace smelting was able to add the metallurgy properties. Comparing the cost of creating mixed Nam Phi iron furnace with the cost of creating the furnace that the local used, the cost was 14,916.45 Baht and 23,265 Baht respectively. The developed furnace could save the cost for of 8,348.55 baht or 35.88% according to this research objective.

KEYWORDS: Nam Phi iron ore, Mixed Nam Phi iron furnace, Ancient method

1. Introduction

The ancient human living that was founded in many countries civilization since the prehistoric, Stone Age, Iron Age, and ancient history [12] that varies in a period which the significant factor in material civilization changing in each era. More than 5,000 – 10,000 years ago, The human was beginning to craft the tools from natural materials such as basketries, carts, stone tools, and also the bronze smelting, which was the mixed metal between copper and tin [16]. The Thailand oldest evidence of ore

and stone usage, Which was studied and researched, was in the Iron Age, which was the era that human began to smelt the iron ore with higher temperature furnace than the Bronze Age. There were the experiments that tested the ore with different methods and found that smelted iron was more durable than bronze. Iron ore and iron were commonly used since then that assumed to be more than 1,500 – 2,000 years ago [6]. In Thailand, there were many archeological excavation in many regions of Thailand and found many clues of ancient smelting such as Baan Krabueang Nok archaeological site in Nakhon Ratchasima province which was found the slags and Terracotta tubes that used in iron smelting [15] in approximately 2,300 years ago, Chi-Mun river wetlands archaeological site from the research of Silpakorn university that was found the slags in many areas such as Baan Dong Plong and Baan Tung Wua in Satuk district, Baan Non Sung in Ku Mueng district, Buriram province which were 1,700 – 2,500 years before history, U-Tapao archaeological site in Chai Nat province that was found the traces of ancient furnace and smelted pieces in The Ayutthaya Era [14], and the best ore deposit in Northern region was the Baan Nam Phi ore deposit in Nam Phi sub district , Uttaradit province, that was found the Hematite (Fe_2O_3) which consisted of iron in amount of 61.85 wt% [9] and the smelting was also found up until this time. This was the only place in Thailand that had passed on the smelting technique and processed into the “Nam Phi iron product”. The smelting process began with or mining (figure 1a.) in the iron mine behind the Nam Phi folk museum then processing the ore (figure 1b.) and made the terracotta furnace and smelted the ore (figure 2a.) into the Pig iron or Ingot (figure 2 b.) and bar-shaped forming to make the product [8].

a. Nam Phi ore mining [11]

b. Iron ore processing [11]

Figure 1 shows the ore mining in Baan Nam Phi ore deposit and ore processing

a. Nam Phi ore mining [11]

b. Iron ore processing [12]

Figure 2 shows the ancient Nam Phi iron ore smelting method

Nam Phi iron ore mining in the past was simple and used only local tools and equipment such as handmade digging and air pumping tools.

For an ancient smelting, the terracotta furnace would be prepared before smelting the Nam Phi iron ore with the bamboo as a core for the mixed soil to attach then using coal from local woods and the importing thing was the passed on smelting knowledge to create the valuable products as shown in figure 3.

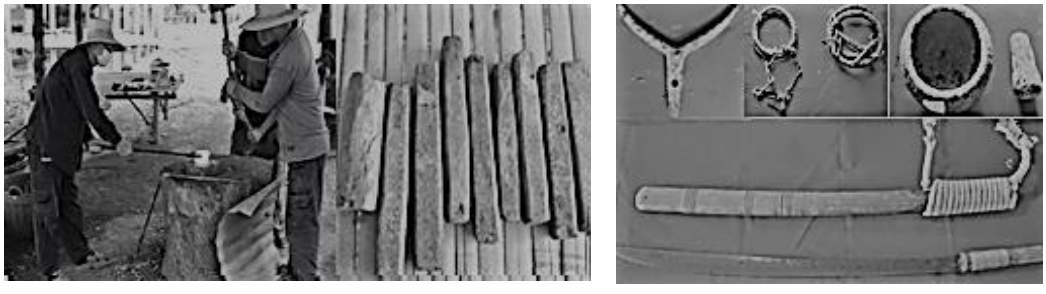


Figure 3 shows the ancient Nam Phi iron products [8]

2. Content

This Nam Phi iron smelting was studied in Baan Nam Phi, located in Nam Phi sub-district, Thong San Khan District, Uttaradit province. The problems in this study were the high furnace construction cost, methods, and the proper smelting efficiency. In previous researches, many researchers performed fieldworks for improving the properties of the Nam Phi iron, studying elemental quantity from slags, studying the old Nam Phi iron and re-smelted Nam Phi iron hardness, Nam Phi iron cost and logistic [10], and developing new iron smelting furnace [11].

This research would retrieve the ancient method to develop the efficient iron ore furnace which lowered the cost that was still not existed in this area.

a. Currently using furnace b. Product forming

Figure 4 shows the Nam Phi iron ore smelting

This study expected to develop the Nam Phi iron ore smelting by using the furnace that mixing the ancient wisdom with the modern technology to lower the Nam Phi iron smelting cost [10] that had more than 5 million baht market value per year from

the demanding of Nam Phi iron product that inspired this research to develop the furnace as mentioned above to lower the Nam Phi iron furnace construction cost.

3. Retrieving iron smelting method

In studying iron ore smelting, the smelting in each country had many different method such as using the big furnace for iron smelting, in European countries, and also using Coke and Limestone as the fuel for high-temperature heat [2] to melt the ore that creates the slag and hot gas. The obtained Pig Iron was attribute added by small, efficient furnace such as Cupola furnace or Bessemer furnace [1] [4] [7].

3.1 The current Nam Phi iron ore smelting in Baan Nam Phi was found that the Nam Phi iron ore furnace was developed into four layers. The furnace wall was made of spherical metal sheet then the layer 1 and 2 were the combustion area and blowing out slags and coated the inner furnace wall with refractory mortar for 30 millimeters and also using local charcoal as a fuel. The smelting preparations were as follows.

First, mining the local Nam Phi iron ore then dressing the ore by cleaning, processing, and size screening the ore before smelting with currently used furnace which was developed from the Nam Phi iron sword community enterprise (as shown in figure 6).

a. Currently using Nam Phi iron furnace

b. Nam Phi Pig Iron

c. Metal bar forming

Figure 6 shows the Nam Phi iron ore smelting by using local furnace

The molten Nam Phi iron ore would become Pig Iron (Figure 6 a, b) as same as the tall furnace smelting but acquiring lesser quantity. In each smelting, 20 kilograms of iron ore would become 2-3 kilograms of iron bar [9]. The acquired Pig Iron would be forged into bar-shaped iron in an amount of 1.5 – 2 kilograms for each time. The Nam Phi iron bar, which cost 3,000 baht per kilogram, would be used for making products and also ship in local and foreign. This was the entire wisdom inheritance of Nam Phi blacksmith families.

3.2 The Nam Phi iron ore smelting in the past was using the furnace which made of clay combining with the local material that was found in the clues of furnace in cylindrical area with 60 – 70 centimeters area and 80 centimeters height and also using

air pressure by compressing air in 1-2 cylindrical objects with human labour to convey the air pressure into the furnace as shown in figure 7.

a. Local ancient furnace ruins b. Smelted iron from an ancient furnace

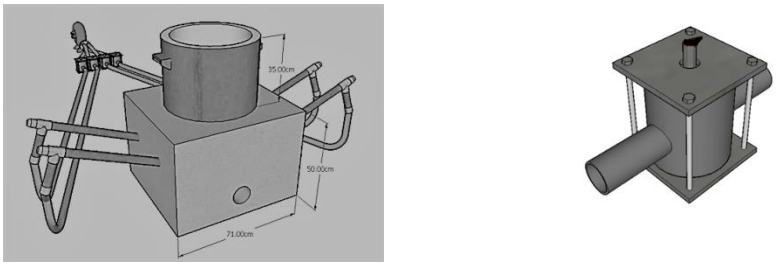
Figure 7 shows the Nam Phi iron ore ancient furnace ruins

From the researches [9], [10] about retrieving the past and present Nam Phi iron production process to find the physical properties of Nam Phi iron and the logistic cost of Nam Phi iron product manufacturers shown that the iron smelting from old furnaces clues were found many of the old slags and old iron ores by performing fieldwork in Baan Nam Phi area and surroundings.

4. Procedures

The objective of developing the furnace with mixed ancient method was to lower the cost, compare the efficiency, and preserve the missing local original wisdom.

4.1 In the mixed ancient method furnace construction design, lower part of the furnace or combustion area, heating process ($CO_2 + C \rightarrow 2CO$) and combustion room ($C + O_2 \rightarrow CO_2$), was designed into cubic shape with 660 millimeters wide, 710 millimeters long, and 500 millimeters of lower furnace height and using refractory bricks as a core and also using 4 pipes of 31.75 millimeters metal pipe to convey the air pressure into the furnace with 600 millimeters length. The upper part of the furnace, ($3Fe_2O_3 + CO \rightarrow 2Fe_3O_4 + CO_2$), was made of rolling steel with 450 millimeters size and 350 millimeters tall. The inner furnace wall was coated with refractory mortar for 30 millimeters. [17] The cracking prevention was designed by using clay combined with local material as same as the ancient method such as husk, sand, clay, and water as shown in figure 8.



a. Nam Phi iron ore furnace designing b. Air pressure adjusting equipment

Figure 8 shows the designing of mixed ancient method furnace

4.2 From studying the smelting method, the air pressure would be used differently in each smelting intervals so there was the air pressure control part designed to control the air pressure that conveyed into the combustion area by using clay with 75 millimeters width, 75 millimeters length, and 110 millimeters height that was able to adjust the air pressure during the smelting process with the adjusting knob which divided the air pressure into 3 levels as follows, 100%, 70%, and 30%.

4.3 Building the mixed ancient method furnace by laying mixed clay as the foundation with 50 millimeters thickness and using refractory brick as a core. There was a slag duct with 50 millimeters size in the first layer to convey the slags out during the heating process then remove slags out of the furnace. There were 4 layers that used 8 refractory bricks per layer, totally 32 bricks. Placing the ventilation tube 300 millimeters above from the ground with 70 tilted degrees. This furnace was hand molded then dried out for 3 days as shown in figure 10 (a, b).

a. Furnace structure b. Air tube installation C. Furnace wall testing

Figure 10 shows the furnace construction and furnace wall testing

After the Nam Phi iron ore furnace construction was completed then it would be tested by Rebound Hammer Test that specified mainly to test 16 points in outer furnace wall, and the averaged hardness result was 109.65 kg/cm^2 as shown in figure 10 (c.).

4.4 Smelting process were as follows, First, warming the furnace for 20 minutes to prevent the early permanent cracking on the furnace wall. Second, adding charcoal into the second layer, light the fire, open the blower and adjust the pressure to the first level (3.7 m/s^2) before putting in the iron ore to heat up the combustion area for 20 minutes. Third, adjust the pressure to the second level (2.6 m/s^2) and putting the ore into the furnace by splitting the ore into 1.43 kilograms for 14 bags (totally 20 kilograms) then putting a bag of ore into the furnace every 6 minutes. Forth, while heating and conveying slags out of the furnace; adjust the pressure to the third level (1.8 m/s^2) for 20 – 30 minutes. Finally, conveying the iron out of the furnace with the steel tongs as shown in figure 11 (b.).



a. Putting Nam Phi iron ore into the furnace

b. Conveying the iron out of the furnace

c. Ingot forming

Figure 11 shows the Nam Phi iron ore smelting by using the furnace with mixed ancient method

5. Efficiency test

The acquired Nam Phi iron from the furnace with mixed ancient method was forming into iron ingot, which was 2.3 kilograms weight as shown in figure 11 (c.) then dividing this testing iron into 2 groups as Group A and Group B with 3 samples per group to test the Nam Phi iron, which was obtained from the furnace, properties that conformed to the Faidra Tzika et.al. 2016 [3], 60Co in cast steel testing design, mixed Iron, combined with 60Co, testing and comparison design, and (Peters B. et.al. 2016) [11] . The test results were shown as follows.

5.1 Element quantity testing with a spectrometer in sample A was found that it was consisted of Iron (Fe) for more than 90 wt% mixing with other elements that caused the Nam Phi iron had high quality as same as the ancient iron and currently local smelted iron as shown in table 1 and 2.

The result of finding mixed elements was found that there were Iron (Fe) in the averaged amount of 99.5 wt%, Carbon (C) in averaged amount of 0.0311 wt%, Silicon (Si) in the averaged amount of 0.0353 wt%, and Nikel (Ni) in the averaged amount of 0.0292 wt%,

Table 1 shows the elemental quantity analysis by the spectrometer of Group A sample (wt%)

Work piece	Fe	C	Si	Mn	P	S	Cr	Mo
1	99.5	0.0322	0.0399	0.0028	0.189	0.0580	0.00043	0.00093
2	99.5	0.0335	0.0371	0.0017	0.194	0.0533	0.00040	0.00087
3	99.5	0.0276	0.0290	0.0014	0.183	0.0420	0.00040	0.0011
averaged	**99.5000**	**0.0311**	**0.0353**	**0.0020**	**0.1887**	**0.0511**	**0.0004**	**0.0010**
Work piece	**Ni**	**Al**	**Co**	**Cu**	**Ti**	**V**	**W**	**Nb**
1	0.0286	0.0129	0.0283	0.0759	0.00056	0.00010	0.00020	0.0010
2	0.0295	0.0092	0.0292	0.0788	0.00030	0.00010	0.00020	0.0010
3	0.0296	0.0103	0.0299	0.0797	0.00033	0.00010	0.00038	0.0010
averaged	**0.0292**	**0.0108**	**0.0291**	**0.0781**	**0.0004**	**0.0001**	**0.0003**	**0.0010**

5.2 Vickers Hardness test: HV in Group B samples before adding properties by heat-treatment was found that the first workpiece hardness testing result was 99.00 HV, the second work piece hardness testing result was 105.00 HV, the third work piece hardness testing result was 113.00 HV, and the averaged hardness testing result was 105.67 HV. After adding properties by heat-treatment, that was the metallurgy process to add the attribute to iron by adjusting the heat-treatment temperature to 850 degrees Celsius then soaking at a temperature for a period of time. After the heat-treatment process, the averaged hardness was increased to 771 HV. Researcher compared the HV value with local researches as shown in table 3.

Table 3 shows the attribute comparison of HV testing

Researcher / furnace	HV testing value before adding properties	HV testing value after adding properties
Anuwat Jutilaptaworn .2010 [5]	29.58 HRC	64.34 HRC
Adul Phuk-in .2014 [11]	155.66 HV	638.33 HV
Suwatchai Watcharatavornsak & Adul Phuk-in .(2015) [14]	319.67 HV	839.67 HV
Adul Phuk-in .(2015) [9]	186 HV	305 HV
Developed mixed furnace	105.67 HV	771 HV

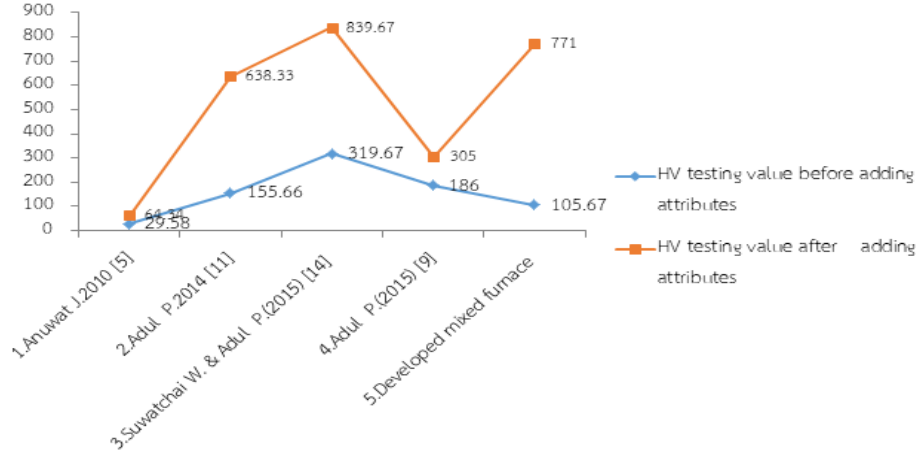


Figure 11 shows the attribute comparison of HV testing

From the HV testing attribute comparison; it was found that the acquired hardness value was similar to the previous Nam Phi iron researches such as the Nam Phi iron volume testing which was found that the volume of Iron (Fe) was in amount of 99.50 % compared with [13], which had the volume of Iron in amount of 70-90% , and [5], which had the volume of Iron in amount of 98.87%. For the Carbon (C) comparison, the developed furnace had 0.031% of Carbon compared with [9], which had

0.012% of Carbon, and [5], which had 0.220% of Carbon. For the Silicon (Si) comparison, the developed furnace had 0.0353% of Silicon compared with [9], which had 0.000% of Silicon, and [5], which had 0.107% of Silicon. For the Nickel (Ni) comparison, the developed furnace had 0.0353% of Nickel compared with [9], which had 0.18% of Nickel, and [5], which had 0.078% of Nickel. The significant point of properties adding in Nam Phi iron was able to increase the metallurgy attribute to the same level as the iron that commonly used in engineering.

5.3 Comparing the cost of furnace construction, there was the construction cost of the furnace with mixed ancient method (Table 4) for comparing with the furnace that the local currently used.

The tool and material cost in creating Nam Phi iron furnace with mixed ancient method was 14,916.45 baht while the tool and material cost in creating the furnace that the local currently used was 23,265 baht. The Nam Phi iron furnace with mixed ancient method could save the tool and material cost in amount of 8,348.55 baht so this could be concluded that the developed furnace had a lower cost than the furnace that the local currently used.

Table 4 shows the cost of creating Nam Phi iron furnace with mixed ancient method

Order	Detail	Unit Price (Baht)
1.	140 kilograms of clay (1.5 baht per kg.)	210 Baht
2.	7 kilograms of husk (2.85 baht per kg.)	19.95 Baht
3.	½ sack of sand for 35 Kg. (3.50 baht per kg.)	122.50 Baht
4.	32 heat-enduring bricks (52 baht per 1 brick)	1,664 Baht
5.	Wage for forming rolling steel in second layer furnace	2,000 Baht
6.	360 cm. of 1.5 inches iron pipe and joints for air blowing	1,000 Baht
7.	8 meters of 1.12 inches rubber tube for air blowing	500 Baht
8.	A 220 V . Blower	7,400 Baht
9.	Wage and material of air pressure adjustment tool	2,000 Baht
	Overall cost	14,916.45 Baht

Conclusion

The research of Nam Phi iron furnace with mixed ancient method had revised the smelting literature from the past up until now that inherited from the generations. The problem that found in smelting the Nam Phi iron was the high cost of furnace construction, so this research had developed the iron furnace with mixed ancient method by using local materials to construct. With designing and developing air pressure control system for better efficient smelting furnace that provided 2.3 kilograms of Nam Phi iron from the developed mixed furnace, which had equal efficiency compared with current general furnaces. The researcher divided the molten iron for testing into 2 groups (A, B). Group A iron was tested the element quantity and found that

there was an iron (Fe) in amount of 99.5 wt% with another elements that made the Nam Phi iron became the high-quality metal such as Carbon (C) in amount of 0.0311 wt%, Silicon (Si) in amount of 0.0353 wt%, and Nickel (Ni) in amount of 0.0292 wt% that conformed to the research of Mr.Anuwat Jutilaptaworn .2010, Singhadech Tangjuang .2006, and Mr. Adul Phuk-in. 2014 while Group B iron was tested the Vickers Hardness test : HV and the result were found that the Vickers Hardness : HV value before and after the attribute addition by Heat-treatment were 105.67 HV and 771 HV respectively. This could be concluded that molten Nam Phi iron from mixed furnace smelting was able to add the metallurgy properties. Comparing the cost of creating mixed Nam Phi iron furnace with the cost of creating the furnace that the local currently used, the cost were 14,916.45 Baht and 23,265 Baht respectively. The developed furnace could save the cost for of 8,348.55 baht or 35.88% . Finally, the developed furnace had disseminated to the community for the Nam Phi product development.

References

[1] Coalbrookdale. Shropshire History. [Internet]. 2017 [cited 2017 June 22]. Available from: http://shropshirehistory.com/iron/iron.

[2] Dong, F. et al. Modeling of iron ore reactions in blast furnace. International Journal of Heat and Mass Transfer 103 (77–86). [Internet]. 2016 [cited 2016 August 16]. Available from: ELSEVIER. http://.sciencedirect.com.

[3] Faidra T. et al. ^{60}Co in cast steel matrix: A European interlaboratory comparison for the characterization of new activity standards for calibration of gamma-ray spectrometers in metallurgy. Applied Radiation and Isotopes 114 (167-172). [internet]. 2016 [cited 2016 August 16]. Available from ELSEVIER. http://.sciencedirect.com.

[4] Fine Arts Department. Tour of Thailand's History Exhibition. Journal of fine Arts Department. Thailand. 2012. p.29-30.

[5] Jutilapthaworn A. Constructing of Kiln and Nam Phi Steel Smelting. Research. Department of Industrial Engineering, Faculty of Engineering, Srinakharinwirot University. 2009.

[6] Jantorn M. Periodization and historical method. [Internet]. 2017. [Last access on April 19, 2017]. URL: http://www.thaigoodview.com /library/teachershow/bangkok/malaiwan_c/ historym1/.

[7] Max Steel Company Limited . Stainless Steel. [Internet]. 2016 [cited 2016 July 16]. Available from: http://maxsteelthai.com/index. php?option=com_content&view=article&id=123:-stainless-steel&catid=42.

[8] Puk-in A. Development of Nam Phi Steel Quality from Newly Smelted Nam Phi Steel. Research Institute of Uttaradit Rajabhat University, Uttaradit Rajabhat University; 2016.

[9] Puk-in A. Investigation of Nam Phi Steel Production Process in the Past and Present for Finding Mechanic Properties of Nam Phi Steel in Nam Phi Sub-District, Thong Saen Khan District, Uttaradit Province. Research, National Research Council of Thailand (NRCT), Industrial Technology Program, Uttadit Rajabhat University; 2015.

[10] Puk-in A. Research on Logistic Costs of Entrepreneurs of Nam Phi Steel Products for the Trading Route of Luang Prabang, the World Heritage. Research, Industrial Technology Program, Uttaradit Rajabhat University, URU; 2015.

[11] Puk-in A. Engineering Comparison of Nam Phi Steel for Comparing Properties of Nam Phi Steel with Hardened Steel. Research, National Research Council of Thailand (NRCT), Industrial Technology Program, Uttadit Rajabhat University, URU; 2014.

[12] Puk-in A. Nam Phi Steel – Thai Sustainable Quality Steel. Academic Journal of Faculty of Industrial Technology, Phranakhon Rajabhat University, 12th Year, Vol. 1, January 2017 – June 2017; 120-127.

[13] Taengjuang S. Steel Smelting Methods of Nam Phi Steel. Faculty of Science and Technology, Uttaradit Rajbaht University, URU;2006.

[14] Silpasuwanchai W. Archeological evidence analysis form U-Tapao city, Manorom district, Chai Nat province. [Bachelor of Arts (Archaeology) Thesis]. Bangkok, Archaeology department Archaeology faculty Silpalorn University; 1995.

[15] Watcharathawornsak, S. & Puk-in A. (2015). Study on Comparison of Engineering Properties of Nam Phi Steel. Academic Journal of Faculty of Industrial Technology, Lampang Rajabhat University, 8th Year, Vol. 1, January 2015 – June 2015; 92-105.

[16] Yupom I. The ancient iron smelting furnace study at Baan Kao Din Tai, Baan Kruad district, Buriram province. [Master of Arts Thesis]. Bangkok, Prehistoric archeology department, Silpakorn University; 2010.

[17] Nerantzis N. et al. An integrated approach to the characterization and dating of furnaces in smelting sites in Macedonia, Greece. International Journal of Archaeological Science 16 (65-72). [Internet]. 2017 [cited 2017 April 16]. Available from: ELSEVIER. http://.sciencedirect.com.