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บทความวิชาการ

NAM PHI STEEL – THAI SUSTAINABLE QUALITY STEEL

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ABSTRACT

Although iron ore could be found in several sources of Thailand, the trace of civilization of iron ore utilization was found at the source of iron ore in Ban Nam Phi located at Thong Saen Khan District in Uttaradit Province, whereas, Nam Phi steel has been smelted since the past to present. In addition, there were some traces found from an old kiln that was built for over 100 years and found at Ban Nam Phi that such method was the traditional local wisdom of villagers started from mining to ore dressing, ore smelting, ore forming by forging, and producing products that are the uniqueness of Nam Phi Ironsmith Family that is still produced in the local area. Such process was the production of products made of Nam Phi steel with methodology, process, and forming of smelted Nam Phi steel as products. To study on this type of steel, scholars have conducted field studies in the area of Ban Nam Phi in order to test Nam Phi steel with engineering methodology. Consequently, we could perceive inheritance of characteristics of excellent and sustainable steel production of Thailand. Local wisdom of ironsmith and scientific testing used in the research enabled us to perceive quality of Nam Phi iron ore while ore smelting and engineering testing enabled us to perceive properties of good Nam Phi steel from the past to present.

Keywords: Nam Phi iron ore, Nam Phi steel smelting, Nam Phi steel product, Nam Phi Ironsmith Family

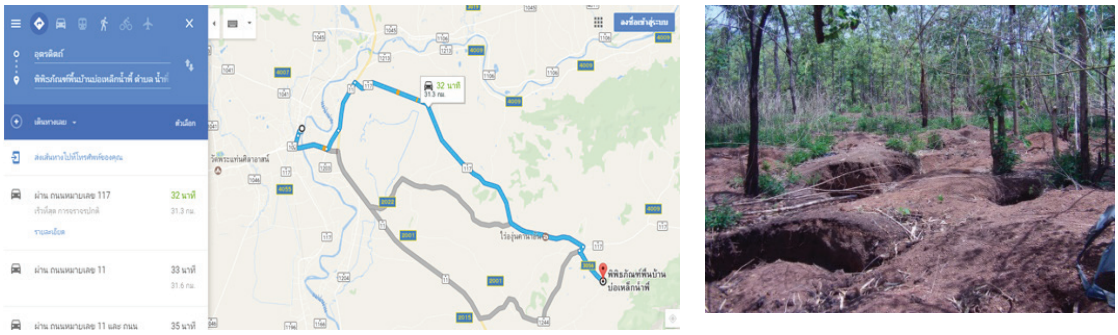
INTRODUCTION

In the past, humans learned to utilize existing materials for their living as evident in excavation of civilizations from pre-historic period to Stone Age, Metal Age, and historical period (Fine Arts Department, 2002). Each period had duration as the important factor causing civilization changing of each period, for example, in Metal Age, humans learned to utilize bronze for producing tools, jewelry, and appliances for hunting and living. Such bronze was generated by mixing and melting copper and tin together. This kind of bronze production has been conducted for over 2,500-4,000 years (Chantorn, 2016) In Iron Age, humans learned to smelt iron ore with higher temperature than that used in Bronze Age. In such age, iron was tested by several methods and found that iron ore was harder than bronze for using. Consequently, iron ore has been utilized since 1,500-2,500 years ago (Chantorn, 2016).

There were several sources in Thailand that iron ore could be found. However, the trace of civilization of iron ore utilization was found at the source of iron ore in Ban Nam Phi located at Thong Saen Khan District in Uttaradit Province, whereas, Nam Phi steel has been smelted since the past to present. In addition, there were some traces found from an old kiln that was built for over 100 years and found at Ban Nam Phi that such method was the traditional local wisdom of villagers started from mining to ore dressing, ore smelting, ore forming by forging, and producing products that are the uniqueness of Nam Phi Ironsmith Family. To study on this type of steel, some researchers have conducted field studies in the area of Ban Nam Phi in order to test Nam Phi steel

with engineering methodology. Consequently, we could perceive inheritance of characteristics of excellent and sustainable steel production of Thailand.

There were several types of iron ore that were found and each type of them gave different percentage of iron upon its type. There were some scholars classifying types of iron ore as follows: Magnetite (Chemical Formula: Fe_3O_4), Limonite (Chemical Formula: $Fe_2O_3nH_2O$), Pyrite (Chemical Formula: Fe_3S_2), Siderite (Chemical Formula: $FeCO_3$). In addition, the iron ore of Nam Phi steel that was classified as Hematite was also found in Ban Nam Phi with chemical formula of Fe_2O_3 that was consistent with a research conducted in 2016 (Phuk-in, 2016) by testing Nam Phi iron ore from 2 sources at Office of Primary Industries and Mines, Region 3. Those 2 sources of Nam Phi iron ore were consisted of Bor Lek Nam Phi Museum (Figure 1 (a.)) that is currently prohibited from mining conducted by any general people and entrepreneur (due to conservation of Uttaradit Province. Percentage of Nam Phi iron ore found in this area was 61.85%. Another source was current mining area located behind the museum (Figure 1 (b.)) for producing Nam Phi steel products. Percentage of Nam Phi iron ore found in this area was 59.06%. Iron ore from both sources provided slightly different percentage. In addition, some traces of mining in the past were also found in the museum, i.e. Bor Phra Saeng and Bor Phra Khan that have been studied further upon inherited recital and found that they were the sources of iron ore for smelting and making swords for offering to the kings in ancient time.



a. Museum area Nam Phi b. Nam Phi iron ore

Figure 1 Museum area Nam Phi

CONTENT

Utilization of ore by mining with local tools, ore dressing performed by cleansing, ore crushing and ore sorting performed for sorting good quality ore for smelting as show in Figure 2.

Figure 2 Nam Phi Iron Ore Sources, Crushing, and Dressing

NAM PHI STEEL SMELTING

In European countries, high kilns were preferred for ore smelting and fuel used in such smelting was Coke and Limestone causing high temperature (Steel Smelting, 2016), Consequently, steel can be melted yielding Pig Iron, slag and gas. The obtained Pig Iron is improved by using small but high efficient kiln, for example, Cupola furnace, Bessemer furnace, etc. The properties of good steel were based on each job description, for example, steel used for manufacturing industrial tools, Chromium (Cr), special alloy steel (Max Steel Company Limited, 2016)

In the past, Nam Phi iron ore was smelted by using kilns made of clay mixed with other local materials that could be found from a cylinder kiln found in the area with the dimension of 60 centimeters wide and 80 centimeters tall. It was operated by using air pressure caused by compressing air in 1-2 cylinder objects and air pressure was generated by human labors as shown in Figure 3.

Figure 3 Devices for Generating Air Pressure used in Nam Phi Steel Smelting

To smelt such Nam Phi steel, human labors play such an important role. Based on the researches conducted in 2015 on Investigation of Nam Phi Steel Production Process in the Past and Present for Finding Mechanic Properties of Nam Phi Steel (Phuk-in, 2015) and Logistic Costs of Entrepreneurs of Nam Phi Steel Products for the Trading Route of Luang Prabang, the World Heritage (Phuk-in, 2015) the traces of iron ore smelting performed by using kilns for smelting slag and some old iron ore were found in the area in large amount. (Research on Logistic Costs of Entrepreneurs of Nam Phi Steel Products for the Trading Route of Luang Prabang, the World Heritage) as shown in Figure 4.

A. Old Kilns B. Slag and Old Pig Iron

Figure 4 Old Kilns and Nam Phi Pig Iron

Accordingly, Nam Phi Village has been considered as the largest and best iron ore smelting since the past to present time. Therefore, it is possible that this village has been the place for forging and forming Nam Phi steel as the products used in living, weapons, or even transporting smelted Nam Phi steel to other provinces or capitals for producing tools, device, and weapons since ancient time.

Currently, Nam Phi steel smelting is conducted by using kiln developed by the research conducted by (Jutilapthaworn, 2009) and Nam Phi Steel Swords Community Enterprise Group as shown in Figure 5. To develop kiln to be suitable for smelting Nam Phi steel, site conditions and fuel are important enabling production of Nam Phi steel products to be produced continuously. According to inherited local wisdom and wisdom of Nam Phi Ironsmith Family, Nam Phi steel has had good quality in several kinds of operation.

Figure 5 Current Nam Phi Iron Ore Smelting

Smelted Nam Phi yields Pig Iron as same as that smelted by high kiln in other countries but its quantity may be smaller than that smelted by kiln of Ban Nam Phi yielding 2-5 kilograms per smelting (Phuk-in, 2015). The obtained Pig Iron is processed and forged by human labors to gain the stick of Pig Iron as shown in Figure 6.

Figure 6 Pig Iron Forging and Forming by Human Labors

UTILIZATION OF NAM PHI STEEL

To utilize Nam Phi steel, since the quantity of produced Nam Phi steel is smaller than that of general industrial sector, its production is sufficient for producing Nam Phi steel products only yielding the value of distribution over 4 million baht per year (Phuk-in, 2015) Before being improved on its properties and production of products based on the research on Development of Nam Phi Steel Quality from Newly Smelted Nam Phi Steel (2016), it was found that Nam Phi steel is consisted of 98.8% of iron (Fe), 0.941% of Carbon (C), 0.0143% of Silicon (Si), 0.0021% of Manganese (Mn), 0.0132% of Phosphorus (P), 0.0063% of Sulphur (S), 0.00030% of Chromium (Cr), 0.0027% of Molybdenum (Mo), 0.0032% of Nickel (Ni), 0.0060% of Aluminum (Al), 0.0066% of Cobolt (Co), 0.0486% of Copper (Cu), 0.0074% of Titanium (Ti), 0.0002% of Vanadium (V), 0.0047% of Tungsten (W), 0.0040 of Lead (Pb), 0.00094% of Tin (Sn), 0.0002% of Niobium (Nb), 0.00062% of Magnesium (Mg), 0.080% of Arsenic (As), 0.00037% of Zirconium (Zr), 0.0066% of Bismuth (Bi), 0.0060% of Calcium (Ca), 0.00082% of Cerium (Ce), 0.00040% of Antimony (Sb), 0.0237% of Selenium (Se), 0.0008% of Tellurium (Te), 0.0001% of Boron (B), 0.0139% of Nitrogen (N). This is the test of Nam Phi steel before producing any product of the community. In this research, mineral content was tested by using Spectrometer Optic yielding information on properties of Nam Phi steel that were consisted of the researches conducted by (Taengjuang, 2006) and that conducted by (Jutilapthaworn, 2009) as well as that conducted by (Watcharathawornsaand, Puk-in, 2015) studying on mixed mineral content in Nam Phi steel before producing any product and improvement of properties through metallurgical methods of Nam Phi Ironsmith Family.

Formerly, utilization of Nam Phi steel products was producing some devices and tools for Agriculture and weapons For wars through forging and forming performed by human labors with expertise on improving iron to be steel. Based on the investigation of a research (Puuk-in, 2015), such method used kiln for heating and melting iron until it was able to be forged and formed. Subsequently, it was added with Carbon (C) by using charcoal that was used as fuel for heating and forging. Improvement of properties performed by coating after forging caused Nam Phi steel to be harder with toughness that was consistent with metal coating performed in the research on Nam Phi Steel Engineering Test for Comparing Properties of Nam Phi Steel and Hardened Steel (2014). In improving hardening property of Nam Phi steel (Phuk-in, 2014), it was found that Nam Phi steel was consisted of Carbon (C) that was increased by 1.14 times approximately. In addition, such method also required expertise of Nam Phi Ironsmith Family that has been inherited up till now as shown in Figure 7.

Figure 7 Nam Phi Products of Nam Phi Ironsmith Family

Figure 7 illustrated Nam Phi steel products of Nam Phi Ironsmith Family inheriting characteristics, method of good properties improvement that met with metallurgical theories on hardening. However, in the actual operation, toughness and hardness should be integrated due to vibration occurred from using that may break such metal.

IMPROVEMENT OF STEEL PROPERTIES

Improvement of steel's properties in modern industry is smelting Pig Iron in small kiln such as Bessemer Furnace and Induction Heating, to be efficient in smelting iron with sulfur (FeS). Subsequently, it was compressed with oxygen by spraying oxy gen in the kiln for reacting with sulfur yielding SO_2 (Sulfur Dioxide) and oxide steel that was consistent with the research conducted by (Fu et al, 2016) who studied on steel smelting in kiln. Consequently, temperature for smelting good quality steel could be perceived.

In ancient time, improvement of Nam Phi steel's properties improved toughness of ore (obtained from percentage of Carbon). If steel was hard in the beginning of smelting, frequent forging and heating would increase Carbon but it required expertise of forger.

Faidra Tzika et al. (2016) designed ^{60}Co in cast steel test for comparing with ^{60}Co and (Peters, B., Hoffmann, F., 2016) studied on ore smelting and estimation of smelting methods in kiln with high temperature causing several types of gas in kiln as same as that of Nam Phi steel smelted in kiln. In addition, its properties were also improved by using metallurgical methods as same as that done in the field study on investigation of properties of Nam Phi steel generated by Nam Phi Ironsmith Family. Whereas, Nam Phi steel was tested by various methods, i.e. Vickers Hardness Test, and Mixed Mineral Finding as follows.

Vickers Hardness Test was conducted with 6 work pieces of Nam Phi steel before properties improvement, it was found that work piece with the highest level of hardness was work piece No. 01006 with maximum hardness of 186 HV and hardness after coating of 305 HV. For design of smelting of Nam Phi steel obtained from ore smelting, the obtained quantity of Nam Phi steel was 15 kilograms and this research was cooperated with some experts of Faculty of Metallurgical Engineering of Suranaree University of Technology, to improve properties of Nam Phi steel by adding some important minerals while the melting temperature of Nam Phi steel was ranged from 1,700 – 2,000 Degrees Celsius. The main minerals added in Nam Phi steel were 2% of Carbon based on its weight and 0.5% of molybdenum based on its weight in order to improve the property of anti-corrosion. According to the results of improvement of properties, it was found that it was consisted of: 95.3% of iron (Fe), 3.86% of Carbon ©, 0.00013% of Silicon (Si), 0.0127% of Manganese (Mn), 0.0447% of Phosphorus (P), 0.0447% of Sulphur (S), 0.0452% of Chromium (Cr), 0.0743% of Molybdenum (Mo), 0.141% of Nickel (Ni), 0.0032% of Aluminum (Al), 0.0157% of Cobolt (Co), 0.266% of Copper (Cu), 0.0080% of Titanium (Ti), 0.0011% of Vanadium (V), 0.0069% of Tungsten (W), 0.0054 of Lead (Pb), 0.00018% of Tin (Sn), 0.0002% of Niobium (Nb), 0.0001% of Magnesium (Mg), 0.080% of Arsenic (As), 0.00093% of Zirconium (Zr), 0.0099% of Bismuth (Bi), 0.0060% of Calcium (Ca), 0.0493% of Cerium (Ce), 0.0004% of Antimony (Sb), 0.0008% of Tellurium (Te), 0.0001% of Boron (B), 0.0146% of Nitrogen (N).

Properties of Nam Phi steel studied in this research were able to be improved to be equal to industrial steel and general steel. However, there is currently no source of Nam Phi steel for industry in the area and it is only produced for responding to demands of people demanding to conserve Nam Phi steel and Nam Phi steel products only. However, in the future, steel smelting for industry may be occurred soon.

There are many steel standards such as JIS, ASTM and TISI standard which concern about mechanical requirement, tensile strength, yield strength, elongation, and chemical composition requirements, etc. However, There is no valid comparison standard between Nam Phi steel and Industrial or Structural steel. Therefore, further study and testing of Nam Phi steel is needed for these standards comparison.

Comparison on Improvement of Properties of Nam Phi Steel for Representing Good Characteristics of Nam Phi Steel that could be Improved Equally to Those of Steel Used in Industrial Sector that was Consistent with the Researches of some Scholars was shown in Comparison Table 1.

Table 1 Comparison on Properties obtained from Field Test

Researchers Name/ Year	Testing Methods	Test Results before Improving Properties	Test Results after Improving Properties
(Taengjuang, 2006)	Study on Elements of Nam Phi Steel's minerals	Consisted of Iron ranged from 70 - 99% and over	-
	Physical Properties of Nam Phi Steel	From the test on micro structure, it was found that it was mostly mixed phase between ferrite and perlite.	-
	Micro Vickers Hardness Test (HMV)	Average hardness was ranged from 19 - 327 (HMV)	-
(Jutilapthaworn, 2009)	Research on Smelting Methods of Nam Phi Steel and Development of Kiln of Nam Phi Steel	Test hardness prior hardening at 29.58 HRC	Test hardness after hardening at 64.34 HRC
(Puk-in, 2015)	Study on Nam Phi Steel from Current Mining Site	Nam Phi steel classified as hematie was found with chemical formula of Fe_2O_3	-
(Puk-in. 2016)	Vickers Hardness Test (HV)	Hardness before hardening was 186 HV	Hardness after hardening was 305 HV
	Design of Nam Phi Steel Smelting for Improving properties by adding mixed minerals	Contained 0.941% of Carbon (C)	Contained 3.86% of Carbon (C)

CONCLUSIONS

Utilization of current Nam Phi steel is conservation of civilization of Nam Phi steel production that has been inherited through Nam phi Ironsmith Family who have knowledge on mining, ore smelting, and metallurgical works. Based on researches f several scholars, it was found that the properties of Nam Phi steel were equal to those of iron ore generally found in this world. In addition, Nam Phi steel was also consisted of smelting, forging, forming, and improvement of metallurgical properties. Moreover, some areas have been studied continuously. Improvement of these properties of Nam Phi steel could be performed through new smelting as well as that of general steel industry. Improvement of any property must be based on job description, for example, anti-corrosion, steel with high carbon content, etc. As a result, Nam Phi steel is considered as the legend of iron and sustainable hope of metallurgical industry of Thai people with belief and legend along with long-term inheritance of ironsmith family from the past to present.

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