THE EVALUATION OF DRILLING PERFORMANCE OF NAM PHI DRILL BIT

Adul Phuk-in

Abstract

This research used the smelted Nam Phi iron and melted it by an induction cooker to enhance the alloy element during melting and getting the enhanced-property of iron bar. It was shaped by turning, grinding, forming by the automated machine, Computer Numerical Control machine (CNC), enhancing metallurgy properties, coating titanium-aluminum-nitride (TiAlN). The product was taken to analyze the quantity of alloy. Nam-Phi-iron drill bit was tested by using 2^2 factorial methods to determine rotation speed and cutting speed suited to drill 15-mm.-thick SCM440 steel. The results revealed that the suitable rotation speed was 400 rpm, and the cutting speed was 36 meters per minute. The result was used to randomly compare 3 general industrial steels: SS41, S45C and SCM440. The result of mean difference using pairwise comparison showed that the pairs of SCM440 (Y_3) and SS41 (Y_1) and SCM440 (Y_3) and S45C (Y_2) was different in statistical significance at the level of .05, as shown by Duncan's multiple range test (DMRT). The drilling design used 150 pieces of SCM440 steel to find the percentage of yield. The percentage of yield of Nam Phi drill bit was 66.67 yield, the steel scrap twisted roundly, had no-colored burned scraps, and the percentage of yield of general industrial drill bit was 15.34, the steel scrap twisted less and had colored scraps from drilling burnt.

Keywords: Property enhancement of Nam Phi Iron, Drill bit cutting machine creation, Re-vulcanization, Induction cooker

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Introduction

The development of cutting tools has been used in various states of works (Grigoriea et al., 2020), such as drilling, boring, and milling processes, but these cutting processes often occur with the vibration and the cutter blades wear out while cutting (Kirsten, 2017). Therefore, the cutting efficiency and the quality of cutting surfaces are crucial (Wang et al., 2021). For the past two-three decades, there has been a rapid development of cutting tools that are more efficient; they have been designed the material structures to make various cutting devices (Ozel et al., 2021). present cutting tools have strengths and weaknesses as follows:

1. Engineering design process is the systematic problem-solving operation (Chutima, 2002) that propagates the ideas of designers through the ways of decision making to design devices, tools and machines. The ways of designing have to work together by mainly using scientific and mathematical knowledge with combining other branches of various sciences, so those make the results or the ways have the most efficient under constraints. There are 6 steps of engineering design process that are problem identification, related information search, solution design, planning and development, testing evaluation and design improvement, and presentation (Thongmee, 2019). Analysis of variance is popular to be used to find performance efficiency and helpful for better decision making. The statistical analysis of models would be fixed effects that the factor levels studied have been certainly set by the needs of experiment (Chutima, 2002; Montgomery, 2018). After reviewing related research, it showed that design of cutting tools was the crucial cost of production in the factory, since the production took lots of times for cutting process (Adam et al., 2021). During cutting, a drill bit scratched with materials and there was high temperature (Jinfu et al., 2021). Tool coating is helpful to prolong the drill bit and makes less wearing out (Grigoriea et al., 2021). Furthermore, it is trembling while drilling (Wang et al., 2021) that affects drilling time and tool efficiency. Therefore, the design of experiment is the important reason for research of material drilling in general industry (Adam et al., 2021; Liu et al., 2021; Montgomery, 2018; Chutima, 2002).

2. Jinfu et al. (2021) studied “Tool coating effects on cutting temperature during metal cutting processes. comprehensive review and future research directions” showed that tool coating helped the cutting tools for wear state with heat and

temperature factors, and affected the cutting performance in various ways. Therefore, the study design was set forecast model of cutting at different temperature levels. Adam et al. (2021) studied “Design and analysis on textured cutting tool” and showed that the design of cutting tools was the vital cost in factory production since it took a lot of time in cutting. The study found that to enhance the efficiency of cutting process and to prolong the cutting tools might be from adjusting the quality of cutting-tool production process by tungsten carbide coating. The experimental design of alloy turning showed the highest cutting force from this cutting tool.

This research had the guideline for Nam Phi ore being developed its properties for cutting drills of local industries. It was experimental design with factorial method in order to find the appropriate parameters for drilling 3 general industrial steels (Adam et al., 2021, Wang et al., 2021). The results from parameters, rotation speed (A) and cutting speed, were to selected the most appropriate for drilling design of SS41, S45C and SCM440 steels, and to compare the drilling results, including the surface roughness, with Nam Phi drill bit and general industrial drill bit, and drilling performance as yield percentage (Arun et al., 2020, Jinfu et al., 2021). The results would be analyzed with ANOVA as Completely Randomized Design (CRD). Hence, this research proposed to use the drill bit for boost drilling in agricultural vehicle production, to compare drilling time and sharpening time of the drill bit.

Methods

1. This research used the induction cooker to enhance the properties of Nam Phi iron (Peters & Hoffmann, 2016; Phuk-in, 2018; 2019; 2020). Steps of smelting Nam Phi iron by induction cooker were as follows: warm up the induction cooker, bring Nam Phi iron bar into the blast furnace, and add the alloy element by using the induction cooker.

The research and team wore personal protective equipment in every step as shown in Figure 1.

Figure 1 Quality development of Nam Phi Iron by Induction Cooker

Figure 1 showed the quality development of Nam Phi iron by using induction cooker (Binay, 2021) that spent for two and a half hours for melting and added two elements, C and Mo in the cooker (Zhanchao et al., 2021). Meanwhile, the researcher provided casting mold that pressed pattern in the sand-casting mold, adjusted a sprue and opened riser with pouring the melting iron into the mold, and lastly, got the enhanced-property-process iron bar as shown in Figure 2.

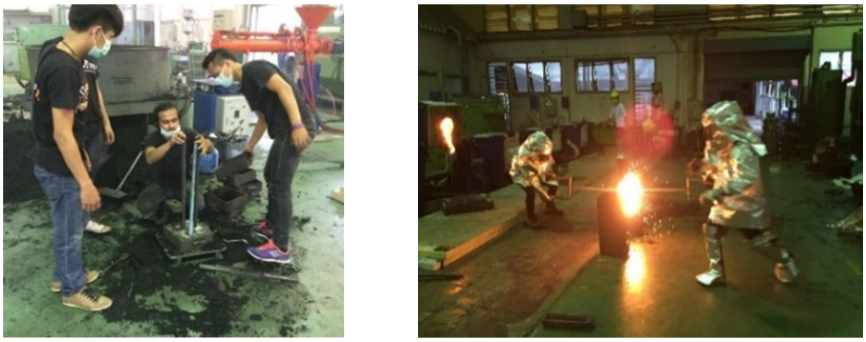

Figure 2 Providing Nam Phi Casting Mold and pouring the enhanced-property-process iron into the mold

2. Cutting tool forming (Grigoriea et al., 2020) The researcher designed drill bit cutting tools 16 millimeters in diameter, 100 millimeters of cutting-edge length. Specifically, forming the drill bit by turning, enhancing the metallurgy hardness and grinding the cutting edge by the automated machine, Computer Numerical Control machine (CNC) as shown in Figure 3 and 4.

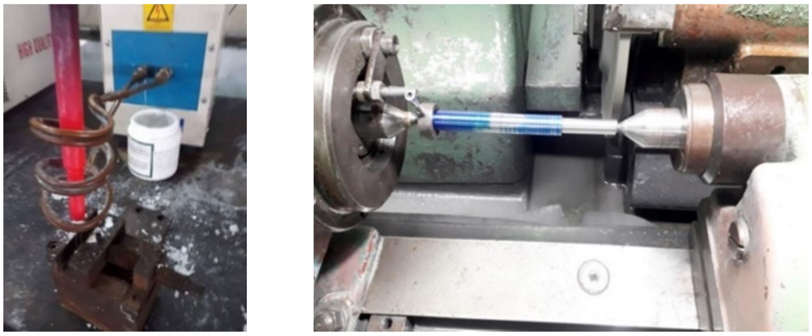

Figure 3 Forming the Nam Phi Drill Bit Cutting Tool

Figure 4 Drill bit after forming

3. Hardness coating – This step was for coating the drill bit with nano layer coating titanium-aluminum-nitride (TiAlN) (Jinfu et al., 2021; Kirsten, 2017; Dina, 2021). After forming the drill bit, the researcher set TIAlN 8-15 μm of thickness, -1.1 Gap of internal stress, grey feature, enhanced the drill bit temperature to 900 degrees Celsius, and the coefficient of friction force was 0.30-0.35 compare with dried steel. The Nam phi drill bit after coating was shown in Figure 5.

Figure 5 Nam Phi Drill Bit after Coating titanium-aluminum-nitride (TiAlN)

4. The analysis of quantity of alloy element (Faidra et al., 2016) of Nam Phi drill bit cutting tool was shown in Figure 6. The researcher analyzed the quantity of elements by providing the work piece, analyzing the elements with spectrophotometer machine and recording the results, including having test of general industrial drill bit as shown in Figure 6.

Figure 6 Analysis of alloy element quantity by spectrophotometer machine

Results

1. The results' analysis of alloy element quantity of Nam Phi drill bit and general industrial drill bit were shown as the following:

1.1 The results' analysis of alloy element quantity of Nam Phi drill bit by spectrophotometer machine revealed that the percentages of Iron (Fe) was 95.33, of Carbon (C) was 1.19, of Manganese (Mn) was 0.29 and of Tungsten (W) was 0.61. (Watcharathawornsak & Phuk-in, 2015).

1.2 The results' analysis of alloy element quantity of a general industrial drill bit by spectrophotometer machine revealed that the percentages of iron (Fe) was 98.39, of Carbon (C) was 1.07, of Manganese (Mn) was 0.62 and of tungsten (W) was 0.10.

2. Experiment of 2^2 factorial design (Chutima, 2002; Gary, 2010) of Nam Phi cutting tool to test the factors of rotation speed (A) and cutting speed (B) with the factors of low level (0) and high level (1), including the variance analysis of Nam Phi drill bit as shown in Table 1.

Table 1 Experiment of 2^2 factorial design of drilling with Nam Phi drill bit

Factors	Low level (0)	High level (1)
(A) Rotation speed	400 rpm	800 rpm
(B) Cutting speed	18 meters/minute	36 meters/minute

According to Table 1, there were 4 tests of the experiment of 2^2 factorial design by using Nam Phi drill bit (Arunkumar et al., 2021; Neeraj & Shishu, 2021). Drilling test was to use Nam Phi drill bit with 8 pieces of 15-mm.-thick SCM440 steel and record the drilling time used, then compared the drilling time used with the replicate test process and got through the main effects of suitable drilling method of Nam Phi drill bit. The results of 4 full factorial tests (Montgomery, 2018; Chutima, 2002) showed the results of ANOVA with the statistical significance at the level of .05 as shown in Table 2

Table 2 The results of ANOVA of Nam Phi drill bit tests

Source	Degree of freedom (DF)	Sum of Square (SS)	Mean of Square (MS)	F
A (Rotation speed)	1	105.13	105.13	2.31
B (Cutting speed)	1	0.13	0.13	0.00
A*B Interaction	1	0.13	0.13	0.00
Error	4	144.50		
Total	**7**	**249.87**		

According to Table 2, the ANOVA results of Nam Phi drill bit tests found that rotation speed (A) and cutting speed (B) affected Nam Phi drill bit from the probability, F at 2.31, 0.00 with the statistical significance at the level of .05 shown in and A and B were related significantly, A*B interaction referred that rotation speed was related with cutting speed in this test. Besides, the relationship of rotation speed and cutting speed and ANOVA analysis was shown in Figure 7.

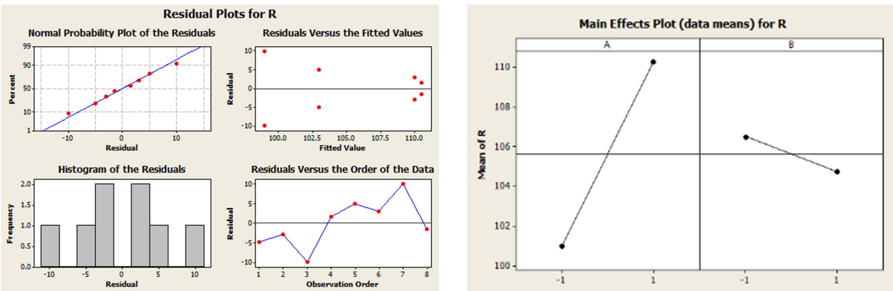

Figure 7 The relationship of rotation speed and cutting speed and ANOVA analysis

According to Figure 7, the analysis of statistical significance level of Nam Phi drill bit and the relationship of rotation speed and cutting speed were shown in Table 2 and Figure 7 that rotation speed and cutting speed affected the performance of drilling, and the appropriate rotation speed and cutting speed was 400 rpm, 36 meters per minute, respectively. Those speeds made a good performance of Nam Phi drill bit drilling.

3. Rotation speed and cutting speed resulted from the experiment of factorial design for the drill test with general industrial steel before drilling test, the researcher provided three groups of steel with 15-mm.-thick and did the hardness test in Rockwell (HRC). The results of hardness test showed that the average hardness of SS41, S45C and SCN440 were 32.3, 37.33 and 39.33, respectively. The hardness test is shown in Figure 8.

Figure 8 The hardness test in Rockwell (HRC)

4. Engineering design process of drilling's Nam Phi drill bit (Liu et al., 2021) used rotation speed and cutting speed to design drilling, accordingly, the appropriate speeds of rotation and cutting were at 400 rpm and 36 meter per minute, respectively. So, the test started to drill provided one steel (6 M) of 3 groups; SS41, S45C and SCM440 randomly in the room temperature that all tested steels were in general industrial quality. After the drilling test with Completely Randomized Design (CRD) (Montgomery, 2018; Chutima, 2002; Aleksandar et al., 2021; Hongcheng et al., 2021; Grigoriev & Volosova, 2020) the results came out as shown in Table 3.

Table 3 The results of drilling 3-groupped steels with Nam Phi drill bit

	Treatments		
Results	SS41 (t_1) (seconds)	S45c (t_2) (seconds)	SCM440 (t_3) (seconds)
N = 15	81	85	88
	82	81	84
	81	84	89
	79	83	92
	80	85	85
Total	**403**	**418**	**438**
Average	**80.60**	**83.60**	**87.60**

4.1 Setting Hypotheses among drilling 3 groups of steel with the statistical significance at the level of 0.05 (α = 0.05)

$$H_0 = \mu_1 = \mu_2 = \mu_3$$
$$H_1 = \mu_1 \neq \mu_2 \neq \mu_3 \text{ at least one pair}$$

4.2 Finding Corrected of Mean : CM

$$CM = \frac{(\sum\sum x_{ij})^2}{n} \quad 1.1$$

$$\frac{(\sum\sum x_{ij})^2}{n} = \frac{(1259)^2}{15} = 105{,}672.10$$

4.3 Finding Total Sum of Square (SST)

$$SST = \sum\sum x_{ij}^2 - CM \quad 1.2$$

$$= 81.35^2 + 82.52^2 + 81.33^2 + 79.63^2 + 80.65^2 \ldots + 85.37^2$$

= 105,853 – 105,672.10 = 180.94

4.4 Finding Between Groups Sum of Square (SSB)

$$SSB = \sum[\frac{(\sum x_i)^2}{n_i}] - CM \quad 1.3$$

$$= \left[\frac{403^2}{5} + \frac{418^2}{5} + \frac{438^2}{5}\right] - 105{,}672.10$$

= $105{,}795.40 - 105{,}672.101$ SSB = 123.34

4.5 Finding Within Group Sum of Square (SSE)

$$SSE = \sum_{i=1}^{k}\sum_{j=1}^{n_i}(x_{ij} - \bar{x}_i)^2 \quad 1.4$$

or = SST – SSB = 180.94 –123.34 = 57.60

Table 4 The results of ANOVA

Source of variation	Degree of freedom (DF)	Sum of Square (SS)	Mean of Square (MS)	F
Within Group Sum of Square (SSB)	2	123.34	61.67	12.84
Between Group Sum of Square (SSE)	12	57.60	4.80	
Total Sum of Square (SST)	**14**	**180.94**		

The table above showed the results of ANOVA, the critical value of $f_{0.05,2,12}$ = 3.89 < f that was 12.84; H_0 = 12.84, and in reject area of H_0. That means 3 types of steels that were drilled with Nam Phi drill bit have a difference at least one pair significantly at the level of .05.

4.6 Make a comparison with Duncan's multiple range test (DMRT) – set the steel group of DMRT, group of SS41, $\bar{y}_1$= 80.60, group of S45C $\bar{y}_2$ = 83.60 and group of SCM440, $\bar{y}_3$ = 87.60.

4.6.1 Rank the average from the highest to the lowest as follows:

$\bar{y}_3$ = 87.60 $\bar{y}_2$ = 83.60 $\bar{y}_1$= 80.60

4.6.2 Calculate a compared pair

Formula: $\binom{t}{2} = \frac{t!}{(t-2)!\times 2!}$

Solution: $\binom{3}{2} = \frac{3!}{(3-2)!\times 2!} = \frac{3\times 2\times 1}{1\times(2\times 1)} = \frac{6}{2} =$ 3 pairs that need to be compared.

4.6.3 Calculate the difference of the average of 3 compared pairs:

Pair 1: $\bar{y}_3 - \bar{y}_1$ = 87.60 – 80.60 = 7

Pair 2: $\bar{y}_3 - \bar{y}_2$ = 87.60 – 83.60 = 4

Pair 3: $\bar{y}_2 - \bar{y}_1$ = 83.60 – 80.60 = 3

4.6.4 Calculate the critical value

Formula: $L_{SR_\alpha} = SSR_{\alpha(P,V)\sqrt{\frac{MSE}{n}}}$

Consider P value; pairs of treatment that want to compare

$SSR_{0.05}(2{,}12)$ (Tables for Duncan's) = 3.081

$SSR_{0.05}(3{,}12)$ (Tables for Duncan's) = 3.225

Solution:

$L_{SR_{0.05}} = SSR_{0.05(2,12)\sqrt{\frac{MSE}{n}}}$ = 3.081 $\sqrt{\frac{4.80}{5}}$

= 3.081 x 0.98 = 3.019 (was a critical value use to compare with the difference)

$L_{SR_{0.05}} = SSR_{0.05(3,12)\sqrt{\frac{MSE}{n}}}$ = 3.225 $\sqrt{\frac{8.133}{5}}$

= 3.225 x 0.98 = 3.160 (was a critical value use to compare with the difference)

4.6.5 Compare the difference of the calculated 3-pair averages with a critical value; $L_{SP_{\alpha 0.05}}$

$$\bar{Y}_3 - \bar{Y}_1 = 7 > 4.112(L_{SR_{0.05,P_3}}),\ \bar{Y}_3 - \bar{Y}_2 = 4 > 3.928(L_{SR_{0.05,P_2}}),\ \bar{Y}_2 - \bar{Y}_1 = 3 < 3.928(L_{SR_{0.05,P_2}})^{*}$$

According to the results above, we can see that mean differences for both Y3-Y1 and Y3-Y2 are contained in the critical region (7 > 4.112 and 4 > 3.928). So that, the null hypotheses, H_0 will be rejected and the alternate hypotheses, H_1, is assumed to be correct (or different). But mean difference for Y2-Y1 is not contained in the critical region (3 < 3.928), thus, H_0 cannot be rejected (or no difference).

The analysis results with ANOVA and Duncan's methods revealed that SCM440 was the most appropriate steel for this experiment according to its hardness and average drilling time were at high level, meanwhile, the comparison of drilling performance (percentage of yield) between Nam Phi drill bit and general industrial drill bit was shown as follows:

5. A comparison of drilling test between Nam Phi drill bit and general industrial drill bit used the percentage of yield ($\%\ Yield$) from drilling SCN440 steel: 15-mm.-thick workpiece by using 118 degrees of cutting angle, 135 degrees of rake angle, 12 degrees of lip clearance angle and 59 degrees of point angle, 400 rpm of rotation speed and 36 meters per minute of cutting speed. There were records of time used, checks randomly of scrap type for 3 periods and temperature measurement while drilling. Then stop drilling for measuring the scrap quantity of from drilling bit that could not drill SCM440. The formula of the percentage of yield of drilling used is shown as follows.

$$\%\ Yield = \frac{Number\ of\ pieces\ drilled\ with\ various\ types\ of\ drill\ bit}{Number\ of\ all\ work\ pieces} \quad ....(1.5)$$

5.1 Design of drilling was set with 150 15-mm.-thick workpieces, without cooling and drilled continuously (Yongrong & Domos, 2020) and the result showed the performances of using two types of drill bits in Table 5.

Table 5 The performances of using 2 types of drill bit

Type of drill bit	Numbers of pieces drilled	Percentage of yield
Nam Phi drill bit	100	66.67
General industrial drill bit	23	15.34

The performance of using 2 types of drill bit showed that Nam Phi drill bit could drill 100 workpieces, 66.67% of yield in 112.77 seconds with 54.16 degrees Celsius of average temperature, and general industrial drill bit could drill 23 workpieces, 15.34% of yield in 116.16 seconds with 58.28 degrees Celsius of average temperature.

The results of drilling SCM440 steel with two types of drill bit showed that general industrial drill bit wore away and could not drill after drilling 23 pieces. But Nam Phi drill bit could drill the same type of steel for 100 pieces. The drilling performance was under the same conditions, drill-bit sharpness and cutting temperatures.

5.2 Surface roughness performance of using 2 types of drill bit measured the averages in micrometer (μm)by surface roughness tester (Arun et al., 2020) found that the surface roughness of drilling by Nam Phi drill bit was 0.34; R_a = 0.34 μm and by general industrial drill bit was 0.54; R_a = 0.54 μm. Furthermore, scraps of drilling with these drill bits were shown in Figure 8.

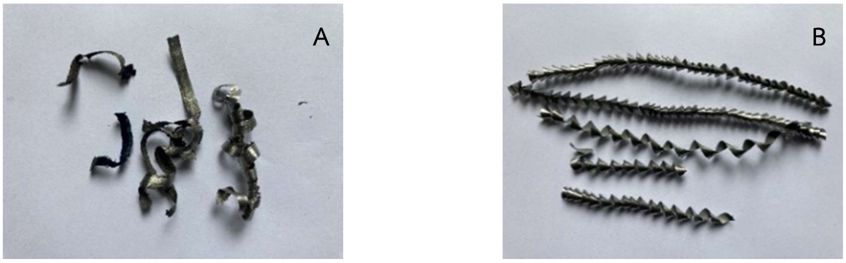

Figure 8 Scraps of drilling with 2 types of drill bit

A) Scraps of using general industrial drill bit B) Scraps of using Nam Phi drill bit

According to figure 8, the features of drilling scraps showed that scraps from general industrial drill bit twisted a little and had burnt-color on them, but scraps from Nam Phi drill bit twisted very roundly and had no burnt-color on them. After the drill bit had been developed, it was used with the works in local industry, drilling in agricultural vehicle production of SD Tractors Company Limited. It was able to reduce time of drilling boost for 8%, and 7% of drill bit sharpening time. Therefore, it enabled to reduce 15% of total drilling time.

Discussions

This research was to develop the quality of Nam Phi iron in Uttaradit province. The development of Nam Phi iron quality started with enhancing its standard as same as general standard steels by re-melting with the induction cooker, adding the element property to form the drill bit cutting tool, and finding mechanical values for designing the experiment of 2^2 factorial with 4 tests. It came out with the appropriate rotation speed and cutting speed at 400 rpm and 36 meters per minute, respectively. Nam Phi drill bit was used to drill 8 pieces of 15-mm.-thick SCM440 steel, the test was consistent with research of (Adam et al., 2021) about design of experiment of cutting tools. The researcher took the results of drilling 3 types of general industrial steels: SS41, S45C and SCM440 with hardness values of 32.3, 37.33 and 39.33 respectively, to design the variance analysis. Before the test of drilling randomly 5 workpieces of 6-meter steel, the results of Pairwise comparison showed that the first pair (Y_3 and Y_1) and the second pair (Y_3 and Y_2) had the difference. But the pair of Y_2 and Y_1 had no difference (ab). The design of experiment showed that Nam Phi drill bit could drill 100 workpieces, 66.67% of yield in 112.77 seconds with 54.16 degrees Celsius of average temperature and the surface roughness of 0.34 µm, and general industrial drill bit could drill 23 workpieces, 15.34% of yield in 116.16 seconds with 58.28 degrees Celsius of average temperature and the surface roughness of 0.54 µm. The result is consistent that the surface of Nam Phi drill bit was coated with coating titanium-aluminum-nitride (TiAlN); coating enables to enhance the drill bit property.

Conclusions

The researcher brought Nam Phi iron ore from the area of Ban Nam Phi, Thong Saen Khan district, Uttaradit province. Nam Phi iron ore is sponge iron and can be forged. So, the researcher smelted Nam Phi iron and melted by induction cooker, in order to enhance the alloy element during melting and get the enhanced-property iron bar. It was shaped by turning, grinding, forming by the automated machine, Computer Numerical Control machine (CNC), enhancing metallurgy properties, and coating titanium-aluminum-nitride (TiAIN). The developed drill bit was analyzed with the spectrophotometer machine. The result revealed that the percentages of iron (Fe) was 95.33 and of carbon (C) was 1.19. After that Nam Phi drill bit cutting tool was used for the experiment design of 2^2 factorial design for finding the appropriate rotation speed and cutting speed with 15-mm.-thick SCM440 steel. The appropriate rotation speed was 400 rpm and the cutting speed was 36 meters per minute. Design of experiment was made for drill test with 3 samples of general industrial steel: SS41, S45C and SSM440, with Completely Randomized Design (CRD) and the results of drilling 3 types of 6-meter-long steel bar randomly showed that the results of ANOVA, the critical value of $f_{0.05,2,12}$ = 3.89 < f that was 12.84; H_0 = 12.84, and in reject area of H_0. Those means 3 types of steels that were drilled with Nam Phi drill bit have a difference at least 2 types of steel significantly at the level of .05, and compared the averages with Duncan's multiple range test (DMRT) revealed that the third pair S45C $\bar{y}_2$ and SS41, $\bar{y}_1$ had no difference with drilling with Nam Phi drill bit, but the first pair: Y_3 and Y_1, and the second pair: Y_3 and Y_2 had the differences. The comparison of drilling with Nam Phi drill bit and general industrial drill bit showed that Nam Phi drill bit could drill 100 workpieces, 66.67% of yield in 112.77 seconds with 54.16 degrees Celsius of average temperature and the surface roughness of 0.34 μm, and general industrial drill bit could drill 23 workpieces, 15.34% of yield in 116.16 seconds with 58.28 degrees Celsius of average temperature and the surface roughness of 0.54 μm. The research used Nam Phi drill bit to drill vehicle boost in agricultural vehicle production of SD tractors company limited. The results showed that drilling with Nam Phi drill bit could reduce drilling time totally for 15% that 8% of boost drilling and 7% of drill bit sharpening.

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Reference

Adam M, Winowlin J, Gandhimathinathan M, Thirumalai R, Muthuraj K. Design and analysis on textured cutting tool. Materials Today: Proceedings 2021; doi:https://doi.org/10.1016/j.matpr.2021.07.464.

Aleksandar J, Gaurav C, Francesco G. Designing the design of experiments (DOE)–An investigation on the influence of different factorial designs on the characterization of complex systems. Energy and Buildings 2021;250:111298.

Arun KP, Ram KS, Prathap P, Ragul K, Raghul KS. Optimization of reaming parameters to improve surface roughness of En1A leaded material with the approach of particle swarm optimization. Materials Today: Proceedings 2020;37:1003-1008.

Arunkumar P, Muthukumaran N, M.Muthu S, Prabhu L, Rajeshwari R. Investigation on effect of process parameters in abrasive Jet Machining process using full factorial design. International Conference on Sustainable materials, Manufacturing and Renewable Technologies 2021; 47(15):5395-5400.

Binay K, Gour G, Roy P, Kumar S. Comparative energy analysis between rotary hearth furnace-electric change. Energy and Climate Change 2021;1:100-016.

Chutima P. Design of experiment in engineering. Bangkok: Chulalongkorn University Press; 2002.

Dina K, Robiah Y, Rozita O, Suraya AR, Badrul MJ. Rheological investigation of synthetic-based drilling fluid containing non-ionic surfactant pentaerythritol ester using full factorial design. Colloids and Surfaces A: Physicochemical and Engineering Aspects 2021;625:126700.

Faidra T, Oleksiy B, Mikael H, 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 2016;114:167-172.

Gary W.O. A first course in design and analysis of experiments. Publisher: W. H. Freeman.

Grigoriea SN, Volosova MA, Vereschaka AA, Sitnikov NN, Milovich F, Bublikov JI, Fyodorov SV. et al. Bionic design of tools in cutting: Reducing adhesion, abrasion or friction. Wear 2021;482- 483:20395.

Grigoriev SN, Volosova M. Properties of (Cr, Al, Si) N-(DLC-Si) composite coatings deposited on a cutting ceramic substrate. Ceramics International 2020;46:18241-18255.

Hongcheng M, Longsheng Y, Qian WX, Binghang Z. Preparation and optimization of a low-cost adsorbent for heavy metal ions from red mud using fraction factorial design and Box-Behnken response methodology. Colloids and Surfaces A: Physicochemical and Engineering Aspects 2021;627:127-198.

Jinfu Z, Zhanqiang L, Bing W, Jianrui H, Yi W. Tool coating effects on cutting temperature during metal cutting processes: Comprehensive review and future research directions. Mechanical Systems and Signal Processing 2021;150:107-302.

Kirsten B. High-performance coatings for cutting tools. CIRP Journal of Manufacturing Science and Technology 2017;18:1-9.

Liu S, Li J, Xu C, Zhou H, Liao C, Fei W, Luo E. Effect of computer-assisted design and manufacturing cutting and drilling guides accompanied with pre-bent titanium plates on the correction of skeletal class II malocclusion: A randomized controlled trial. International Journal of Oral and Maxillofacial Surgery 2021;50(10):1320-1328.

Montgomery DC. Design and analysis of experiments. New York. John Wiley & Sons; 2018.

Neeraj K, Shishu Gi. Development, characterization and preclinical evaluation of nanosized liposomes of itraconazole for topical application: 3^2 full factorial design to estimate the relationship between formulation components. Journal of Drug Delivery Science and Technology 2021;66:102785.

Ozel T, Biermann D, Enomoto T, Mativenga P. Structured and textured cutting tool surfaces for machining applications. CIRP Annals 2021; 70(2): 495-518.

Peters B, Hoffmann F. Iron ore reduction predicted by a discrete approach. Chemical Engineering Journal 2016;304:692-702.

Phuk-in A. Comparison of alloy elements and mechanical properties between Nam Phi Iron and other iron ore in Uttaradit Province. Ayuthaya Rajabhat University National Conference 2018;1:519-524.

Phuk-in A. Development of Nam Phi Iron ore smelter from local knowledge to find engineering properties. Asia-Pacific of Science and Technology 2018;23:1-7.

Phuk-in A. The solution for optimum size of product to anticipate the requirement of Nam Phi Iron ore for smelting of Nam Phi Iron sword community enterprise. Rajamangala University of Technology Tawan-ok Social Science Journal 2019;8(2):166-174.

Phuk-in A. Comparison of alloying elements between Nam Phi Iron ore in Uttaradit Province and iron ore of Bu Hom Sub-District, Chiang Khan District, Loei Province. Academic Journal, Uttaradit Rajabhat University, Science and Technology (For Local Development) 2019;14(1):121-133.

Phuk-in A. Thai local Nam Phi Iron; good iron of Uttaradit. Phitsanulok: Phitsanulok Dom; 2020.

Thongmee P. Design of experiment in engineering. 2019. Available at: www.https://sites.google.com/site/technology1111161/bth-thi-6-krabwnkar-xxkbaeb-cheing-wiswkrrm. Accessed April 5, 2021

Wang M, Qin P, Zan T, Gao X, Han B. Zhang Y. Improving optimal chatter control of slender cutting tool through more accurate tuned mass damper modeling. Journal of Sound and Vibration 2021;513:116393. doi:https://doi.org/10.1016/j.jsv.2021. 116393.

Watcharathawornsak S, Puk-in A. A study on comparison of engineering properties of Nam Phi steel. Journal of Faculty of Industrial Technology, Lampang Rajabhat University 2015;8(1):92-105.

Yongrong L, Domos R. Enhancing single channel MQL through bypass-controlled design for deep hole drilling with small diameter tool. Procedia Manufacturing 2020;43:88-94.

Zhanchao L, Yun L, Wenhui M, Yakun Z, Wang C. Preparation of high-purity TiSi2 and eutectic Si–Ti alloy by separation of Si–Ti alloy for clean utilization of Ti-bearing blast furnace slag. Separation and Purification Technology 2021;265:118473.