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Test Analysis and Study on Cutting Destruction Properties of Solid Ice-snow Road

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Abstract

Build cutting resistance measurement system based on single-chip microcomputer and high speed camera in order to analysis cutting destruction of solid ice-snow. The experimental model has been built according to the rotating orthogonal experiment methods when tests, take the cutting resistance as objective function, A significant factor in the depth of cutting, rake angle as well as tool installation angle as influencing factors, and analysis found that the relationship between the primary and secondary factors were setting angle>density>cutting depth. By comparing theoretical models and experimental models found both the maximum error is about 8.7%, the minimum error is about 12.8%, the median error of about 12%, which verified the availability of theoretical model. Affecting the snow removal efficiency of parameters were carried out the optimal tests study, and found that the best setting angle of cutting tool is from 46°to 52°on the condition that the temperature is lower than -15℃, the thickness of snow and ice is less than 35mm, and rake angle -10°~ -9°.Optimal combination of parameters meet not only the job requirements but also provide a valuable reference for the optimum design of snow removal tool structure and process parameters, and the overall design of a prototype in the future.

Keywords: *Solid ice-snow; cutting destruction; Mechanical properties; Optimization test*

1. Introduction

Snow and iced of road affect seriously the traffic safety of city. The difficult problem of solid ice and snow to clear in effective method always confuses worker. Recently, at home and abroad scholars have done a lot of research aiming at ice-snow removal means [1-2], but mostly for the new floating snow, and for repeatedly rolling, repeated thawing of solid ice-snow removal technology is relatively immature. Mainly because most of the researchers analysis from the design and optimization of machine point of view, and don’t conduct tests and trials in terms of ice-snow characteristics, most tests are based on prevention of avalanches for analyzing ice-snow characteristics in foreign [3-4]. Domestic Jilin University Deng Hongchao conducted experiments on pavement snow by using GPR [5]; Jilin University Li Wenfeng did a simple test on ice-snow feature [6]; ice-snow was tested from the aspects of the tool into the snow angle by Harbin Polytechnic University Qi Xiaojie [7], However, the report is rare on analyzing ice-snow fracture failure properties from the mechanics mode of ice-snow views. Therefore analyzed solid ice-snow fracture failure mechanism on the basis of the mechanical properties, it has more practical significance to ice-snow removal equipment optimized design on the basis of clearing mechanism.

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2. The Analysis on Cutting Force Model of Solid Ice-snow Influencing Factors

Failure process analysis based on solid ice-snow, its cutting force mathematical model can be used formula (1) [8-10].

$$F = \sqrt{F_x^2 / F_y^2} \quad (1)$$

$$F_x = k\sigma_c h_c \tan\varphi \cos(\delta - \varphi) + \frac{2h_D \sigma_T \sin(\delta + \varphi)}{(2+n)(A+h_D)[1-\sin(\delta+\varphi)]} \quad (2)$$

$$F_y = k\sigma_c h_c \tan\varphi \cos(\delta + \varphi) + \frac{2h_D \sigma_T \sin(\delta - \varphi)}{(2+n)(A+h_D)[1-\sin(\delta+\varphi)]} \quad (3)$$

k − Dimensionless coefficients;
σ_c − Compressive strength (Pa);
σ_T − Tensile strength (Pa); $\sigma_T = 0.32\sigma_c$
h_c − Maximum critical cut depth (m)
δ − Installation angle;
φ − Friction angle;
h_D − Cutting depth (mm);
n − Stress distribution index;
$A = 0.616h_c$

By the formula (2), (3) can be seen the factors effected the cutting force of solid ice-snow mainly consist of two sides: On the one hand, it related to the parameters of solid ice-snow(compressive strength and tensile strength of ice-snow, internal friction angle of ice-snow, external friction coefficient and cutting depth of ice-snow and ice-snow density). On the other hand, it related to the parameters of tool (tool rake angle, tool installation angle).

In addition to these above factors, temperature is also an important factor in the impact of cutting resistance. Temperature will directly affect the compressive strength σ_c, the internal friction angle of ice-snow φ, external friction coefficient of ice-snow β [11-13] and so on. Because of the limitations of test, the test temperature was set up an average temperature on the same day, the test cutting speed was set at a constant speed.

3. The Test Analysis of Solid Ice-snow Cutting Resistance

The test was carried on the test-bed to measure the cutting resistance F. Determination of cutting forces with octagonal ring three-dimensional dynamometer. The snow samples are artificial production on the outside.

3.1 Sample Preparation

The test snow was the instant snow down in the Heilongjiang Jiamusi winter. It needed to prepare $70 \times 40 \times 15$cm cement block sample before making snow sample. Throwing snow on the cement block sample(each about 2 cm thickness), watering, vehicle rolling, to observe the frozen intact after about two hours, the ice-snow surface treatment level, and then throwing snow, watering, vehicle rolling, this work was repeated, which lasted three days. The specimen surface needs to treat smoothly before the test, otherwise the cutting depth error would increases. The sample original state was shown in Figure 1. The outdoor average temperature was -21 ℃ during the sample preparation.

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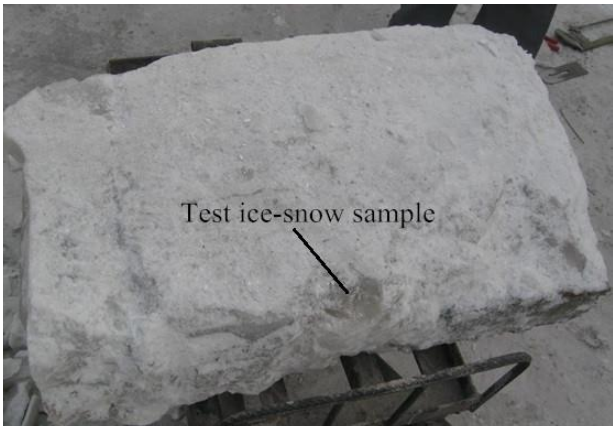

Figure 1. Test Ice-snow Sample

3.2 Test Conditions

During that test day, outdoor temperature was -18 ℃, humidity was 43%, laboratory room temperature was -1 ℃, table feed speed was 1.2m/min and ice-snow the average compactness was 2040Pa. It can be obtained $\varphi = 30.4°$ $\beta = 1.1°$ based on the known ice density table [15].

3.3 Building of Test evice

Solid ice-snow cutting resistance measurement system includes data acquisition systems based microcontroller acquisition and image acquisition system based high-speed video camera.

The dater acquisition system is composed of SDC-C4M23 octagonal ring three-dimensional dynamometer, SDY2102 dynamic resistance strain gauges, homemade SCM data acquisition and PC machine. The cutting resistance F measured by dynamometer during test, then sent the signal to the dynamic resistance strain gauges, and then inputted to the microcontroller data acquisition, after that, transported to the PC by the microcontroller after processing, at last, using Matlab software for data processing, finally displayed of the measured value of three-dimensional cutting resistance.

Image acquisition system consists of high-speed camera device, news lights and image acquisition software. In the test, the measured image captured by News lighting through high-speed video camera, the signal was then fed to the computer and the image captured, saved by image acquisition software. The Measurement device was shown in Figure 2.

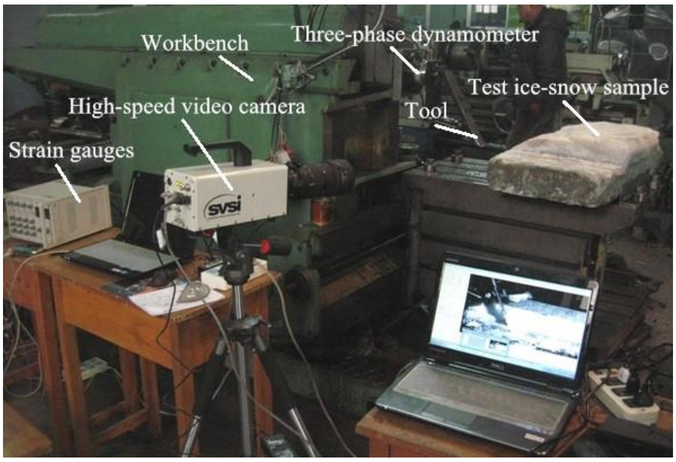

Figure 2. Solid Ice-Snow Cutting Resistance Measurement Device

4. Test Results and Analysis

4.1 Experimental Design

By univariate analysis found that installation angle A, rake angle B and cutting depth C are significant factors, so considering these three factors in the test: installation angle, rake angle, the cutting depth, factors level table shown in Table 1. Experimental designed by using rotating orthogonal design test methods.

Table 1. Rotary Design Factors Coding Table

Level	Factor		
	Installation angle（°）	Tool rake angle（°）	Cutting depth（mm）
γ	67	-13	60
1	60	-12	50
0	50	-10	35
-1	40	-8	20
-γ	33	-7	10

4.2 Test Results

The test results are shown in Table 2

Table 2. Test Design and Results

Factor / Test No.	Installation angle（°）	Tool rake angle（°）	Cutting dept（mm）	Cutting resistance F（KN）
1	40	-12	20	2.4
2	60	-12	20	7.7
3	40	-8	20	5.1
4	60	-8	20	8.0
5	40	-12	50	4.8
6	60	-12	50	8.9
7	40	-8	50	6.1
8	60	-8	50	6.8
9	33	-10	35	5.3
10	67	-10	35	8.6
11	50	-13	35	3.1
12	50	-7	35	8.9
13	50	-10	10	5.2
14	50	-10	60	8.3
15	50	-10	33	3.2
16	50	-10	33	3.3
17	50	-10	33	3.9
18	50	-10	33	2.9
19	50	-10	33	3.1
20	50	-10	33	2.8
21	50	-10	33	3.6
22	50	-10	33	3.4
23	50	-10	33	2.6

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The data from test were processed through using design expert software(Design-Expert 6.0), established the cutting resistance regression equation(4), built the contrast surface chart of test model and theoretical model by using Matlab software, as Figure 3shown. According to the analysis, it could find that both the maximum error(the ratio of difference between the cutting resistance theoretical maximum point with the test maximum point and theoretical value) are about 8.7%, the minimum error(the ratio of difference between the cutting resistance theoretical minimum point with the test minimum point and theoretical value) are about 12.8%, the median error(the ratio of difference between the cutting resistance theoretical median point with the test median point and theoretical value) are about 12%, the overall error is less than 20%, which proving the applicability of the theoretical model.

$$F = 81987.6 - 1402.6x_1 + 7704x_2 + 460x_3 + 11.8x_1^2 + 254.2x_2^2 + 4.9x_3^2 - 36.2x_1x_2 - 15.8x_2x_3 \quad (4)$$

x_1 as installation angle, x_2 as tool rake angle, x_3 as cutting depth.

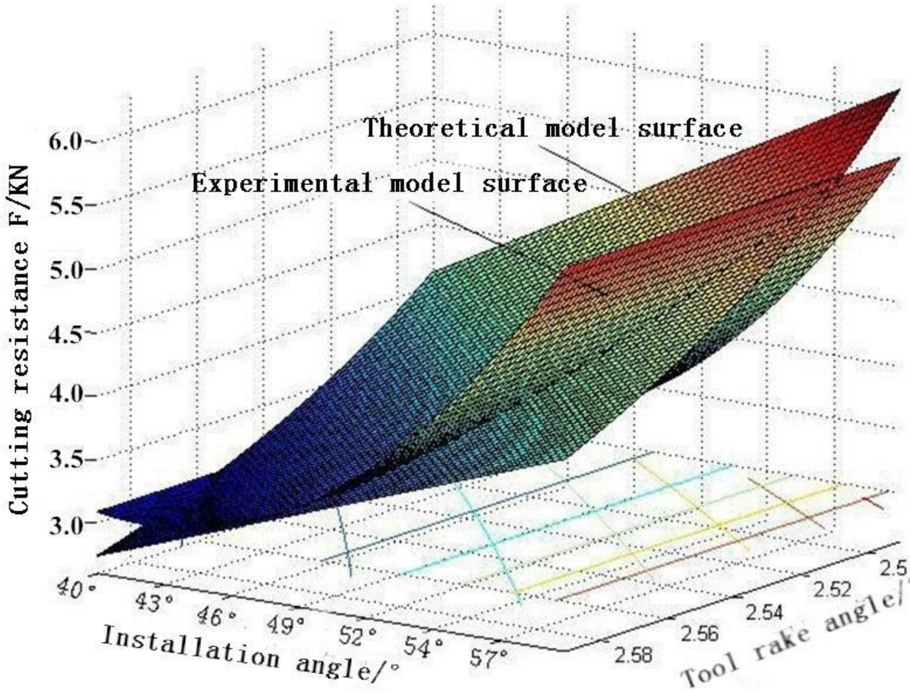

Figure 3. Contrast Surface Chart of Test Model and Theoretical Model

Table 3. Analysis of Variance Table

Sources of variance	Sum of squares	Freedom	The average sum of squares	Value F	The critical value>F
Model	97.16	8	12.15	21.86	<0.0001
A	25.20	1	25.20	45.34	<0.0001
B	3.5	1	3.5	6.29	0.0215
C	5.43	1	5.43	9.78	0.0074
A^2	21.97	1	21.97	39.54	<0.0001
B^2	16.43	1	16.43	29.57	<0.0001
C^2	19.41	1	19.41	34.93	<0.0001
AB	4.21	1	4.21	7.57	0.0156

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BC	1.8	1	1.8	3.25	0.0931
Sum	7.78	14	0.56		
Error	104.9	22			

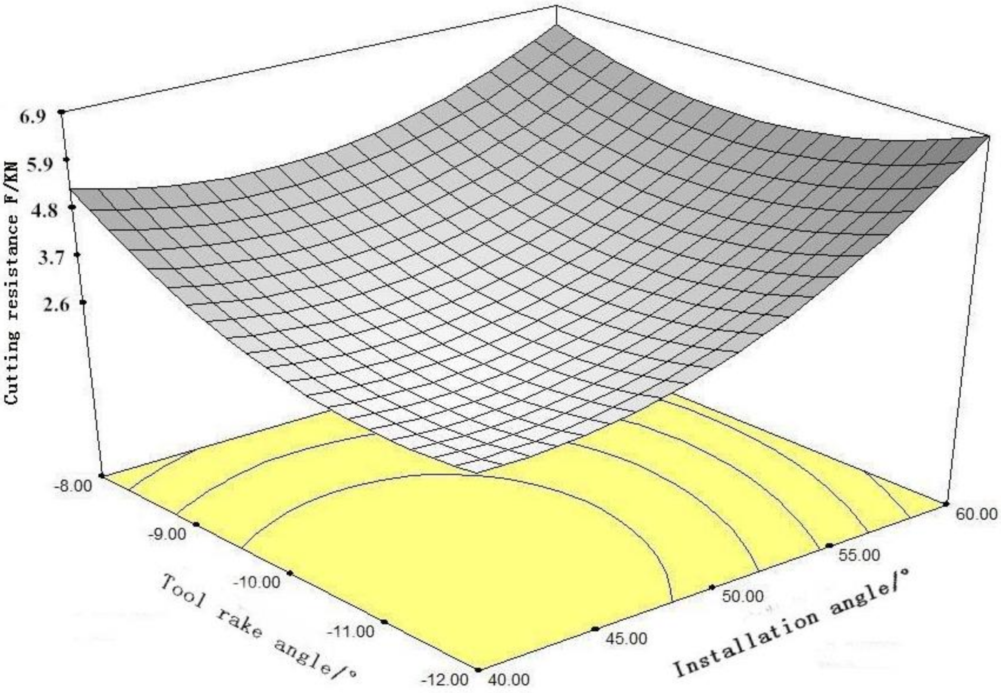

Figure 4. The Response Surface Plot of Factors AB on Cutting Resistance

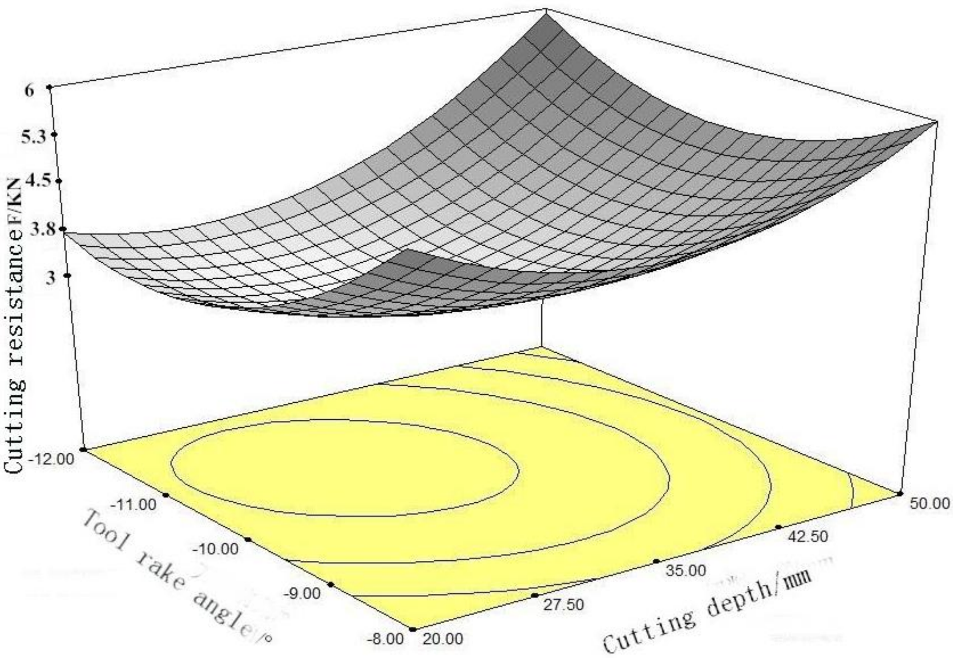

Figure 5. The Response Surface Plot of Factors BC on Cutting Resistance

According to the variance analysis table 3, it can be obtained that the primary and secondary relationship between factors A, B, C are A>C>B, which are installation angle>cutting resistance>tool rake angle. There are interactions between installation angle

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and tool rake angle as shown in Figure 4. It can be found by the rotating orthogonal interaction response surface plot: the cutting force is increasing gradually with the increases of the tool rake angle, but under the influence of the installation angle, cutting resistance will appear minimum value even tool rake angle increases, therefore, there is an optimal combination of operating parameters. According to the univariate analysis to know that the cutting resistance gradually increased and then decreased with the increase of cutting depth. Figure 5 shows the interaction response surface plot of tool rake angle and cutting depth, from the figure: the cutting resistance decreases and then increases after the first under the joint action of the tool rake angle and cutting depth, however, the increasing trend is smaller than univariate analysis, thus the optimal values of the two factors can be obtained, which makes the cutting resistance least.

4.3 Optimization Analysis

According to the principle that the cutting resistance of objective function as small as possible, with each factor level section as constraints, the optimization results are shown in Figure 6. When the parameter combination as follow: cutting depth 35mm, tool rake angle-10 °~ -9 °, installation angle 46 °~ 52 °, the cutting force is 3.1KN~3.4KN.

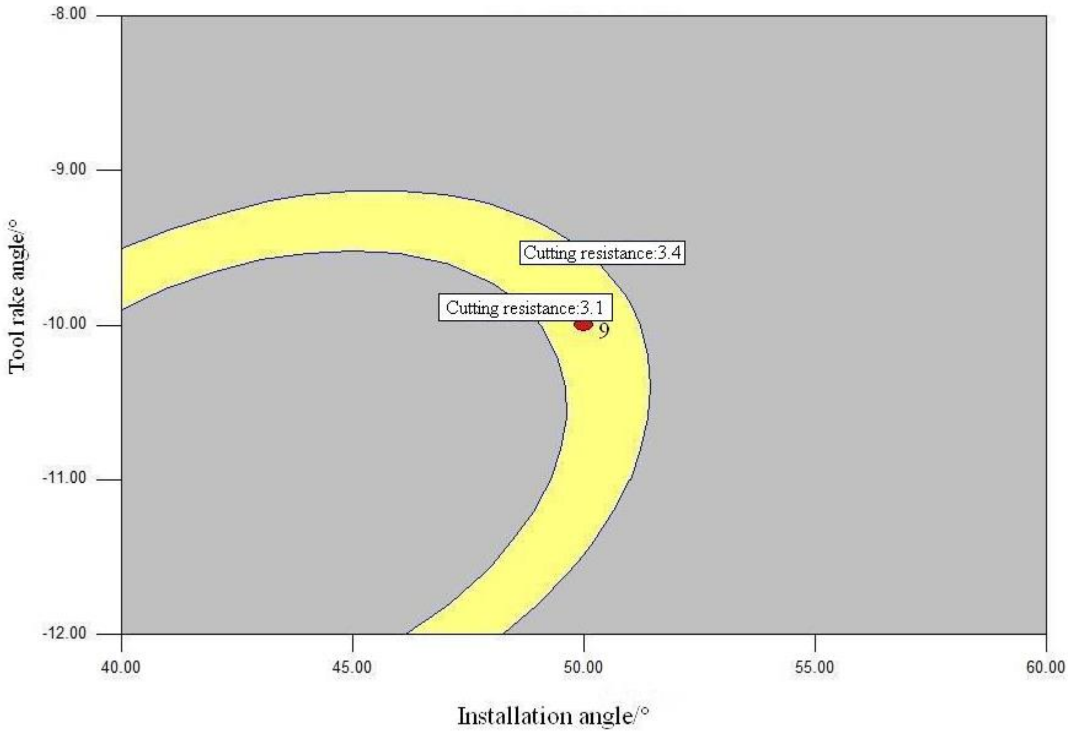

Figure 6. Parameter Optimization Analysis Chart

4. 4 Verification Test

Within the optimized range of the best operating conditions, selecting cutting depth 35mm, tool rake angle -100, installation angle 500, the optimal cutting force predicted by software is 3.3KN, error is 3.1%, verified test results in optimized performance range, which shows that the optimization is credible.

5. Conclusions

(1) According to the test of solid ice-snow cutting resistance finds that the influence order that each factors on cutting resistance from the primary to the secondary are

installation angle, cutting depth, tool rake angle. The optimal combination of job parameters was found and the applicability of the mathematical model of cutting resistance was verified. The model expresses well on cutting destruction of solid ice-snow.

(2)The homemade snow sample was used to ice-snow removal test trials, there are slightly differences between ice-snow characteristics and the actual solid ice-snow rolled on the road; Since the test conditions, the test temperature was set to the average temperature of the test day, the cutting speed was uniform, which would affect the test results. Test will consider cutting speed, temperature, time histories and other variable factors in the future.

Acknowledgements

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