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Research on the quality of laser marked data matrix symbols

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Abstract. To evaluate the quality of the laser direct part marked Data Matrix symbols on titanium alloy substrates, the quality assessment methods at home and abroad were compared. A new quality assessment method of combining the effect of the laser on substrate materials and symbol grade of laser marked Data Matrix was put forward. Depending on previous research works, orthogonal experiment results were analyzed again and a modified nonlinear mathematics model was established. Analysis results indicate that this modified model can explain 90.6% of symbol contrast change and it is statistically significant. So it is better than previous linear regression model and can be used to estimate the quality of laser marked Data Matrix symbols on titanium alloy substrates. The nonlinear mathematics model can also explain the laser parameters influence on the symbol contrast.

1. Introduction

There is a growing need in the industry to track and trace product during production or during its lifetime. As the product identification is required to last its entire lifetime, the marking must be permanent. Laser marking can generate permanent marks on a wide variety of materials. In the entire supply chain, two-dimensional barcode which is the carrier of information has played an important part all along. So more and more people start to pay close attention to the quality of the barcodes. A Data Matrix has many advantages over other barcodes. For example, it can encode a lot of information in the smallest space and its error correction provides safeguards for poorly printed or damaged symbols. So it is the most popular two-dimensional barcode. In industry, many associations select Data Matrix in product tracking and the quality of the laser marked Data Matrix symbol has become the focus of research.

At present, there is no unified quality evaluation method. Some scholars such as Sheu [1] and Hayakawa [2] use barcode identification equipment to evaluate the quality of laser marked Data Matrix, they utilize readability characteristic as a quality indicator. The functions and characteristics of barcode identification equipment are different and the manufacturers try to improve their decoding algorithm to maximize the performance of their product. Thus the barcode identification equipment may decode some poorly printed Data Matrix. So this approach is not accurate enough. Some scholars such as Qi et al. [3] and Ba [4] and Leone et al. [5] use mark contrasts, mark depth, mark width, and surface roughness in the marked area as the quality indicator. The mark contrast is one of five performance measures (i.e. decode, symbol contrast, print growth, axial nonuniformity and unused error correction) which are specified in ISO/IEC 16022 standard [6]. Jangsombatsiri et al. [7] use the five performance measures to assess the quality of laser marked Data Matrix on carbon substrates. But ISO/IEC 16022 standard is set for paper-printed two-dimensional Data Matrix. Whether this standard is applicable to laser marked Data Matrix is not known yet. Qiu [8] use symbol grades measured by barcode verifier to assess the quality of laser marked Data Matrix on aluminum substrates. Barcode

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verifier adopted standardized reference decoding algorithm, and the opticator was calibrated, so it can make a unified objective evaluation about the quality of the barcode. But the process of laser direct part marking is thermal effect. Heat affected zone can't be completely eliminated. In addition, the formation of micro cracks and recast layer will affect the physical properties of the base material. There might provide for a situation when a laser marked Data Matrix symbol grade is A, but the substrate material deformation occurs. So symbol grade measured by barcode verifier cannot stand for the quality of laser marked Data Matrix fully. Therefore the quality of laser marked Data Matrix symbol can be judged by the effect of laser on base materials and symbol grade.

The author has studied the effect of laser on base material in previous research, which showed that deformation and crack did not exist in substrate materials after laser marking [9]. One can say that the effect of laser on base materials is negligible in this research. According to ISO/IEC 16022 standard[6] and previous research [10], the symbol grade for a Data Matrix symbol can be determined by symbol contrast. Whereas the symbol contrast is closely related to the laser parameters. So the aim of this study is to investigate the relationship between symbol contrast and laser parameters.

2. Experimental details

2.1. Experimental setup and materials

A neodymium-doped, yittrium-aluminium-garnet (Nd :YAG) laser was used in the study, whose pumping source is krypton lamp. The laser operated at 80W MAX average power, wavelength of 1064nm, operating frequency of 0-20kHz, pulse width of 80~260ns, and laser spot diameter of 0.010~0.150mm [10]. The marking depth is less than 2.0mm [11]. The substrate materials used in this study are TC4 titanium alloy sheets.

2.2. Reference Data Matrix Symbol

The reference Data Matrix symbol encodes the data string 1A2B3C4D5E and its dimensions are 16×16 modules [9-12]. An example of a reference Data Matrix symbol is given in Figure 1 (a). The size of a laser maked Data Matrix symbol is is 10×10mm and its image is given in Figure 1 (b).

(a) (b)

Figure 1. a) Example of a reference Data Matrix symbol, b) Image of a laser marked Data Matrix symbol.

2.3. Experimental procedure

OFAT experimental results showed that the current intensity, effective vector step, Q-switch frequency, and laser line spacing had a statistically significant effect on the contrast of laser marked Data Matrix symbols on titanium alloys[12]. Based on this conclusion a set of orthogonal experiments were carried out, the experimental results were analyzed with the method of analysis of variance(ANOVA) and signal to noise ratio analysis[11], and a multiple linear regression model was constructed[10]. But the interpretative capability of the model is just 79.5% which is not very good. Based on orthogonal experimental results, interactions plot matrix for symbol contrast is shown in Figure 2.

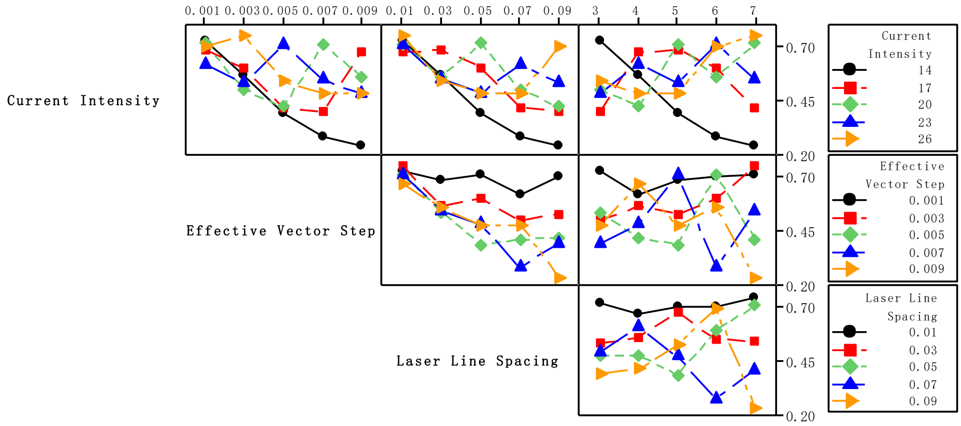

Figure 2. Interactions plot matrix of laser parameters.

Figure 2 indicates the interactions plot matrix of laser parameters. There are obvious interactions between the laser parameters. From this figure, one can say that the relationship between the symbol contrast and laser parameters are nonlinear. So nonlinear mathematical model is more suitable in interpreting the experimental data.

3. Development a regression model

For the convenience of analysis in SPSS software, nonlinear problems should be converted to linear problems. The regression analysis and ANOVA results are shown in Table 1 and the following nonlinear mathematics model was obtained based on Table 1.

$$y = 0.659 - 323.251 \cdot b \cdot c - \frac{30.704}{a^2} + \frac{1.02\times10^{-7}}{b^2} + \frac{1.347\times10^{-5}}{c^2} \qquad (1)$$

Where, y is the symbol contrast, a is the current intensity, b is the effective vector step and c is the laser line spacing.

Table 1. Regression Analysis and ANOVA Results.

Parameters	Coefficient	t	p
(Constant)	0.659	22.895	0.000
b • c	-323.251	-5.491	0.000
a^{-2}	-30.704	-4.433	0.000
b^{-2}	1.020E-7	3.630	0.002
c^{-2}	1.347E-5	4.794	0.000
ANOVA	SS	F	p
Regression	0.447	58.992	0.000
Model Summary	R	R Square	Adjusted R Square
	0.960	0.922	0.906

The coefficient in Table 1 indicates the coefficient values of variables in the nonlinear mathematics model. The subsequent p indicates whether there is a significant correlation between each coefficient toward a parameter and symbol contrast. If the p value is lower than 0.05, then the parameter is significant. The p value in ANOVA results in Table 1 shows the developed mathematics model is statistically significant. The model summary in Table 1 indicates the model fitting. It represents interpretative capability of the model. The bigger the adjusted R square, the greater the interpretative capability of the model. The adjusted R square in Table 1 is 0.906 which illustrate the model can explain 90.6% of symbol contrast change. The predicated symbol contrast value can be obtained when the 25 orthogonal experimental conditions were inserted into the nonlinear mathematics model. Results were shown in Table 2. Comparing results of experimental measured value and predicted value for symbol contrast are given in Figure 3.

Table 2. The predicated symbol contrast value.

No.	Predicted symbol contrast value
1	0.7361
2	0.4997
3	0.4312
4	0.3490
5	0.2436
6	0.6602
7	0.5212
8	0.4466
9	0.3530
10	0.6598
11	0.6737
12	0.5286
13	0.4427
14	0.6966
15	0.5114
16	0.6833
17	0.5268
18	0.7238
19	0.5503
20	0.4623
21	0.6884
22	0.7501
23	0.5843
24	0.5081
25	0.4141

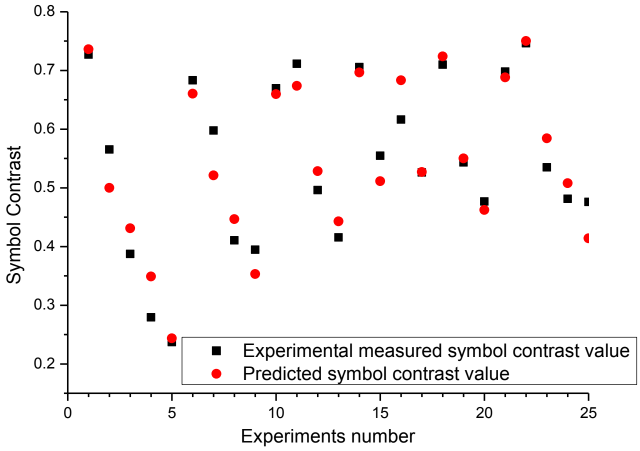

Figure 3. Comparing results of experimental measured value and predicted value for symbol contrast.

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From Table 2 and Figure 3, one can say that the experimental measured value and predicted value for symbol contrast is very close. So the modified nonlinear mathematics model can be used to estimate the quality of laser marked Data Matrix symbol.

4. Conclusions

To evaluate the quality of the laser marked Data Matrix symbols, the research status at home and abroad was reviewed. A further quality assessment methods of combining the effect of the laser on base materials and symbol grade was put forward. Previous works have demonstrated that the effect of laser on base materials is negligible and the symbol grade for a Data Matrix symbol can be determined by symbol contrast. Whereas the symbol contrast is closely related to the laser parameters. So previous orthogonal experiment results were analyzed again and a modified nonlinear mathematics model was established. Analysis results indicate that this modified model can explain 90.6% of symbol contrast change and it is statistically significant. So it is better than previous linear regression model and can be used to assess the quality of laser marked Data Matrix symbol. This can also explain the influence of laser parameters and substrate materials on the symbol contrast.

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6. References

[1] Daniel Sheu D 2000 A laser marking system for flexible circuit identification *J. Manuf. Syst.* **19** 202-12
[2] Hayakawa H 2000 A laser method for marking bar codes on glass substrates *Proc. SPIE* 4088 363-6
[3] Qi J, Wang K L and Zhu Y M 2003 A study on the laser marking process of stainless steel *J. Mater. Process Tech.* **139** 273-6
[4] Ba F 1998 Technical Study on Laser Marking of Slide Calipers *Proc. SPIE* **3550** 336-41
[5] Leone C, Genna S and Caprino G 2010 AISI 304 stainless steel marking by a Q-switched diode pumped Nd:YAG laser *J. Mater. Process. Tech.* **210** 1297-303
[6] ISO, 2004, ISO/IEC 16022: 2000 Information technology-Automatic identification and data capture techniques-Bar code print quality test specification-Two dimensional symbols, 1st ed., International Organization for Standardization, Geneva, Switzerland.
[7] Jangsombatsiri W and Porter J D 2007 Laser direct-part marking of data matrix symbols on carbon steel substrates *J. Manuf. Sci. Eng.* **129** 583-91
[8] Qiu H D, Lu C H and Xiao R J 2011 Laser parameters influence in direct-part marking barcodes on aluminium alloy *Chin. J. Lasers* **38** 95-9
[9] Li C L 2014 Study of effect of laser marking data matrix symbols on titanium alloy sheets using Nd:YAG laser *Adv. Mater. Res.* **941-944** 2165-68
[10] Li C L 2014 Contrast prediction for laser direct part marked data matrix symbols on titanium alloy substrates *Adv. Mater. Res.* **941-944** 2161-64
[11] Li C L 2014 Impact of laser parameters on the contrasts of laser direct marked data matrix symbols on titanium alloy substrates *Adv. Mater. Res.* **915-916** 1018-22
[12] Li C L 2014 OFAT experimental study of laser direct-part marking of data matrix symbols on titanium alloys *Adv. Mater. Res.* **915-916** 1027-31