Scientific Research

Uncertainty Evaluation of Key Items Measurement of Corrugated Packaging Paper

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Abstract: According to the general rule of uncertainty evaluation, the uncertainty source of key items of corrugated packaging paper was analyzed by taking machine direction tensile strength of corrugating medium for example. The uncertainty of measurement was evaluated, and the key factors influencing the uncertainty of measurement were found.

Keywords: tensile strength; ring crush resistance; edgewise crush resistance; bursting strength; uncertainty; measurement

1. Introduction

Measurement is an indispensable work for science and technology, industrial and agricultural production, domestic and foreign trade, and every field of daily life. In order to get the desired results, a lot of measurements are done every day. In the past, the measurement error is used to express the quality of the measurement results obtained. In order to improve the quality of the measurement results, the International Organization for Standardization (ISO) and other six International Organizations issued "Guide to the Expression of Uncertainty in Measurement" in 1993. Uncertainty means the dispersion of the measurement value round of measurement results, indicates the shadiness degree of the validity of measurement results, is a parameter which be related with measurement results [1].

Corrugated packaging papers including corrugating medium, liner board and corrugated fiberboard, are the main raw materials for corrugated boxes manufacture. So the accuracy and the reliability of quality testing results of corrugated packaging papers are very important for corrugated boxes manufacture. In addition, with the development of international trade, the accuracy of testing results need to be evaluated and recognized. To evaluate and express uncertainty of key items measurement of corrugated packaging paper has important practical significance for supply and demand. We can find the critical points of quality testing of corrugated packaging paper. To control the critical factors which impact measurement uncertainty, the accuracy and the reliability of quality testing results can be clearly increased.

2. Key items of corrugated packaging paper

Corrugated packaging papers include corrugating medium, liner board, corrugated fiberboard and so on. According to related national standard, GB/T 13023-2008 "Corrugating medium", GB/T 13024-2003 "Liner board" and GB/T 6544-2008 "Corrugated fiberboard", the key items of corrugating medium are cross-direction ring crush resistance and machine direction tensile strength, the key items of liner board are cross-direction ring crush resistance and bursting strength, the key items of corrugated fiberboard are edgewise crush resistance and bursting strength [2-4].

3. Experimental

3.1. Materials

Corrugating medium: grammage 105g/m^2, from Nine Dragon Paper Ltd.

Liner board: grammage 127g/m^2, from Lee & Man Paper Manufacturing Ltd.

Corrugated fiberboard: minimum combined weight 465g/m^2, from Dongguan Meijia Paper Ltd.

3.2. Equipment

Paperboard bursting strength tester: SE181F, precision 1kPa, Lorentzen & Wettre Testing Equipment Co., Ltd.

Paper tensile strength tester: SE62, precision 0.1N, Lorentzen & Wettre Testing Equipment Co., Ltd.

Electronic compression Tester: YQ-Z-40, precision 1N, Sichuan Changjiang Papermaking Testing Equipment Co., Ltd.

4. Uncertainty evaluation of key items measurement of corrugated packaging paper

It is very hard to evaluate uncertainty of measurement results scientific and rationally. "Guide to the Expression of Uncertainty in Measurement" only provides general methods of the expression of uncertainty in measurement. For specific measurements, specific analysis must be carried out. The difficulty of uncertainty evaluation is to analyse and grasp the sources of uncertainty. For the testing of corrugated packaging paper, the sources of measurement uncertainty are mainly from measurement repeatability, equipment calibration, sample size error, temperature and humidity of testing environment. Burst-

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ing strength is measured directly, does not need secondary calculation, so sample size error does not affect the measurement uncertainty of bursting strength [5-7].

According to the general rule of uncertainty evaluation, the uncertainty source of key items of corrugated packaging paper was analyzed by taking machine direction tensile strength of corrugating medium for example. The uncertainty of measurement was evaluated. The measurement uncertainty of other items are similar with tensile strength, so it is no longer to go into details.

4.1 Uncertainty evaluation of machine direction tensile strength of corrugating medium

4.1.1 Testing Method

Before Testing, the corrugating medium samples are deposited in the circumstances of temperature (below 40℃) and constant humidity (10%RH-35%RH) for more than 24 hours, then the samples are deposited in the circumstances of constant temperature (23℃±1℃) and constant humidity (50%RH±2%RH) for 4 hours. At least ten specimens are required with paper cutter, each specimen should be (15 ± 0.1) mm in width, at least 250 mm in length, and length is horizontal with machine direction. Set the specimen on tester, read and record the maximum breaking force [8].

4.1.2 Formulas and mathematical models

To calculate the tensile strength use the following formula:

$$S = \frac{\overline{F}}{W}$$

Where

S = tensile strength, kN/m

$\overline{F}$ = average tensile force，N

W = specimen width, mm

Formula is from the measurement principle, the measurement uncertainty is not impacted by all kinds of random factors. A repeatability coefficient which equal one is introduced to reflect the random effects. So the mathematical model of uncertainty evaluation is:

$$S = \frac{\overline{F}}{W} \times f_{rep}$$

4.1.3 The sources of uncertainty

According to JJF 1059-1999, analyse the sources of uncertainty of machine direction tensile strength of corrugating medium, and create causality diagram. Different factors and their impact parameter see Figure 1.

Testing is carried out according to national standard, temperature and humidity of the environment accord with standard requirement. So uncertainty from temperature and humidity of the environment can be ignored. The measurement uncertainty sources of corrugating medium machine direction tensile strength are mainly from the following areas: (1) uncertainty of measurement repeatability, including mobility of measurement instrument, personnel operation and inhomogeneity of samples, it can be received by Bessel formula. (2) uncertainty of tensile strength tester calibration. (3) uncertainty of sample width error.

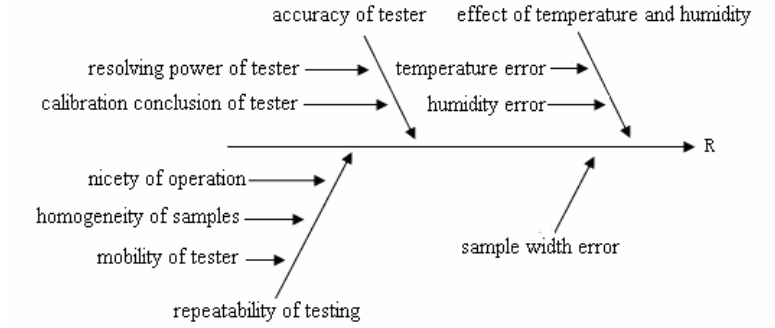

Fig. 1 The uncertainty sources of corrugating medium machine direction tensile strength

Tab. 1 The testing results of tensile force

No.	1	2	3	4	5	6	7	8	9	10
F_i/N	71.4	74.4	75.2	74.9	76.1	72.1	77.5	75.7	76.1	76.3
$\overline{F}$/(N)					75.0					

4.1.4. Calculation of uncertainty

4.1.4.1 Uncertainty from measurement repeatability

Ten testing results see Tab. 1. Calculate standard deviation of tensile force by Bessel formula:

$$s(F) = \sqrt{\frac{\sum_{i=1}^{10}(F_i - \overline{F})^2}{10-1}} = 1.90\text{N}$$

Standard deviation of average tensile force is:

$$s(\bar{F}) = \frac{s(F)}{\sqrt{10}} = \frac{1.90}{\sqrt{10}} = 0.60\text{N}$$

Relative standard uncertainty is:

$$u(f_{rep}) = \frac{s(\bar{F})}{\bar{F}} = \frac{0.60}{75.0} = 0.008$$

4.1.4.2 Uncertainty from tensile strength tester calibration (u_{1rel})

According to calibration certificate of tensile strength tester, expanded uncertainty of tensile strength tester is 1%. Assumed to be uniform distribution, the coverage factor k is $\sqrt{3}$. So relative standard uncertainty from tensile strength tester calibration is:

$$u_{1rel} = \frac{0.01}{\sqrt{3}} = 0.0058$$

4.1.4.3 Uncertainty from sample width error (u_{2rel})

Sample width is (15±0.1) mm, so sample width error is ±0.1 mm. Assumed to be uniform distribution, the coverage factor k is $\sqrt{3}$. So relative standard uncertainty from sample width error is:

$$u_{2rel} = \frac{0.1}{15 \times \sqrt{3}} = 0.0038$$

4.1.5. Combined standard uncertainty

Since uncertainty from measurement repeatability, from tensile strength tester calibration and from sample width error are independent, so the combined standard uncertainty is:

$$u_c(S) = \frac{\bar{F}}{W} \times \sqrt{u(f_{rep})^2 + u_{1rel}^2 + u_{2rel}^2}$$

$$= 5.00 \times \sqrt{0.008^2 + 0.0058^2 + 0.0038^2} = 0.05 \text{ kN/m}$$

4.1.6 Expanded uncertainty

In this testing, the coverage factor k=2, confidence level is approximately 95%, the expanded uncertainty U is:

$$U(R) = k u_c(R) = 2 \times 0.05 = 0.10 \text{kN/m}$$

4.1.7 Measurement result and uncertainty report

In this testing, the tensile strength of corrugating medium is (5.00±0.10) kN/m, the coverage factor k=2, confidence level is approximately 95%.

4.2 Uncertainty evaluation of other key items measurement

The measurement uncertainty evaluation of other key items are similar with the tensile strength of corrugating medium, so it is no longer to go into details. Uncertainty evaluation of key items measurement of corrugated packaging paper see Tab. 2.

Tab. 2 The results of uncertainty evaluation

Products	Items	Testing results	Expanded uncertainty	Notes
Corrugating medium	cross-direction ring crush resistance / kN/m	0.76	0.012	the coverage factor k=2, confidence level is approximately 95%
	machine direction tensile strength / kN/m	5.00	0.10	
Liner board	cross-direction ring crush resistance / kN/m	1.13	0.028	
	bursting strength / kPa	146.9	1.94	
Corrugated fiberboard	edgewise crush resistance / kN/m	7.81	0.013	
	bursting strength / kPa	1122.7	47.8	

Tab. 3 Relative standard uncertainty components

Products	Items	Relative standard uncertainty components		
		measurement repeatability	instrument calibration	sample size error
Corrugating medium	cross-direction ring crush resistance	0.0079	0.0017	0.00076
	machine direction tensile strength	0.008	0.0058	0.0038
Liner board	cross-direction ring crush resistance	0.012	0.0017	0.00076
	bursting strength	0.0059	0.0029	—
Corrugated fiberboard	edgewise crush resistance	0.0076	0.0017	0.0029
	bursting strength	0.021	0.0029	—

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5. Analysis of uncertainty

Relative standard uncertainty components see Tab. 3. From Tab. 3, we can see that the effect of uncertainty from measurement repeatability is most marked. Uncertainty from measurement repeatability is a major component. Uncertainty from sample size error and from instrument calibration have less influence. Uncertainty from measurement repeatability include mobility of measurement instrument, personnel operation and inhomogeneity of samples. So when the operations of testing accord with the related national standards, uncertainty of key items measurement of corrugated packaging paper are mainly affected by the homogeneity of samples. If samples are equable, uncertainty of measurement result is small.

6. Conclusions

When the operations of testing accord with the related national standards, uncertainty of key items measurement of corrugated packaging paper are mainly affected by the homogeneity of samples. If samples are equable, uncertainty of measurement result is small. Contrarily if samples are unequable, uncertainty of measurement result is large. Therefore, when key items measurement of corrugated packaging paper are carried out, sampling must be strict accordance with GB/T 450 “Paper and board—Sampling for testing and identification of machine and cross direction, wire side and felt side”. Reducing the sampling on the impact of sample homogeneity, could improve the accuracy of test results.

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