ORIGINAL ARTICLES

EVALUATION METHOD OF FRP SKI POLES UNDER IMPACT LOAD

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Abstract: Research and development for introducing new material technology and new structural design technology in ski poles has been conducted in recent years. Although the CFRP pole is light, the impact is strong. We studied the impact on the shoulder and arm when a human pokes a ski pole on the floor. We proposed the appropriate objective measurement apparatus, then performed impression evaluation and impact tests using nine types of poles. As a result, we clarified the relationship between human estimation and estimation by the measuring device. The apparatus objectively evaluates the impact on the shoulder and arm and is therefore useful for developing ski poles.

Keywords: *Impact load, Flexural rigidity, Sensory evaluation, Mechanical evaluation.*

1. INTRODUCTION

Skiing is becoming one of the growth sports in the leisure sport industry. The ski industry is evolving due to an increase in game skiing, changing consumer age bracket, and a diversification in the needs of skiers. Moreover, research and development on an introductory technique of a new material and a new configuration design technique has affected the take-off-run technique. Ski poles and other ski equipment have thus evolved through the years.

Until 30 years ago, ski poles were made of bamboo and aluminum alloy. From the late 1960s, newly developed fibers were applied to personal-use products and sporting goods. The current mainstream materials for ski poles are fiber reinforced plastic (FRP) that uses polyamide and carbon fiber. The FRP ski poles are light and highly popular. However, reports from users indicate, that the shock from CFRP poles is larger than that of aluminum poles. The evaluations of the shock are from feeling of players and maker designer now. These evaluations are subjective in nature and are not useful for product design.

There are many studies of static characteristics of ski poles, including an evaluation method based on JIS S7026 [1] and ISO 7331 [2]. This is useful for design and development of ski poles. However, little research on the impact of ski poles has been done except for the research

on grasping force by Tokuyama [3] and the research on swing by Kitajima [4]. Since the manufacturer evaluates the shock using human evaluation, many elements of the mechanism remain unclear.

In this research the impact on the shoulder or arm when poking a ski pole is observed based on kansei engineering technology. This apparatus provides objective measurements and therefore the impact relaxation of a ski pole is clarified.

2. EXPERIMENT

2.1 Test specimens

Nine commercial FRP ski poles were used as standard samples in this research. The ski pole structures are identified in Table 1 as T1 through T9. The FRP pole consists of glass fiber, carbon fiber, polyarylate (VECTRAN®) fiber, and laminated material. The ski poles are tapered. "No taper" in Table 1 means the taper is small. Pole's length is 1180mm.

Baskets and grips of a ski pole influence shock to the shoulder. In this research, ski poles without any attachments are used as test specimens, and only the impact effect of poles are observed. The experiment was repeated five times.

2.2 Impact experiment

To make an apparatus that objectively measure the

impact on the shoulder or arm when poking a ski pole, we studied the behavior (impact, compression, and bending) of the ski poles. Figure 1 depicts the tester holding a ski pole and poking a plate. We attached strain gauges to both sides of the ski pole, and measured the strain of the ski pole by the strain gauges and a sensor interface board (PCD-100, KYOWA Co. Ltd.). We attached a load sensor (LN-20KA, KYOWA Co. Ltd.) on the bottom of the plate, and measured the impact load of the ski pole. In this experiment, the impact was caused by a human.

Table 1 FRP Ski poles used for impact test.

Sample	Structure	Material	Mass (g)
T1	Taper	Carbon fiber and glass fiber	121.0
T2	No taper	Carbon fiber and glass fiber	122.1
T3	No taper	Carbon fiber and glass fiber	110.6
T4	No taper	Carbon fiber	134.5
T5	No taper	Glass fiber	190.0
T6	Taper	Carbon fiber and glass fiber	120.0
T7	Taper	Carbon fiber and glass fiber	112.5
T8	Taper	Glass fiber	126.2
T9	Taper	Polyarylate fiber and Glass fiber	124.8

Figure 1: Schematic diagram of impact test.

Figure 2: Test data of load sensor and strain gauges.

Figure 2 is an example of measuring the loads and the strains resulting from a human-induced impact (sample is T3). All the data of load are collected by an amplifier and a computer. To reduce the dispersion of the poking force, the data is processed as follows.

$$\text{Bending strain} = \frac{\text{strain1} - \text{strain2}}{2} \quad (1)$$

$$\text{Compression strain} = \frac{\text{strain1} + \text{strain2}}{2} \quad (2)$$

$$\text{Bending strain per load} = \frac{\text{Bending strain}}{\text{Load}_{\text{max}}} \quad (3)$$

$$\text{Compression strain per load} = \frac{\text{Compression strain}}{\text{Load}_{\text{max}}} \quad (4)$$

Bending strain and compression strain are obtained by Equation (1) and (2); bending strain per load and compression strain per load are obtained by Equation (3) and (4). Since human impact load varies each time, bending strain per load and compression strain per load are used. Bending strain per load and compression strain per load are the functions of time.

Figures 3 and 4 depict results of the experiment by human-induced impact test. Here, the vertical axis is compressive strain per load (Figure 3) and bending strain per load (Figure 4). From the results of tests conducted by many persons, we determined that T6 has a smaller impact than T3. The chart shows that the ski pole, which makes a small impact, has a large compression deformation and small bending deformation.

Figure 3: Compressive strain from the human-induced impact test.

Figure 4: Bending strain from human-induced impact test.

2.2 Impact experiment by measurement apparatus

Figure 5 illustrates the apparatus developed to measure shock on the shoulder or arm. An arm is made to poke a ski pole for imitating an action of skier. And a rail is attached on the wall to make the arm fall freely. Mass of the arm is 1.11kg. Strain gages are placed on the upper and lower sides of the arm, and the impact load is measured with an FFT analyzer (CF-350Z, ONOSOKKI Co. Ltd.) through an amplifier (CDV-700A, KYOWA Co. Ltd.) when the arm falls. The impact speed of a pole is 1.4m/sec (fall height: 100mm). Bending strain and compressive strain of the ski pole are measured simultaneously. FFT analyzer records output of amplifier.

Figures 6 and 7 illustrate the results of an impact experiment using the measurement apparatus. Here the vertical axes are compressive strain per load (Figure 6) and bending strain per load (Figure 7). The impact experiment results produced by the measurement apparatus are basically the same as those obtained from the impact experiment using a human (Figure 3 and 4). Figure 8 illustrates the curve of the impact load measured by the measurement apparatus. Impact load of T3 is larger than that of T6, indicating that the impact on a shoulder or arm is related to the compression characteristics of the material (FRP) and flexural rigidity of the ski poles.

Figure 5: Experimental apparatus for impact test.

Figure 6: Compressive strain obtained by experimental apparatus.

2.3 Bending test

To investigate the relation between the flexural rigidity and the impact relaxation, we performed a

three-point bending test (support span is 1000mm and radius of loading point is 50mm) (reference: ISO7331). Figure 9 is the schematic diagram.

Figure 10 presents a graph of load (P) and deflection of the poles from the three-point bending test. Table 2 shows flexural rigidity from the graph of Figure 10.

Figure 7: Bending strain obtained by experimental apparatus.

Figure 8: Impact load curve of the ski pole in the impact test.

Figure 9: Three-point bending test for the ski poles.

Figure 10: Relation between load and deflection (by three-point bending test)

Table 2. Flexural rigidity (Nm^2) of the ski poles

T1	T2	T3	T4	T5	T6	T7	T8	T9
729	579	625	1094	486	833	856	694	99

Figure 11 illustrates the relationship between impact load (with the impact measurement apparatus) and flexural rigidity (by three-point bending test). These impact loads are the maximum values of the load curve in the figure 8. The relation between flexural rigidity and impact load is not clear since flexural rigidity is different everywhere.

Figure 11: Relationship between impact load and flexural rigidity (all poles).

However, there is a relation between flexural rigidity and impact load for poles without taper, according to Figure 12. The impact load decreases when the contact pressure increases. The bending test method in ISO7331 and JIS S7026 is not suitable for estimating the impact on shoulder and arm.

Figure 12: Relationship between impact load and flexural rigidity of poles without taper.

3. COMPARISON BETWEEN SENSORY AND MECHANICAL EVALUATION

There is no evaluation standard or international standard (ISO) in sensory evaluations of the impact on the shoulder and arm when a human strikes a ski pole on the floor. Each company does it with their own method. We performed a sensory evaluation to compare the evaluation by the proposed apparatus to that by a human.

Figure 13 Test by an evaluator.

As shown in Figure 13, a tester evaluates the impact on the shoulder and arm when a ski pole is struck on the floor. In order to eliminate the influence of diameter and coating on the pole's grip, we attach a clip with the same shape to the pole.

We used the Kendall ranking method⁵⁾ and divided the impact score into five levels.

Score	Feeling
1	Strong
2	Somewhat strong
3	Normal
4	Somewhat Weak
5	Weak

In order to differentiate the sensory evaluation, from the preliminary experiment result, we selected T3 as the data standard to ensure the evaluation is uniform. We first evaluate T3 and take the result as normal. When a shock is weaker than that of T3, we assign a score larger than 3. When the shock is stronger, we assign a score of less than 3. We next compare T3 to the other eight poles (T1, T2, T4, T5, T6, T7, T8, T9), and then grade the poles in order of impact on the shoulder. Ten men (students of Shinshu university), ages in twenties, were selected as evaluators.

Table 3 Sensory evaluation scores of 10 testers

Tester \ Pole	T1	T2	T3	T4	T5	T6	T7	T8	T9
1	2	2	3	5	2	5	1	4	3
2	3	1	3	5	3	5	2	3	1
3	3	2	3	4	2	4	1	2	3
4	3	2	3	5	1	5	1	4	1
5	3	3	3	5	3	3	2	5	2
6	3	2	3	5	2	5	1	4	3
7	4	2	3	5	3	5	2	3	2
8	1	1	3	5	3	4	1	5	2
9	3	2	3	5	3	4	1	2	3
10	2	2	3	5	2	3	1	5	2
Average	2.70	1.90	3.00	4.90	2.40	4.30	1.30	3.70	2.20
Standard deviation	0.82	0.57	0.00	0.32	0.70	0.82	0.48	1.16	0.79

Figure 13 illustrates an evaluator performing the test. Table 3 presents the scores in the sensory test. An average value is taken and compared to the results of 10 human evaluators.

We assigned a mean ranking to data of the same order in Table 3. The coefficient of consistency (W) obtained from testers' scores was 0.738. $\chi^2_0 = 59.08$ in Table 3 exceeds $\chi^2(8,0.01) = 20.1$ based on the χ^2 test, confirming the consistency of evaluation from testers.

Figure 14 Relation between the result by sensory evaluation and the result by experimental apparatus.

Figure 14 depicts the relation between the result obtained by sensory evaluation and the result obtained by the experiment apparatus. The impact load of Figure 14 represents measurements by the experimental apparatus (Figure 5) for all poles. The values of sensory evaluation are average values from Table 3. The human evaluation results are almost linearly proportional to the experiment apparatus results. The line is plotted using the equation obtained by the least-squares method. The correlation coefficient (r) is 0.798 which was significant from $r > 0.632 (p < 0.05)$. The results show good agreement, so the experiment apparatus can replace humans in performing the test.

4. CONCLUSIONS

In this research, we evaluate the impact on the shoulder and arm when a human pokes a FRP ski pole against the floor.

We developed a measurement apparatus to measure the impact load. The result from human impact test and the result from the experiment apparatus are the same.

Ten evaluators performed a sensory evaluation. The experiment revealed that the apparatus performs the test as humans do. The apparatus objectively evaluates the impact on the shoulder and arm and is therefore useful for developing ski poles.

Acknowledgement

This work was supported by a Grant-in-Aid for COE Research (10CE2003) and Scientific Research (C)(2) 13650081 by the Ministry of Education, Culture, Sports, Science and Technology of Japan.

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