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The flexural toughness of round plastic fiber reinforced shotcrete specimens with ring-supports

Seung-Hwan Han, Sang-Don Lee & Jeong-Un Lee
Expressway and Transportation Research Institute, Korea

In-Chang Jin
Hicofiber co, Korea

ABSTRACT: The functionality of shotcrete is measured by determining its two-dimensional flexural performance in tunnel structures. Though beam specimens have prevailingly been used to determine flexural toughness in Korea to date, the need for a more effective testing method has arisen and the panel specimens used in some other countries are being investigated. The round panel specimens with three support points have been recognized as a realistic method for testing shotcrete performance. However there are concerns that this testing method presumes too much about the crack point and is difficult to manage in the field. The objectives of this research are to investigate the behavior of round fiber reinforced shotcrete specimens with ring supports, and to evaluate its applicability as the standard testing method for evaluating flexural performance. It is anticipated that this method would not presume the crack path without disturbing the 2-dimensional flexural behavior and that it would also be easy to handle. The specimens used in this study were manufactured by being sprayed in the field and were tested against other specimens that met Korean. The conclusion of this study is that the round specimens with ring support provide a quite consistent and rational means for evaluating the flexural toughness of plastic fiber reinforced shotcrete. Also, this study confirmed that some values may be provided for classifying the grade of fiber reinforced shotcrete.

1 INTRODUCTION

Fibers have prevailingly been used for reinforcing the shotcrete lining in tunnel construction. One of their major roles is to maintain structural stability under the loose surface of rock spall. This capacity can be evaluated by examining toughness to endure loads under the excessive deflections of lining. There are several specified methods to evaluate the toughness characteristics, such as ASTM C 1018, ASTM C 1550, and EFNARC (European Specification For Sprayed Concrete).

These specifications can be classified by specimen types, namelypanel shape and beam shape. Panel specimens are widely accepted as having advantages in simulating the actual 2D behavior of tunnel linings. Round panels have not been adopted yet in Korea, because of perceived usage difficulties and arguments regarding thepresumption of the cracking line in the process of testing , which is induced from the point support condition.

In our research, we examined the feasibility of the smaller round panel in comparison to theASTM C 1550. This considered the easiness of handling of specimens. Furthermore the ring type boundary condition is used for discarding the pre-assumption of the crack path. This could let the cracks initiate and propagate to the weakest parts of the specimen.

2 TOUGHNESS OF SHOTCRETE

2.1 *Definitions*

Toughness isdefined as the capacity to resiststatic and impact loading. More precisely, it is the energy absorption capacity of structural elements under static, dynamic, and impact loads.

Every agency has its own methods to estimate this characteristic. The methods vary according to specimen type, test procedure, and representing index. All methods have their own advantages and disadvantages. Therefore it is important to use the method that is best suited to the details of the situation in which one is working.

2.2 *Specimens*

Generally, specimens can be classified as either beam type or panel type specimens. Furthermore panel type can be divided into the subcategories of square panel and round panel. It is widely accepted that the beam type specimens have the advantage of ease in handling and testing, but also have the disadvantage of poorly simulating actual 2D behavior in tunnel lining. On the other hand, the panel specimens are widely accepted as more accurately simulating the 2D lining behavior. The square panel is usedin the EFNARC guide and the round panel is used in the ASTM.

The line support is recommended in the EFNARC square panel, while the three point support is prescribed in the ASTM round panel. As mentioned before, each has the meaning whether it does determine the crack path or not. In testing the square panel system, we discovered some irregular distortion of boundary lines in the process of loading. Specifically, part of the linear support deformed upward and lost contact with the support. We concluded that these irregularities possiblyincrease the uncertainty of the results.

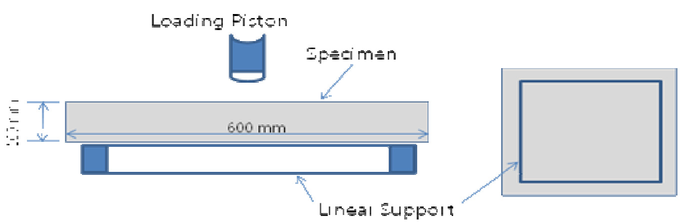

Figure 1. Square panel specimen.

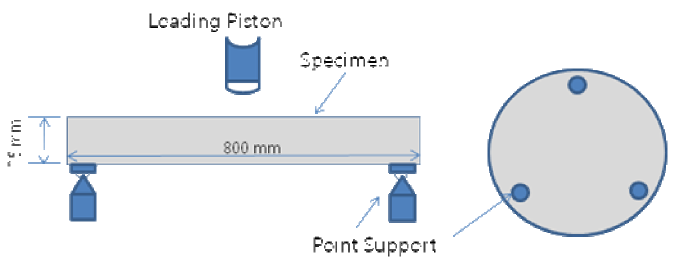

Figure 2. Round panel specimen.

2.3 *Toughness Index*

There are various ways to express the toughness of fiber reinforced concrete or shotcrete, such as residual strength, equivalent flexural strength, and energy absorption.

Residual strength, which is only one stress or the average of stresses in the specified deflections, is described not only as a discrete value, but also in various ratios to strength. The equivalent strength is a mixed form of strength and energy, expressed as a virtual average strength to certain deflections (Fig. 3). When using the panel specimens, the ratio of absorption energy to a certain deflection is regarded as its toughness value.

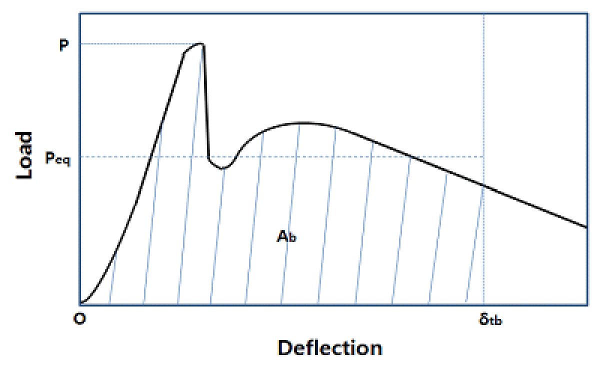

Figure 3. Absorption energy and equivalent strength.

3 TEST VARIABLES AND SPECIMENS

3.1 *Test Variables*

The purpose of this research is to investigate the feasibility of the proposed specimen type: the round shape with ring support. Therefore, round panel specimens of ASTM C 1550 are considered as control specimens for comparison with the proposed round panel specimens with ring support.

Fiber types containing plastic fiber (Polypropylene Fiber) and steel fiber, were used to evaluate the variability of fiber contents. The contents of plastic fiber were varied by 8kgf/m^3, 10kgf/m^3, and 12kgf/m^3.

3.2 *Specimen Preparation*

The preparation of the specimens and the execution of the test procedures followed the prescribed standard methods. The test specimens were prepared by being casted and sprayed in the field. The mix proportions are described in Table 1.

Table 1. Mix proportion of concrete.

Ingredients	Cement	Water	F.A.	C.A.	SP
Quantity(kgf/m^3)	478	174	976	663	4.78

Two types of round panel were fabricated. One was the round panel with the size of ϕ800×75mm, which is the standard specimen according to the ASTM C 1550, the other is the ϕ600×75mm round panel—the subject ofthis research. Not only the size of the specimens, but also the support conditions are different. Specifically, the ϕ800×75mm round panel has the three point support as described in Figure 2 and Figure 6, but the ϕ600×75mm round panel has the ring support as shown in Figure 4 and Figure 7.

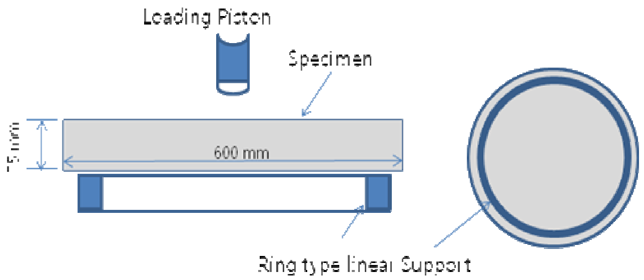

Figure 4. Round Panel Specimen with ring support.

3.3 *Test Procedures*

Mounted specimens, which were positioned symmetrically as shown in Figure 9, were center-loaded at a constant rate of 4.0±1.0mm/min to certain specified deflections. The net center deflections were measured by a displacement gauge at the center bottom of the specimens asthe load was applied. The measurement of deflections was conducted to more than 40mm for the ϕ800×75mm specimens with point support, and more than 25mm for the ϕ600×75mm specimens with ring support.

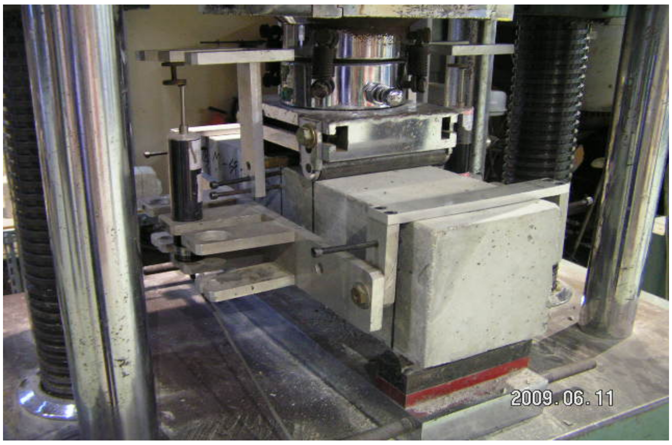

Figure 5. Toughness test of beam specimen.

Figure 6. Apparatus for the point supported panel.

Figure 7. Apparatus for the ring sopported panel.

Figure 8. The ring supported panel specimen.

Figure 9. View of tested panel specimen.

4 TEST RESULTS

4.1 *Cracking Pattern*

The ϕ800×75mm point supported panels have formalized cracking patterns due to the predictable crack lines that form as a result of theirsupport condition. The three primary cracks occur at the center of the two adjacent point supports, and they propagate outward from the center to the edge as shown in Figure 10. However, the ϕ600×75mm ring supported panels have no predetermined failure line due to their continuous support condition. The crack location and number of cracks might vary according to the specimen characteristics. The five or six cracks generally occur in the specimens as shown in Figure 11 and Figure 12. It is not easy to distinguish one crack pattern in the ring supported panel, and it is inferred that the varianceof crack patterns is a natural phenomenon of these specimens.

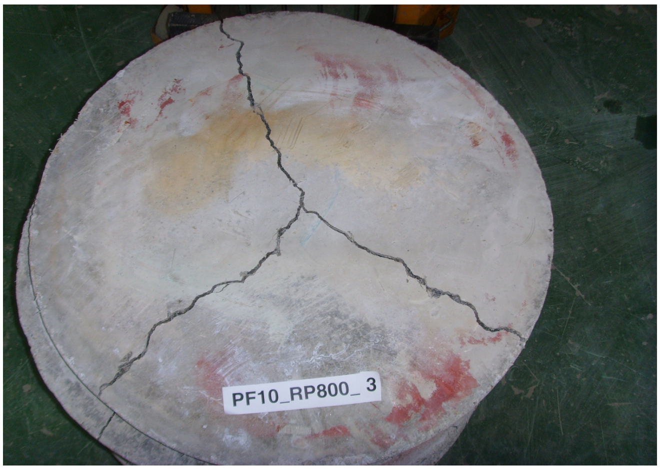

Figure 10. Typical crack pattern of point supported panel.

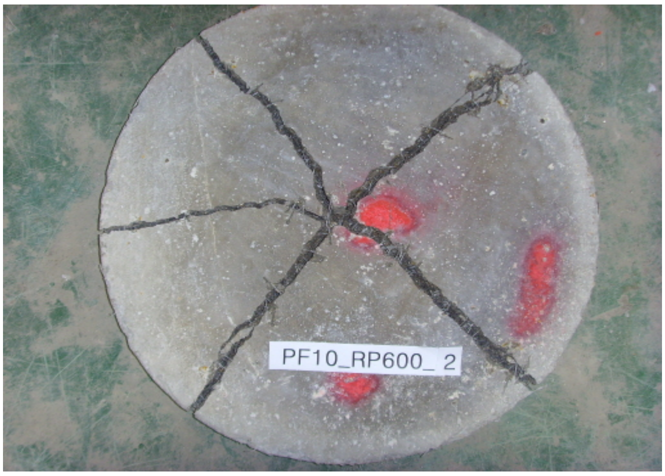

Figure 11. Crack pattern-1 of ring supported panel.

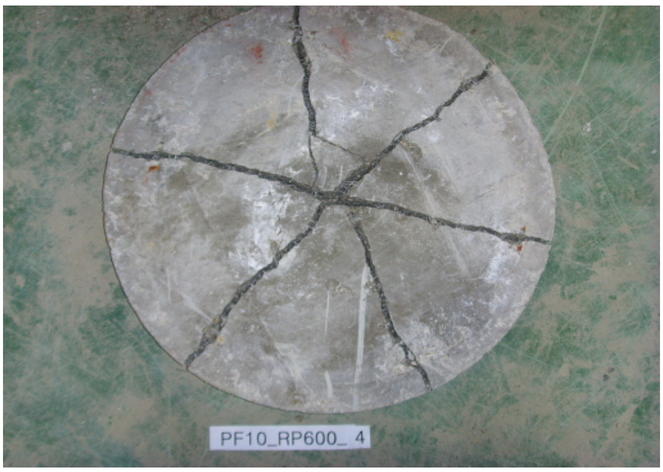

Figure 12. Crack pattern-2 of ring supported panel.

4.2 *Peak Load*

There are small differences of peak load as the fiber contents and fiber types were varied in the ϕ800×75mm specimens, but it is difficult to distinguish a trend in variables (Fig. 13 & Fig. 14). Steel fiber reinforced concrete and shotcrete show a slightly higher peak load value than the plastic fiber.

Figure 15, and Figure 16 show that the ϕ600×75 ring supported panels demonstrate similar trends in peak loads. Sprayed panels with steel fiber produce slightly higher average peak loads than plastic fiber panels.

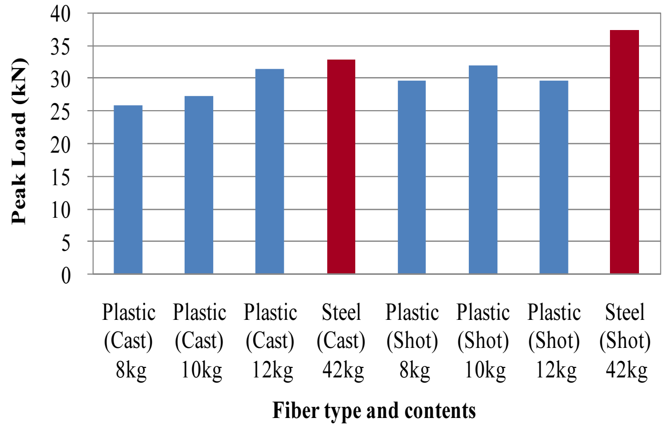

Figure 13. Peak load of ring supported panel.

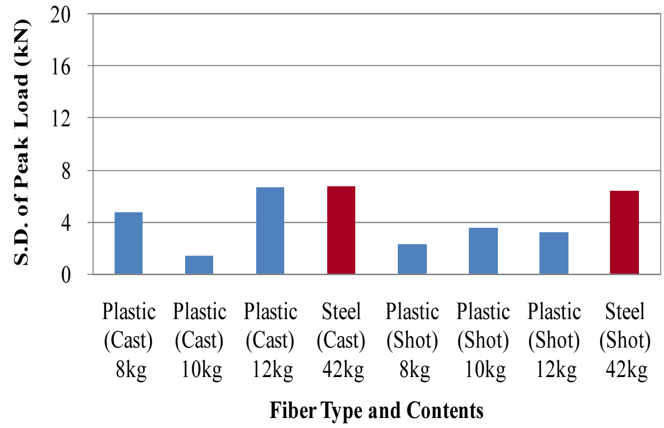

Figure 14. Variation of Peak load of ring supported panel.

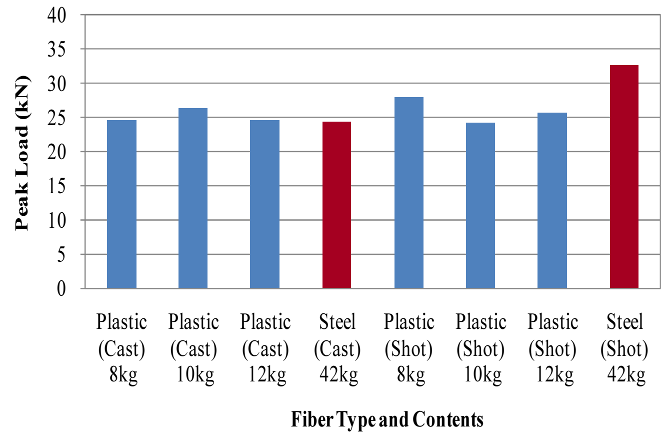

Figure 15. Peak load of point supported panel.

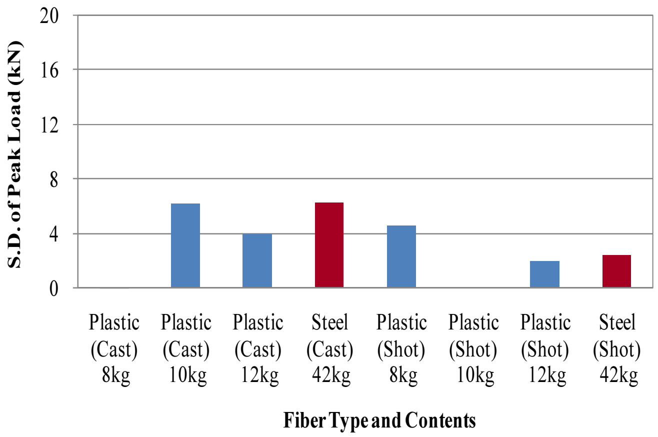

Figure 16. Variation of Peak load of point supported panel.

Flexural strength of beam specimens was also evaluated for the same batch of concrete. From the test results, it was concluded that there were no significant variation of flexural strength among the variables. Even higher contents, 12% of plastic fiber shotcrete showed a higher flexural strength of beam specimens as shown in Figure 17.

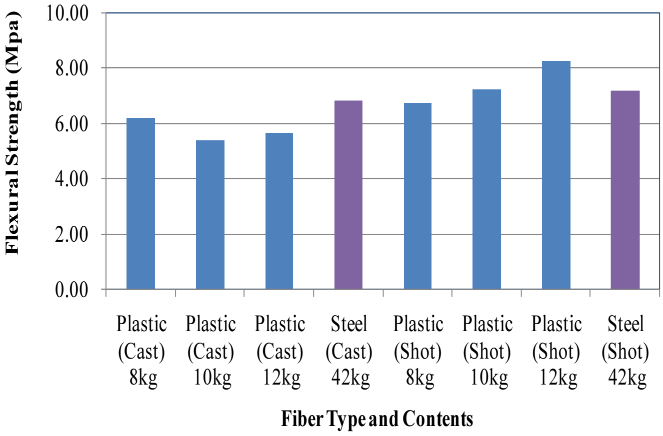

Figure 17. Flexural strength of beam specimens.

4.3 *Energy Absorption*

Normally, the toughness of tunnel shotcrete lining is expressed in terms of energy absorption. The EFNARC and ASTM standard test specificationmethods for calculating energy absorption were followed in this research.

It was expected that the specimens with ring support would have no distinct failure surface and would show some fluctuating results. The crack generally propagates through the structure by following the weakest path according to the applied loads, and this has relevance toreal-world behavior.

The test results of absorption energy are shown in figures 18 through 21The first two figures show the energy value and its variance of $\phi 600\times 75$mm panels with ring support, and the last two figures show the energy values and variance of $\phi 800\times 75$mm with point support.

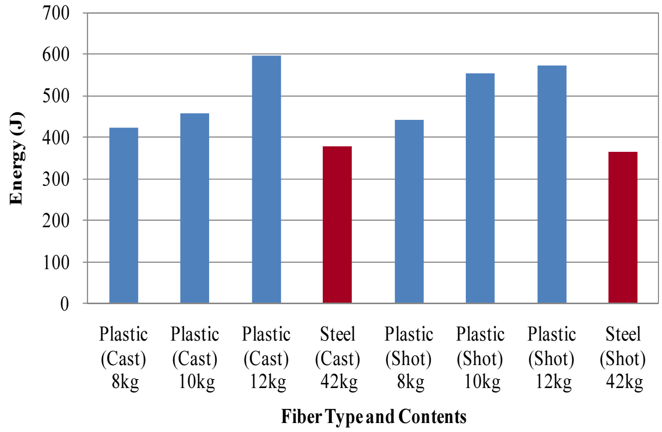

Figure 18. Absorption energy of ring supported panel.

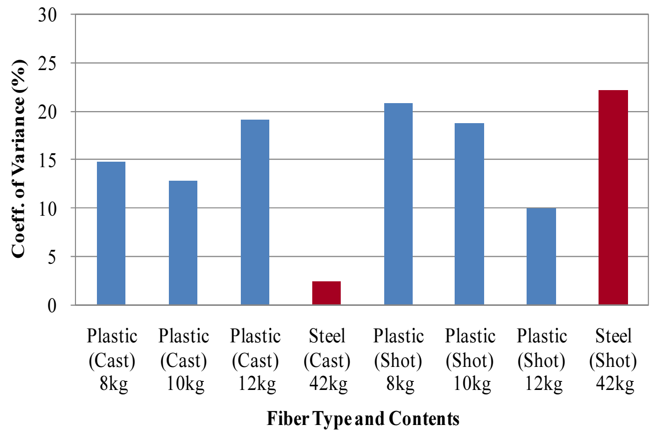

Figure 19. Variance of energy in ring support panel.

As can be seen in the figures, the plastic fiber reinforced concrete and shotcrete specimens both reveal a rise in absorption energy as fiber contents are increased. Insufficent datafor the performance of the plastic fiber specimens with 10kg/m^3 fiber contents make the resultsomewhat inconclusive. However, the plastic fiber reinforced concrete and shotcrete showed higher absorption energy than even the steel fiber reinforced panels.

The variance of test results is slightly higher in the ring supported panels than the point supported panels, as was expected. The ASTM specifies the allowable discrepancy as 17% between specimens in the same test. Some test results of $\phi 600\times 75$mm panels have a higher variance than this value, but all have less than 23%.

It can be assumed that this variance can be reduced to the specified value if we increase the number of specimens to a certain value. For convenience, only three specimens were tested at each variable, but more than six specimens are recommended.

4.4 *Correlation Between Energy Absorption*

We attempted to ascertain if there was a correlation between the ring supported panel and the point supported panel as specified in the ASTM. Some correlation can be confirmed as shown in Figure 14, but the correlation is notdistinct. This may beovercomed as more test resultsare accumulated. However, according to the results of this study, we cannot describe the correlation as certain. However, the difference between two support conditions, provide the individual failure mechanism from the other.

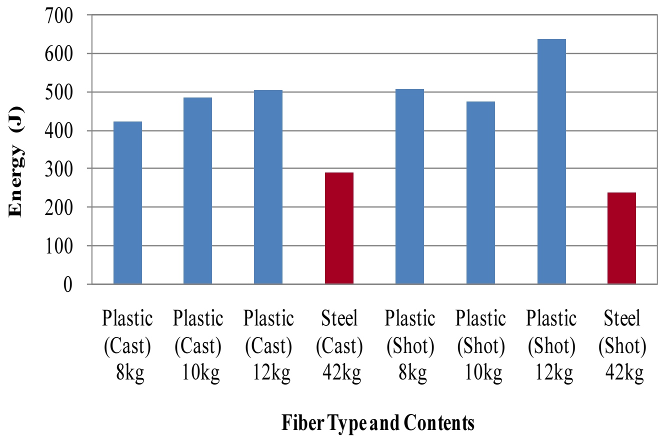

Figure 20. Absorption energy of point supported panel.

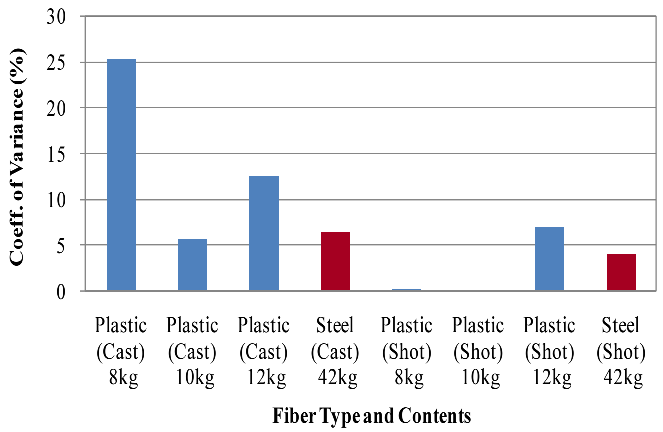

Figure 21. Variance of energy in point support panel.

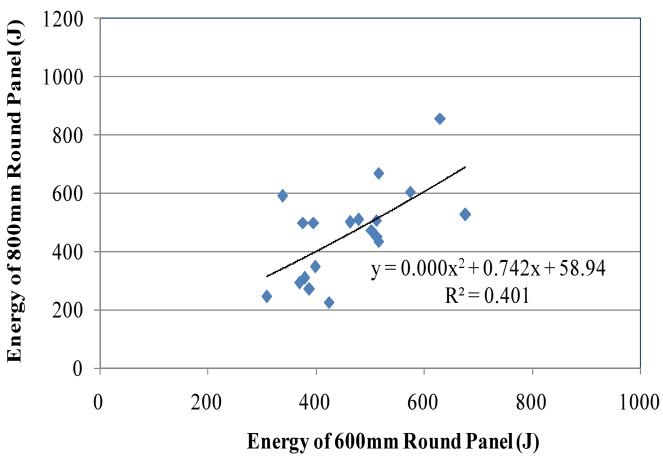

Figure 22. Correlation between two test results.

5 CONCLUSIONS

It is not easy to define the characteristics required for the safety of permanent shotcrete lining, but toughness, as defined by absorption energy, is the accepted standard. The panel specimens accurately represent the two dimensional behavior of lining, and have been preferred for this reason.

However, the square panel has the disadvantage of an irregular support condition, so that, in the process of loading,parts of the support lose their contact. The predetermined crack line might have a possibility of the non-conservative estimation in the round panel specimens with point support. Some field managers also complain that the ϕ800×75mm round panel specimens have quality control difficulties. The applicability of the ϕ600×75mm panels is evaluated in this research for evaluating the toughness of the test specimen.

(1) The crack patterns of the ϕ600×75mm panels with ring support, are not uniform among the specimens. But we did not find that these variable crack patterns seriously influenced the test results of toughness.
(2) The toughness results of the ϕ600×75mm panels with ring support, might discern the toughness of the fiber reinforced shotcrete with variable fiber contents.
(3) It is found that the ring supported panel have a higher fluctuation of data than the point supported panel, but the increase is not quite as high as was assumed.
(4) There are many efforts stillneeded in order to use the ϕ600×75mm panels for evaluating the toughness of fiber reinforced concrete and shotcrete, such as developing the energy requirement, setting updetailed procedures to ensure consistent methods, and inducing the correction factor.

ACKNOWLEDGEMENT

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